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DRAFT

EVALUATION OF QUENCH TOWER EMISSIONS

PART I

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509306

PREFACE

Coke quenching is a process involving the cooling of incandescent coke by direct application of water sprays. It is common practice in the United States steel industry to quench incandescent coke with water contaminated by prior quenching and by plant process waste streams. The quenching process takes place in towers which are so constructed as to draft much of the quench plume up from the immediate work area.

It has long been known that quench towers are sources of considerable pollutant emissions. Certain research efforts have documented the presence of large sized (greater than 60 μm) particulate emissions through the use of greased impaction plates and Petri dishes, and have attempted to quantify these emissions. It is on the basis of these crude measuring attempts that the current quench tower emission factor of 0.9 lbs of particulate per ton of coal was formulated.

The conventional method of controlling quench tower emissions is by means of baffles installed in the tower above the quench car. The baffle systems have an unknown emission control efficiency. Preliminary evidence indicates that they are of limited effectiveness in abating small diameter particulate and droplet emissions. In fact, the quantity of small diameter particulate produced in the quench process from thermal shock to the coke or by evaporation of contaminated quench water has not been well documented. Unknown quantities of gaseous pollutants also are present in quench tower emissions.

In order to answer these and other questions about quench tower operations, the Division of Stationary Source Enforcement (DSSE)

509307

of the U.S. Environmental Protection Agency contracted with York Research Corporation in early 1976 to perform a feasibility study of quench tower emission testing. Subsequently, a field test program was conducted. Funds for this program were provided by DSSE under Contract Nos. 68-01-3161 and 68-01-4138 and by the Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP) under Contract No. 68-02-1401.

Because of the lack of significant existing data concerning quench tower emissions and the need to develop emission standards to meet National Ambient Air Quality Standards, a program was required to develop a broad information package on the quench process. Of primary importance was the need to develop a full characterization of the pollutants exiting a quench tower using both "clean" and "contaminated" quench water. This characterization would include mass rate concentration, size distribution, phase distribution, and chemical and physical parameters.

It was required that the test program be extensive enough to provide empirical evidence of relationships between pollutants entering the quench process as contaminants in quench water or on hot coke, and pollutants exiting the quench process as air emissions, sump feedback, or contaminants on quenched coke. Essentially, it was necessary that a mass balance for various constituents be developed. Empirical evidence would also indicate possible relationships between quench emissions and various coke process parameters such as greenness, coking time, and flue temperature.

An overall objective of the quench test program was to develop an understanding of the mechanisms by which quench tower air emissions are evolved. This understanding would be based on energy transfer information, quantity and quality of quench water and sump return water, and other factors. An assessment of baffle effectiveness for abatement of particulate emissions was also required. Mass rates and size distribution of droplets

509308

and solid particulates were to be considered.

The characterization of quench tower emissions is important for a number of reasons. As stated earlier, those fractions of the total air emissions which were most poorly characterized prior to the onset of this program included small diameter droplets and particulate matter. These small particles (down to sub-micron size) have much higher atmospheric residence times than the coarse (> 60 μm) particles measured in earlier tests. Hence, their potential for environmental transport and damage is high. Those particles less than 5 - 10 μm in diameter comprise the fraction known as respirable emissions. These particles may comprise a significant threat to human health in steel plant environs. The unknown composition of quench gases and the possibility that some of them might be adsorbed onto small particles was further incentive to research. Several gases believed to be present in the quench emissions were known carcinogens.

Further EPA requirements for this test program included the stipulation that particulate emissions be determined in an isokinetic manner, using only approved variations from standard EPA methods. Similarly, laboratory analysis of collected samples were to be in accordance with published EPA methods. Finally, every effort was to be made to derive empirical relationships between process parameters and emissions data using, where appropriate, regression and correlation analysis and hypotheses testing techniques.

509309

TABLE OF CONTENTS

Section		Page
	ACKNOWLEDGEMENTS	ii
	PREFACE	iii
	TABLE OF CONTENTS	vi
	LIST OF FIGURES	vii
	LIST OF TABLES	viii
1.0	SUMMARY	1
2.0	PARTICULATE EMISSIONS	5
	2.1 Overall Relationships	5
	2.2 Evaluation of the Individual Components of the Sampling Train	13
	2.3 Grit	15
	2.4 Oils	18
3.0	GASEOUS EMISSIONS	19
	3.1 Relationships between Emissions, Concentrations of Contaminants, and Vapor Pressure	23
	3.2 Adsorptive Capacity of Coke	27
	3.3 Organic Emissions	28
4.0	SUMP EMISSIONS	33
5.0	BAFFLE EFFICIENCY	35
6.0	RECOMMENDATIONS FOR EMISSION CONTROL	41
	6.1 Tower Design Improvements	42
	6.1.1 Baffles	42
	6.1.2 Sprays	44
	6.2 Emission Control Equipment	45
	6.2.1 Mist Elimination	46
	6.2.2 Scrubbers	47
	6.3 Quench Water Treatment	49
	6.4 Alternate Quenching Processes	51
	6.4.1 Dry Quenching	51
	6.4.2 PCT Process	53
REFERENCES		55
APPENDIX		
	A. Statistical Methods	

509310

LIST OF FIGURES

Figure		Page
2-1.	TOTAL QUENCH TOWER PARTICULATE EMISSIONS VERSUS DISSOLVED SOLIDS IN QUENCH WATER	7
2-2.	TOTAL QUENCH TOWER PARTICULATE EMISSIONS LESS OILS AND GRIT VERSUS DISSOLVED SOLIDS IN QUENCH WATER	9
2-3.	TOTAL QUENCH WATER PARTICULATE EMISSIONS VERSUS VARIOUS COMPONENTS IN QUENCH WATER	10
2-4.	TOTAL QUENCH WATER PARTICULATE EMISSIONS LESS OIL AND GRIT VERSUS VARIOUS COMPONENTS IN QUENCH WATER	12
2-5.	HIGH-VOLUME AEROTHERM SAMPLING TRAIN	14
2-6.	SIZE DISTRIBUTION BY WEIGHT OF PARTICULATE EMISSIONS	16
2-7.	PARTICULATE EMISSIONS SIZE BREAKDOWN	17
6-1.	VARIOUS DESIGNS OF QUENCH TOWERS	43
6-2.	THE DRY QUENCHING PROCESS	52

509311

LIST OF TABLES

Table		Page
3-1.	AVERAGE GASEOUS EMISSION RATES (LB/QUENCH)	19
3-2.	COMPARISON OF CONTAMINANT LEVELS PRESENT IN THE QUENCH WATER, AND AS GASEOUS EMISSIONS	20
3-3.	VAPOR PRESSURE, BOILING POINTS, AND MELTING POINTS FOR VARIOUS COMPOUNDS FOUND IN QUENCH EMISSIONS	25
3-4.	RELATIVE CONCENTRATION (AMMONIA/PHENOL RATIO)	26
3-5.	ORGANIC COMPOUND TYPES FOUND IN QUENCH EMISSIONS (LB/QUENCH)	30
3-6.	POLYNUCLEAR AROMATIC HYDROCARBONS FOUND IN QUENCH EMISSIONS (LB/QUENCH)	31-32
4-1.	SUMP EMISSIONS (LB/HR)	35

509312

1.0 SUMMARY

This work clearly shows that coke quench towers are sources of considerable pollutant emissions. The plume exiting the stack at Lorain contained 3.5 pounds of particulate per ton of coal when contaminated water was used for quenching. This is significantly more than the present emission factor of 0.9 pounds of particulate per ton of coal. In addition, gaseous emissions such as carbon monoxide, sulfur dioxide, ammonia, phenol, hydrogen, and cyanide contributed 1.8, 0.5, 0.3, 0.2 0.1, and 0.01 pounds per ton of coal, respectively.

The particulate emissions were dramatically reduced when clean water was used as make-up for the coke quench tower. Overall reduction was by more than one-half, and gaseous emissions were reduced by more than one order of magnitude.

The large size ($>$ 10 μm) grit (breeze) which was apparently formed by the fracturing of the coke was only a small fraction (6 percent) of the total particulate matter emitted. Some large grit is always to be expected when incandescent coke is cooled quickly with large quantities of water. The amount of large grit varied from 0.1-0.2 pounds per ton of coal when using clean and contaminated water, respectively, for quenching. It is likely that the contribution of particulate matter by the coke is consistent regardless of the quality of the water used. Therefore, the difference in measured particulate matter originates from the salts and other compounds present in the contaminated quench water.

It is the particles greater than 10 μm in size which will be the most affected by improved control devices, such as baffles.

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This study has shown that this size range comprises a relatively small percentage of the total particulate emissions. Thus, in order to substantially reduce emissions, a deeper look into the control device problem is warranted. This is new information, since at present, baffles are widely used by the coke industry. Prior studies regarding size distribution of the quenching emissions revealed information only about the larger sized particles and droplets which were obvious in the tower's fallout. Attempts at control were done with baffles similar to those in use at Lorain.

The quantity of large sized particles and droplets collected by prior investigations is about the same order of magnitude as the larger sized particles found in the Lorain plume. However, the quantity of smaller particles collected was greater than the larger ones by a factor of 15. Therefore, it is concluded that the average particle size is considerably smaller than had been expected. Specifically, it is in the 3-4 μm range. Of this, a portion was found to originate from the oil pretreatment of the coal; a process used for controlling the bulk density. If this practice were to be eliminated, the overall amount of pollutants could be reduced by 0.6-0.7 pounds per ton of coal. Another major reduction in pollutants is expected if clean water were used as make-up, even if the recycled quench water were not cleaner than at Lorain. There is reason to believe that using clean make-up for long periods would reduce the contaminant level in the recycled sump water below that found at Lorain during the abbreviated clean water test period. If these two suggestions were followed, it is believed that pollutants would be reduced to below 0.8 pounds per ton. There is some evidence that changes in process parameters such as blend and coking temperatures; and equipment modifications, such as a spray type scrubber, and improvements in baffles and tower design, could further reduce these pollutant levels.

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One further step is obvious. If clean water were used only once (and oil treatment eliminated), a reduction to 0.6 pounds/ton of coal could be achieved. With modifications as indicated above, the level of pollutants could be reduced even lower.

Organic matter was also found in the stack effluent which consisted of various types of organic compounds.

- These organic emissions are substantial (range between 1-8 pounds per ton of coal.
- The chemical nature of this material is primarily aromatic.
- The amount of the organic material emitted is probably more dependent on the processing condition of the coke than upon the quality of the quench water used.

This area is currently being explored under another program.

There were some emissions from the surface of the sump and the quenched coke which were obvious to the casual observer, and were obnoxious especially when contaminated water was used as make-up.

It is likely that many reactions occur in or near the incandescent coke bed, such as:

$$2\ NH_3 \longrightarrow N_2 + 3\ H_2$$

$$H_2O + C \longrightarrow H_2 + CO$$

The reducing environment in this zone is maintained during the high temperature portion of the quench, and would support such reactions. In addition, significant amounts of chemical compounds such as oxides of sulfur, ammonia, and phenol were found. These compounds would have been dissociated by the temperature of incandescent coke, but they were evidently liberated after the incandescent coke had been partially cooled.

The data in this report indicate that the primary source of the

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coke quench pollutants at Lorain was the chemicals found in the contaminated water normally used as make-up. Those chemicals are liberated from the coal by the coking process and enter the water used in other plant operations, which later is used as make-up for the quench process. The overall quantity of pollution was dramatically reduced when clean make-up water was used. This is an important conclusion of this work. Pollutants now found in the environment around a quench tower can be greatly reduced by using quench water with a low level of total solids. Further reduction can be achieved by reducing or eliminating the oil used for oven density control. Beyond this, reductions may be possible by modification to baffles and spray systems, but the magnitude of these modifications may be small and need to be substantiated. Dry quenching would apparently be the process most likely to result in a minimum of air pollution.

Example of Solution

For such measures to reduce overall pollution, they would involve increasing emphasis on recovery of the coal chemicals and/or expanded and improved waste treatment facilities.

A further conclusion is that a serious study of all alternate methods for providing further reduction in coke quench tower pollution should now be undertaken. The size, type, quantity and source of pollutants have been spelled out in detail for the first time. Economic and environmental impact studies can now be made to consider such other options as possible control devices on both existing towers and new tower design.

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2.0 PARTICULATE EMISSIONS

2.1 Overall Relationships

The quench process was found to be a significant source of particulate emissions. Data obtained during the field program indicate that a strong relationship exists between particulate emissions and the amount of certain dissolved contaminants present in the quench water.

Investigations were made into possible relationships between particulate emissions and various quench water components as follows:

- Chlorides
- Ammonia
- Phenol
- Cyanide
- Calcium
- TOC
- Oils
- Sulfide
- Sulfate
- Total Solids
- Dissolved Solids
- Suspended Solids
- Volatile Solids
- Sodium

Near linear relationships between stack particulate emissions and quench water contaminants were found only for cyanide, phenol, TOC, ammonia, and total and dissolved solids. Before looking more closely at these parameters, let us briefly discuss those water parameters which had no consistent correlation to stack particulate emissions.

It is apparent that certain quench water contaminants were emitted from the stack primarily in gaseous form.

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For instance, compounds of sulfur and compounds of chlorine, both of which were present in quench water, were detected in stack particulate matter only at low levels.

Interestingly, suspended solids did not demonstrate a significant correlation with total stack particulate emissions. This is despite the fact that dissolved solids and total solids each provided a positive correlation. Suspended solids, in most cases, comprise only about 10% of the total solids level in quench water. Given the existence of analytical error and other quench variables, this quantity was not sufficient to systematically affect stack particulate emission measurements.

Certain quench water parameters, as stated earlier, show near linear relationships with stack particulate emissions. Figures 2-1 through 2-4 show particulate emissions (pounds of particulate per ton of coal quenched) as a function of the quench factor for various contaminants, where the quench factor for each contaminant is defined as:

$$\frac{\text{Contaminant concentration (lbs/liter)} \cdot \text{liters emitted/quen}}{\text{tons coal/quench}}$$

Figure 2-1 shows the total amount of particulate matter measured by the sampling train versus the total dissolved solids in the water lost up the quench tower stack. Each is expressed in pounds per ton of coal. Data points also indicate spread resulting from errors associated with stack and water sampling (see Appendix). This graph shows a strong relationship between quench tower emissions and contamination in the quench water. However, it also shows that not all of the emissions were related to the water contamination levels. For example, the relationship shows that even if water with no dissolved solids was used to quench, approximately

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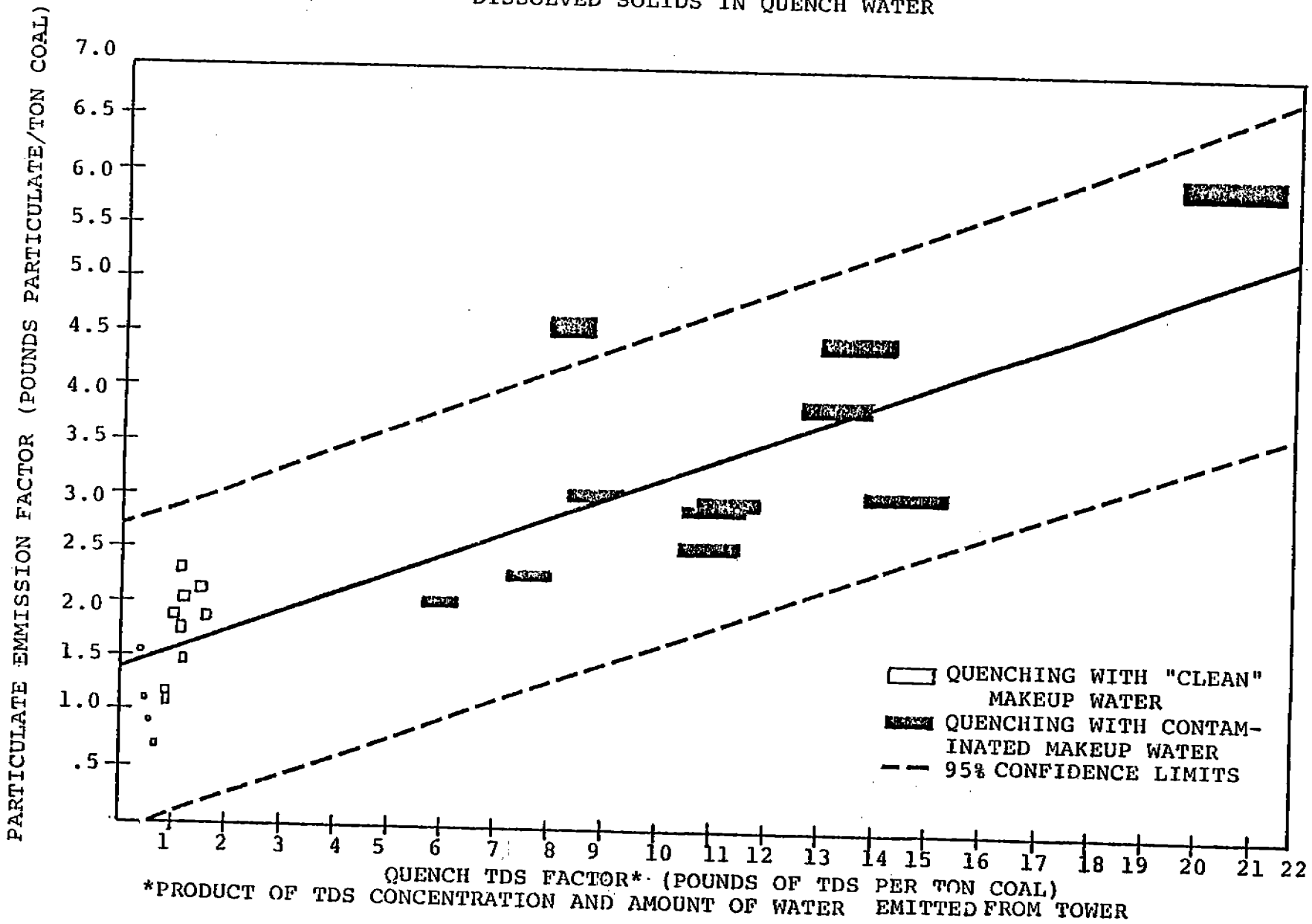
FIGURE 2-1.
TOTAL QUENCH TOWER PARTICULATE EMMISSIONS
VERSUS
DISSOLVED SOLIDS IN QUENCH WATER



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1.4 pounds of particulate matter per ton of coal would be emitted (see Y-intercept).

Figure 2-2 is similar to Figure 2-1 except that the value plotted on the ordinate is the stack particulate emission minus oil and grit. This is plotted in order to demonstrate a theoretical emission level attainable if oil pre-treatment of the coke was discontinued and if baffle control efficiency was such that grit (particles ≥ 10 μm in diameter) was not carried up the stack. This level, indicated by the Y-intercept (where dissolved solids in the quench water are equal to zero), is approximately 0.5 pounds of particulate per ton of coal. The tighter grouping of data in Figure 2-2 than in Figure 2-1 indicates that the oil and grit components of stack particulate emissions are not related strongly to dissolved solids in the quench water.

Figure 2-3 plots stack particulate emissions versus a number of dissolved quench water contaminants showing linear relationships.

It is not surprising that a number of dissolved contaminants show a positive correlation with particulate emissions. The slope of the plotted relationships, however, is unexpectedly high and probably misleading.

Ammonia compounds were present in significant amounts in quench water. They appear to exert a strong influence on total stack particulate emissions. Particulate matter collected in the stack sampling train was not analyzed for ammonia. However, it would appear that a significant weight percentage of the particulate was composed of ammonia salts.

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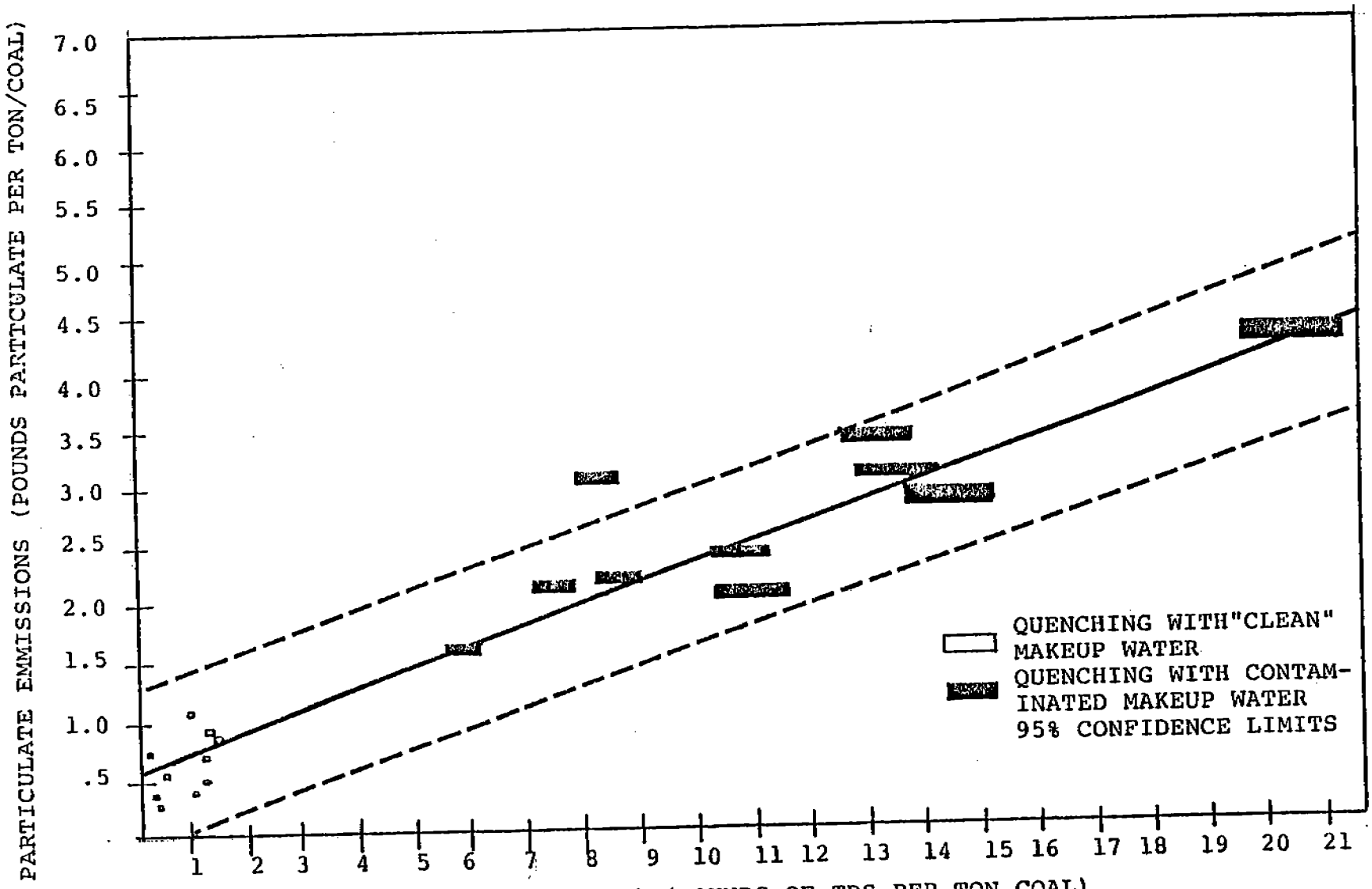
FIGURE 2-2.
TOTAL QUENCH TOWER PARTICULATE EMMISSIONS LESS OILS AND GRIT
VERSUS
DISSOLVED SOLIDS IN QUENCH WATER



*PRODUCT OF TDS CONCENTRATION AND AMOUNT OF WATER EMITTED FROM TOWER

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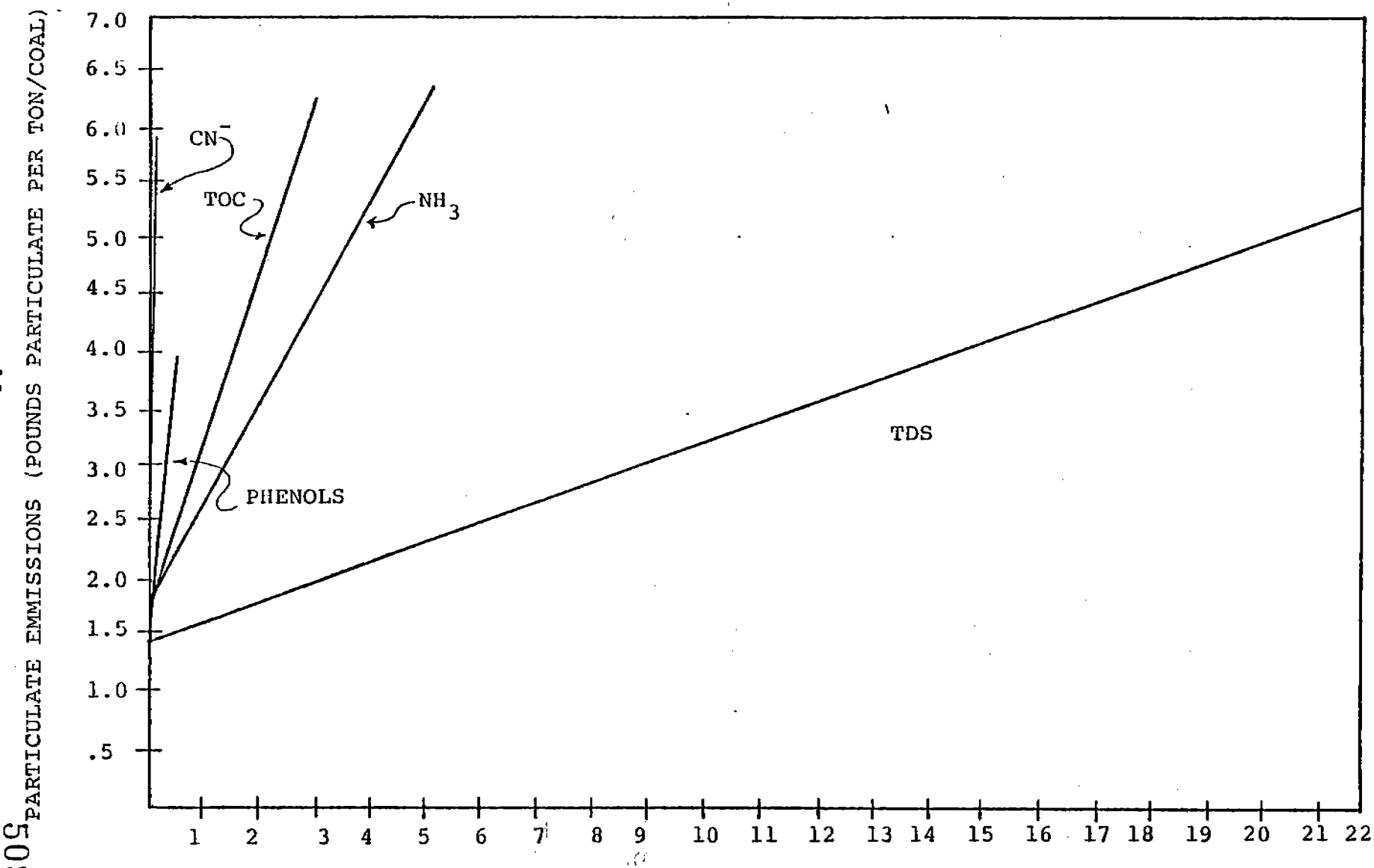
FIGURE 2-3

TOTAL QUENCH TOWER PARTICULATE EMMISSIONS
VERSUS
VARIOUS COMPONENTS IN QUENCH WATER



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Total organic carbon (TOC) consists mostly of volatile organic compounds, easily adsorbed onto particulate surface areas. Therefore, high levels of TOC in quench water could cause a direct increase in the total weight of particulate emissions. The rapid increase in particulate associated with TOC in Figure 2-3, however, may be partially due to analytical error, small number of data points, or other process influences.

Cyanide and phenols collectively form a small percentage of total dissolved solids in quench water. They represent even a smaller weight percentage of total stack particulate emissions. It should be noted that the sampling train was not designed to capture phenols and cyanide. Therefore, the indicated relationship between these compounds and particulate emissions should be viewed with caution. Very small increases in phenols and cyanide are apparently associated with dramatic increases in particulate emissions. It is unlikely that this is direct cause and effect. Rather, because quench water contaminants tend to increase collectively (although at different rates), the increase in particulate emissions is probably attributable to other quench water and process parameters.

Particulate emissions minus oil and grit are plotted against the various quench factors in Figure 2-4. In Figures 2-3 and 2-4, the plotted line for TDS versus particulate emissions is indistinguishable within analytical error from a similar plot for Total Solids versus particulate emissions.

In summary of this section, it is noted that the observed relationships between particulate emissions and the quench factors of CN^-, TOC, NH_3, and phenols should best be considered as qualitative. They are

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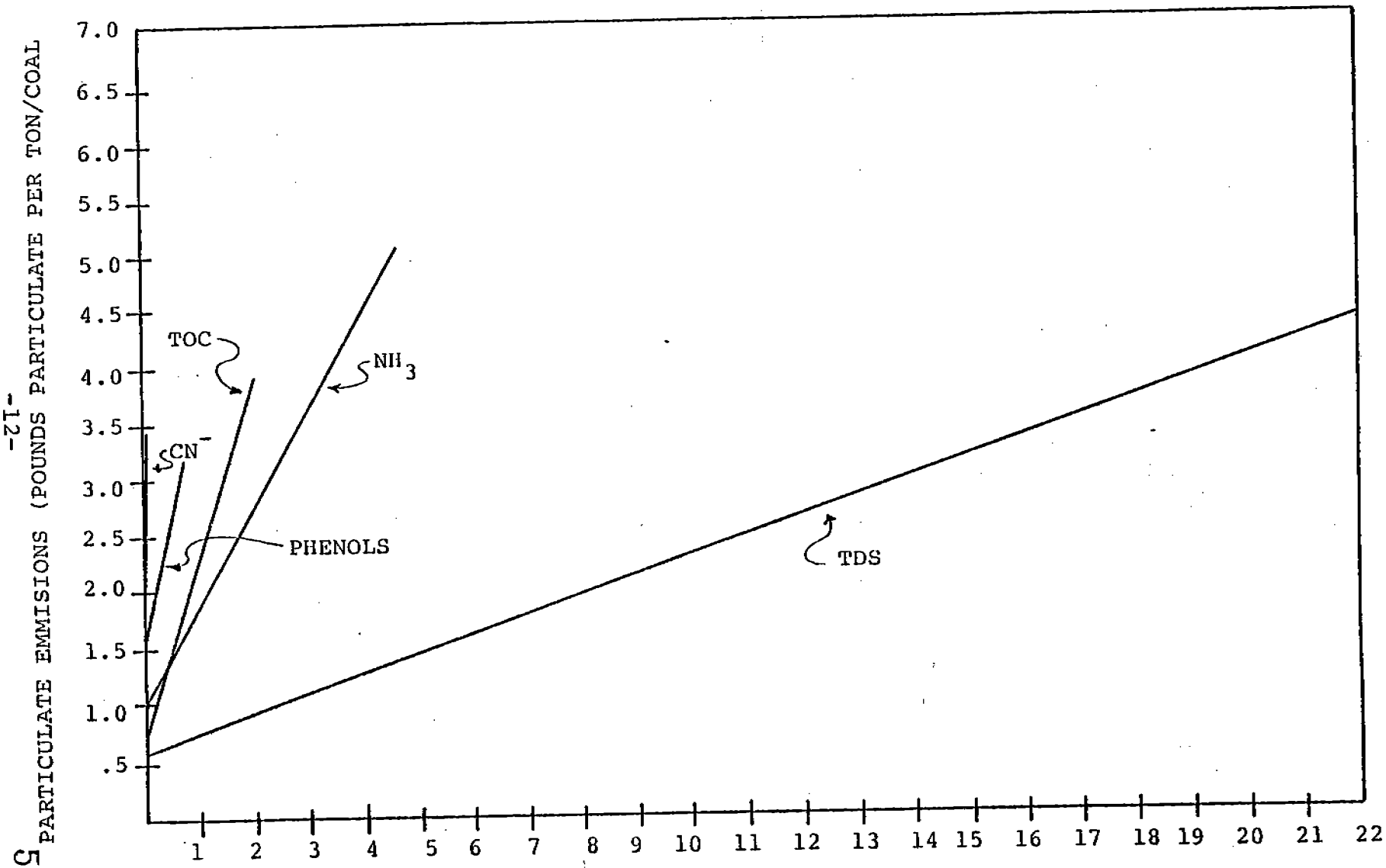
FIGURE 2-4

TOTAL QUENCH TOWER PARTICULATE EMMISIONS LESS OILS AND GRIT
VERSUS
VARIOUS COMPONENTS IN QUENCH WATER



QUENCH FACTOR* (POUNDS OF CONTAMINANT PER TON COAL)
*PRODUCT OF CONCENTRATION AND AMOUNT OF WATER EMITTED FROM TOWER

509324

indicative of trends but are not reliable for the determination of rates and precise relationships.

Dramatic observations regarding total particulate emissions (Figures 2-1 and 2-2) are:

- There is a "baseline" particulate emission factor for the quench tower even in the theoretical case of quench water containing zero dissolved or suspended solids.
- Above the baseline, there is a strong correlation between quench water contamination and elevated levels of total stack particulate emissions.
- By subtracting grit and oil (presumably due to thermal shattering of coke and pre-treatment with oil, respectively) from total particulate emissions, the resultant correlation with TDS and other quench water factors is even more pronounced.

When contaminated quench water was used, an average emission rate of approximately 47 pounds of particulate per quench ($\sim$ 13.1 tons of coal per quench) resulted. This is equivalent to 1000 tons of particulate matter emitted per year from this single tower. When clean quench water was used, particulate emissions were reduced to an average 21 pounds per quench, or 460 tons per year.

2.2 Evaluation of the Individual Components of the Sampling Train

The various elements of the sampling train (Figure 2-5) provide a good indication of the size distribution of the particulate matter collected, since particles within specific size ranges are either collected by or are settled out in these elements. Specifically:

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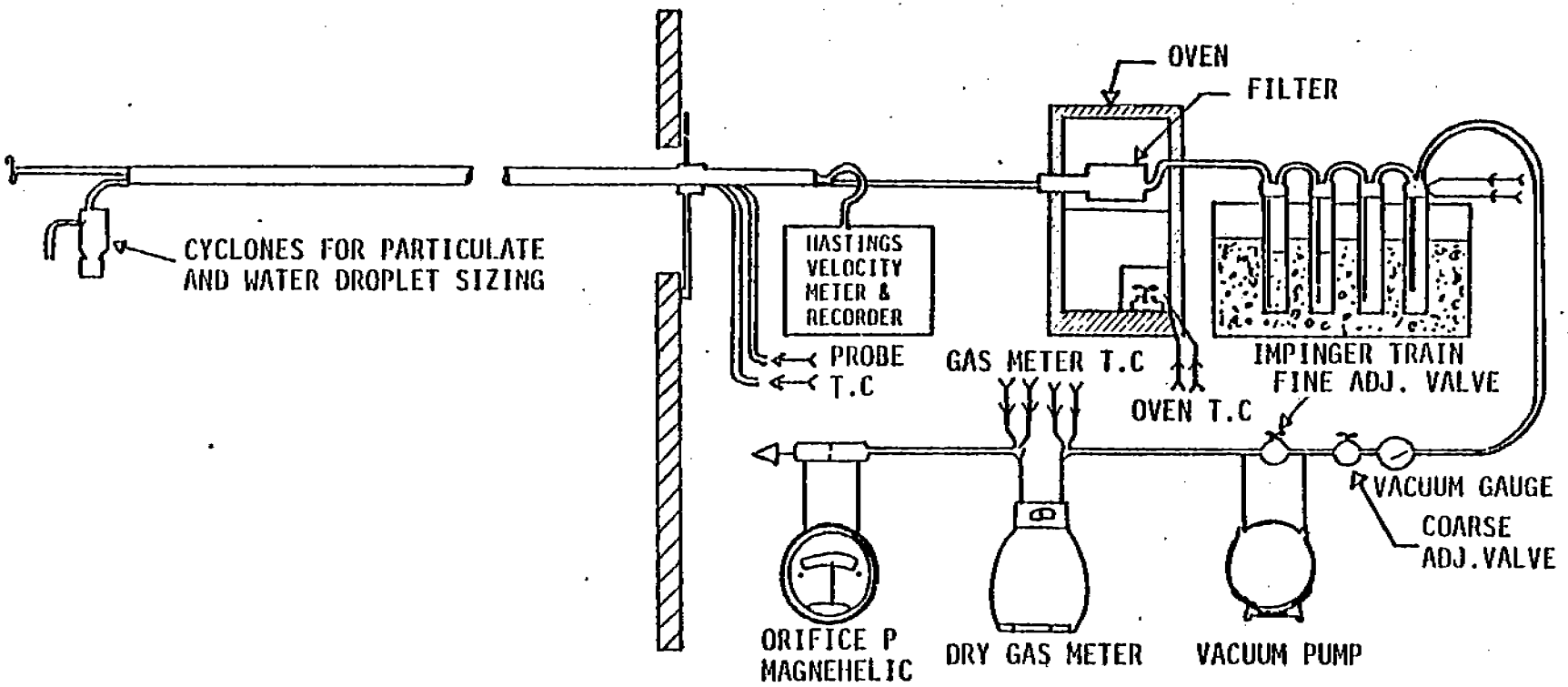

FIGURE 2-5.

HIGH-VOLUME AEROTHERM SAMPLING TRAIN

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- The cyclone collected particles and droplets ≥ 10 µm.
- Particles and droplets between 10 µm and 0.3 µm (averaging 3-4 µm) were deposited in the probe.
- The filter collected particles ≥ 0.3 um.
- The impinger collected SO_3 and particles < 0.3 um.

Based upon this size-discriminating methodology, it has been possible to determine the size distribution of the particulate emissions from the Lorain Quench Tower. This size distribution does not include those particulate emissions derived from evaporation of droplets containing dissolved solids. Since these dissolved solids are not included, the subject particulate emissions are considered to be caused primarily by the fracturing of the coke. For this reason, the level of dissolved contaminants in the quench water is of minor importance. The particulate size distributions presented in Figures 2-6 and 2-7 are based upon combined data from clean and contaminated tests.

2.3 Grit

The limited number of data points available for grit and other emissions is not adequate for a direct correlation analysis. However, several trends were apparent between particulate emission rates and various process measurements. Total <u>grit emission rates</u> were found to vary directly with:

- An increase in coke surface temperature.
- An increase in the acceleration of the initial up-stack gas flow.
- An increase in the suspended solids level in inlet water.

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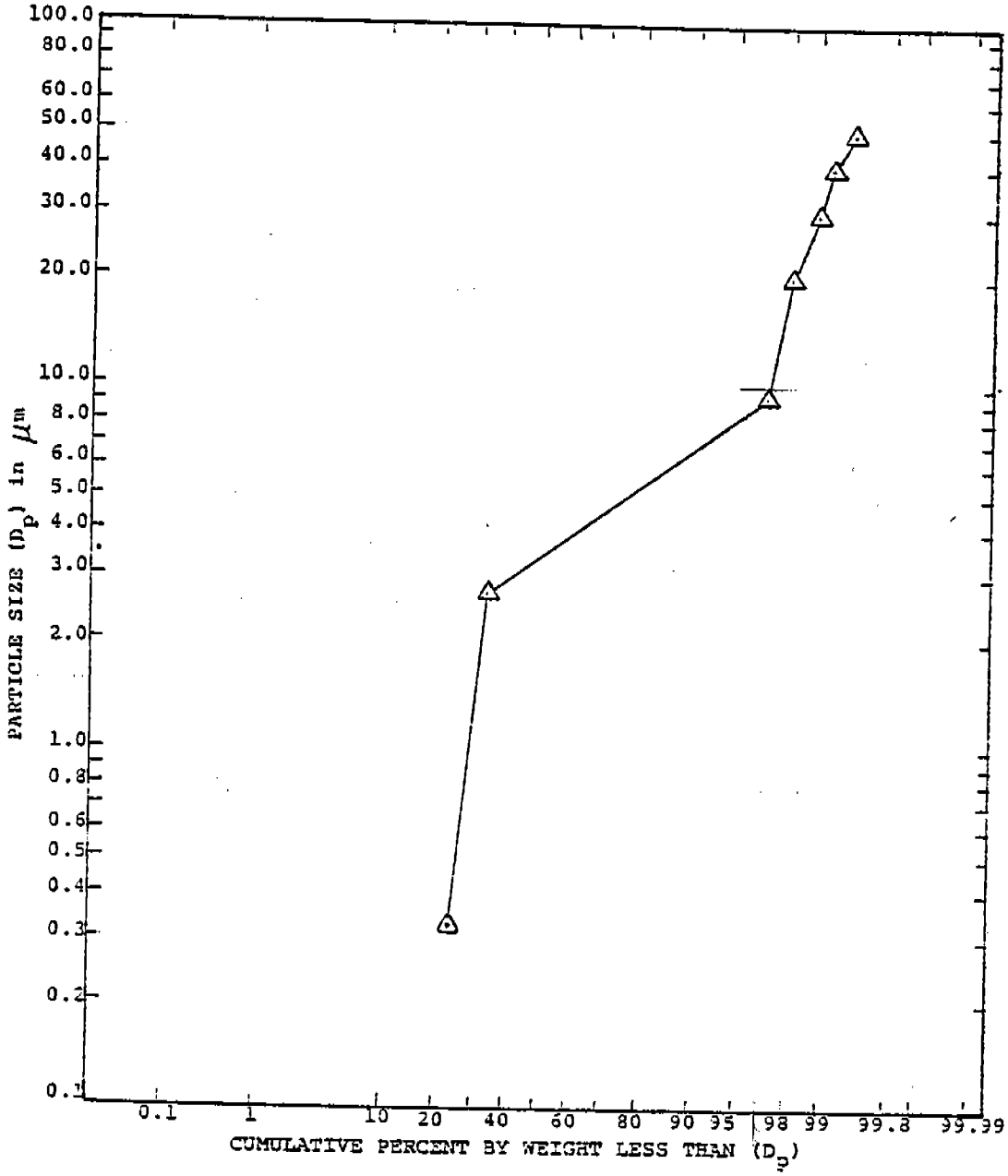

FIGURE 2-6.

SIZE DISTRIBUTION BY WEIGHT OF PARTICULATE EMISSIONS

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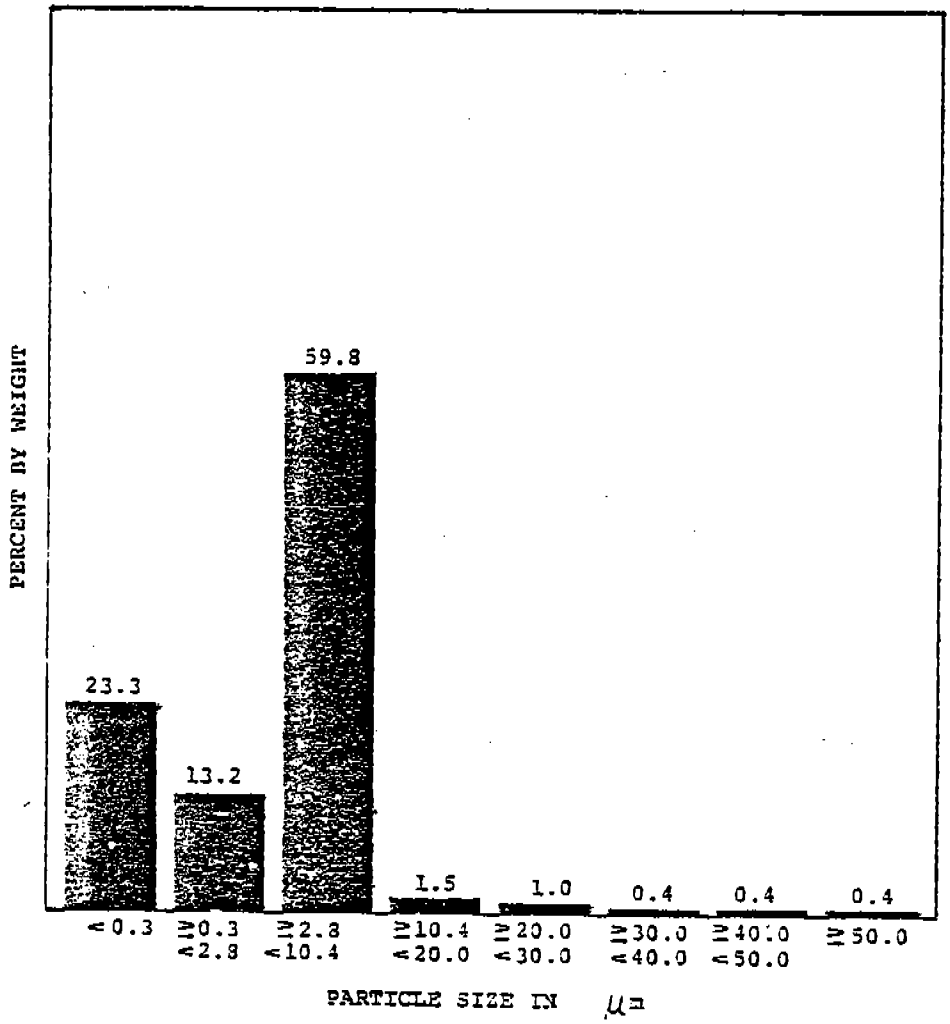

FIGURE 2-7.
PARTICULATE EMISSIONS SIZE BREAKDOWN

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2.4 Oils

An unexpected component was observed in the quench emissions. Approximately 80 percent of the catch collected from the acetone wash of the sampling train was identified as a mixture of oils. A number of statistical analyses were performed in an attempt to correlate the presence of these oils with one or more process parameters, including:

- Coking time (duration).
- Coke greenness.
- Temperature of incandescent coke.
- Battery and oven number.
- Presence of oils in inlet water.

No correlations were established for these parameters. However, it has been learned that Number 2 fuel oil is added to the coal prior to charging in order to control the bulk density of the charge. The nature of the oils found in the acetone washes were such that they could have originated from this pretreatment process.

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3.0 GASEOUS EMISSIONS

A significant task within the overall quench emissions measurement program was the quantification of specific chemical compounds found in the gaseous emissions. These emission rates are presented in Table 3-1.

TABLE 3-1. AVERAGE GASEOUS EMISSION RATES (lb/quench)

Compound or Element	With Contaminated Quench Water	With Clean Quench Water
Sulfur Dioxide	6.0	0.07
Phenol	2.9	0.05
Ammonia	4.3	0.35
Cyanide	0.13	0.03

For purposes of comparing gaseous emissions with the levels of compounds found in the quench water, Table 3-2 is presented.

As is evident in this table, the amount of gaseous compound present in the stack emissions is found to be strongly dependent upon the quantity found in the quench water.

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TABLE 3-2. COMPARISON OF CONTAMINANT LEVELS PRESENT IN THE QUENCH WATER, AND AS GASEOUS EMISSIONS

Quench Water Condition	Compound	Gaseous Emissions (lb/quench)	Quench Water Contaminant Level (lb/quench)
Clean	Phenol	0.05	0.06
Clean	Ammonia	0.35	1.70
Clean	Cyanide	0.03	0.02
Contaminated	Phenol	2.90	2.70
Contaminated	Ammonia	4.30	10.30
Contaminated	Cyanide	0.13	0.72

The gaseous contaminants found in inlet quench water and subsequently in stack emissions are evolved from several sources. The greatest single contribution is from contaminated make-up water consisting of coke oven flushing liquor. This liquor picks up a heavy burden of dissolved gaseous contaminants during exposure to coke oven gases. A second source is contaminants in the incandescent coke which contribute to emissions up the stack as well as contamination of sump return water. In some cases, measurable amounts of contaminant gases are present in sump sediments. These may have served as a reservoir of contaminants during clean water operation so that the gaseous emission during the clean tests are not as low as they would be if clean water were used one time rather than recycled.

In the following discussion, each of the primary gaseous contaminants in the quench plume is considered. Mechanisms contributing to the presence of these contaminants in the plume are discussed.

Except for nitrogen, oxygen, and carbon dioxide (these gases are not considered primarily to be products of the quench process), carbon monoxide was the most abundant gas in the quench plume. The presence of abundant carbon monoxide is indicative of the reducing environment of the high temperature zone around the

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incandescent coke. The reaction mechanisms which would form abundant carbon monoxide under these conditions is:

$$H_2O + C \longrightarrow H_2 + CO$$
$$2\ C + O_2 \longrightarrow 2\ CO.$$

Sulfur dioxide and sulfur trioxide in the quench plume were formed from various sulfur compounds brought into the quench process by the coke and make-up water contaminated with flushing liquors.

The level of sulfur oxides in the quench plume during clean water tests was low (see below). They were probably formed from sulfur in the coke.

	Clean Tests	Contaminated Tests
SO_2 (lbs/quench)	0.07	6.0
SO_3 (lbs/quench)	1.60	8.1

The sulfur oxides level in the quench plume during tests with contaminated quench water was significantly higher than when clean water was used. The apparent entry point for these additional sulfur oxides is through contaminated flushing liquor make-up water. However, a relatively low level of sulfate was measured in the make-up water for both clean and contaminated tests. Some sulfate in make-up water may have been reduced to SO_2 or SO_3. The analytical procedures involved with the make-up water were concerned only with sulfates.

The main source of sulfur in all tests is probably the coal itself. Most of the sulfur originally present in coal is removed during the coking process. Much of this sulfur is recovered during the cooling of coke oven off-gases by flushing liquor. In the case of contaminated quenches, some of this sulfur is returned to the system as make-up water. In the case of clean quenches, sulfur which is not driven off the coal during coking is the greatest single source of sulfur in the stack emission.

Ammonia was introduced in significant amounts in make-up water

509333

during contaminated quenches. Considerable ammonia emissions were recorded from stack and sump during these tests. However, the measured emissions from stack and sump are probably not sufficient to account for the quantities of ammonia entering the quench. It is likely that some ammonia was dissociated during the quench into hydrogen and nitrogen.

Relatively low levels of ammonia were recorded in inlet water during clean quenches. It is possible that some of this ammonia was derived by extraction from sump sediments. The level of contaminants in sump sediments during these clean quenches were somewhat higher than in sumps which had been on clean water for long periods of time. Ammonia emissions during clean quenches, while much lower than during contaminated tests, may reflect sump contamination.

Emissions of phenol appear to be related to the amount of phenol present in quench inlet water.

Free hydrogen was probably formed in the high temperature zones of the quench by a number of reaction mechanisms, two of which have already been discussed. These are the dissociation of ammonia and the reaction which formed carbon monoxide from carbon and water:

$$2\ NH_3 \longrightarrow N_2 + 3\ H_2$$
$$H_2O + C \longrightarrow H_2 + CO$$

Cyanide was found at relatively low levels in both inlet water and gaseous emissions for clean water tests. Levels were significantly higher for contaminated tests and there was a greater contribution of cyanide in make-up water for contaminated quenches than clean quenches.

Of the gaseous materials discussed, only carbon monoxide and hydrogen were formed almost exclusively in the quench process. The other compounds; sulfur dioxide, ammonia, phenol, and

509334

cyanide, were brought into the quench process in contaminated make-up water or possibly, to a much lesser degree, in the coke itself.

In all cases, a direct relationship was found to exist between inlet water concentrations and stack emissions. It is likely that other processes were at work also. For instance, depending on the reactions and conditions involved, contaminants can be either adsorbed by or stripped from the coke. The chemical environment in the vicinity of the hot coke bed was highly reducing. Very little oxygen would be available until the gas mixture had left the high temperature zone and mixed with cooler ambient air. At these reduced temperatures, additional chemical reactions would be slowed.

Because of the unknown nature of many reactions in the high temperature quench zone and certain difficulties in establishing a reliable mass balance for various gaseous contaminants, it is not possible to accurately assess contributions by the coke to the gaseous stack emissions. However, since the gaseous emissions with clean water were very low, it would seem that the contribution from the coke was minimal.

3.1 Relationships Between Emissions, Concentrations of Contaminants, and Vapor Pressure

The rate of emission of gaseous compounds from the quench tower is dependent upon a number of factors, including the partial pressure of each compound in the quench water. A directly proportional relationship is expected to exist between these two. An increase in the partial pressure of a compound in the mixture should increase the emission rate of that compound. The partial pressure of a gas or liquid dissolved in the quench water is, in turn, dependent upon concentration and vapor pressure. Theoretically, if a number of substances are present in equal concentrations in the quench water, the substances with higher vapor pressures should be found in highest concentrations in the gaseous

509335

emissions. Because of this expected relationship, attempts were made to correlate gaseous emissions with vapor pressures of individual compounds, as was done with the sump emissions.

Before discussing this attempted correlation, a brief discussion of the quench process is appropriate. Prior to quenching, the temperature of incandescent coke is approximately 2000°F (1100°C). Within seconds of the initiation of the quench, the temperature of the coke is reduced to 200°F (93°C). This drastic reduction in temperature involves the release of huge quantities of heat from the coke as heat of vaporization to the quench water. Much of the water and dissolved liquid and gaseous contaminations which contact the coke at this high temperature stage are instantly evaporated. Only as the temperature of coke lowers, or in the low temperature fringes of the initial quench period, might relative differences in vapor pressure for various contaminants be significantly expressed as variations in emission rates.

Table 3-3 presents information related to vapor pressures, boiling points, and melting points for a limited number of quench gas constituents. It was not possible to perform reliable correlations of vapor pressure and emission rate for the most abundant contaminant gases because of the few data points available. No vapor pressure data could be located for hydrogen cyanide. Reliable inlet concentration data was not available for sulfur dioxide because of the numerous sulfur-containing compounds which were presumably present in the inlet water. Sulfur analysis performed on inlet water was for sulfates only. Ammonia and phenol, two important contaminant gases, were measured both at inlet to the quench process and as stack emissions. The vapor pressure of ammonia is over two orders of magnitude greater than the vapor pressure of phenol at 100°C (comparative

509336

TABLE 3-3. VAPOR PRESSURES, BOILING POINTS, AND MELTING POINTS FOR VARIOUS COMPOUNDS FOUND IN QUENCH EMISSIONS

Compound	Melting Point (°C)	Boiling Point (°C)	Vapor Pressure in mm of Hg at Varying Temperatures (°C)				
			60°	100°	200°	300°	400°
Ammonia	-77.7	-33.35	6×10^{-4}	1.4×10^{-3}	--	--	--
Phenol	43	181.75	3.7×10^{-7}	3.2×10^{-6}	9.3×10^{-5}	6.6×10^{-4}	2.4×10^{-3}
Hydrogen Cyanide	-14.0	26.0	1.25×10^{-4}	--	--	--	--
Sulfur Dioxide	-72.7	-10	4×10^{-4}	1×10^{-3}	5×10^{-3}	1.3×10^{-2}	2.6×10^{-1}
Anthracene	216.2	342	--	.068	1.687	23.60	325.9
Phenanthrene	101	340.2	NA	NA	NA	NA	NA
Fluoranthene	110	250	NA	NA	NA	NA	NA
Pyrene	149	404	NA	NA	NA	NA	NA
Chrysene/Benzo (a) Phenanthrene	254	448	NA	NA	NA	NA	NA

509337

figures were not located for higher temperatures). If vapor pressure is a significant determinant of gaseous emissions at quench temperatures, ammonia should be enriched relative to phenol in the stack gases because of its high vapor pressure. This relationship was not found to exist. Rather, relative concentrations of these two compounds in the stack gases appeared to be similar to their relative inlet concentrations. This is illustrated in Table 3-4.

TABLE 3-4. RELATIVE CONCENTRATION (Ammonia/Phenol Ratio)

Clean Quench	
Quench Water	Stack Gas
28.3	7.0
Contaminated Quench	
Quench Water	Stack Gas
3.8	1.5

There is no indication, on the basis of these limited data, of ammonia enrichment due to its relatively high vapor pressure.

Correlations could not be established between vapor pressure and emission rates for PAH compounds because of the absence of published vapor pressure data for most of these compounds. Boiling point information was available for most polynuclear aromatic hydrocarbon (PAH) compounds. An inverse relationship usually holds between vapor pressure and boiling point for any given substance. Therefore, emission rates (lbs/quench) were plotted versus boiling points and a linear regression was run. The best fit line for these data points had a sufficiently low correlation coefficient to indicate that no relationship exists.

509338

A linear regression analysis was also performed for emission rates versus quench water concentration. A significant correlation was indicated in this relationship. As in the case of the major gaseous emissions, emission rates of PAH compounds appears to be more strongly related to inlet concentrations of these compounds than to vapor pressure (or boiling point).

3.2 Adsorptive Capacity of Coke

The coking process, which involves the distillation of coal in a low oxygen environment, drives off much of the volatile material in the coal. The resulting coke is "activated" in that there is a high potential for adsorption of soluble organics. There are several environmental factors which affect adsorption capacity of an activated carbon. These include the nature of the material to be adsorbed (such factors as solubility, molecular size, and polarity); the temperature and pH of the solution containing the material to be adsorbed; and properties of the carbon itself (such surface area).

Temperature and pH are particularly important factors in a consideration of adsorption by the coke. In general, a high pH value (approximately 9) will tend to inhibit adsorption in an activated carbon system. Contaminated quench water has a measured pH of approximately 8.5 due to ammonia in solution. Elevated temperatures also tend to decrease adsorption or even to cause desorption of organic materials.[1] In fact, baking or steam heating at temperatures of 1500°C is used to strip organic decomposition products from spent carbon adsorbents. There may be a net loss of organic material from the coke in this manner.

Clean quench water would not have the inhibitory effect on coke adsorption attributed to the elevated pH of contaminated quench water. Stream stripping would tend (as above) to remove

509339

tars and other decomposition products from interstices in the coke during the initial parts of the quench period. This stripping may expose pore openings and widen existing pores, further activating the carbon. Adsorption might occur on some of these sites as temperatures lowered during the quench.

3.3 Organic Emissions

A special testing scheme was developed to determine the amount, character, and origin of organic material emitted from the tower during quench operations. The sampling and analytical procedures used are described fully in Part II of this report. Basically, a porous polymer adsorbent was placed in the sampling train to trap organic materials. Infrared spectroscopic analysis was performed on a concentrated extract produced by liquid chromatographic separation. In addition, a separate mass spectroscopy scan for polynuclear aromatic hydrocarbons was performed. Grab samples of water (clean and contaminated) and coke were analyzed in a similar manner to obtain correlations between these and quench emissions.

The total organic emissions recorded were substantial, ranging over an order of magnitude from approximately 10 to 100 pounds per quench. The bulk of the organic material was aromatic in nature. However, polynuclear aromatic hydrocarbons (PAH) represent only a small weight percent of the total organic emission.

Analyses of water and coke samples show no clear trends in organic content or mass flow. This is not unexpected in view of the small number of samples and data points. Only one grab sample each of make-up, inlet, and return contaminated water was taken and analyzed, along with a composite sample of clean water. The available evidence does indicate, however, that total organic emissions are dependent more on

509340

the quality of coke or its processing conditions than on the quality of the quench water used. This is due to the lack of any systematic relationship between quench water quality (in terms of total organic content) and total organic emissions. Reliable organic data on coke is difficult to obtain because quenched samples, or even samples cooled by ambient air, may have an organic content significantly different from that of the incandescent coke as it enters the quench.

Table 3-5 presents the weights of organic material found in air, water, and coke samples, separated according to liquid chromatographic fraction. Certain compound types are associated with each of the eight fractions.

Aliphatic hydrocarbons are typical of Fraction 1 and are found there at expected concentrations. Aromatic hydrocarbons are characteristic of Fractions 2 and 3. Fractions 2 and 3 were heaviest for air emission samples, indicating the basic nature of the air emissions is aromatic. Also, aromatic hydrocarbon levels were greater than the MATE limits for both air and water samples.*

Fractions 4, 5 and 6 encompass the moderately polar compounds such as phenols, nitriles, aldehydes, and ketones. Concentrations of these fractions in air and water samples far exceeded the MATE limits. In addition, phthalates were repeatedly detected in Fractions 4,5, and 6. Phthalates have been discovered in other Level I type analyses and have been considered to be contaminants. However, the large amount of this material collected in these tests indicates that it is actually present in the quench tower.

*Minimum acute toxicity effluents (MATE's) describe approximate pollutant concentrations which should be harmless to humans. See Multimedia Environmental Goals for Environmental Assessment, Volume I, EPA-600/7-77-136a, November 1977.

509341

TABLE 3-5. ORGANIC COMPOUND TYPES FOUND IN QUENCH EMISSIONS (lb/quench)

Level I* Fraction	Contaminated Water Tests			Clean Water Tests		
	Air Emissions	Make-up Water	Quenched Coke	Air Emissions	Water Composite	Quenched Coke
1	.49	.008	.76	.34	.092	.33
2	.056	.003	.021	41.8	.019	.029
3	8.0	.18	.036	42.4	.058	.065
4	.62	.39	.07	9.4	.038	.047
5	.29	.83	.11	1.5	.28	.066
6	.87	.14	.04	.44	.023	.065
7	2.4	.47	.18	4.4	.30	.11
8	1.1	.016	.036	1.3	.022	.086
TOTAL	13.8	2.0	1.3	101.6	.83	.80

*Level I Fraction - refers to liquid chromatographic separation of the sample as in: LEVEL I PROCEDURES MANUAL, EPA Report No. EPA-600/2-76-160A, June 1976

509342

TABLE 3-6. POLYNUCLEAR AROMATIC HYDROCARBONS FOUND IN QUENCH EMISSIONS (lb/quench x 10^{-5})

Compounds	Contaminated Water			Clean Water		
	Air Emissions*	Make-up Water	Quenched Coke	Air Emissions**	Water Composite	Quenched Coke
Anthracene/ Phenanthrene	3.12	.246	2.97	1.82	.419	2.87
Methyl Anthracenes	1.27	.253	0.38	0.88	.347	0.38
Fluoranthene	1.63	.171	2.30	0.92	.358	2.30
Pyrene	1.22	.171	2.30	0.69	.337	2.20
Methyl Pyrene/ Fluoranthrene	0.93	ND	ND	0.56	.286	ND
Benzo(c) Phenanthrene	0.98	ND	ND	0.64	ND	ND
Chrysene/Benzo(a) Anthracene	1.34	ND	ND	0.67	.398	ND
Methyl Chrysenes	ND	ND	ND	0.06	ND	ND
Dimethylbenzo (a) Anthracene	ND	ND	ND	0.74	ND	ND
TOTAL:	10.49	.841	7.95	6.98	2.15	7.75

Chemical analyses were also performed for the following compounds, which were not detected (detection limit was 1 ng): Benzo Fluoranthenes, Benzo(a)Pyrene, Benzo(e) Pyrene, Perylene, Methylbenzopyrenes, 3-Methylcholanthrene, Indene (1,2,3-cd) Pyrene, Benzo (ghi) Perylene, Dibenzo (a,h) Anthracene, Dibenzo (c,g) Carbazole, Dibenzo (ai and ah) Pyrenes, and Coronene.

* (Results of one test)
** (Average of two tests)
ND Not detected

509343

Fractions 7 and 8 of the liquid chromatographic scan are characterized by strongly polar compounds. These compounds were detected at normal concentrations.

The issue of PAH compounds is an important one, despite the low levels of PAH emissions detected. This group of compounds contains numerous known or suspected human carcinogens which may be toxic even at extremely low levels. A number of PAH compounds were determined to be present in the stack emissions, water, and quenched coke, as presented in Table 3-6.

Direct comparisons of the organic levels found in air, water, and coke samples are not possible because so few tests were made. In addition, three separate samples (make-up, inlet, and return) were analyzed for contaminated water samples, whereas a single combined sample was analyzed for the clean water series. Contaminated make-up water values are presented here as an indication of the quality of water entering the quench process.

509344

4.0 SUMP EMISSIONS

It became apparent during the test program that the sump, which collects the quench water after the quenching is completed, could be a significant contributor to gaseous atmospheric pollution. More specifically, it could pose a health hazard to workers in the area. The elevated temperature of the sump liquor, and the sump's surface area (1662 ft^2) provide a source of gaseous effluent which diffuses gases on a 24-hour per day basis while the quench tower is operating. Emission rates for phenol and ammonia are presented in Table 4-1.

Since sump emissions are continuous, the rate is given as pounds per hour rather than the customary pounds per quench.

TABLE 4-1. SUMP EMISSIONS (lb/hr)

Compound	With Contaminated Quench Water	With Clean Quench Water
Ammonia	154.0	5.5
Phenol	0.63	0.001

The emission rates of these compounds were determined based upon the average temperature of the sump liquor, the individual compound's vapor pressure, and the exposed liquid surface area. The detailed calculations are presented in Part II - Appendix.

509345

5.0 BAFFLE EFFICIENCY

Previous efforts to characterize quench tower emissions and to evaluate the control efficiency of baffle systems used in quench towers have concentrated on large particles and droplets in the quench plume. Throughout the performance of this study, considerable effort was directed toward describing the size distribution of the particulate emissions through the application of specialized sampling and analytical methods. Attempts were made through the use of mathematical analysis to characterize the effectiveness of the tower baffle system at abating these emissions.

The presence of large droplets and particulate matter in quench emissions is well known. Various workers have used impaction measuring devices to indicate average particle sizes generally greater than 50-70 µm. However, large quantities of steam are readily observable in quench tower emissions, and such aerosol is known to range between 1-2 µm. At Lorain, visual evidence indicated that the plume approached saturation at peak periods of water flow. Specifically, the inside surface of the thick masonry walls of the stack were wet and dripping, and there was an obvious fallout of drizzle from the plume as it passed over any area. Other research efforts[2] have reported a median droplet size of 450 um for quench drizzle.

The baffle system installed at Lorain Quench Tower No. 1, which is described elsewhere in this report, is suitable primarily for the control of large sized particulate and droplets. This is due to the tendency of smaller particles entrained in a gas stream to be carried around a barrier or flow obstruction. The tendency of

509346

a particle (or droplet) in a gas stream to impinge on a barrier (baffle) is actually dependent on a number of factors, including particle diameter, particle density, relative velocity, gas viscosity, and the size and shape of the baffles. These factors are used to calculate the dimensionless separation number, N_s, which is related to the effective control efficiency of the baffle system for various sizes of droplets and particulate.

The values of impact efficiency calculated from the separation number indicate that the baffles have no significant effect on water droplets below 40 μm in diameter, or on particulate matter below 30 μm in diameter. However, the impact efficiency of droplets greater than 100 μm in diameter and particles greater than 70 μm in diameter would be greater than 70 percent. The average impaction efficiency for particulate matter is somewhat higher than that for droplets because the higher density of the particulate matter results in a greater separation number (N_s) and a higher impact rate.

It is apparent then, that earlier measurements of quench tower aerosols measured the fraction of the aerosol which is best controlled by the baffles. The smaller droplets and particulates which passed through the baffles and were found in the quench plume constituted a large percentage of the total stack emissions. In order to properly assess the control efficiency of the baffles, it was necessary to consider possible mechanisms of particle or droplet formation in the tower above and below the level of the baffles. The mechanisms considered included:

- Mechanical formation of droplets caused by turbulence and thermal shock near the nozzles and the coke.
- Formation of particulate matter by the violent break-up of the coke, and by evaporation of water containing dissolved solids.
- Agglomeration of small droplets into larger droplets.
- Condensation of vapor in the rising plume.

509347

Mechanical formation of droplets in the quench plume is a process confined mostly to the area below the baffles. Here, violent jets and turbulence would be expected to create droplets mechanically as the water left the distributive nozzles. The thermal shock created by the contact between hot coke and cold water would also cause the formation of some droplets. Above the baffles average air velocities would be too low to cause mechanical formation of new droplets.

Formation of particulate matter is also confined largely to that zone beneath the baffles where violent thermal shock and water agitation causes break-up of coke. Small sized particulate matter is formed here as dissolved solids are liberated by evaporating quench water. There is little chance that this mechanism is significant above the baffle level, as the nearly saturated nature of the plume would prevent additional evaporation.

It has been demonstrated mathematically that agglomeration of droplets takes place in the rising quench plume, resulting in the formation of larger droplets above the baffles. Small droplets in the quench plume rise more rapidly than large droplets. Therefore, the smaller droplets tend to overtake and collide with larger ones, resulting in some overall growth. The agglomeration of droplets above the baffle level tends to alter the apparent baffle efficiency by resulting in greater numbers of large droplets and fewer total droplets in the exiting plume.

In an effort to obtain further data on the possible condensation of water vapor in the tower, several temperature profiles of the tower were recorded. These measurements, plus the results of heat and mass balance indicate that ample water vapor was present in the stack to account for the cooling of the coke. Furthermore, there was not enough heat in the coke to have vaporized all of the water which was found in droplet form in the stack. Thus, much of these droplets had passed through the baffles as droplets rather than as vapor which was subsequently condensed. Finally, there

509348

is no evidence of heat release caused by vapor condensing to droplets on the way up the stack.

Tests conducted by IITRI [2] determined that substantial concentrations of dissolved salts are present in quench tower drizzle. This is an additional indication that the droplets are formed by mechanical entrainment of initial spray rather than by condensation of water vapor. Therefore, it is unlikely that condensation of water vapor has a significant effect on overall baffle efficiency.

Having established the likelihood that most of the quench aerosol was formed below the level of the baffles, it is appropriate to look at the mass rate and size distribution of the aerosol sampled above the baffles.

A number of interesting facts are apparent in the mass rate and size distribution data, when compared to the work of other researchers. The total particulate emission from the Lorain quench tower averaged from 2 to 20 times higher than typical measurements made by earlier workers (1.65 to 3.54 lbs per ton of coal versus 0.2 to 1.1 lbs per ton of coal) sampling only large sized particulate. However, the grit fraction (> 10 μm) collected in the large cyclone of the modified sampling train used at Lorain compares well with the work of earlier workers on baffled quench towers. It is the fine aerosol and dissolved solids, not sampled by other workers, which greatly boost the total particulate emission recorded at Lorain. The sampling train employed at Lorain did not always permit complete discrimination of dissolved solids and small particulate matter. However, these fractions were collected with a high overall efficiency. It is clear that these fractions were not adequately collected by previous sampling attempts.

Significantly, 99 percent by weight of the particles in the quench plume were found to be smaller than 35 μm in diameter. The

509349

average size of the particulate was approximately 4 μm in diameter. It has been demonstrated in mathematical terms that the control efficiency of the baffles for an aerosol of this size is very low. The small size of the aerosol in the plume after the baffles tends to confirm the theoretical calculations of the baffles' separation efficiency.

An engineering appraisal of the baffle system at Lorain No. 1 indicates that its collection efficiency (for both droplets and particulate) is limited by a number of factors. Because of a 1-inch vertical spacing between baffle slats and the absence of some baffle rows, 26 percent of the tower cross-sectional area is open to unimpeded flow. Even large particles and droplets would not be impacted here. A relatively low-pressure drop across the baffles was necessary in order to minimize fugitive emissions from the base of the tower and the average vertical velocity of the stack at the entrance to the baffles was only 16 feet per second, further reducing impaction efficiency as determined by the separation number.

Certain improvements in baffle collection efficiency could be achieved by careful baffle design and by increasing the pressure drop across the baffle system. There appears to be an inherent limit to a natural draft system. Fans could conceivably be used to provide additional pressure drop in conjunction with more closely spaced, thin-edged baffles. Undesirable fugitive emissions at the tower base might be reduced by enlarging the total cross-sectional area of the baffles.

The significance of this work in characterizing the mass rate and size distribution of the quench aerosol is particularly high in terms of environmental and possible health effects. Most of the large droplets and particulate matter measured in earlier quench tests would fall out in the immediate vicinity of the tower or plant. (In fact, some of the earlier tests consisted of measurements of fall-out adjacent to the tower.) Smaller particles,

however, have higher atmospheric residence times and become more widely distributed throughout the environment. These may compose significant threats to health. As reported by Stupfel[3] and Morrow,[4] particles larger than 10 μm are stopped in the nose and pharynx by inertia and impaction. Particles between 0.5-5.0 μm are deposited by sedimentation in the tracheobronchial tree and alveoli. Below 0.5 μm, particles penetrate into the alveoli by diffusion forces and Brownian movement. In addition, the bronchial bifurcations with their associated turbulent zones favor impact deposition at certain sites.

These environmental and health considerations, as well as the evidence presented in this paper concerning size distribution of the quench aerosol indicate the need for a renewed look at the emission control performance of quench tower baffle systems.

509351

6.0 RECOMMENDATIONS FOR EMISSION CONTROL

It has been established that quench tower emissions are primarily associated with the level of contaminants in the quench water, the thermal fracturing of the coke, and the oil pretreatment of the coal. To a lesser degree, gaseous diffusion from the car and the sump's surface contributes to the total process emissions.

Any attempt to control emissions from a natural-draft quench tower with a minimum of design and operational changes is limited to a few choices. A process change, such as eliminating the coal's oil pretreatment would have a positive effect. Design optimization of the baffle system would likely have a positive effect as well; but to a limited degree, since natural-draft places a limitation upon the degree of allowable impediment to the plume's flow. Or, put another way, the efficiency of baffles as droplet and particulate removal devices is a direct function of pressure drop, and the natural-draft concept does not provide much potential pressure drop.

The use of significantly cleaner water for quenching would have the effect in reducing emissions, but in accomplishing this, economic and environmental problems arise as to the disposition of the contaminated water. These problems are inherent in any plan which does away with the use of contaminated plant water (such as flushing liquor).

In the following Sections, the various options open for consideration are discussed. These range from relatively simple optimization of the existing system to alternative quench processes.

509352

6.1 Tower Design Improvements

There are three fundamental types of emissions that must be dealt with regarding the quench tower. These are:

- Particulate emissions
- Gaseous emissions
- Water vapor drift

In considering the basic natural-draft tower, the first two types of emissions are dealt with by a combination of baffles and sprays. Figure 6-1 shows the various designs of quench towers commonly in use. One of the more basic designs, which is in use at the Lorain Plant, is simply the use of water spray for quenching and a single set of baffles for large particulate and droplet removal. As is shown in Figure 6-1, it is possible to utilize secondary sprays for the removal of finer particulate matter and to effect a degree of gaseous removal. Dealing with water vapor drift is a problem not generally considered in the operation of conventional quench towers. Since this section is primarily concerned with modifications that could be made to the existing tower at a minimum of cost, the problem of mist elimination is discussed in a later Section dealing with other (and more sophisticated) equipment for emission control.

In the following subsections, the use of baffles and sprays are discussed.

6.1.1 Baffles

The quench process involves the cooling, over a short time period, of hot coke ($> 2000^{\circ}F$) to a temperature of about $200^{\circ}F$. This action produces violent rushes of gaseous and particulate emissions. Generally, the emissions and the cooling medium possess highly corrosive and contaminated properties. During the cooling period, entrainment of particulate matter occurs through mechanical and thermodynamic

509353

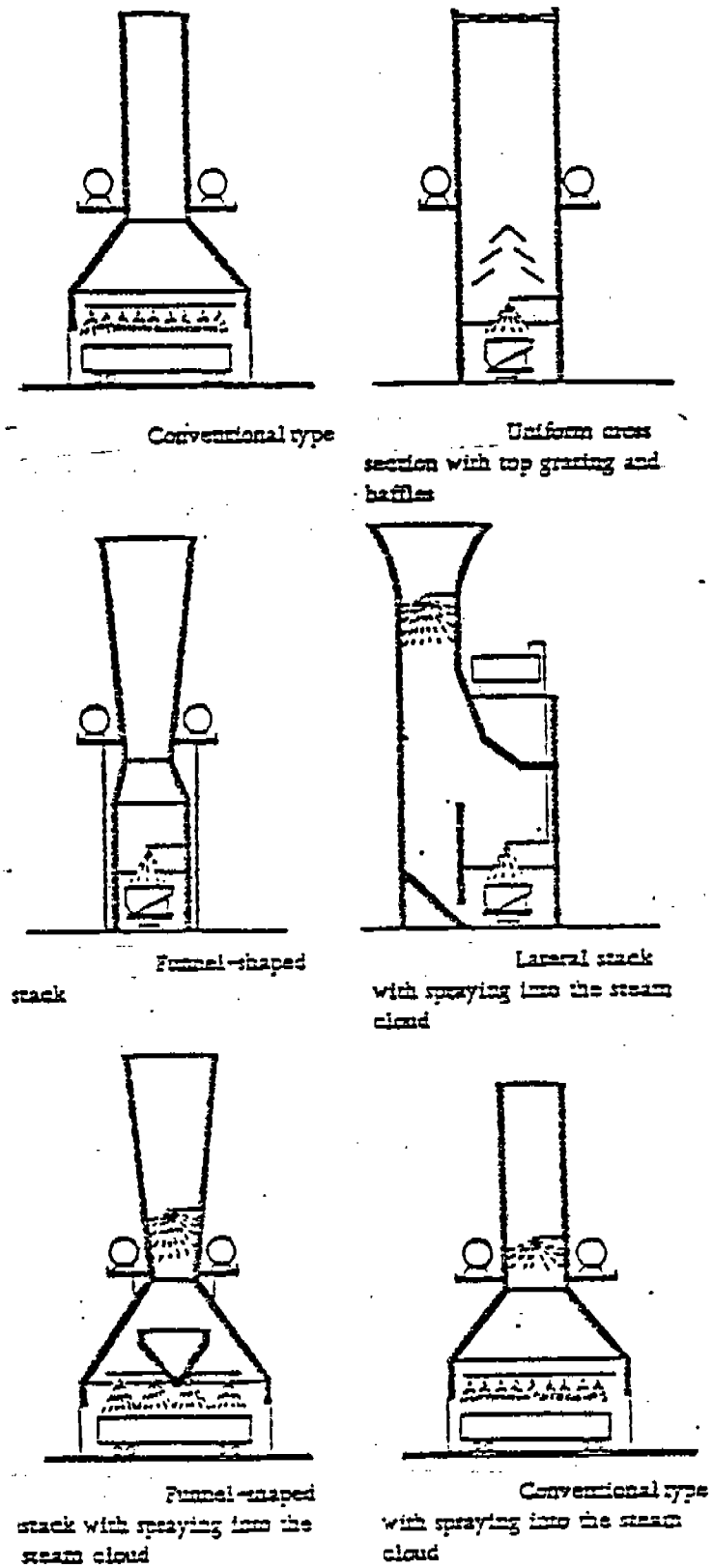


FIGURE 6-1

VARIOUS TYPES OF COKE QUENCHING TOWERS

(Reprinted from: Auswurf begrenzung von Staub beim Loschen von Koks Kokereien und Gaswerke)

509354

processes. Collection of droplets within the gas stream causes further growth. The baffle impingement system must be designed to maintain a balance between maximum pressure drop across the baffles (increasing removal efficiency), and minimum impediment to up-stack flow. If this latter is significant, excessive emissions will be emitted through the car entry and exit doors. Obviously this feature is the major controlling factor with a natural-draft system.

6.1.2 Sprays

The primary purpose of the water spray system in the quench tower is to quench the incandescent coke - i.e., to reduce the coke's temperature at such a rate as to retard further oxidation while maximizing product recovery. For the purpose of emission control, the spray may be used on the exiting plume to remove particulate matter and some gaseous content. To evaluate this method, it is necessary to re-examine what is desired from an efficiently run quenching operation.

Such an operation would provide the following:

- Mean coke moisture at 2-4 percent.
- Uniform moisture within the coke batch.
- Minimized water use.
- Minimized quench duration.
- Maximize the coke's mechanical strength.
- Minimize the quantity of breeze (grit).
- Minimum expended energy.

The spray system can effect the amount of the pollutants in a number of ways. If the sprays are located too high in the tower or are set to atomize the water into fine droplets, the possibility exists that some of the droplets will evaporate prior to reaching the coke. The material present in the quench water as

509355

suspended or dissolved solids, therefore, will to some extent be directly entrained in the gas stream and carried out of the tower. A second mechanism of pollution generation is from water spray impaction. A spray having a high velocity as it reaches the coke could directly entrain material by collision. A third mechanism is normal off-gassing and breeze entrainment from the incandescent coke as it enters the tower but prior to quenching. Proper timing of the spray system is a factor here. Finally, there is the mechanical weakening and subsequent grit generation caused by the impact of the water on the coke itself.

In a similar manner, the type of pollutants which are generated in a quenching operation are governed somewhat by the spray system. Fine atomization of the spray might enable the oil-derived or organic based portion of the spray water to be directly entrained depending upon the droplet size produced (a function of the surface tension of the oil or organic based droplets as well as physical parameters of the spray system). Carbon will be the main constituent of coke grit generated by spray impaction.

As has been previously discussed, a problem not commonly dealt with is that of mist elimination or water vapor drift. Where contaminated water is used, the plume contains suspended and dissolved solids; many of which are potentially injurious to the public health and welfare. In addition, these substances cause rapid and extensive corrosion of plant equipment.

6.2 Emission Control Equipment

In the following Sections, mist elimination techniques are discussed, as well as a more unorthodox method for particulate and gas removal - scrubbers. The latter,

509356

when provided with sufficient mist elimination capabilities, may provide an alternative method of emission control.

6.2.1 Mist Elimination

Mist control devices must be designed in accordance with the specific type of mist encountered. The following, excerpted from Stern[5], summarizes mist classifications:

- Mist, as defined, generally refers to liquid droplets which range in size from less than one micrometer to several millimeters.
- Droplets less than one micrometer are formed by nucleation and condensation of vapor.
- Larger droplets are formed by the bursting of bubbles, entrainment from surfaces and sprays, or, splash-type liquid disturbances.
- Smaller droplets are spherical in geometry, maintaining shape due to their liquid surface tension. Larger droplets (droplets greater than 1 micrometer), however, are spherical, changing between oblate to prolate, relative to their direction of motion.
- The size and stability of the mists depend on their method of formation, and on such factors as temperature, humidity, and the presence and frequency of solid nuclei.

Mist droplet collection from a gas stream is basically the same as solid particle collection, but there are some simplifying features. Small mist droplets are always spherical. Therefore, theories developed from spherical particles can be applied without modification. The mist eliminator devices most commonly used in pollution and process controls are cyclones, wire mesh, and to an increasing extent, impingement vanes. When comparing the relative merits of these

509357

three types, the impingement type exhibits the following advantages:

- Higher efficiency for droplets 10 μm and above.
- High liquid loading capacity.
- Low pressure drop at high velocity.
- High efficiency over wide velocity range.
- Very low clogging risk.

Impingement eliminators are curved profile blades, which are so arranged as to create separate parallel flow channels. The elimination process can be divided into three stages, namely:

1. Gas flow is divided
2. Inertial force on droplets from deflection of gas stream causes droplets to impinge on profiles and form a liquid film.
3. Liquid film is forced toward phase separating chambers (hooks) by the force of the gas stream. The force becomes ineffective due to low pressure area in front of phase separator (hook) and the liquid then drains by gravity.

The unique phase separating feature not only permits liquid separation, but reduces turbulence and pressure loss, and prevents droplets from being re-entrained. These devices would be subject to corrosion and plugging problems, but their application in quench towers might be worthy of investigation.

6.2.2 Scrubbers

It would be beyond the scope of this work to discuss in any detail all the possible applications of the available add-on control devices. However, it seems appropriate to briefly discuss one possibility; i.e., scrubbers. It would require a great deal of investigation to select the particular scrubber type for the quench process. To be considered in

509358

this decision-making process would be the costs associated with maintenance due to the highly corrosive nature of the effluent and the problems associated with removing the particulate matter to prevent plugging of the gas passages.

Available data show that over half of the scrubbers used for eliminating gases (i.e. H_2O acrylic monomers, Formaldehyde, HF, N_2O_4, SO_x, NH_3) are packed towers. The efficiency of packed tower scrubbers are in the high range (99.9%) for many gases. Packed towers are also very efficient in eliminating liquid mist.

A packed tower scrubber consists of a hollow tower containing manufactured elements such as Raschic rings, Pall rings, Intalox saddles, or other home-made packing such as crushed rocks. Liquid is usually introduced at the top of the tower and trickles down through the packing element. The packing reduces the liquid to a film with high surface area. The gas stream flows up through the packing from the bottom or countercurrent to the liquid. Packed towers are often used for mass transfer operations and are able to remove pollutant gases to any concentration. The main problem is economic however, for the better the separation needed, the greater the packing depth and the higher the pressure drop. For quench tower applications, baffles would be required to remove some of the larger particulate matter. Several scrubbers in parallel would allow frequent back washing to minimize plugging. Mist elimination would be needed as a final step before discharge of the cleared gases to the atmosphere.

509359

Although the exhaust gases would be free of particulate matter and gases such as ammonia,phenol and cyanide, there would remain the problem of disposing of the collected pollutants which would now be contained in the scrubber liquids. In addition the corrosion and plugging problem and additional operating costs such as fan and pump energy costs would need to be compared to other possibilities, such as dry quenching that is discussed in a subsequent section.

6.3 Quench Water Treatment

The quantity of emissions has been shown to be directly related to the quality of the quench water. Quenching with clean or cleaner water would reduce these emissions.

Water returning from the quench process carries suspended solids which enter the sump. These settle out to some extent depending on the size, shape, and mass of the particle. There are two commonly used methods for removing these particles, and these are generally used in combination. The first method consists of a sieve, or membrane such as a screen or filter which retains a certain size component and lets others pass. The second method utilizes the rate of sedimentation of particles as they move through a liquid.

Filtration is removal of solid particles from a fluid by passing the fluid through a filter medium. Liquid-solid filters are divided into four groups depending on the service they perform: strainers, clarifiers, coke filters and filter thickeners.

Coarse substances suspended or floating in water can be removed by straining or screening from flowing water. Applicable screening devices are:

- Racks or bar screens.
- Perforated plate or fine screen.

These are generally rotated through a back-wash cycle. Another method involves the sedimentation rate.

For a rectangular basin with unhindered settling, the efficiency of the basin is a function of the settling velocities of the particles, the depth and surface area of the basin, and the detention time of the sump liquid in the basin. Efficiency is reduced by the following:

- Eddy currents set up by incoming fluid.
- Wind induced currents.
- Thermal convection currents.
- Density currents caused by the addition of cold water.

In order to design a basin with optimum efficiency, a thorough study of particle characteristics must be undertaken. The above is a summary of the principles involved necessary to remove particles prior to reuse of contaminated quench water.

Removal of chemical contaminants in coke plant flushing liquors can also be accomplished. One method is biological treatment which utilizes aerobic or anaerobic micro-organisms specific to the contaminant. The chemicals are metabolized and the micro-organisms collected, thus removing the substances from the liquor.[6]

Given the proper concentration (less than 500 to 700 mg/l) phenol can easily be removed (sometimes up to 99.8 and 99.9 percent) via biological treatment. Ammonia concentration should be below 1800 to 2000 mg/l. Higher concentrations must be diluted or reduced by other processes. High con-

509361

centrations of thiocyanates and cyanides can also cause treatment problems but up to 4300 mg/l can be successfully degraded when a catalyst such as phenol or dextrose is present. Lowering the pH also leads to greater thiocyanate removal.

Another method of phenol removal is through adsorption by granular activated carbon. Research has been done by Zogorski and Faust[7] on this method and it was found to be quite successful. Only one phenolic compound (2,4-dichlorophenol) was used in tests and the results may or may not hold for other phenols. As long as conditions for adsorption are optimized, efficient removal of phenols should be accomplished via carbon filters of three to five feet in depth. The used carbon must then be disposed of.

6.4 Alternate Quenching Processes

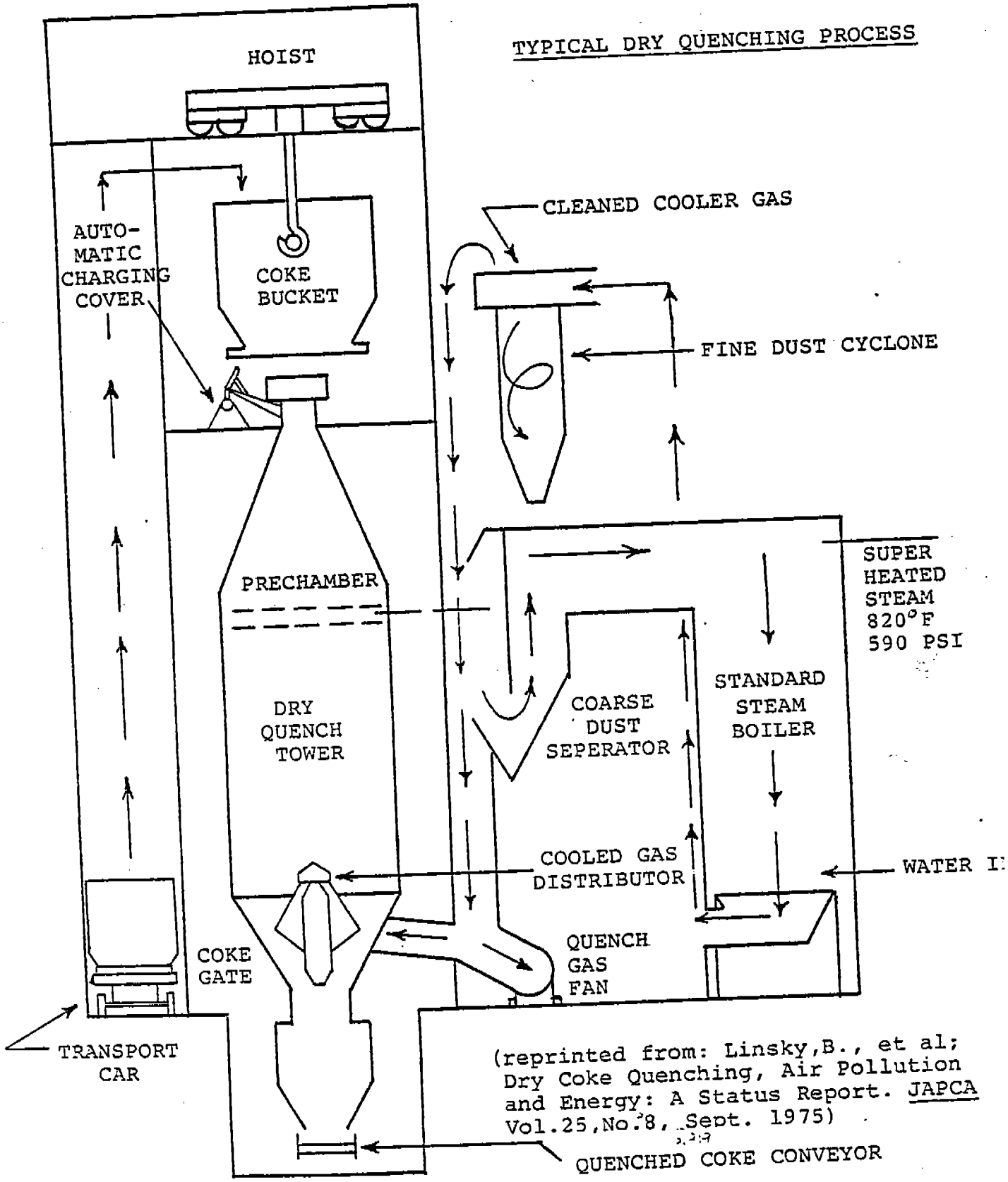
6.4.1 Dry Quenching

Dry quenching is a process that has been in use in Europe for many years, and several facilities are currently being constructed in Japan.

In dry coke cooling, (Figure 6-1), practically inert gas is continuously recirculated through a vertical refractory-lined bunker where the incandescent coke is cooled. The heat recovered can be used for any of the following applications:

- Process steam
- Process electricity
- Preheat combustion air
- Preheat coal
- Dry coal
- Preheat feedwater

509362



(reprinted from: Linsky,B., et al; Dry Coke Quenching, Air Pollution and Energy: A Status Report. JAPCA Vol.25,No.8, Sept. 1975)

509363

FIGURE 6-2

Incandescent coke, at a temperature ranging between about 1750° - 2100°F, is collected in a closed transfer basket and carried to the top of the cooling bunker. The bunker is charged in such a manner that the coke passes into the bunker without discharging dust into the atmosphere. For a period of approximately 3-4 hours, the cooling gas passes through the coke. During this period, the cooling gas is heated from about 300°F to more than 1200°F, while the coke is cooled to less than 400°F. The cooled coke is discharged through a lock system in order to avoid losses of the cooling gases.

The cooling gas passes through multicyclones for removal of dust to protect the blowers in the re-circulation system. This coke dust is withdrawn at several points and is collected in a dust silo.

Dry coke quenching provides the following advantages:

- It controls air pollution emissions.
- It causes no water pollution.
- Energy recovery is a feasible by-product.
- It produces dry coke of uniform size.
- It reduces breeze, and thus increases usable coke output by 2-3 percent.

It also involves the following disadvantages:

- Relatively high capital cost.
- It is a potential explosion hazard.

6.4.2 PCT Process

Other quench processes may be available and could be considered, such as the PCT process; a non-recovery type, that takes partially burned combustion products

509364

and burns them to contribute to coking heat. Quench emissions, also, are reportedly heated to about 1800°F in the consumption furnace. Most of the chemical compounds typically found in quench waters would be oxidized. The nature of such oxidized pollutants remains to be investigated.

509365

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509366

APPENDIX A

STATISTICAL METHODS

509367

Statistical Methods

Figure 1 - Total Quench Tower Particulate Emissions vs. dissolved solids in quench water.

The linear relationship between these two parameters is characterized by the following equations:

SSE = Error sum of squares = $\sum(Y_i - \hat{Y}_i)^2 = 9.5521$

MSE = Error Mean square = $\frac{SSE}{n-2} = 0.4342$

SSE indicates the sum of the differences squared between the observed Y_i and calculated Y_i.

MSE is the estimate of the variance of the errors of observation.[1]

[1] Statistical Analysis System, Mark III Foreground Service User's Guide, Revision C, General Electric Co., Dec. 1975 pp. 261-265

509368

X_i	Y_i	$\hat{Y}_i$	SSE $(Y_i-\hat{Y}_1)^2$	$(X_i - \bar{X})^2$
13.54	3.05	3.83	.6115	61.31
5.84	2.1	2.45	.1225	.02
10.8	2.63	3.34	.5044	25.91
14.47	3.12	4.00	.7725	76.74
10.95	2.98	3.37	.1499	27.46
13.59	4.51	3.84	.4476	62.09
11.13	3.03	3.40	.1365	29.38
8.69	3.01	2.96	.0192	8.88
7.49	2.35	2.75	.1570	3.17
8.27	4.64	2.89	3.0760	6.55
20.44	5.97	5.07	.8093	216.97
1.06	2.12	1.59	.2786	21.62
1.03	1.53	1.59	.0032	21.90
1.32	2.17	1.64	.2822	19.27
0.99	1.83	1.58	.0627	22.28
1.01	2.36	1.58	.6035	22.09
0.29	1.60	1.45	.0213	29.38
0.32	1.17	1.46	.0837	29.05
0.45	0.98	1.48	.2527	27.67
0.85	1.95	1.55	.1564	23.62
0.58	0.76	1.51	.5565	26.32
1.24	1.15	1.62	.2251	19.98
1.25	1.23	1.63	.1570	19.89
1.49	1.92	1.67	.0628	17.81
137.09	58.16	58.25	9.5521	819.36

$\bar{X} = 5.71$ $\bar{Y} = 2.42$ $\bar{Y} = 2.43$

509369

Calculations of Confidence Limits of Linear Regression

Estimated variance of regression coefficient

$$S^2 = MSE \left[\frac{1}{n} + \frac{\bar{X}^2}{(X_i - \bar{X})^2} \right]$$

$$= 0.4342\ (1/24 + 32.60/819.36)$$
$$= 0.4342\ (.0417 + .0398)$$
$$= .0354$$

Estimated variance of slope coefficient

$$S^2_{\hat{b}} = \frac{MSE}{(X_i - \bar{X})^2}$$

$$= .4342/819.36$$
$$= .000530$$

Variance of an estimate (Y)

$$S^2_{\hat{Y}} = MSE \left[1 + \frac{1}{n} + \frac{(X - \bar{X})^2}{(X_i - \bar{X})^2} \right]$$

$$= .4342 \left[1.0417 + \frac{(X-5.71)^2}{819.36} \right]$$

Student's t-distribution value for k = 22 degrees of freedom and 95% limits is equal to 2.074

509370

Table of Confidence Limits for Linear Regression

	Quantity	Estimated Variance	Lower Limit	Upper Limit
	a	.0354	1.01	1.79
	b	.000530	.131	.227
$\hat{Y}$				
1.40	Y (X = 0)	.4696	-.02	2.82
1.58	(X = 1)	.4640	.17	2.99
1.76	(X = 2)	.4596	.35	3.17
2.12	(X = 4)	.4539	.72	3.52
2.47	(X = 6)	.4524	1.08	3.86
2.83	(X = 8)	.4551	1.43	4.23
3.19	(X = 10)	.4621	1.78	4.60
3.55	(X = 12)	.4733	2.12	4.98
3.91	(X = 14)	.4887	2.46	5.36
4.26	(X = 16)	.5084	2.78	5.74
4.62	(X = 18)	.5323	3.11	6.13
4.98	(X = 20)	.5605	3.43	6.53

509371

Figure 2 - Total Quench Tower Particulate Emissions less acetone wash and filterable cyclone solids vs. dissolved solids in quench water.

The linear relationship between these two parameters is studied through the following methods: the estimated variance of observed Y_i about the mean $\bar{Y}$ (Total Mean Square), the estimated variance of calculated $\hat{Y}_i$ about the mean $\bar{Y}$ (Regression Mean Square), and the estimated variance of the errors of observation ($Y_i - \hat{Y}_i$, Error Mean Square). Also shown are calculations for the confidence limits of the linear regression.

Analysis of Variance Table

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Total	23	27.443	1.193
Regression	1	25.256	25.256
Error	22	2.225	.1011

$$F \text{ ratio} = \frac{MSR}{MSE} = \frac{25.256}{0.1011} = 249.81$$

with 1 degree of freedom in numerator
with 22 degrees of freedom in denominator

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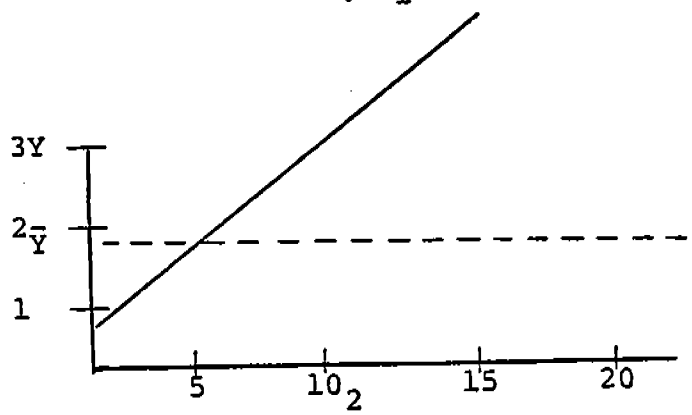
Analysis of Variance Calculations

SST = total sum of squares = $\sum(Y_i - \bar{Y})^2 = 27.443$



SSR = regression sum of squares = $\sum(\hat{Y}_i - \bar{Y}) = 25.256$

SSE = Error sum of squares = $\sum(Y_i - \hat{Y}_i)^2 = 2.2249$

MSE = Error Mean Square = $\frac{SSE}{N-2} = 0.1011$

MST = Total Mean Square = $\frac{SST}{n-1} = 1.193$

MSR = Regression mean square = SSR = 25.256

Index of determination = $\frac{SSR}{SST} = 0.9190$

Correlation Coefficient = 0.9586

509373

Xi	Yi	$\hat{Y}i$	SSR $(\hat{Y}_i-\bar{Y})^2$	SST $(Yi-\bar{Y})^2$	SSE $(Yi-\hat{Y}i)^2$	$(Xi - \bar{X})$
13.54	2.73	2.94	1.904	1.369	.0429	61.31
5.84	1.6	1.59	.001	.002	.0002	.02
10.8	2.42	2.46	.810	.740	.0013	25.91
14.47	2.88	3.10	2.372	1.742	.0485	76.74
10.95	2.07	2.48	.846	.260	.1703	27.46
13.59	3.09	2.95	1.932	2.34	.0208	62.09
11.13	2.08	2.51	.903	.270	.1886	29.38
8.69	2.22	2.09	.281	.436	.0180	8.88
7.49	2.13	1.88	.102	.325	.0650	3.17
8.27	3.07	2.01	.203	.2280	1.1183	6.55
20.44	1.26	4.15	6.788	7.290	.0126	216.97
1.06	0.69	.75	.656	.757	.0033	21.62
1.03	0.39	.74	.672	1.370	.1241	21.90
1.32	0.92	.79	.593	.410	.0161	19.27
0.99	0.76	.74	.672	.540	.0006	22.28
1.01	1.1	.74	.672	.212	.1304	22.09
0.39	0.74	.61	.902	.672	.0162	29.38
0.32	0.79	.62	.884	.593	.0297	29.05
0.45	0.29	.64	.846	1.613	.1230	27.67
0.85	0.71	.71	.723	.723	.0001	23.62
0.58	0.55	.66	.810	1.020	.0129	26.32
1.24	0.65	.78	.608	.828	.0167	19.98
1.25	0.53	.78	.608	1.061	.0630	19.89
1.49	0.86	.82	.548	.490	.0014	17.81
137.09	37.53	37.54	25.256	27.443	2.2249	819.36

$\bar{Y}$=1.564

5.712 = mean value of X

509374

Calculation of Confidence Limits of Linear Regression

Estimated variance of regression coefficient $= S_a^2 = MSE \left[\frac{1}{n} + \frac{\bar{X}^2}{\sum(X_i - \bar{X})^2} \right]$

$$= .1011 \left[\frac{1}{24} + (32.60/819.36) \right]$$

$$= .1011 \quad (.0417 + .0398)$$

$$= .0082$$

Estimated variance of slope coefficient, $\hat{b}$

$$s_{\hat{b}}^2 = \frac{MSE}{\sum(X_i - \bar{X})^2}$$

$$= .1011/819.36$$

$$= .000\ 1233$$

Variance for the mean of the estimates $(\hat{Y}_M)$

$$S_{\hat{Y}M}^2 = MSE \left[\frac{1}{n} + \frac{(X-\bar{X})^2}{\sum(X_i-\bar{X})^2} \right]$$

$$= .1011 \left[\frac{1}{24} + \frac{(X-5.71)^2}{819.36} \right]$$

Variance of an extimate (Y)

$$S_{\hat{Y}}^2 = MSE \left[\frac{1}{n} + 1 + \frac{(X-\bar{X})^2}{\sum(X_i - \bar{X})^2} \right]$$

$$= .1011 \left[1 + \frac{1}{24} + \frac{(X-5.71)^2}{819.36} \right]$$

Student's t-distribution value for K = 22 degrees of freedom and 95% limits is equal to 2.074

509375

TABLE OF CONFIDENCE LIMITS FOR LINEAR REGRESSION

	Quantity	Estimated Variance	Lower Limit	Upper Limit
	a	.0082	.374	.7498
	b	.0001233	.1520	.1980
$\hat{Y}$				
.562	Y_{M3} (X=0)	.00824	.374	.750
.737	(X=1)	.00695	.564	.910
.912	(X=2)	.00591	.753	1.071
1.262	(X=4)	.00458	1.122	1.402
1.612	(X=6)	.00423	1.477	1.747
1.962	(X=8)	.00486	1.817	2.107
2.312	(X=10)	.00649	2.195	2.479
2.662	(X=12)	.00909	2.464	2.860
3.012	(X=14)	.01270	2.778	3.246
3.362	(X=16)	.01728	3.089	3.635
3.712	(X=18)	.02285	3.400	4.026
4.062	(X=20)	.02941	3.706	4.418
$\hat{Y}$				
.562	Y (X=0)	.1093	.124	1.25
.737	(X=1)	.1080	.055	1.42
.912	(X=2)	.1070	.234	1.59
1.262	(X=4)	.1057	.590	1.94
1.612	(X=6)	.1053	.940	2.28
1.962	(X=8)	.1060	1.29	2.64
2.312	(X=10)	.1076	1.63	2.99
2.662	(X=12)	.1102	1.97	3.35
3.012	(X=14)	.1138	2.31	3.71
3.362	(X=16)	.1184	2.65	4.07
3.712	(X=18)	.1240	2.98	4.44
4.062	(X=20)	.1310	3.31	4.81

509376

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EVALUATION OF QUENCH TOWER EMISSIONS
PART II

by

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Contract No. 68-01-4138
Task No. 3

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509377

CONTENTS

Section		Page
1.0	INTRODUCTION	1
1.1	Process Description	1
1.2	Background	14
1.3	Test Program	17
1.3.1	Site Selection	18
1.3.2	Equipment Modifications	18
1.3.3	Pre-Test Survey	19
1.4	Discussion of Results	20
2.0	TEST PROCEDURES AND PRECISION	33
2.1	Test Objective	33
2.2	Sampling Problems	34
2.3	Phases of the Study	38
2.3.1	Quench Tower Selection	38
2.3.2	Sampling Equipment Design	39
2.3.3	Preliminary Field Tests	41
2.3.4	Sampling Technique	45
2.3.5	Test Sequence	45
2.3.6	Full Field Test	47
2.3.7	Sample Recovery-Particulate Tests	56
2.3.8	Laboratory Analysis	58
2.3.9	Precision and Accuracy	63
2.3.10	Calculations	70
3.0	STACK FLOW DYNAMICS	73
3.1	Background and Effect of Velocity on Reproducibility	74
3.2	Field Tests	78
3.3	Data Analysis	78
3.4	Angular Velocities	81
3.5	Fugitive Emissions	85
3.6	Ambient Weather Conditions	106
4.0	STACK EMISSION RESULTS	109
4.1	Mass Rate and Concentration	116
4.2	Chemical and Physical Composition	178
4.2.1	Physical Characteristics	178
4.2.2	Chemical Characteristics	226
4.3	Sampling and Analysis of Organic Emissions	274
4.3.1	Summary	274

509378

CONTENTS (Continued)

Section		Page
4.3.2	Conclusions	274
4.3.3	Results	275
4.3.4	Data Presentation	283
4.3.5	Sampling and Analysis	296
4.3.6	Calculations	301
5.0	WATER FLOW AND CONTAMINATION PARAMETERS	303
5.1	Water Flow	306
5.1.1	Water Balance	306
5.1.2	Thermodynamics of the Process	335
5.2	Water Contamination	349
5.2.1	Sump Emissions	378
5.2.2	Sump Sediment	378
5.2.3	Water Supply	385
6.0	SOURCE PROCESS PARAMETERS	397
6.1	Coal and Coke Quality	398
6.2	Battery Operation	413
6.3	Baffles	428
	APPENDIX	
A.	Films	
B.	Plant Drawings	
C.	Calculations of Sump Emissions	
D.	Field Data Sheet	
E.	Project Participants	
F.	Instrument Specifications	

509379

FIGURES

		Page
1-1.	DIAGRAM OF LORAIN COKE PLANT CONTAMINATED QUENCH WATER SYSTEM	4
1-2.	QUENCH CAR WITH INCANDESCENT COKE ENTERING THE QUENCH TOWER	5
1-3.	QUENCH TOWER PLUME SHOWING QUENCH WATER FLOW AND TEST PLATFORM	6
1-4.	"CAR IN"	7
1-5.	"WATER ON"	8
1-6.	START OF QUENCH WATER FLOW	9
1-7.	FUGITIVE EMISSIONS A FEW SECONDS BEFORE THE UP-STACK DRAFT IS WELL ESTABLISHED	10
1-8.	1-9, 1-10. THREE VIEWS SHOWING THE FIRST ERUPTION OF STEAM (TAKEN 2-3 SECONDS APART)	12
1-11.	THE STACK FLOW WELL ESTABLISHED, ABOUT 10 SECONDS AFTER "WATER ON"	13
2-1.	HIGH VOLUME (AEROTHERM) PARTICULATE SAMPLING TRAIN AND VELOCITY TRAVERSE AND MASS SAMPLING LOCATIONS	40
2-2.	STACK VELOCITY DURING FOUR TYPICAL QUENCHES	43
2-3.	SAMPLE POINT LOCATION	46
3-1.	CONCEPTUAL VELOCITY PROFILE	75
3-2.	CONCEPTUAL VELOCITY PROFILE	76
3-3.	TYPICAL VELOCITY AND SAMPLING RATE PROFILES	77
3-4.	ANGULAR FLOW DETECTOR	82
3-5.	VELOCITY CROSS-SECTION	83
3-6.	VELOCITY CROSS-SECTION	84
3-7.	QUENCH TOWER LAYOUT -9/10	92
3-8.	QUENCH TOWER LAYOUT -9/11	93
3-9.	QUENCH TOWER LAYOUT-9/12	94
3-10.	QUENCH TOWER LAYOUT-9/13	95
3-11.	QUENCH TOWER LAYOUT-9/14	96
3-12.	QUENCH TOWER LAYOUT-10/5	97
3-13.	QUENCH TOWER LAYOUT-10/7	98
3-14.	QUENCH TOWER LAYOUT-10/9	99
3-15.	QUENCH TOWER LAYOUT-10/29	100
3-16.	QUENCH TOWER LAYOUT-10/30	101

509380

FIGURES (Continued)

		Page
3-17.	QUENCH TOWER LAYOUT-11/1	102
3-18.	QUENCH TOWER LAYOUT-11/2	103
3-19.	QUENCH TOWER LAYOUT-11/3	104
4-1.	SAMPLE POINT LOCATION	118
4-2.	SIZE DISTRIBUTION OF PARTICLES COLLECTED BY CYCLONE, PROBE, FILTER, AND IMPINGER	188
4-3.	COMPARING SIZE DISTRIBUTION OF PARTICLES COLLECTED BY CYCLONE, PROBE, FILTER, AND IMPINGER DURING "DIRTY" WATER TESTS VS. "CLEAN" WATER TESTS, AND COMBINED RESULTS.	189
4-4.	D_{50} CUT POINT IN MICRONS VS. CUBIC FEET PER MINUTE FOR 3 SIZES OF CYCLONES	191
4-5 -	THROUGH 4-9. PARTICLE SIZE ANALYSIS BY COULTER COUNTER	194-198
4-10.	SHUTTER APPARATUS TO EXPOSE SENSITIVE PAPER TO THE DROPLETS RISING IN THE QUENCH TOWER	203
4-11.	DROPLET MEASUREMENT INSIDE THE QUENCH TOWER AT THE TEST PLATFORM	204
4-12.	DROPLETS MEASURED INSIDE THE QUENCH TOWER AT THE TEST PLATFORM BY KLD COUNTER	206
4-13 -	THROUGH 4-18. PARTICLE SIZE ANALYSIS BY COULTER COUNTER	220-22
4-19.	GASEOUS EMISSION TRAIN, EPA METHOD 6 AS MODIFIED	232
4-20 -	THROUGH 4-34. ENRICHMENT FACTORS	258-27
4-35.	TOTAL WEIGHT OF ORGANIC EMISSIONS	278
4-36.	STACK EMISSIONS	279
4-37.	TOTAL WEIGHT OF POM's IN EACH MEDIUM FOR CONTAMINATED AND CLEAN WATER IN USE	282
4-38.	SAMPLING TRAIN	297
4-39.	ADSORBENT SAMPLING SYSTEM	298
5-1.	WATER BALANCE	307
5-2.	CLAMPITRON TRANSDUCER LOCATIONS	311
5-3.	WATER PIPING INDICATING LOCATION OF FLOW MEASURING TRANSDUCER	312
5-4.	TRANSDUCER INSTALLED AT 2	323
5-5.	DIMENSIONS OF SUMP QUENCH TOWER NO. 1	327
5-6.	CLASSES, GALLONS (BY TEST CODE)	330

509381

FIGURES (CONTINUED)

		Page
5-7.	NO. 1 SUMP SHOWING DAM/SCREEN SEPARATING THE SETTLING CHAMBER (FOREGROUND) FROM THE PUMP SUPPLY PIT (BACKGROUND)	332
5-8.	FLOAT CONTROLLED VALVE ON THE FLUSHING LIQUOR SUPPLY LINE TO THE MAKE-UP	334
5-9.	THERMODYNAMICS	337
5-10 -	THROUGH 5-13. STACK TEMPERATURE PROFILE	339-342
5-14.	LOCATION OF THERMOCOUPLES ON STACK	344
5-15.	LOCATION OF THERMOCOUPLES (TC) ON STACK	345
5-16.	PROCESS FLOW	350
5-17.	CONTAMINANTS	359
5-18.	SUMP EMISSIONS - CAR ENTERING	379
5-19.	SUMP EMISSIONS	380
5-20.	SUMP SHOWING DAM	383
5-21.	SUMP	384
5-22.	PLANT PLAN	386
6-1.	DEVIATION OF SECONDARY OBSERVERS' RATINGS FROM PRIMARY OBSERVER'S RATINGS	423
6-2.	SERVICE AND PROCESS WATER - COKE PLANT	424
6-3.	PROCESS FLOW DIAGRAM	425
6-4.	BAFFLES	429
6-5.	OPEN AREA BETWEEN BAFFLES	430
6-6.	BAFFLE FLOW PATTERN	431
6-7.	BAFFLES	432
6-8.	BAFFLES	433
6-9.	VIEW UP THE TOWER, LOOKING THROUGH THE BAFFLES	435
6-10.	QUENCH TOWER	437
6-11.	STREAMLINES AROUND CYLINDER	438
6-12.	STREAMLINES AROUND A PLATE	439
6-13.	STREAMLINES USING A DYE IN WATER	440
6-14.	TARGET EFFICIENCY OF IMPINGEMENT	443
6-15.	BAFFLE EFFICIENCY OF WATER DROPLETS AND PARTICULATE VS. SIZE	444

509382

TABLES

		Page
1-1.	COMPARISON OF LORAIN DATA WITH PRE-EXISTING DATA	20
1-2.	SUMMARY OF QUENCH EMISSION TEST RESULTS	21
1-3.	NOMINAL QUENCH WATER CONTAMINANT CONCENTRATIONS AND MASS RATES	27
1-4.	SUMMARY OF WATER FLOWS	28
1-5.	DISSOLVED SOLIDS BALANCE	29
2-1.	POTENTIAL PROBLEMS AND SOLUTIONS IN TESTING QUENCH TOWER EMISSIONS	36-37
2-2.	SUMMARY - PARTICULATE EMISSION TESTS	49
2-3.	SUMMARY - GASEOUS EMISSION TESTS	50
2-4.	SUMMARY - VOLUMETRIC FLOW MEASUREMENTS	51
2-5.	SUMMARY - BATTERY AND TOWER PROCESS MEASUREMENTS	52
2-6.	SUMMARY - WATER QUALITY MEASUREMENTS	53
2-7.	SUMMARY - SUMP SEDIMENT MEASUREMENTS	54
2-8.	PROBABLE ANALYTICAL ERRORS	55
3-1.	SUMMARY OF VARIATIONS BETWEEN INDIVIDUAL TESTS	80
3-2.	SUMMARY OF MAJOR PARAMETERS FOR ALL TESTS	80
3-3.	FUGITIVE EMISSIONS	86
3-4.	FUGITIVE EMISSIONS	87
3-5.	FUGITIVE EMISSIONS	88
3-6.	FUGITIVE EMISSIONS	89
3-7.	FUGITIVE EMISSIONS	90
3-8.	FUGITIVE EMISSIONS	91
3-9.	FUGITIVE EMISSIONS TIME PERCENTAGE	105
3-10.	AMBIENT CONDITIONS	107
4-1.	SUMMARY OF QUENCH EMISSION TEST RESULTS	110
4-2.	GASEOUS EMISSION	113
4-3.	COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS (CONTAMINATED WATER)	115
4-4.	COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS (CLEAN WATER)	115
4-5.	KEY TO REFERENCE CODING SYSTEM	117

509383

TABLES (Continued)

		Page
4-6.	SUMMARY OF QUENCH EMISSION TEST RESULTS	119
4-7.	THROUGH 4-35. TEST DATA SHEETS	120-177
4-36.	WEIGHT FRACTION (%) OF EACH COMPONENT COLLECTED IN SAMPLING TRAIN (EPA METHOD 5)	182
4-37.	WEIGHT FRACTION OF PARTICULATE COLLECTED FROM COKE QUENCH EMISSIONS BY MODIFIED EPA METHOD 5 SAMPLE TRAIN - COMBINED AVERAGE FOR ALL TESTS	186,187
4-38.	CUT SIZE OF "IN STACK" CYCLONE AT TEST CONDITIONS	190
4-39.	CUT SIZE COMPARISONS	193
4-40.	ACTUAL GAS VELOCITY AND REYNOLDS NUMBER - ENTERING THE PROBE	211
4-41.	MASS TRANSFER COEFFICIENT, K	213
4-42.	CALCULATED DIAMETER OF PARTICULATE DEPOSITED IN PROBE	216
4-43.	D_{50} CUT SIZES	219
4-44.	CHEMICAL COMPONENTS OF PARTICULATE EMISSIONS	226
4-45.	COMPARISON OF LORAIN DATA TO THAT FROM OTHER QUENCH TOWERS - PARTICULATE STACK EMISSIONS	227
4-46.	TRACE ELEMENTS (HIGH CONCENTRATIONS)	227
4-47.	TRACE ELEMENTS (LOW CONCENTRATIONS)	227
4-48.	MASS SPECTROGRAPHIC ANALYSES OF FILTER SAMPLES	228-229
4-49.	MASS SPECTROGRAPHIC ANALYSIS OF CYCLONE SAMPLE	230
4-50.	GASEOUS EMISSIONS (AVERAGE)	234
4-51.	GASEOUS EMISSIONS (SULFUR DIOXIDE)	235
4-52.	GASEOUS EMISSIONS (PHENOL)	236
4-53.	GASEOUS EMISSIONS (CYANIDE)	237
4-54.	GASEOUS EMISSIONS (AMMONIA)	238
4-55.	GASEOUS EMISSIONS (SULFIDE)	239
4-56.	EVACUATED FLASK SAMPLING	241
4-57.	COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWERS TO EMISSIONS FROM OTHER TOWERS (CONTAMINATED WATER)	242
4-58.	COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWERS TO EMISSIONS FROM OTHER TOWERS (CLEAN WATER)	242
4-59.	INCREASES WHEN CONTAMINATED QUENCH WATER WAS USED	243
4-60.	MECHANISMS BY WHICH SULFUR DIOXIDE IS CONVERTED TO SULFATE	245

509384

TABLES (Continued)

		Page
4-61.	FLUCTUATION OF WATER CONCENTRATION RATIOS CALCIUM	248
4-62.	THROUGH 4-69. CLEAN WATER TESTS - NORMAL RATIOS BASED ON Cl.	249-256
4-70.	CONTAMINATED WATER IN USE	276-277
4-71.	POM QUANTIFICATION	280-281
4-72.	FINDINGS IN STACK AND WATER SAMPLES OF SELECTED POLYNUCLEAR AROMATIC MATERIALS	286
4-73.	TEST DATA SHEET	287
4-74.	TEST DATA SHEET	288
4-75.	TEST DATA SHEET	289
4-76.	LEVEL-I GRAVIMETRIC ANALYSIS OF EACH FRACTION	290
4-77.	LEVEL-I INFRARED ANALYSIS	291-294
4-78.	POM QUANTIFICATION	295
5-1.	WATER FLOW	305
5-2.	UP-STACK WATER FLOW AS EXTRAPOLATED FROM CYCLONE AND IMPINGER CATCH	308
5-3.	WATER FLOW (INLET TO NOZZLE) MEASUREMENTS	315-321
5-4.	TABULATION OF SUMP DEFICIT DATA	324
5-5.	QUANTITATIVE COMPARISON OF WATER DISAPPEARANCE FROM THE SUMP TO THE WATER RECOVERED FROM STACK GASES	326
5-6.	MOISTURE IN INDUCED AIR	328-329
5-7.	HEAT BALANCE - BASED ON WATER	336
5-8.	HEAT BALANCE - BASED ON COKE	346
5-9.	TEMPERATURE OF QUENCHED COKE ON THE WHARF (^{o}F)	347
5-10.	HEAT BALANCE - BASED ON AIR	348
5-11.	HEAT BALANCE - SUMMARY	348
5-12.	OVERALL QUENCH PROCESS EQUILIBRIUM	351
5-13.	ENTIRE SYSTEM EQUILIBRIUM	352
5-14.	AVERAGE CONCENTRATION OF VARIOUS PARAMETERS IN THE QUENCH PROCESS STREAM (in mg/l)	353
5-15.	AVERAGE CONCENTRATION OF VARIOUS PARAMETERS IN THE QUENCH PROCESS STREAM (in mg/l)	354
5-16.	AVERAGE QUANTITIES OF CONTAMINANTS PER QUENCH	355
5-17.	CONTAMINANT PATHWAYS AND QUANTITIES	356
5-18.	SUMP EQUILIBRIUM - CONTAMINATED TESTS	360
5-19.	CAR EQUILIBRIUM - CONTAMINATED TESTS	361

509385

TABLES (Continued)

		Page
6-5.	INCANDESCENT COKE ANALYSIS	404
6-6.	MASS SPECTROGRAPHIC ANALYSIS OF COKE SAMPLES	405-407
6-7.	ELEMENTS FOUND IN COAL LISTED IN ORDER OF DECREASING ABUNDANCE	409
6-8.	QUENCHED COKE ANALYSIS	410
6-9.	ELEMENTAL EMISSIONS FROM THE QUENCH PROCESS	412
6-10.	BATTERY OPERATION	414
6-11.	COKE PRODUCTION DURING TEST PERIOD	415
6-12.	COKE PRODUCTION DURING TEST PERIOD	416
6-13.	GREENNESS RATING FOR COKE ENTERING QUENCH TOWER	417-419
6-14.	AVERAGE GREENNESS RATING FOR EACH TEST	421
6-15.	DRAWINGS RECEIVED BY U.S. STEEL CORPORATION	427
6-16.	BAFFLE OPEN AREA	434
6-17.	WATER DROPLET IMPACT EFFICIENCY	442
6-18.	PARTICULATE STACK EMISSIONS	446
6-19.	BAFFLE EFFICIENCY	447

509386

TABLES (Continued)

		Page
5-20.	SUMP EQUILIBRIUM (CLEAN TEST)	362
5-21.	CAR AND TOWER EQUILIBRIUM (CLEAN TEST)	363
5-22.	ANALYSIS OF EACH QUENCH WATER SAMPLE (CHLORIDES)	364
5-23.	ANALYSIS OF EACH QUENCH WATER SAMPLE (AMMONIA)	365
5-24.	ANALYSIS OF EACH QUENCH WATER SAMPLE (PHENOLS)	366
5-25.	ANALYSIS OF EACH QUENCH WATER SAMPLE (SULFIDE)	367
5-26.	ANALYSIS OF EACH QUENCH WATER SAMPLE (SULFATE)	368
5-27.	ANALYSIS OF EACH QUENCH WATER SAMPLE (CYANIDE)	369
5-28.	ANALYSIS OF EACH QUENCH WATER SAMPLE (CALCIUM)	370
5-29.	ANALYSIS OF EACH QUENCH WATER SAMPLE (C.O.D.)	371
5-30.	ANALYSIS OF EACH QUENCH WATER SAMPLE (T.O.C.)	372
5-31.	ANALYSIS OF EACH QUENCH WATER SAMPLE (TOTAL SOLIDS)	373
5-32.	ANALYSIS OF EACH QUENCH WATER SAMPLE (DISSOLVED SOLIDS)	374
5-33.	ANALYSIS OF EACH QUENCH WATER SAMPLE (SUSPENDED SOLIDS)	375
5-34.	ANALYSIS OF EACH QUENCH WATER SAMPLE (VOLATILE SOLIDS)	376
5-35.	SODIUM	377
5-36.	SUMP EMISSIONS	378
5-37.	SEDIMENT COMPOSITION	382
5-38.	COMPARISON OF RIVER WATER/SERVICE WATER AND FLUSHING LIQUOR TYPICAL OF MAKE-UP TO SUMP FOR CLEAN AND CONTAMINATED TESTS	387
5-39.	OUTFALL 002-COKE PLANT SEWER ENTERING BLACK RIVER	388
5-40.	SUMP SEDIMENT COMPARISON TESTS	389
5-41.	CONDUCTIVITY MEASUREMENTS AT BEGINNING OF CLEAN TEST (10/5/76-10/7/76)	392
5-42.	CONDUCTIVITY MEASUREMENTS DURING CLEAN TEST	393
5-43.	SUMP COMPARISON TESTS	394
5-44.	DATA SUPPLIED BY U.S. STEEL - 1973	396
6-1.	COAL AND COKE ANALYSIS	400
6-2.	QUENCHED COKE ANALYSIS	401
6-3.	QUENCHED COKE ANALYSIS	402
6-4.	INCANDESCENT COKE ANALYSIS	403

509387

1.0 INTRODUCTION

It has been common practice in the U.S. Steel industry to use contaminated water ~~in the~~ to quenching of incandescent coke - that is, water contaminated by prior use in either quenching or other processes within the plant. Typically, 10-20 ton loads of hot (upward of 2000°F) coke are quenched by 6,000 - 12,000 gallons of water. Each quench takes 2-3 minutes and produces huge billowing clouds of steam, water droplets, and air contaminants. In order to draft these emissions out of the work area, quenching takes place under towers which are open at the bottom to admit the coke car. Baffles are often fitted above the quench car in order to reduce the amount of large diameter particles emitted, and at the same time reduce water losses and thus the amount of make-up water required.

In order to quantify emissions from the quenching process, and to determine the differences in these emissions arising from the use of clean or contaminated quench water, York Research Corporation (YRC) was contracted by EPA to evaluate the process. The site selected for testing was U.S. Steel Company's Lorain Works; a fully integrated steel plant producing finished and semi-finished steel products.

1.1 Process Description

The integrated steel mill manufactures coke to be used as a basic raw material for the blast furnace. There are two generally accepted methods for manufacturing coke in this country. These are known as the beehive process, and the by-product or chemical recovery process. This latter process produces about 99 percent of all metallurgical coke and is the process used at Lorain.

509388

In the by-product coke manufacturing process, bituminous coal is heated in an oxygen-deficient atmosphere (coke oven) during which volatile components of the coal are driven off. At the completion of this process, the residue remaining in the oven is coke, the volatile components having been recovered and processed in the by-product plant to produce gas, tar, light oils, and other materials. The coking process is accomplished in narrow, rectangular, silica brick ovens which are arranged side-by-side in groups called batteries.

In order to charge the ovens, the coal is loaded into a hopper car. This car holds approximately 13 tons of coal in three hoppers. At Lorain, there were scales for weighing the coal, but they were not used. After loading the hopper car, it is moved to the top of a battery, where the coal is dumped through three ports in the oven top. This coal (oven density: 48-50 pounds per cubic foot), fills the oven to a point level with the top of the leveling bar door.

The coal used is generally blended from lots originating from many different sources. During the time of testing, 16 different coals were available and 6-8 were used in any given blend.

At Lorain, the coke ovens are about 40 feet long and average 19 inches wide, being wider at the car end than at the pusher end. The recovered coal gas is burned in flues located between the walls of adjacent ovens (typically, coke plants use about 40 percent (1) of the gas to heat the ovens, with the remainder being used elsewhere in the steel mill). There are 413 coke ovens in use in seven batteries: each battery consisting of 59 ovens. These ovens are normally operated three shifts per day, seven days per week, and convert upwards of 7,000 tons of coal per day to coke. Normal coking time is 17.3 hours. However, this may vary with the condition of the oven.

509389

During the test period, batteries H and I always had several ovens on a 24-hour schedule. During the total coking period, the gases and volatile materials driven off are collected through pipes from each oven into a gas main running the length of the battery and are withdrawn from the main under suction by exhausters. These hot gases are given an initial cooling by spraying with weak liquor and cooled to below 212°F. This initial cooling condenses a major portion of the tar and other condensibles into a mixture called the flushing liquor. This mixture flows down the suction main to a tar decanter tank. The gas is then further cooled in the primary cooler by river water to about 110°F, as shown in Figure 1-1, and then proceeds to storage. There is an approximate 6 percent net increase in water due to the free moisture in the coal and the water formed in the pyrolysis of the coal.

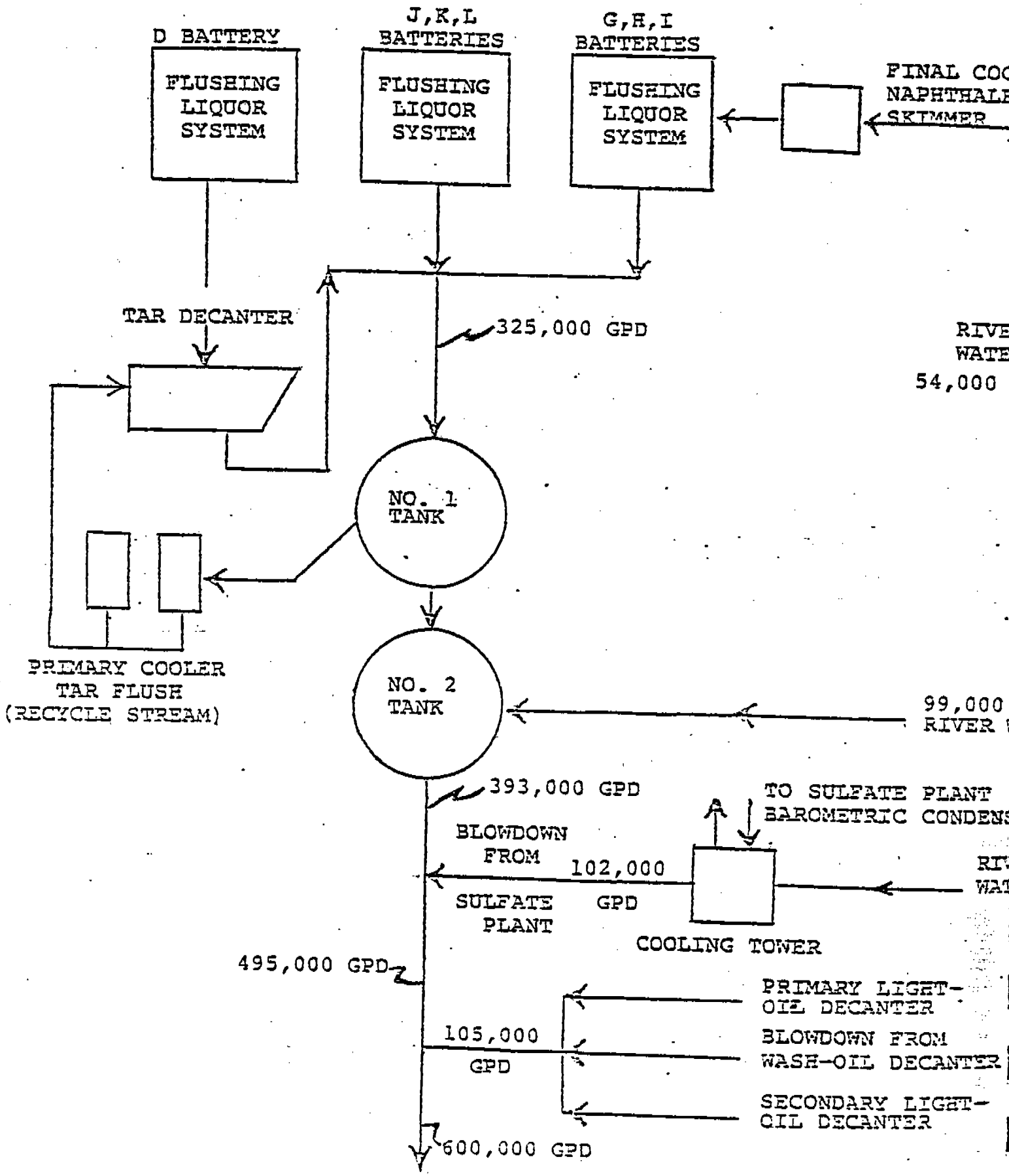
At the end of the coking period the doors are removed from each end of an oven and the pushing machine pushes the incandescent coke into the quenching car. The quench car is moved by a small electric engine to the closest quench tower (see Figures 1-2 and 1-3). The car is placed in position under the tower. This position varied from test to test by about one foot. At this point the car operator pulls a switch which activates a valve in the 16 inch pipe leading from the head tank to the spray nozzles. After a safety delay of about 15 seconds, 7-9 thousand gallons of water flows through a header and 10 nozzles onto the incandescent coke. Figures 1-4, 1-5, and 1-6 show photographs taken a few seconds apart through the first 20-30 seconds of the quench.

The hot coke is quickly cooled to about 250°F by the evaporation of about 20 percent of this water. Violent jets of superheated steam result from this process; and the steam, being less dense than the surrounding air, flows up the

509390

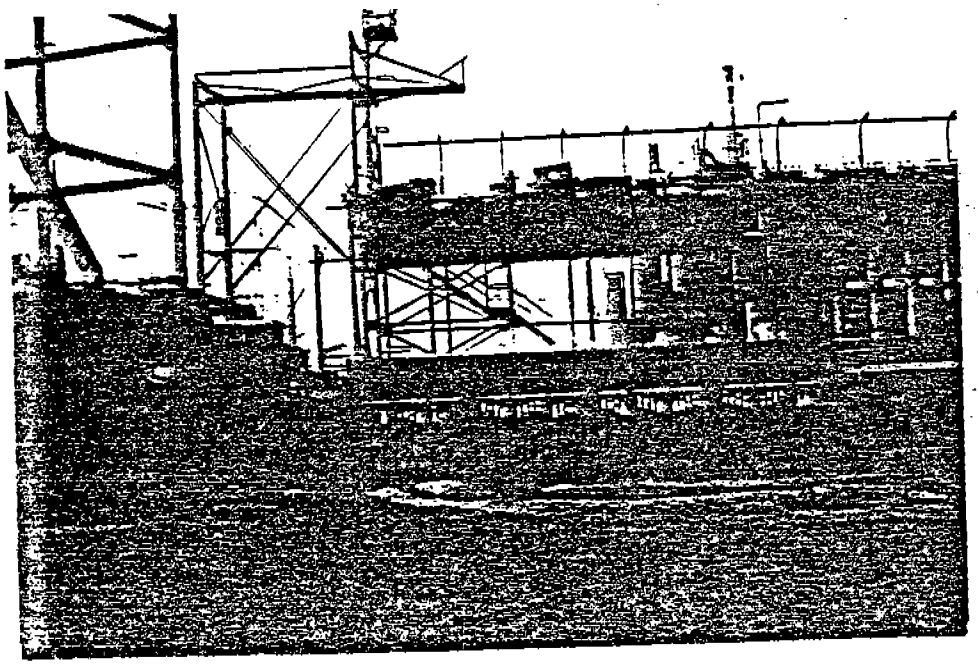
FIGURE

DIAGRAM OF LORAIN COKE PLANT CONTAMINATED QUENCH WATER SYSTEM



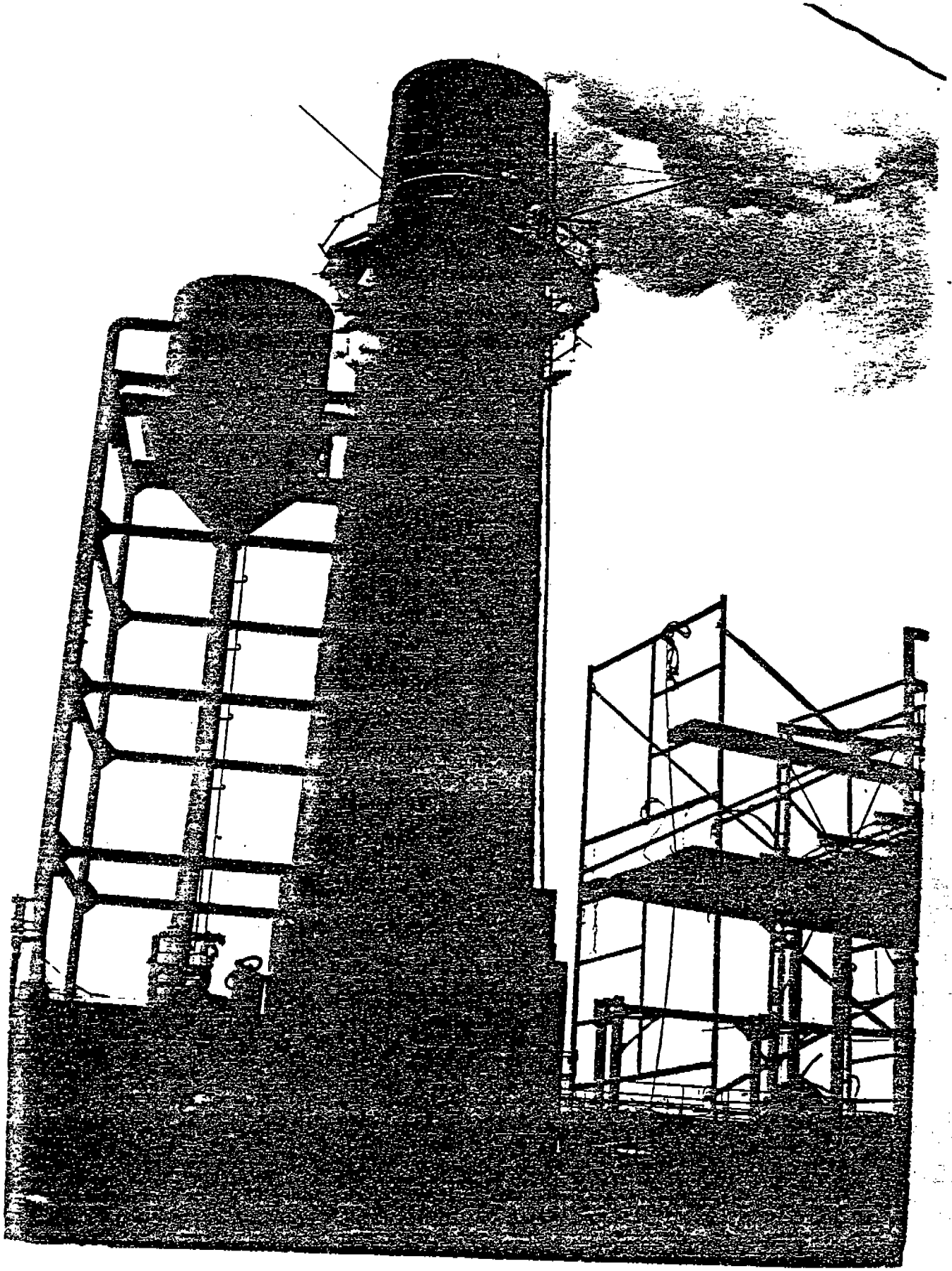
TO QUENCH TOWER NOS. 1, 2, 3, 4
(QUENCH TOWER NO. 5 ON D-BATTERY USES ONLY RIVER WATER FOR QUENCHING)

509391



QUENCH CAR WITH INCANDESCENT COKE ENTERING THE QUENCH TOWER

FIGURE 1-2



QUENCH TOWER PLUME & SHOWING QUENCH WATER FLOW AND TEST PLATFORM

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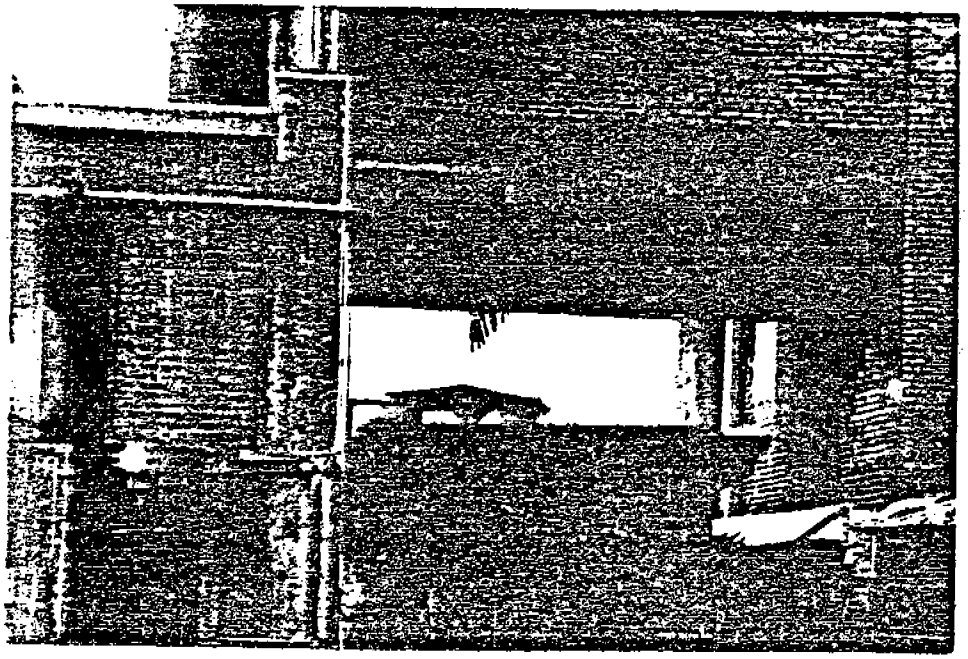
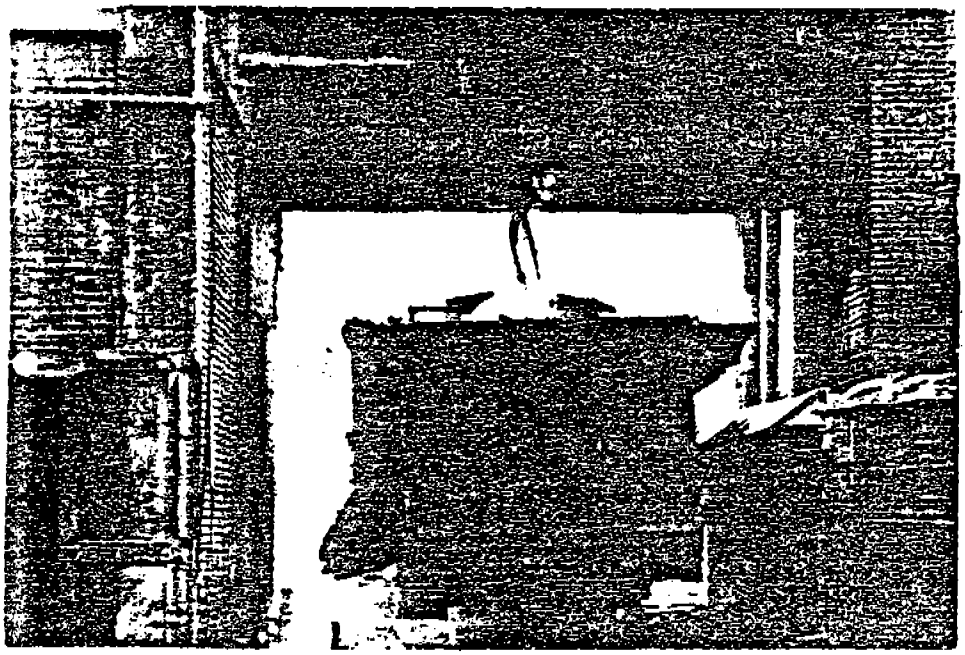
FIGURE 1-3



" CAR IN "

FIGURE 1-4



"WATER ON"

FIGURE 1-5

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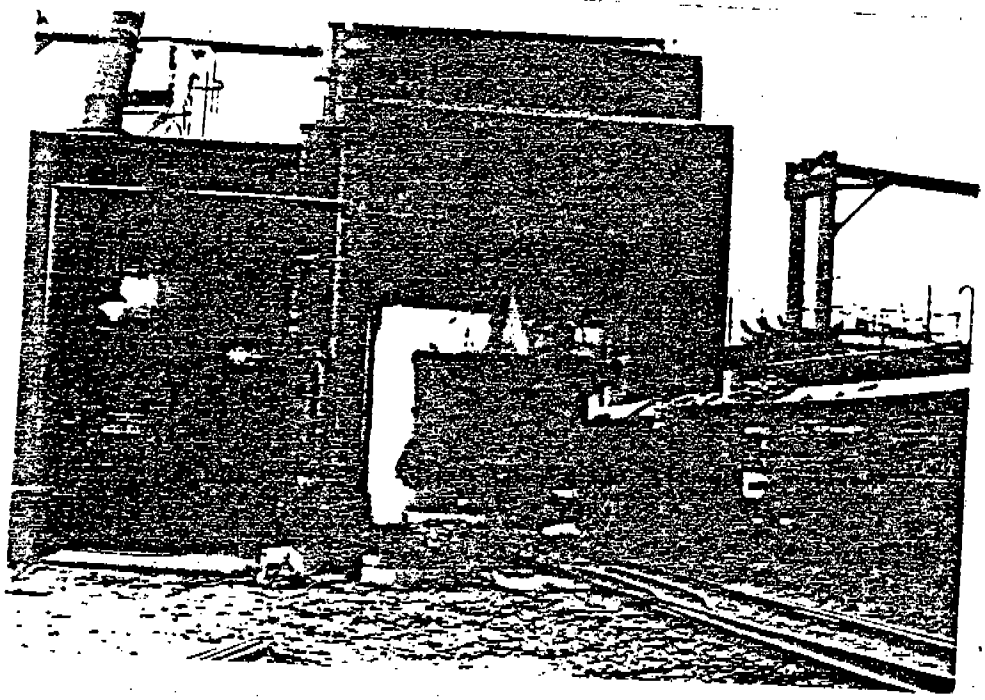


START OF QUENCH WATER FLOW

FIGURE 1-6

FUGITIVE EMISSIONS A FEW SECONDS BEFORE THE UP-STACK DRAFT IS WELL ESTABLISHED

FIGURE 1-7

509397

tower, inducing a flow of cooler air through the car ports. Figures 1-7, 1-8, and 1-9 show the first eruption of steam, while 1-10 and 1-11 show the tower (stack) flow well established. During the rapid cooling, some of the coke fractures, and small particles are broken off and carried away by the gas and water stream. Some of the particles are ejected from the car as if by an explosion. The quench towers are built to contain the violence and turbulence of this cooling process, and the geometry of the tower directs most of this hot mixture of steam, air, water droplets, and coke particles upwards so that it can be partially removed from the immediate working area, and so that as much of the cooling water as possible may be recovered.

A small amount of water is mechanically entrained as droplets and carried upward by the jets of steam and air leaving the car. Most of the large droplets are eliminated by a single row of baffles, but about four percent of the total water flow continues up the stack. The balance of the water drains from the car and returns to a storage sump. The sump is designed to collect the quench water for re-use, while allowing the settling of coke particles. This settling action results in a layer of coke sediment in the bottom of the sump. This sediment is cleaned out and hauled away whenever a truck load or two accumulates. The cooled coke is dumped on an inclined area, called the wharf, which feeds a conveyor belt where it is transferred for storage and eventual use in the steel making process.

During normal operation, Quench Towers No. 1 and 2 are used for G, H, and I batteries; Towers No. 3 and 4 are used for J, K, and L batteries; and Tower No. 5 is used for D battery. The hot coke is taken to the nearest tower, with a quench occurring every 10-12 minutes (16-18 minutes in the case of D battery).

509398

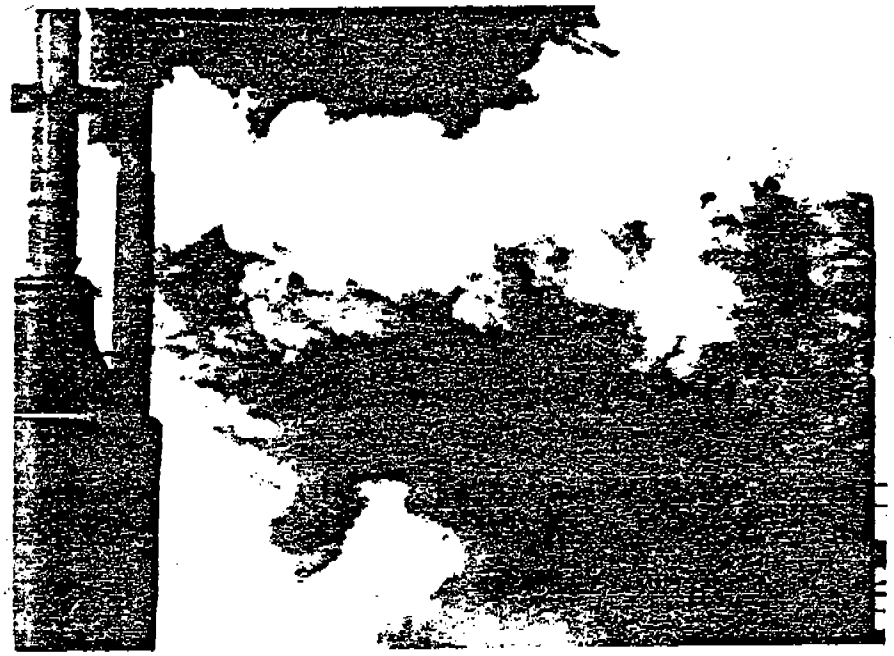


FIGURE 1-8

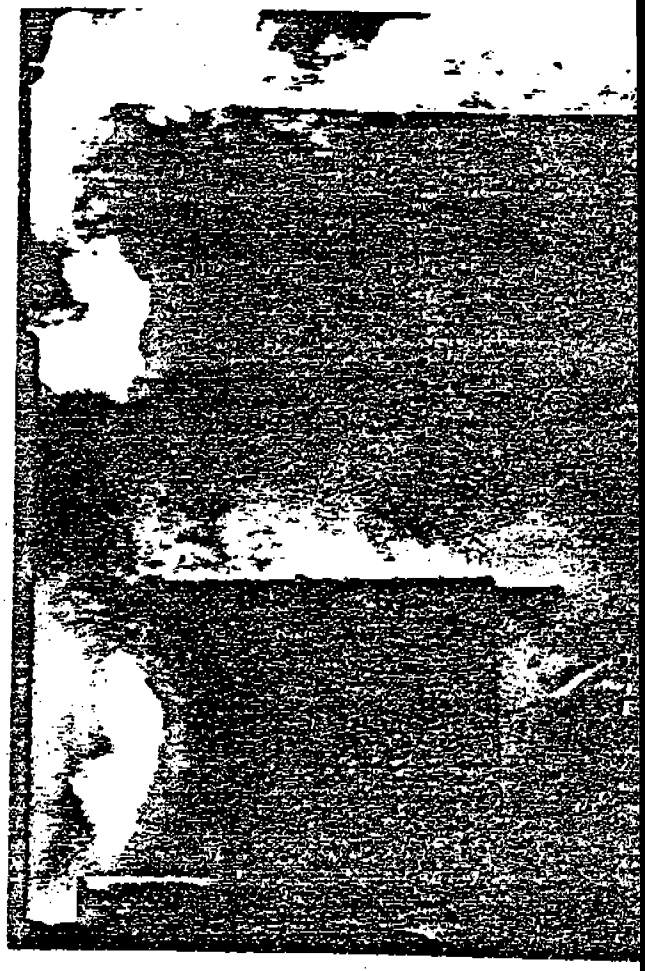
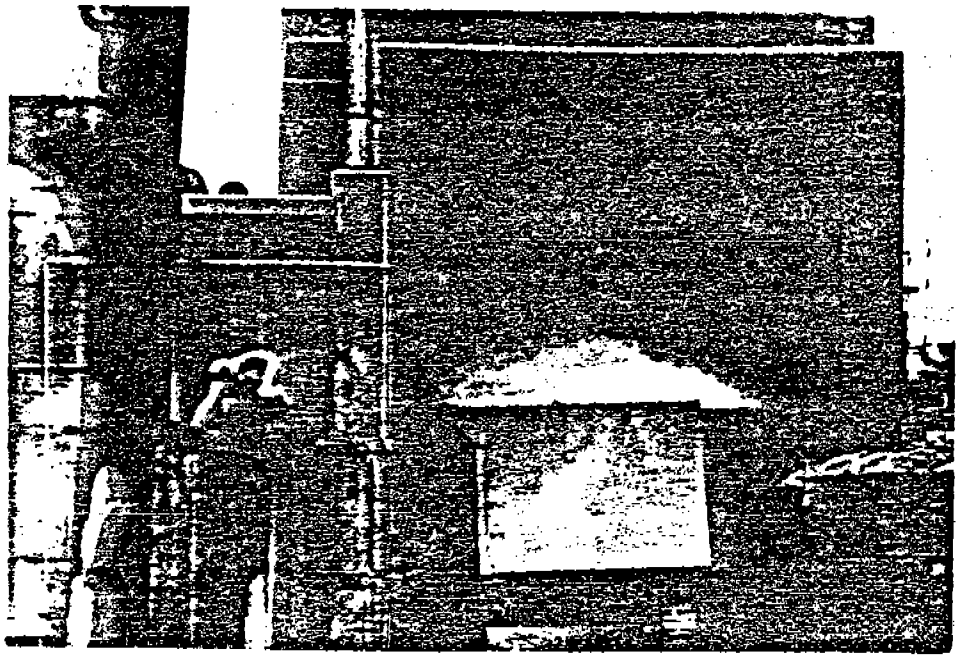


FIGURE 1-10

THREE VIEWS SHO
THE FIRST ERUPTI
OF STEAM (TAK
2-3 SECONDS AFT

FIGURE 1-9



THE STACK FLOW WELL ESTABLISHED, ABOUT 10 SECONDS AFTER "WATER ON"

FIGURE 1-11

All testing was performed on Tower No. 1. During the test period this tower was not frequently used during the day shift. Thus, most testing was done between 1600 hours and midnight.

The various steps associated with separating the crude coal tar and crude light oil are summarized in Figure 1-1. Ammonia is also removed as ammonium sulfate from the coke oven gas stream but is not removed from the flushing liquor.

All of the excess flushing liquors and blowdown from the ammonium sulfate plant apparently are used to quench the coke produced in batteries G, H, I, J, K and L. D battery is normally quenched with river water, although at one time the water and residue from the debenzolized wash oil decanter was reported (2) as being sent to D Battery No. 5 sump. Apparently, this practice has been discontinued.

In addition to the physical processes of evaporation, and the cooling and fracturing of the coke; chemical reactions are also ongoing. For example, the coke and water reacts in the reducing atmosphere to form hydrogen and carbon monoxide. Some of the other components of the quench water (such as ammonia) dissociate to form hydrogen. Additionally, certain components of the quench water, including ammonia, phenol, and cyanide, evaporate from the sump. These substances are also found in the stack gases.

1.2 Background

It has previously been theorized (3) that significant amounts of coke quench water contaminants are transformed by the quenching process into air pollutants which pass through baffles and enter the atmosphere. It was also recognized that contaminants could leave the quenching process after being deposited on the cooled coke; or by dredging after settling in the sump.

509401

Prior to this test program, an accurate assessment of the nature and magnitude of stack emissions from this process had not been done. This was partially due to the hostile conditions which, until now, have prevented accurate measurements from being made. These conditions have included variability in stack gas flow rate, high moisture content of the stack gas, the presence of droplets, and the short, intermittent bursts of emissions.

The basis for the current quench tower emission factor of 0.9 pounds of particulate per ton of coal (for a tower not equipped with baffles) is a 1967 study (3) by R. W. Fullerton, and a United Nations report (4) which was published in 1968. In his work, Fullerton sampled emissions from a tower using a flat, greased plate. In doing so, he collected only large diameter solid particles which had enough momentum to stick to the plate. While the U.N. report is vague, it is likely that the emission facotrs it presents were based upon particulate matter which fell to the ground from the plume. This type of test is performed by setting out an array of Petri dishes on the ground beneath the plume's path, filtering or desiccating the collected matter, and back-calculating tower emissions. Again, as in Fullerton's work, only large particles and droplets would be collected.

Very little data has been reported as to the ultimate destination of contaminant produced by the quench tower when these contaminants were present in the quench water. The United Nations report included some data on stack emissions. These data were regarding the grit or breeze fraction, and generally agree with that portion of the stack emissions observed at Lorain. Taken as a whole, however, the emissions measured at Lorain generally exceed all previous data by at least one order of magnitude.

The lack of information concerning quench tower emissions set the stage for an interplay between air and water pollution regulations which became an issue early in 1976. This occurred when the Environmental Protection Agency was forced by economic circumstances to decide whether to grant certain steel mills in Ohio's Mahoning Valley relief from full compliance with air and water pollution requirements. Although extensions were granted for compliance with water pollution standards, EPA ruled that companies in the area would be required to provide for treatment of coke plant wastes. This decision was based primarily on the difference between the Air and Water Pollution Control Acts. However, major consideration was given to engineering estimates that showed emissions from quench towers (with baffles) could be as high as 4.0 pounds of particulate per ton of coal.

As a result of the Mahoning Valley decision, and the presence of EPA-imposed effluent limitations of 1974, the decision was made to obtain more representative emission data. To do this, over forty coke plants were surveyed by the Division of Stationary Source Enforcement (DSSE), and YRC was contracted to perform the study.

The project's objectives were to:

- Determine the magnitude and character of quench tower emissions
- Determine the extent to which variations in quench water quality affect emissions
- Determine how emissions can be accurately measured

509403

1.3 Test Program

U.S. Steel's Lorain Works was selected for testing on the basis of tower configuration, and ability to switch from contaminated to clean quench water at the same tower. Concurrently, new sampling techniques and equipment was devised to overcome prior sampling problems. These techniques were designed to correlate to established techniques.

In early September 1976, twelve particulate sampling runs were made while the tower used contaminated quench water. After these tests, the quench tower make-up water was switched to service water. Three weeks were allowed for the sump to cleanse itself to a level of contamination equivalent to a nearby quench sump which used only clean water. Testing was resumed in early October, halted due to inclement weather, and completed at the end of October and beginning of November.

Concurrent with particulate emissions tests, stack samples were also taken for various gases and organic compounds, water quality samples were taken, and samples of coke were obtained for analysis. In addition, measurements were made of water flows, the greenness of coke was rated, all available process parameters were recorded, and a number of other physical parameters were recorded.

The following conclusions may be stated:

- The tests were as precise as, and correlatable to Standard EPA measurement techniques.
- Quench towers can be a major source of particulate, carbon monoxide, and sulfur oxide air pollutants.
- Quench particulate emissions are greatly dependent upon the quality of the quench water.
- Quench towers may be a major source of aromatic hydrocarbon emissions.

1.3.1 Site Selection

In order to most accurately determine the impact of water quality on quench emissions, the criteria for selecting a test site were:

- Tower configuration which would produce uniform cross-sectional flow.
- Ability to quench with a wide range of total dissolved solids (TDS) concentrations in the water.
- Ability to add or remove baffles.

After a general survey of quench towers, a quench tower at U.S. Steel's Lorain Works was selected for testing. This tower was a circular brick chimney which, after baffles, did not have internal buttressing. In addition, the company had the ability to re-route contaminated water to other quench towers in the plant and use service water for quenching at the selected tower. However, the baffles in the tower could not be removed during the test program. Since the major concern was the degree to which particulate matter escaped baffles, satisfying the third criterion was considered to be much less important than meeting the first two.

1.3.2 Equipment Modifications

In order to minimize sampling error, a number of modifications were made to the standard EPA particulate sampling train. Major changes were:

- A high volume sampler was used to minimize the amount of time needed to collect a sufficient volume of gas and weight of particulate for each test run.
- A cyclone collector was fitted on the front of the probe (50% cut size was about 15 to 20 micrometers) to collect droplets and large diameter solids. This addition would allow more accurate determination of the percent of moisture in the stack gases, prevent plugging of the filter, and provide a rough indication

of aerosol sizing.

- A continuous velocity recorder was used to more accurately record velocities during the test and enable more precise evaluation of isokinetic sampling rates.

1.3.3 Pre-Test Survey

A pre-test survey was conducted in August 1976, to determine whether the sampling equipment would adequately function, and to refine test protocol. Principal findings were:

- Sampling location - Velocity profiles were obtained for at least two quenches at each of the 36 sampling points recommended by the EPA particulate sampling specifications. An analysis of these profiles showed that velocity was not greatly affected by position and followed a uniform pattern for each quench. Based on these findings, it was decided to sample at a single point for each test run and that at least 12 runs would be performed at three positions on each axis for both clean and contaminated quench water conditions.
- Duration of Sampling - Three particulate tests showed that sufficient weights of particulate (over 100 mg) and volumes of dry, stack gas (over 15 cubic feet) could be obtained from four quenches. Based on these findings, it was decided that each sampling run would consist of four quenches. Sampling began and ended when the quench car entered and left the tower.

Velocity profiles taken at the USS Lorain Works from Quench Tower No. 1 during preliminary tests in August 1976 indicated slopes and plateaus that were more defined than previously suggested or shown in published articles, and that sampling rate calculations could be performed to insure isokinetic results. Throughout the program variations of the velocity profile during ang given test sequence (approximately one hour) were minimal and all tests were within ± 10% of 100% isokinetic conditions.

1.4 Discussion of Results

In order to relate the pollutant emissions observed at Lorain to previously obtained data, Table 1-1 is presented. Since only insignificant amounts of such pollutants are destroyed or leave the process site either in the quenched coke or in the sump sediment, it appears that the stack gas is by far the most significant vehicle by which the pollutants leave the quenched coke.

For purposes of comparison, Table 1-1 also lists the effluent guidelines under the best available technology economically achievable (BATEA), and the best practicable control technology currently available (BPCTCA), for the coke quenching process.

TABLE 1-1. COMPARISON OF LORAIN DATA WITH PRE-EXISTING DATA

	Pounds of Pollutant emitted per Ton of Coke Quenched			
Pollutant	Lorain, Using Contaminated Water	Typical Raw Wastewater Used as Quench Water*	BATEA(5)	BPCTCA(5)
Ammonia	1.8	1.8	0.008	0.18
Cyanide	0.01	0.2	0.0002	0.04
Phenol	0.2	0.5	0.0004	0.003

* From Reference 6; Dunlap, R.W., and F. C. McMichael, 1976: Reducing Coke Plant Effluent. ES&T

Table 1-2 reveals some important aspects of the type of particulates emitted and their size distribution. The sampling train provides a rough breakdown of the size of particulates emitted. The cyclone was designed to capture aerosols generally large enough to be easily visible - the 50% cut size was about 10 micrometers.

The most striking difference in emissions was the 30 fold decrease in particulate deposited on the filter (from 5.9 pounds per quench for contaminated water to 0.2 pounds per quench using clean water). The aerosols reaching the filter were almost

TABLE 1-2. SUMMARY OF QUENCH EMISSION TEST RESULTS

(Obtained from 13 "clean" and 12 contaminated test runs; ranges of values are shown in parenthesis.)

PARAMETER	USING "CLEAN" MAKE-UP WATER	USING CONTAMINATED MAKE-UP WATER
FLOW CONDITIONS		
PERCENT ISOKINETIC SAMPLING RATE (%)	99.0 (92.8 to 109.2)	99.4 (91.1 to 109.5)
VOLUMETRIC FLOW RATE (10^3 dscfm)	190.7 (152.6 to 236.1)	183.3 (153.8 to 233.5)
PERCENT MOISTURE (%)	34.8 (22.1 to 43.4)	38.7 (25.8 to 55.1)
PARTICULATE EMISSIONS (IN POUNDS PER QUENCH)		
• Cyclone (~20μm, 50% cut size)	1.72(0.51 to 3.23)	2.78 (1.24 to 10.35)
- Filterable Solids	1.72 (0.51 to 3.23)	2.78 (1.24 to 10.35)
- Dissolved Solids	1.99 (0.73 to 3.65)	12.54 (7.09 to 19.75)
Subtotal	3.71 (1.24 to 6.88)	15.32 (8.91 to 21.93)
• Probe		
- Water Wash	4.72 (1.83 to 8.70)	6.93 (4.25 to 10.27)
- Acetone Wash	10.60 (0.44 to 15.83)	8.19 (1.08 to 20.10)
Subtotal	15.32 (3.85 to 23.72)	15.12 (6.11 to 30.37)
• Filter	0.20 (0.00 to 0.95)	5.89 (3.82 to 9.72)
TOTAL FRONT HALF OF SAMPLING TRAIN CATCH	19.32 (8.83 to 26.98)	36.33 (22.86 to 58.88)
TOTAL BACK HALF OF SAMPLING TRAIN CATCH (Impingers)	2.04 (0.62 to 4.22)	10.63 (4.57 to 23.05)
TOTAL QUENCH TOWER PARTICULATE EMISSIONS	21.27 (9.93 to 30.95)	46.96 (27.46 to 78.23)

509403

certainly of small diameter (i.e., less than 10 micrometers but greater than 0.3 micrometers).

Fully 20 percent of the total particulate emissions in the contaminated make-up water tests (and 10 percent of the total weight in clean water tests) was found in the impingers of the sampling train after the sampled gases had passed through the filter. The switch to cleaner quench water was accompanied by almost a 5-fold decrease in these emissions.

Physical Characteristics

- Particulate matter in quench emissions is not primarily large sized. Based on size distribution analysis, 99 percent of the particulate matter collected was below 35 micrometers in diameter. The weight of larger aerosols collected by the initial cyclone was only 33 percent of the total weight emitted when quenching with contaminated water and 17% of the clean water quench emissions. The average size of the particulate in the plume aerosol is less than 4 micrometers.
- During clean water tests, the greatest weight fraction (71 percent) of particulate was recovered from the probe/nozzle washes. During contaminated tests, particulate matter was found to be distributed more evenly throughout the probe/nozzle and cyclone washes (33 percent in each). Particles collected in the probe averaged about 3 micrometers in size. Overall, the greatest amount of particulate was found in the probe and nozzle washings.
- The amount of particulate recovered from the probe/nozzle water washes was less in the clean water tests than in contaminated water tests. However, the amount of particulate matter in the acetone wash was greater in the

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clean water tests than in the contaminated water tests. The reason for this observation is not known at present. It would appear that this fraction of the quench emissions does not correlate with the known composition of the quench water. It may be derived from some other source, such as the coke being quenched.

- There was a striking reduction in quantity of emissions when the switch was made from contaminated to clean quench water. The greatest reduction was in the amount of particulate matter collected on the filter. Most of the material collected on the filters was smaller than 3 micrometers and larger than 0.3 micrometers.

- More than 20 percent of the total particulate collected during the contaminated water series was collected in the impinger. This was reduced to 10 percent in the clean water tests.

DROPLETS

- About 300 to 400 gallons of water per quench (out of a total of 1800 gallons in the aerosol) was entrained in the aerosol as water droplets larger than 10 micrometers and smaller than 150 to 200 micrometers. The balance of the water was present in the aerosol mostly as vapor with a small amount as an aerosol less than 10 micrometers in size. The larger water droplets were probably formed directly and mechanically from the water as it left the nozzles and sprayed on to the coke.

- Larger droplets increase in size in the rising plume due to agglomeration since the smaller drops then tend to catch up and collide with the larger droplets.

- Analysis on clean and contaminated cyclone and filter particulate matter indicate that those parameters at the highest concentration levels are chloride for filter

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particulates and sulfate for cyclone particulates. These are in the range reported in previous tests on other quench towers.

Chemical Characteristics

- Those elements at high concentrations in the filter were in relatively low concentrations in the cyclone. Conversely, those in high concentration in the cyclone are not detected at all in the filter (except for sulfur which is in much higher concentration). Sodium, magnesium, and silicon seem to be associated with larger particles or with the water and are deposited in the cyclone, whereas the calcium, chloride, barium and potassium are associated with finer fractions of the aerosol and are carried through to the filter.
- Substantial chemical constituents of the particulate matter and droplet phase of the aerosol seem to be:

Cl^-
SO_4 or S
Ca
Ba
K
Sr

Chloride, sulfate, and calcium are introduced by contaminated and clean makeup water and incandescent coke.

Gaseous Emissions

- A definite dependence of the composition of gaseous emissions on the quality of quench water is indicated. The chemicals concentrated in gaseous emissions reflect those found concentrated in quench water. In contaminated water, the concentration of phenol increases about 500

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times, ammonia about 50 times, cyanide about 40 times over that found in clean quench water. Sulfide remains about the same. This pattern of decrease in relative concentrations exactly follows that for gaseous emissions. The only exception here is sulfur dioxide. Sulfide and sulfate concentrations did not change from clean to contaminated water.

- Substantial concentrations of sulfur dioxide, phenol, and ammonia are found in emissions when contaminated quench water is used. These values can be compared with those from previous tests at other coke quench towers. The results for the Lorain Quench tower agree quite well with the rest.

- The concentrations of all the chemicals (except for sulfide) are greatly increased when contaminated water is used instead of clean water. The approximate rise in concentration for each chemical when contaminated water is used is as follows:

SO_2	80 times
Phenol	60 times
Ammonia	12 times
Cyanide	4 times
Sulfide	1 time

Organic Emissions

A special testing scheme was conducted to determine the amount and character of organic pollutants being emitted from the tower during quenching operations. The conclusions from this testing are as follows:

- The organic emissions from a coke quenching tower are substantial. (Ranging between 15-115 lbs per quench)
- The chemical nature of these emissions is primarily aromatic.

- The amount of this material emitted is likely more dependent on the coke, its processing conditions or other factors, than it is on the quality of the water used for quenching.

Water Flow Rates

Table 1-3 is presented to show the differences in contaminant levels present in the contaminated and uncontaminated (or clean) quench water.

At Lorain the coke plant wastewater typically used as make-up was as saline as sea water, and contained a broad range of organic materials, oil and grease, suspended solids, sulfur compounds and ammonia.

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TABLE 1-3. NOMINAL QUENCH WATER CONTAMINANT CONCENTRATIONS AND MASS RATES

Contaminant	Clean			Contaminated		
	Concentration (mg/l)	Lb/ Quench	Lb/ton	Concentration (mg/l)	Lb/ Quench	Lb/ Ton
TOTAL DISSOLVED SOLIDS (TDS)						
Sprayed on Coke	1050	80	8	9850	775	80
Returned to Sump	1040	60	6	9670	590	60
Make-up Water	520	8	0.8	5370	85	9
TOTAL SUSPENDED SOLIDS (TSS)						
Sprayed on Coke	60	5	0.5	165	13	1
Returned to Sump	270	16	1.7	340	21	2
Make-up Water	2.5	0.04	0.004	140	2.2	0.2
Total Quench tower particulate emissions at Lorain		20	2.1		45	5

The flows in the quenching process are summarized in Table 1-4.

TABLE 1-4. SUMMARY OF WATER FLOWS

Description	(gals/quench) Minimum	Maximum	Average
Stack Flow	900	2500	1800
Inlet to Nozzle (Sprayed on Coke)	8100	10500	9200
Losses			
- retained by coke	NA	NA	150
- car drainage			
- evaporation			
Return to sump	NA	NA	7300
Make-up to Sump	NA	NA	1900
Moisture in induced air	7	50	20

In the quench process, 11.7 million Btu's were removed from the hot coke and distributed to the aerosol exiting the stack as heat contained in evaporated water vapor.

Contaminants

The contaminants in the quench water originated from two sources - the coke itself, and the flushing liquor. A significant difference existed in the concentration of various chemicals which were dissolved in the quench water on occasions when the quench make up contained flushing liquor, and when river water (service water was used as make up:

- Chloride content in the quench water was approximately 10 times higher when flushing liquor was used in the make-up.
- Ammonia content was approximately 50 times higher.
- Phenol content was approximately 500 times higher.
- Cyanide content was about 40 times higher.
- Total organic carbon was about 100 times higher.
- Total and Dissolved solids were about 10 times higher.

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The concentrations of four of the chemicals found in the quench water: namely, chlorides, ammonia, phenol, and cyanide, were characterized by the following patterns:

- They were present in the flushing liquor at a substantially higher level than in the service water.
- They were concentrated by the recycling of the quench water and were found in even higher concentrations in the quench water, than in the make-up.
- In examining the ratios of clean vs. contaminated quench water constituents, it is evident that relative concentrations remained approximately constant.

The fate of the dissolved solids contained in the makeup water is summarized below in Table 1-5.

TABLE 1-5. DISSOLVED SOLIDS BALANCE

	Pounds per quench	
	Contaminated	Clean
Entering in the make up water	85	8
On the quenched coke	6	(4)
In the cyclone catch	12	2
As gas in the stack aerosol	13	0.5
Estimated to have been adsorbed by the 10-11 pounds of grit in the sump	10	10
Chemicals evaporated from the sump	55	2
Leaving the tower	96	10.5

It was evident that emissions from quench towers are related to:

- The amount of dissolved solids in the quench water
- The contaminants found in flushing liquors when used in the quench water
- Contaminants introduced by the coke.

Those contaminants that were at a maximum during the tests with contaminated quench water, were also present in the flushing

liquor make up in much higher (by at least 10 times) concentration than in the service water.

The 15 elements most abundant in coal were also found to be the most abundant in coke and they were found in about the same relative order as in coal.

When flushing liquor was used as make up, the contaminated water recovered some of these elements and redeposited them on the quenched coke as well as enriching the aerosols exiting the quench tower.

Process Parameters

Oven temperatures averaged 2258°F, and the coke surface temperatures while in the car averaged 1737°F. Coking times averaged 17-18 hours, although at times they reached 24 hours in duration.

Based upon the above, production during the test period appeared to be typical of the industry.

Greenness

Greenness of the coke for each push tested was rated on a scale of 0 to 5 for each car tested. 0 was the least smoke and 5 was the most. The tests (4 quenches each) averaged 1.75 and varied test to test from 1 to 3.25.

Baffles

The baffles in the quench tower at Lorain had no significant effect on water droplets below about 40 micrometers, nor on particulate matter below about 30 micrometers. However, larger droplets with diameters more than 100 micrometers, and particulate matter over 70 micrometers are expected to impact with efficiency well over 70 percent; The average size of aerosol which passed

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through the baffles and was exiting the stack was about 3 micrometers.

No other operating or process parameters were observed as being in an upset or unusual condition which would have affected the results of the quench emission tests.

2.0 TEST PROCEDURES AND PRECISION

2.1 Test Objective

Many pollution control engineers have theorized that significant amounts of coke plant water contaminants directed to quench tower sumps for disposal are transformed by the quenching process into air pollutants which escape the baffles.

This potential interrelationship of water and air pollution has become an issue in a number of EPA's standard setting and enforcement actions. In order to resolve these issues, a study of quench system emissions was initiated by EPA's Office of Enforcement and Office of Research and Development. York Research Corporation (YRC) of Stamford, Connecticut was contracted to perform the study. The objectives of the study were to resolve the following:

- Quantitative and qualitative characterization of quench tower emissions
- Correlation between quench water quality and gaseous and particulate emissions
- Measurement techniques for gaseous and particulate emissions

The measurement program showed the quench tower to be a major source of particulate emissions. When using contaminated water for make-up to the sump, emissions averaged about 45 pounds per quench; the equivalent of about 1,000 tons of particulate matter per year under normal operating conditions. When using relatively clean water for sump make-up, particulate emissions were reduced to about 21 pounds per quench (or

about 460 tons per year). Gaseous emissions were greatly reduced when clean water was utilized.

As a result of the precautions in site selection, equipment modification, preliminary velocity profiles tests, and the mass emission reproducibility tests; all of the particulate stack tests of with both contaminated and clean quench water were within ± 10% of 100% isokinetic sampling.

Wide variations in the mass emission rates were shown to be affected by the following:

- Water quality (Total Dissolved Solids (TDS))
- Cyclone filterable solids (grit)
- Benzene soluble oils in the acetone wash

Eliminating both the cyclone solids and acetone wash weights from the data results in a lowering of the mass emission rate variation to a standard deviation for contaminated quench water to ± 10.0 lbs per quench and for clean water to ± 2.8 lbs per quench. Confidence intervals are 6.68 lbs per quench and 1.69 lbs per quench, with standard deviations of 0.29 and 0.32, respectively.

2.2 Sampling Problems

Previous test techniques and methods used in attempts at characterization of air pollution emissions from quench towers were often plagued with difficulties. These included the exclusion of certain size ranges of particulate matter in particulate measurements, and limitations in obtaining measurements of important process parameters. Early attempts at particle measurement using greased plates [3] and petri dishes [4] succeeded in measuring only large diameter, heavy droplet and/or solid particles. Further attempts by State and Local agencies to measure particulate emissions utilizing standard EPA sampling equipment were limited in their scope and also encountered a number of sampling difficulties.[7,8]

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Major problems occurred because, in operation, the quench tower generates short, violent rushes of steam which hamper efforts to accurately read and adjust the sampling instrumentation to maintain isokinetic conditions. In this case, the EPA guidelines are not usable because they recommend measuring velocities and making adjustments every 3 to 5 minutes. This time interval is more than the total duration of a quench. The short duration of the quenches made capturing the prescribed volume of gases extremely difficult. The square shape of most quench towers, and the use of internal partitions compounded these problems by causing uneven flows across the tower cross-section. In addition to the above problems, droplets in the exhaust stream plugged filters, and made determinations of the molecular weight of the gases nearly impossible.

Potential problems that had existed during earlier testing attempts were overcome by an extensive planning period in which previous tests were scrutinized, test equipment was researched, and engineering judgments were made as to the most effective methods to conduct the tests.

Table 2-1 lists the major problems, their possible effects on test accuracy, and the solutions that were utilized to overcome these problems.

TABLE 2-1. POTENTIAL PROBLEMS AND SOLUTIONS IN TESTING QUENCH TOWER EMISSIONS

Potential Problems	Effect on Accuracy	Solution
nticipated small differential n TDS between clean and con-aminated quench water.	A wide TDS range desired to show effects on clean and contaminated quench water on emissions.	At Lorain, the ratio of contaminated water TDS to clean water TDS was on the order of 10:1.
ower Configuration	Square, squat, sectionalized towers likely to produce non-uniform flow	Tall circular tower with no internal buttressing was selected.
hort duration of quench re-ulting in velocity profiles hanging faster than can be easured or recorded by usual ethods.	Velocities move up and down so rapidly as to make accuracy difficult to achieve.	Use of Hastings-Raydist velocity meter with continuous recording.
roplets in stack sample	Inability to measure actual moisture content, molecular weight of stack gas, and filter plugging.	Cyclone (50% cut size about 7-13 microns) was fitted to the front of the probe.
roplets and grit in stack ases	Plugging of pitot tubes	Used Hastings Raydist velocity meter with continuous purge.
ugitive emissions	Emissions exiting from entrances of tower causing non-representative sampling.	Entrance emissions monitored and testing halted when excessive (longer than one minute per quench or at Project Director's discretion).
ampling locations	Possible uneven velocity patterns throughout stack.	Performed traverse of 36 points-velocity was not affected by position.

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TABLE 2-1. (CONTINUED). POTENTIAL PROBLEMS AND SOLUTIONS IN TESTING QUENCH TOWER EMISSIONS

Potential Problems	Effect on Accuracy	Solution
Number of quenches	Method 5 would require sampling 20 quenches to get a one hour test, however, this would have resulted in plugging and other errors.	Pre-survey tests showed that four (4) quenches would provide sufficient weight of particulate (over 100 mg) and volumes of dry stack gas (over 15 cubic ft.) using a high volume sampler.
Skewed flow	The vertical component of velocity differs from the linear velocity along a skewed flow.	Vane measurements were made to determine probe positioning.
Some water flow measurements	Mass balance of water flows in the quench processes not related directly to each stack measurement.	Sonic measurements device installed on header pipe. Sump level measurements performed, and results for a series of quenches were averaged.

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2.3 Phases of the Study

The field testing was conducted in two basic phases to obtain measurements using both:

- Clean (service) quench water.
- Contaminated quench water (from plant operations, i.e., the ammonia still and by-product effluent from the Benzol Plant).

Twelve particulate test runs were performed in early September 1976 when contaminated water was utilized. After the completion of these tests, contaminated make-up water was switched to another tower and clean (service) water was added. The sump was dredged at this time, after which TDS concentration levels were checked over a three week period to determine if the sump levels were equivalent to those of a sump using service water only. (Samples were taken during the contaminated phase of the No. 1 and 5 sumps. Number 5 sump supplies quenching water for a short squat tower and operates with service water only). When the concentration levels were within range of clean water, two tests were conducted. These were in early October. Eleven more tests were conducted in late October and early November.

2.3.1 Quench Tower Selection

In order to most accurately determine the impact of water quality on quench emissions, criteria for selecting a test site included:

- The tower configuration must be such so as to produce uniform cross-sectional flows.
- The tower must have the ability to quench using water with a wide range of TDS concentrations.

After a general survey of quench towers, a tower at U.S. Steel Corporation's Lorain Works was selected for testing. This tower is a circular brick chimney which, after the baffles, does not have internal

buttressing. In addition, the facility was constructed with the ability to re-route contaminated water to other quench towers in the plant and use service water for quenching at selected towers.

A schematic of the tower is shown in Figure 1-1. Tests were conducted approximately 100 feet above ground and 20 feet from the top of the tower.

2.3.2 Sampling Equipment Design

Emissions testing was conducted with a high-volume Aerotherm sampling train to minimize the amount of time required to collect a sufficient volume of gas, and weight of particulate matter (Figure 2-1).

To allow a more accurate determination of moisture a rough indication of particle sizing; a cyclone was fitted to the front of an eleven foot probe. The cyclone was designed to have a 50 percent cut size of approximately 10 micrometers (µm) at the anticipated flow rates. The 50 percent cut size (or D_{50}) is a term used in particle collector terminology where the D_{50} is the size at which the collection efficiency is 50 percent - where half the particles encountered are captured and half escape. Particulate matter and gases were drawn through the unheated cyclone where large diameter particles and water droplets were collected. After passing through the heated (250°F) probe at about 2 cubic feet per minute (cfm) and a heated (250°F) Spectrograde Type AE glass fiber filter where particles larger than 0.3 µm were collected, the gas sample passed through an impinger train-ice bath assembly where additional particulate matter and some condensibles were removed. The gas was then further dried prior to entering the flow

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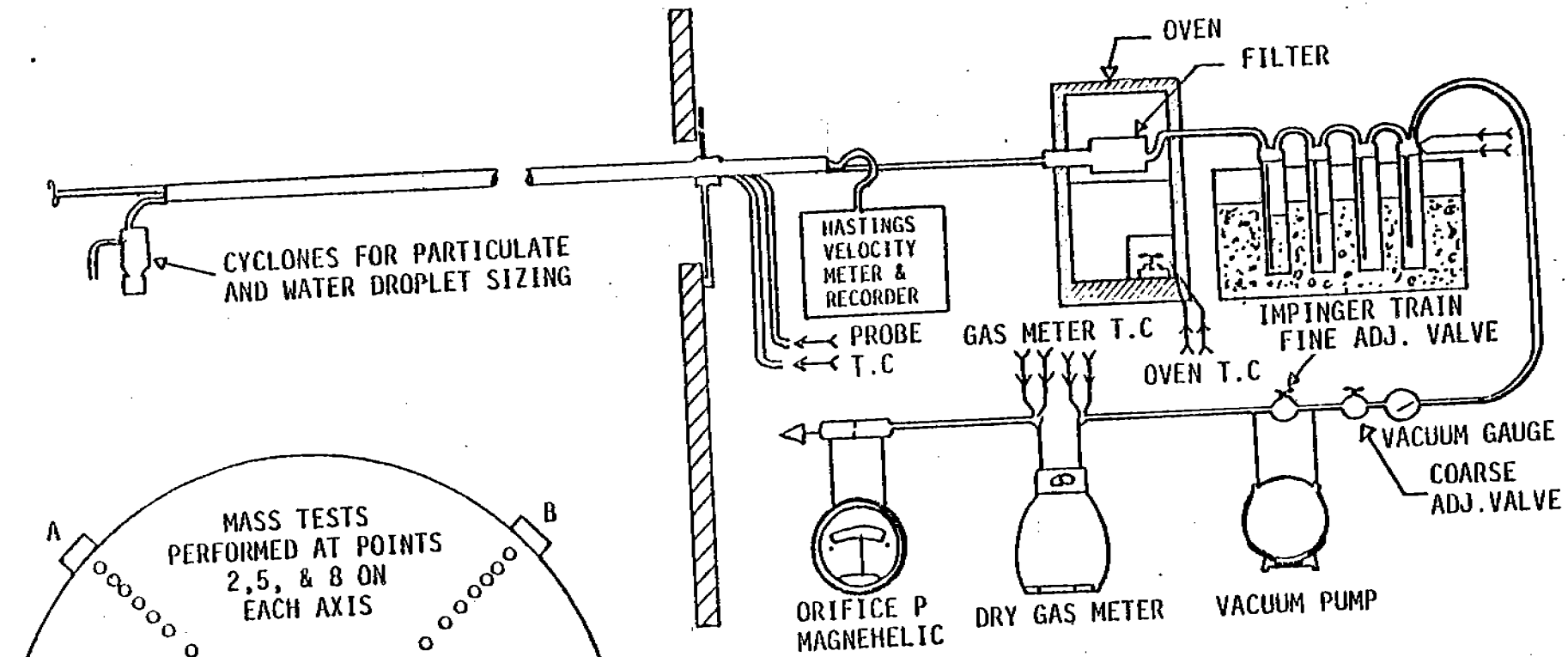

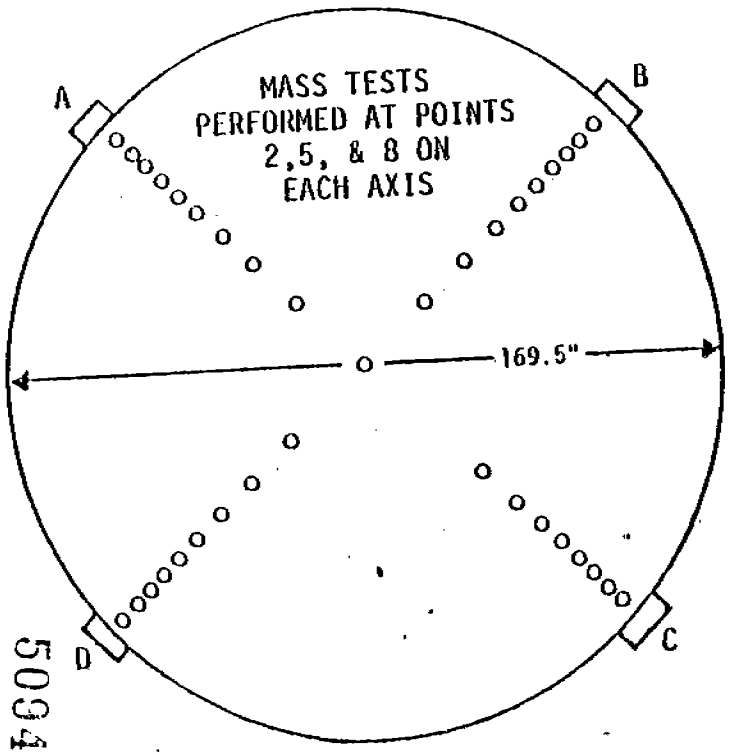

FIGURE 2-1
HIGH VOLUME (AEROTHERM) PARTICULATE
SAMPLING TRAIN
AND
VELOCITY TRAVERSE AND MASS
SAMPLING LOCATIONS

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control module by means of an impinger filled with 300 g of silica gel.

A continuous strip chart recorder was connected to a Hastings meter (Figure 2-1) to record the velocity head pressure (Δp), and to aid in verifying any uneven flow patterns. The unit operated with air continually purging the pitot lines which prevented stack gas from entering the meter. Differential pressure across the pitot tube was measured as a change in the pneumatic bridge, formed by the velocity transducer, manifold, and pitot tube. As flow across the tip occurred, a differential pressure developed, imbalanced the bridge and caused a small amount of purge gas to flow through the transducer. The transducer measured this flow which was related to the main gas flow at the tip of the pitot tube. Purge gas still exhausted through both openings, but at a slightly unequal rate. The instrument allowed accurate measurement of flow in the steam plume even though large diameter solids (coke breeze) and water droplets were present.

2.3.3 Preliminary Field Tests

In August 1976, a pretest survey was conducted to determine the following:

- If the circular tower selected produced uniform velocities across the sampling points required by EPA Method 1.
- If the planned sampling train modification would enable isokinetic sampling.
- If emission results would be reproducible.
- Procedures for the official tests.

Velocity profiles were obtained for at least two quenches at each of the required 36 points. These preliminary profiles were analyzed for each one second time interval for magnitude of Δp. The Δp's of

509427

each interval were then added together and averaged by dividing the time of each quench into the total. Visual comparison of overlaid profiles showed that roughly the same pattern, time, and velocity heads were found for each quench, suggesting that velocity heads for a particular point in the stack could be predicted.

Analysis of the above preliminary velocity work indicated that isokinetic sampling conditions could be maintained throughout the quench process by running a velocity test during the first quench in a series. This test could be quickly analyzed and graphed as velocity versus elapsed time. In the succeeding emission tests, the sampling rates would continually be adjusted based upon the graph, and thus the sampling flow rate would increase and decrease coincidentally with the tower's exhaust flow rate. This type of graphical analysis is illustrated in Figure 2-2. It will be noted that three sections of the profile can be defined, namely:

- Ramp Up - From the time the coke car entered the tower until the water hit the incandescent coke (avg. 30 sec).
- Plateau (or middle) - From the time the peak velocity was reached to the time the water spray ended (avg. 60 sec).
- Ramp Down - From the time the water spray ended until the coke car left the tower (avg. 45 sec).

The declining slope of the profile never fell to a zero velocity pressure, as the steam plume continued after the coke car exited the tower.

From these Δ p's, velocity calculations were prepared utilizing moisture data obtained from previous tests, results from a limited number of wet bulb-dry bulb runs,

509428

STACK FLOW VELOCITY DURING FOUR TYPICAL QUENCHES

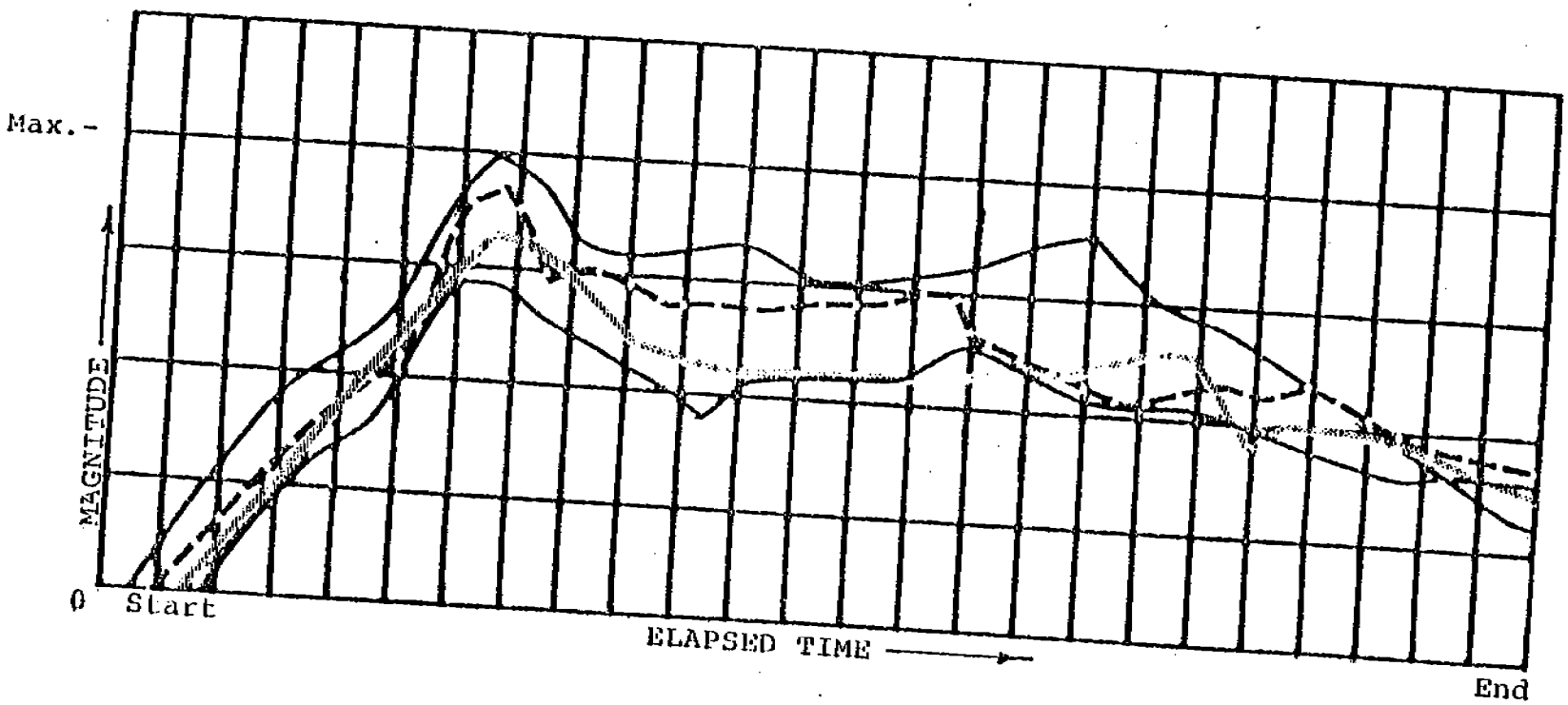

FIGURE 2-2

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and Orsat samples obtained in accordance with EPA Method 3 with the use of two condenser units to trap entrained water droplets. In addition to the velocity traverses, initial measurements were performed with a Fecheimer probe to determine the maximum angle of flow in the tower. Data from these findings were limited but indicated that future traverses and sampling should be conducted near 110 degrees measured from the horizontal. These were later confirmed by further testing conducted with a vane type device, which is discussed in detail in Section 3.0.

Based on this preliminary test information, it was decided to perform three tests of four quenches each at one point in the stack. In order to reflect the total quench emissions, sampling began when the quench car entered the tower and ended when it left. The purpose of these tests was to determine how many quenches would be sampled per run in the official tests, and provide some indication of reproducibility and precision. Process parameters such as water quality, coke greeness, etc., were not recorded. Laboratory results from these three tests showed sufficient weights of particulate matter (over 100 mg), and volumes of dry stack gas (over 15 cubic feet) could be obtained from four quenches instead of the twenty or more quenches which might have been required by EPA Method 5. Variability of these tests ranged from approximately 0.7 gr/scfd to 1.2 gr/scfd (which was acceptable), and isokinetic rates were within 10 percent of 100 percent.

Since the number of quenches could be reduced from twenty or more to four, and flows did not vary much from point to point, the original number of tests

509430

(three to be performed at 36 points in the tower) was increased to twelve with contaminated quench water and twelve with clean water. This allowed statistical verification of the results and the ability to assess the impact of other variables (e.g., fugitive emissions, greeness of coke, water quality changes, and wind direction) which might be hidden by sampling a large number of quenches or by shifting from traverse point to traverse point. Based on the preliminary velocity profiles and the preliminary particulate tests, points on each axis of three rings, twelve points total, were selected as being most likely to give mass emission rates representative of the tower as a whole (see Figure 2-3).

2.3.4 Sampling Technique

Data from the preliminary field tests indicated that velocity head (Δp) was predictable and values for sample rates (ΔH) ramp-up, etc., could be determined based on a preliminary velocity profile taken before each test run. Data from the velocity profile were then utilized to determine:

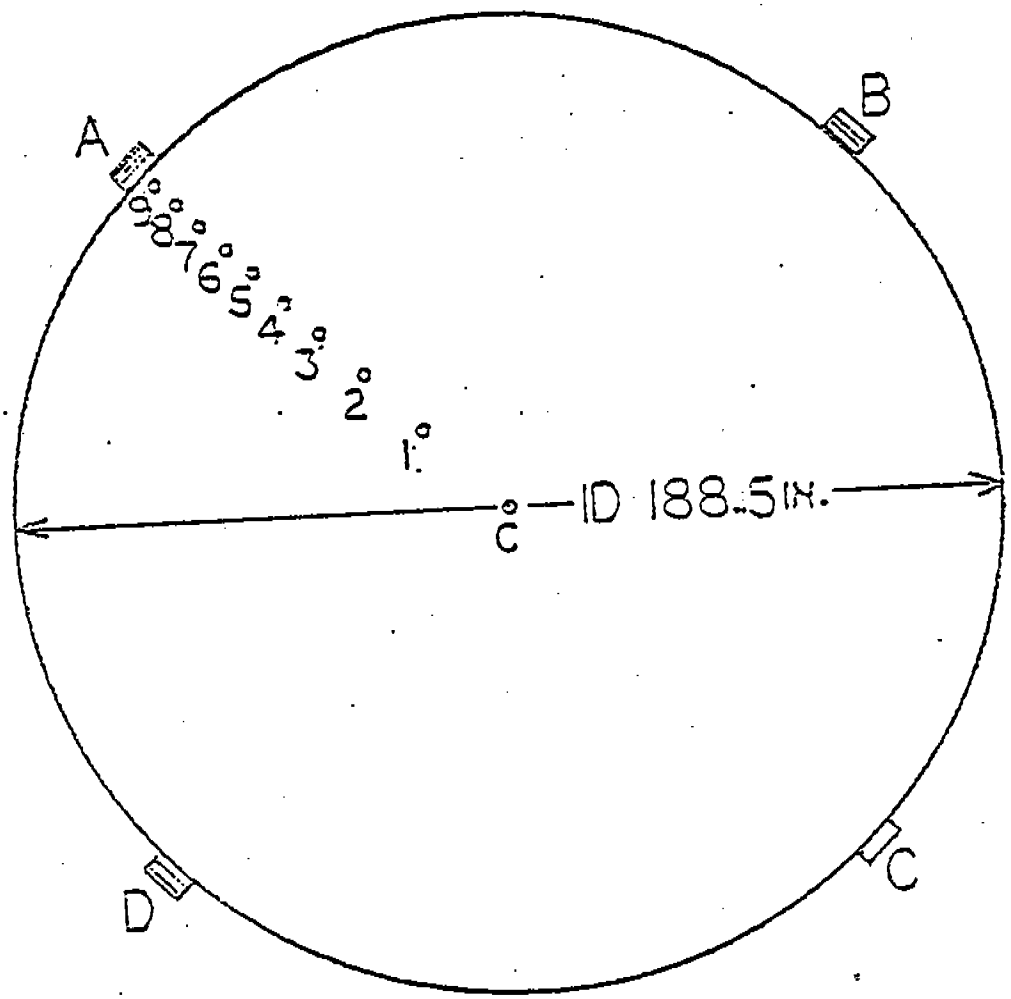
- Velocity Pressure (Δp)
- Velocity (feet per minute)
- Required nozzle size
- Predicted sampling rates

If the preliminary test indicated the presence of an erratic flow pattern, the test was delayed until a predictable flow was established.

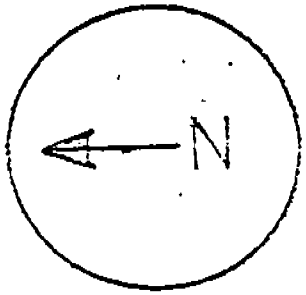
2.3.5 Test Sequence

As previously indicated, the initial traverse was used to establish the rate (length of time) of rise of the velocity head (Δp), the maximum Δp, and the rate of decline of Δp to a selected end point greater than

SAMPLE POINT LOCATION



PT. NO.	INCHES FROM STACK WALL
1	71.60
2	55.60
3	44.40
4	35.40
5	27.50
6	20.50
7	14.10
8	8.25
9	2.65
10	94.25



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zero. Then for each subsequent quench test within the test series, the sampling rate (ΔH) was gradually increased from the signal car-in to approximately 0.50 inches of water over a thirty (30) second period. This maximum sampling rate was maintained until the signal water-off was given and a ramp-down procedure was initiated to a pre-determined rate (approximately 0.26 inches of water) which was established from the averaging of the ramp-down portion of the velocity profile. Sampling was terminated when the car was completely out of the tower.

2.3.6 Full Field Test

Stack particulate tests were conducted in accordance with the procedures outlined in Sections 2.3.4 and 2.3.5. Additional skewed flow measurements were taken with a vane-type device whose results verified earlier test results which indicated that the angle of flow was not a direct function of time. Twelve readings taken with this device indicate a flow in the range of 105-112° from the horizontal. No erratic or oscillatory movements were observed which gave readings outside this range.

During several of the test runs with clean quench water, holes in the center of the filters were found. Laboratory analysis for an etching reagent proved negative, while microphotography showed that the holes may have been produced by bombardment of small diameter particulate matter. It is concluded in Section 4.0 that particulate matter caught on the filter would be smaller than 5 μm, ranging downward toward sub-micron sizes. During the clean water tests, there was a relatively small quantity of particulate matter retained on the intact portion of the filter, while during the contamination water tests, a larger quantity was

509433

caught. This larger quantity of particulate matter may have been initially deposited on the filter directly in front of its inlet, thus protecting this area from the continuing abrasive action of particles smaller than 0.3 μm as they passed through the filter. Test work conducted by YRC at Research Triangle Park[9] for EPA involving wind tunnel tests with low grain loadings and small diameter particles produced much the same effect. Redesign of the inlet to the filter should be considered so as to reduce the velocity of the incoming particles and to disperse them over a larger area of the filter.

Testing techniques and analytical methods are discussed in detail in the following sections, as follows:

• Gaseous	Sec. 4.0
• Water Quality	Sec. 5.0
• Fugitive Emissions	Sec. 3.0
• Particle Size Distribution	Sec. 4.0
• Quenched and Incandescent Coke	Sec. 6.0
• Meteorological Conditions	Sec. 3.0
• Sump Sediment	Sec. 5.0

Tables 2-2 through 2-7 summarize the individual tests showing parameter measured, number of tests on quenches, measurement and analytical techniques, and sampling location. All "tests" consisted of four separate quenches with the exception of the test on September 10, which contained five quenches.

During each test, hourly meteorological data were obtained from the airport located 1.4 miles from the plant. These data included:

- Wind direction and speed
- Dewpoint
- Relative Humidity

509434

TABLE 2-2. SUMMARY - PARTICULATE EMISSION TESTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Mass and Concentrations*	11 w/contaminated	EPA 5 - Modified	EPA 5	(10)
	13 w/clean	EPA 5 - Modified	EPA 5	(10)
Size Distribution (Water Droplets and Particulate)	24	10 µm cyclone	Coulter Counter & Chemical Composition	(10)
	1	Sensitized Paper		(10)
	1	KLD Probe		(10)
Fugitive Emissions		Visible Observation	- -	- -
Elemental Analysis	1	EPA 5 Train	Spark Source Spectrometry	(10)
Mutagenicity	1	EPA 5 Train with Batelle Absorber	Level 1 Analysis	(10)
High Molecular Weight Hydrocarbons	1 w/contaminated	EPA 5 Train	Level 1 Analysis	(10)
	2 w/clean	EPA 5 Train	Level 1 Analysis	(10)
	3 w/contaminated	Water sampled	Level 1 Analysis	(4) (8) (12)
	1 w/clean	Water sampled	Level 1 Analysis	((5) (8) (11) (12) all combined))**

* Consisting of suspended and dissolved solids; and water and acetone wash of nozzle, cyclone and probe, filter, and impingers.

** Water spray on coke, water supply, return, and sump.

5004351

TABLE 2-3. SUMMARY - GASEOUS EMISSION TESTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Cyanide	27 w/contaminated	EPA 6 Train w/moisture traps	EPA 6	(10)
	36 w/clean	EPA 6 Train w/moisture traps	EPA 6	(10)
Ammonia	36 w/contaminated	EPA 6 Train w/moisture traps	EPA 6	(10)
	36 w/clean	EPA 6 Train w/moisture traps	EPA 6	(10)
Sulfide	36 w/clean	EPA 6 Train w/moisture traps	EPA 6	(10)
Phenol	27 w/contaminated	EPA 6 Train w/moisture traps	EPA 6	(10)
	36 w/clean	EPA 6 Train w/moisture traps	EPA 6	(10)
Sulfur Dioxide	36 w/contaminated	EPA 6 Train w/moisture traps	EPA 6	(10)
	36 w/clean	EPA 6 Train w/moisture traps	EPA 6	(10)
Oxygen	10 w/clean	Orsat 40	Orsat	(10)
	2 w/contaminated	Grab Flask Method	G.C.	(10)
Carbon Dioxide	10 w/clean	Orsat 40	Orsat	(10)
	2 w/contaminated	Grab Flask Method	G.C.	(10)
Hydrocarbons	2 w/contaminated	Grab Flask Method	G.C.	(10)
Carbon Monoxide	2 w/contaminated	Grab Flask Method	G.C.	(10)
Total Volatilized Hydrocarbons *	2 w/contaminated	Grab Flask Method	G.C.	(10)

* @ STP

50643

TABLE 2-4. SUMMARY - VOLUMETRIC FLOW MEASUREMENTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Stack Gas Flow				
Velocity Head	96	Hastings-Raydist Meter		
Flow Direction	15	Vane - Fecheimer		(10)
Gas Temperature	40	6 Thermocouples positioned approx. 15 ft. apart up the tower		(10)
Gas Temperature	96	EPA 5 Train		(10)
Water Volumetric Flow and Mass Rates				
Stack-Large Droplets	96	Cyclone		(10)
Small Droplets and Vapor	96	Impinger Assembly		(10)
Spray-on to Coke	90	Sonic Flow Meter		(8)
Return-to Sump	32	Sump Level		(11)
Sump-Makeup	--	Sump Level		(11)

509437

TABLE 2-5. SUMMARY - BATTERY AND TOWER PROCESS MEASUREMENTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Oven Coking Time	96	Plant Data		Pumphouse Roof (8)
Greeness Ratings	96	Visible Observation		
Oven Heat Temp.	96	Plant Data		Pumphouse Roof (8)
Incandescent Coke Temp.	38	Infrared Thermometer		Wharf Area
Quenched Coke Temp.	12	Thermocouple		
Duration & Sequence of Quench Operation	96	Noted on Velocity Profiles		
Coke Composition	Contaminated Q** / Contaminated I*** / Clean Q** / Clean I***			
%Nitrogen	3 / 3 / 3 / 4	Incandescent samples taken from oven doors & quenched samples from wharf area. Coke placed in metal containers, sealed, and shipped to Stamford, CT for analysis.	Ultimate: ASTM D3176-74 Proximate: ASTM D-3172-73	Oven doors & Wharf Area
%Carbon	3 / 3 / 3 / 4			
%Hydrogen	3 / 3 / 3 / 4			
%Moisture*	1 / 2 / - / 2			
%Volatile*	1 / 2 / - / 2			
%Sulfur*	3 / 3 / 4 / 4			
Btu/lb	3 / 3 / 4 / 4			
Contaminant Deposition on Coke				
Cyanide	4 / 3 / 4 / 4	Samples taken from wharf area, placed in metal containers, sealed, and shipped to Stamford, CT. for analysis.	Samples washed, & solutions analyzed by EPA Standard Water & Waste	Wharf Area
TOC	4 / 3 / - / 4			
Dissolved Solids	4 / 3 / 4 / 4			
COD	4 / 3 / 4 / 4			
Phenol	4 / 3 / 4 / 4			
Chloride	4 / 3 / 4 / 4			

* Analytical results from plant data are available for 16 coke samples taken during water tests.
** Q = Quenched
*** I = Incandescent

509438

TABLE 2-5. (CONTINUED). SUMMARY - BATTERY AND TOWER PROCESS MEASUREMENTS

Measured Parameter	No. of Tests				Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
	Contaminated		Clean				
	Q**	I***	Q**	I***			
Calcium	4	3	4	4	Samples taken from wharf area, placed in metal containers, sealed, and shipped to Stamford, CT. for analysis.	Samples washed, & solutions analyzed by EPA Standard Water & Waste Methods	Wharf area
Sulfate	4	3	4	4			
Sulfide	4	3	4	4			
Coal							
Volatiles	18				Plant Data		
Ash	18				Plant Data		
Free Moisture	18				Plant Data		
Sulfur	18				Plant Data		

** Q = Quenched
*** I = Incandescent

5094439

TABLE 2-6. SUMMARY - WATER QUALITY MEASUREMENTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Phenol	80 w/contaminated 104 w/clean	Composite samples taken from lines tapped into inlet header line and return makeup samples obtained by:	EPA Methods for Chemical Analysis of Water and Wastes	Inlet Header Pipe (8)
Cyanide Sulfate Sulfide Ammonia Calcium Oils Chloride COD TOC Electrical Conductivity Total Solids Dissolved Solids Suspended Solids Volatile Solids		- Contaminated - Bucket in open stream - Clean - Service water in wharf area. Two samples taken each test day; one sample for 8 quenches.		Return trough (1) Makeup pipe (4) to sump for contaminated tests. Service water (5) in wharf area for clean tests.

50034

TABLE 2-7. SUMMARY - SUMP SEDIMENT MEASUREMENTS

Measured Parameter	No. of Tests	Measurement Method	Analytical Method	Sampling Location (Figure 1-1)
Conductivity	3 samples	Weighted bucket dragged along sump bottom	EPA Methods for Chemical Analysis of Water and Wastes	Sump (11)
TOC				
Phenol				
Total Solids				
Volatile Solids				
Sulfate				
Cyanide				
Ammonia				
Calcium				
COD				
Oil				
Chloride				

509441

- Temperature
- Barometric pressure

2.3.7 Sample Recovery - Particulate Tests

While many parameters were measured during the field tests, it was of prime importance for purposes of accuracy and reproducibility, that the modified EPA Method 5 train be used with great care so that emission rates could be reliably determined.

The following section covers procedures utilized in the clean-up of the Method 5 train in greater detail than is provided in the standard procedures used in Method 6 (Gaseous Sampling Trains).

At the completion of each test run, the probe and cyclone assembly was removed from the stack and its exterior was wiped clean. Before lowering the train from the test platform, the cyclone cup was removed and its contents poured into a clean labeled container. The cup was then placed back into the cyclone assembly. The filter holder, umbilical line, and impinger unit were disconnected and each was capped. After inspection and recording of any anomalies, the individual units were lowered to the laboratory trailer for clean-up.

In the laboratory trailer, clean-up and disassembly of the sampling train were conducted in the following order:

1. The nozzle was carefully removed and the inside surface cleaned by triple rinsing with distilled water and brushing between each rinse with a pre-cleaned nylon brush. Brushing was continued until the rinse showed no visible particles, then the inside surface was given a final rinse.
2. The inside parts of the probe and cyclone were then brushed and rinsed with distilled water in a manner similar to the nozzle until the rinse showed no remaining visible particles.

509442

3. The probe liner was rinsed by squirting water into the upper end, while tilting and rotating it to assure that all inside surfaces were cleaned. The water drained from the lower end into the sample container. A second rinse using the same procedure was then performed with the aid of a probe brush, which was pushed through the entire length of the liner using a twisting action. The brushing and rinsing operation was repeated until no particulate matter remained in the probe liner upon visual inspection. Upon completion of the brushing and rinsing operation, the brush was rinsed with distilled water and the liner was given a final rinse. These rinsings were collected in the same sample container described earlier.
4. The filter was removed from the holder and was inspected for tears, punctures and other deformations before being placed in a clean labeled petri dish which was then sealed with elastic tape.
5. The inside of the front half of the filter holder was cleaned by double brushing with a nylon bristle brush and rinsing with water until all visible particulate was removed. The brush and the inside surface of the front half of the filter holder was then given a final rinse.
6. A second wash of the nozzle, cyclone, probe, and front half of the filter holder was performed using reagent grade acetone in the same manner and procedure as were used in the water wash.
7. The liquid in the first three impingers and the condensate from the umbilical cord was measured to the nearest ml and recorded. The contents were then placed in a labeled container. Approximately 50 ml of distilled water was then poured into each impinger, agitated, and added to the container. The umbilical cord, back half of the filter holder

509443

and connecting fittings were rinsed twice with distilled water and added to the wash container. Acetone washes were not performed as Lexan impingers were utilized.

8. The silica gel from the last impinger was transferred to a pre-tared container, weighed to the nearest 0.1 g and recorded.

9. The volume of the solution from the cyclone cup was then measured to the nearest ml, recorded, and placed in a separate container.

Contents of the sampling train were sent to the laboratory in nine containers:

Container No. 1 - cyclone solution - glass jar
Container No. 2 - filter - plastic petri dish
Container No. 3 - distilled water wash - glass jar
Container No. 4 - acetone wash - glass jar
Container No. 5 - silica gel - plastic jar
Container No. 6 - impinger condensate and wash - glass jar
Container No. 7 - impinger wash - glass jar
Container No. 8 - distilled water blank
Container No. 9 - acetone blank

2.3.8 Laboratory Analysis

This section outlines the methods and analytical techniques used on samples which were obtained during tests with both contaminated and clean quench water.

Oxygen

Same analysis as Carbon

Sulfate

Two methods were employed in this analysis which are described by method (a) and (b), respectively.

(a) EPA method STORET No. 00945 used in Phase II of the testing. In this method sulfate is complexed to a barium sulfate suspension and the turbidity is

509444

measured by a colorimeter. Range is not more than 40 mg SO_4 /liter.

(b) Gravimetric EPA Method STORET No. 00945 where sulfate is precipitated as barium sulfate in an acid medium, filtered, washed, and weighed as $BaSO_4$ converted to sulfate. Range for concentrations greater than 10 mg SO_4 /liter.

Sulfide

This analysis was performed by EPA Method STORET No. 00745 (total sulfide). In this method the sulfate is used to measure unreacted iodine to indicate the quantity of iodine consumed by sulfide.

Sulfur Dioxide

EPA's Method #6 sulfur dioxide is measured by barium chloride using thorin (1(o-arsonophenylaxo)-2-naphthol-3-6 disulfuric acid disodium salt) as an indicator in isopropanol.

Chemical Oxygen Demand

This analysis was performed by EPA Method STORET No. 00340 where organic substances are oxidized by potassium dichromate in a strong acid medium; the excess dichromate left after reflux is titrated by ferrous ammonium sulfate using orthophenanthroline ferrous complex as an indicator.

Additional Analyses

Oils

The determination of oil and grease on water samples were determined in accordance with EPA Method STORET No. 00556 (separatory funnel extraction) using Freon 113 where the solvent serially extracts oil and grease which is evaporated and the residue weighed in a tared beaker.

British Thermal Units

Determined by combustion in an adiabatic bomb calorimeter using ASTM Standard for bomb calorimetry (D-271).

509445

Electrical Conductivity

Determined by a Hack Meter; measured in micromohms/cm^3.

Particulate Analysis (Stack, Ambient, and Water Samples)

Acetone washes were determined in accordance with EPA Method 5. Wash volumes were recorded, samples were evaporated in tared beakers and final residue was calculated by a blank determination. The residue of these beakers were preserved for analysis of oil and grease.

- Dissolved, Suspended, and Total Solids

Analysis of suspended matter was determined by the procedure outlined in Standard Methods (208D) with the exception of the following:

(a) A 45 μm Millipore filter was used in place of a glass fiber filter.

(b) 10 ml aliquot of the filtrate was used to make 5 daily composites (shown on results for analysis of Cl and SO_4).

The remaining filtrate was then evaporated to determine true dissolved solids. The total of the two give the T.S. concentration.

- Filters

Particulate weights were determined by EPA methods using a 5 place Mettler balance. This type of analysis was done on both stack and ambient air samples.

- Combustibles

The method for determining incomplete combustion was analyzed in accordance with EPA methods. Particulate was weighed accurately to four places, was then placed in a muffle furnace for 7 minutes, desiccated and re-weighed. The difference was recorded as percent combustibles. The procedure was done on the cyclone samples only. Water samples were analyzed according to Standard Methods.

509446

Ammonia

Phase I samples were determined by EPA Method STORET No. 00610. Phase II samples determined potentiometrically by a selective Ion Electrode.

Calcium (Ca)

In both phases of this testing, calcium was determined by Atomic Absorption (Perkin-Elmer).

Carbon (C)

Carbon analysis was performed by combustion on a Perkin-Elmer Model 240 Elemental Analyzer.

Chloride

Due to concentration levels - chloride was analyzed employing three methods which are described by (a), (b), and (c), respectively.

(a) STORET No. 00940 analyzed titrimetrically employing the formation of the blue-violet mercury diphenylcarbazone complex. Range of 10 - 20 mg Cl per 50 ml of sample.

(b) STORET No. 00940 analyzed colorimetrically with thiocyanate ion to form unionized mercuric chloride. Range of this method is 1 - 250 mg Cl/liter.

(c) Analyses potentiometrically by a selective ion electrode.

Cyanide

This parameter was analyzed in accordance with EPA STORET No. 00720 employing the Allihn Condensing Method. The procedure is based upon the reaction of cyanogen chloride and either pyridine-pyrazolone or pyridine barbituric acid, forming a blue complex which is linear with Beer's Law.

Fluoride

Fluoride was determined by EPA STORET No. 00950 (Automated

509447

Compliance Method). This method's range is 0.05 - 1.5 mg F/liter.

Hydrogen

Same analysis as Carbon

Nitrogen

Same analysis as Carbon

Level 1 Organic Matter

Mutagenicity - (Aimes Test)

Phenols

Determined by injection of sample into a Hewlett-Packard Gas Chromatograph and the resulting peaks compared to a known library of phenol standards.

TOC

Total Organic Carbon was automatically determined by a Dohrmann Envirotech Total Organic Carbon Analyzer. The results are read directly as mg/liter TOC.

pH

Determined in accordance with EPA Method STORET No. 00400 using a saturated colomel electrode and/or combination (glass and reference) electrode.

509443

2.3.9 Precision and Accuracy

In order to place a measure of reliability to the data obtained from this program, it is necessary to examine the various processes and measurements carried out in achieving the final numerical result. Once the reliability of each step is assessed, it is then possible to compute the probable error associated with the data point.

Probable error is defined as a plus or minus quantity within which limits the actual accidental error is likely as not to fall. It is an indication of precision and does not signify either the actual error, or the error most likely to occur.

To evaluate quantities derived from field test data, many equations are used in ways that combine one or more measured quantities resulting in determination of such things as the Total Air Emission, Volumetric Flow, and Volume of Sample tested; to mention a few. With each such quantity there exists an associated maximum possible error. When several quantities are combined in some fashion, as in an equation, these errors tend to accumulate and compound themselves. A common procedure for determining the maximum probable error for any combination of quantities is discussed on Page 1 - 6, 7 of the Civil Engineer's Handbook, and was used in the following calculations for maximum probable error.

This method is given as follows for calculating the probable error (Es) for related quantities of differing reliabilities:

(eg. 1) $$E_s = \sqrt{E_1^2 + E_2^2 + E_3^2 + \ldots\ldots + E_n^2}$$

where E_1 through E_n are the probable errors for the independent quantities.

509449

Table 2-8 presents the probable error associated with with the various analyses. Many of these values were obtained by estimate, while others appear in the published methods.

As an example of the procedure used in calculating the probable error, the following example is given:

$$\text{Air Emission (lb/T.C)} = \left[\frac{mg}{V_{m_{std}}}\right]\left[\text{scfm}\right]\left[C\right]$$

where: mg is the sample
$V_{m_{std}}$ is the volume of the sample tested
scfm is the volumetric flow
C is conversion constants (C_1, C_2, ... C_n)

The first three quantities contain other independent quantities that also have errors associated with them; they too must first be analyzed for maximum probable error in order to determine a maximum probable error for the Total Air Emission results.

As a part of the overall calculation, it was necessary to calculate the volume of the sample tested. Maximum errors for each component of the calculation were obtained from a paper by Shigehara, et al.[10]

This sample calculation is shown below in its entirety. It should be noted that dimenstions, like conversions, have no bearing on maximum probable error determinations and have not been included.

$$V_{m_{std}} = (C_1)\left[\frac{V_m\,(P_b + \frac{P_m}{C_2})}{(T_m + C_3)}\right]$$

where: V_m = volume (meter)
P_b = atmospheric pressure
P_m = pressure at meter

509450

TABLE 2-8. PROBABLE ANALYTICAL ERRORS

Parameter	Estimated Error	Source
STACK SAMPLES		
• Filters		
Particulate wt.	± 0.01 mg	EPA Method 5
Chloride	± 0.1 ppm	Estimate
Fluoride	± 0.01 ppm	Estimate
Calcium	± 0.001 mg	Estimate
Sulfate	± 0.001 mg	Estimate
Spark Source	± 1.0 ppb	Estimate
• Cyclone		
Dissolved Solids	± 0.001 g	Estimate
Suspended Solids	± 0.001 g	Estimate
Volatile Solids	± 0.001 g	Estimate
Total Solids	± 0.001 g	Estimate
Sulfate	± 0.001 mg	Estimate
Chloride	± 0.003 g	Estimate
Calcium	± 0.002 g	Estimate
Fluoride	± 0.018 g	Estimate
Spark Source	--	--
Particle Size	--	--
• Acetone Wash		
Particulate Wt.	± 0.001 mg	EPA Method 5
Oils	± 0.001 mg	EPA Method 5
• Impingers & Wash		
Particulate Wt.	± 0.001 mg	EPA Method 5
Toxicity	--	--
Mutagenicity	--	--
Level I Matter	--	--
• Miniature Impingers		
Ammonia	± 5.0%	Estimate
SO_2	--	--
Cyanide	± 0.1 mg	Estimate
Phenol	--	--
Sulfide	± 0.001 mg	Estimate
AMBIENT AIR SAMPLES		
• Filters		
Particulate Wt.	± 0.001 mg	Estimate
Chloride	± 0.003 g	Estimate
Fluoride	± 0.018 mg	Estimate
Calcium	± 0.001 mg	Estimate
Sulfate	± 0.001 mg	Estimate

509451

TABLE 2-8. (CONTINUED)

Parameter	Estimated Error	Source
WATER SAMPLES		
• Inlet		
Dissolved Solids	± 0.001 mg	Estimate
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Oils	--	--
COD	± 0.01 mg	Estimate
Chlorides	± 0.003 mg	Estimate
pH	--	--
Level I Matter	--	--
• Return		
Conductivity	± 10.0 %	Estimate
Dissolved Solids	± 0.001 g	Estimate
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Oils	± 0.001 mg	Estimate
COD	± 0.017 mg	Estimate
Chlorides	± 0.003 g	Estimate
pH	--	--
Level I Matter	--	--
• Sump Sediment		
Conductivity	± 10.0 %	Estimate
Dissolved Solids	± 0.001 mg	Estimate
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Oils	± 0.001 mg	Estimate
COD	± 0.017 mg	Estimate
Chlorides	± 0.003 g	Estimate
pH	--	--
Level I Matter	--	--

509452

TABLE 2-8. (CONTINUED)

Parameter	Estimated Error	Source
• Sump (Liquor & Wharf)		
Conductivity	± 10.0 %	Estimate
Dissolved Solids	± 0.001 mg	Estimate
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Oils	--	--
COD	± 0.017 mg	Estimate
Chlorides	± 0.003 g	Estimate
pH	--	--
Level I Matter	--	--
• River Water		
TOC	--	--
Dissolved Solids	± 0.001 g	Estimate
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Calcium	± 0.001 mg	Estimate
Chloride	± 0.003 g	Estimate
COD	± 0.017 mg	Estimate
COKE SAMPLES		
• Incandescent		
Btu	--	--
% S	± 0.001 mg	Estimate
% N	--	--
% H	--	--
% C	--	--
% O	--	--
% Comb.	± 0.0001 g	Estimate
Calcium	± 0.001 mg	Estimate
• Quenched		
Btu	--	--
% S	--	--
% N	--	--
% H	--	--
% C	--	--
% O	--	--
% Comb.	± 0.0001 g	Estimate
Calcium	± 0.001 mg	Estimate

509453

TABLE 2-8. (CONTINUED)

Parameter	Estimated Error	Source
• Incandescent Extract		
TOC	--	--
Phenol	--	--
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Chloride	± 0.003 g	Estimate
COD	± 0.017 mg	Estimate
• Quenched Extract		
TOC	--	--
Phenol	--	--
Sulfate	± 0.001 mg	Estimate
Sulfide	± 0.001 mg	Estimate
Cyanide	± 0.1 mg	Estimate
Ammonia	± 5.0 %	Estimate
Calcium	± 0.001 mg	Estimate
Chloride	± 0.003 g	Estimate
COD	± 0.017 mg	Estimate

509454

Individual Probable Errors

V_m; ± .004%
P_b; ± .21%
P_m; ± .42%
T_m; ± 1.0%

Then using Eq. 1,

E_s for $V_{m_{std}}$ = ± 1.10%

In the same manner, the maximum probable error was found for scfm to be ± 3.2%. Laboratory analysis determined the weight measurements to be accurate to ± 0.003% of the total weight. The effect of this error on the Total Air Emission figure was negligible.

With maximum probable errors for mg, $V_{m_{std}}$, and scfm all known, Eqn. (1) is then evaluated using the procedure previously mentioned to yield a maximum probable error for the Total Air Emission figures.

Maximum Probable Error for Total Air Emission ± 3.4%.
It was also desirable to determine the maximum probable error for the Total Dissolved Solids parameter. This error was found to be 5.0%.

500455

2.3.10 Calculations

The following are the basic equations used in calculating data.

PARTICULATE

1. Volume of dry gas sampled at standard conditions - 70°F, 29.92" Hg

$$V_{m_{std}} = \frac{17.7 \times V_m \left[Pb + \frac{P_m}{13.6} \right]}{(T_m + 460)}$$

2. Volume of water vapor at 70°F and 29.92" Hg

$$V_{w_{gas}} = 0.0474 \times V_w$$

3. % Moisture in stack gas

$$\%M = \frac{100 \times V_{w_{gas}}}{V_{m_{std}} + V_{w_{gas}}}$$

4. Mole Fraction of dry gas

$$M_d = \frac{100 - \%M}{100}$$

5. Average molecular weight of dry stack gas

$$M\ W_d = \left[\% CO_2 \times \frac{44}{100} \right] + \left[\%O_2 \times \frac{32}{100} \right] + \left[\%N_2 \times \frac{28}{100} \right]$$

6. Molecular weight of stack gas

$$M\ W = (M\ W_d \times M_d) + 18\ (1 - M_d)$$

7. Stack velocity at stack conditions, fpm

$$V_s = 4350 \times \left[P_s \times (T_s + 460) \frac{1}{P_s \times M\ W} \right]^{1/2}$$

8. Stack gas volume at standard conditions, SCFM

$$Q_s = \frac{0.123 \times V_s \times A_s \times M_d \times P_s}{(T_s + 460)}$$

509456

9. Percent isokinetic

$$\%I = \frac{1032 \times (T_s + 460) \times V_{m_{std}}}{V_s \times T_t \times P_s \times M_d \times (D_n)^2}$$

10. $\frac{mg}{V_{m_{std}}} \times 0.0154 \times Q_s \times 0.00857 \times \frac{Hr.}{min.} \times \frac{min.}{quench} = \frac{lb.}{quench}$

i.e. (Test 9C30)

$$\frac{735.2}{10.88} \times 0.0154 \times 155652 \times 0.00857 \times \frac{1}{60} \times \frac{1.69}{quench} = 39.10$$

11. $\frac{lbs}{quench} \times \frac{quench}{\text{tons coal charged}} = \frac{lbs.}{ton\ coal}$

i.e. $39.10 \times \frac{1}{13.1} = 2.98$ lb/ton coal

Gaseous Calculations

$$ppm = \frac{(48.15)(Mg)(Tm + 460)}{(Mw)(Vm)(Pm)}$$

$$lbs/quench = \frac{(7.467 \times 10^{-6})(Mg)(Qs)(Tm + 460)(2.25)}{(Vm)(Pm)(60)}$$

where:
- mg = weight of sample
- Tm = meter temperature (°F)
- Mw = molecular weight of sample
- Vm = metered gas volume (ACF)
- Pm = meter pressure (in.
- Qs = stack gas flow (scfmd)

i.e. Test 3 SO_2 contaminated -

$$ppm = \frac{48.15(20.19)(533.5)}{64.1(3.08)(29.93)} = 88 \text{ ppm}$$

$$lb/quench = \frac{7.467 \times 10^{-6}(20.19)(233506)(533.5)2.25}{3.08\ (29.93)60} = 7.6 \frac{lbs.}{quench}$$

Water Calculations

$$\frac{lbs}{quench} = \frac{mg}{l} \times \frac{Ltr*}{quench} \times \frac{lbs}{mg}$$

* From either: Inlet, Return and make-up using averaged numbers

i.e. chloride mean value (inlet-dirty)

$$\frac{\text{lbs}}{\text{quench}} = \frac{11597\text{mg}}{} \times \frac{9200\text{gals}}{\text{quench}} \times \frac{3785\text{Ltr}}{\text{gals}} \times \frac{\text{lbs}}{454{,}000\ \text{mg}} = 88.9$$

$$\frac{\text{gals(up-stack)}}{\text{quench}} = \frac{\text{total mls collected}}{3785} \times \frac{(\text{diam of tower})^2}{(\text{diam of orifice})} \times \frac{1}{\text{No. of quenches}}$$

i.e. 7C50

$$\frac{301}{3785} \times \frac{(188.5)^2}{(.621)^2} \times \frac{1}{4} = 1832\ \frac{\text{gals(up-stack)}}{\text{quench}}$$

509453

3.0 STACK FLOW DYNAMICS

A number of significant observations were made concerning the velocity charateristics of the stack gas. These allowed the formulation of a sampling methodology specifically adapted to quenching operations. Among the important statements concerning velocity and test reproducibility are the following:

- While significant variations exist in velocity patterns on a test to test basis, varaitions within an individual test were small enough to permit rapid adjustment of the sampling rate.
- The techniques applied to measurement and plotting of velocity profiles assured that all test results were within the required range for standard EPA Method 5 (± 10 percent of 100 percent isokinetic).
- Angular flow patterns were found to exist in the stack. Accordingly, the sample probe and pitot tube were aligned so as to measure the maximum pressure head (Δp) during each quench.
- An observation post was maintained to record fugitive emissions from the base of the quench tower. Tests were halted when these emissions became excessive; assuring that data obtained were representative of the total tower flow.

509459

3.1 Background and Effect of Velocity on Reproducibility

Estimates based on an engineering knowledge of the quench process proposed that profiles of stack velocity during the quenching period would be similar to those shown in Figures 3-1 and 3-2.

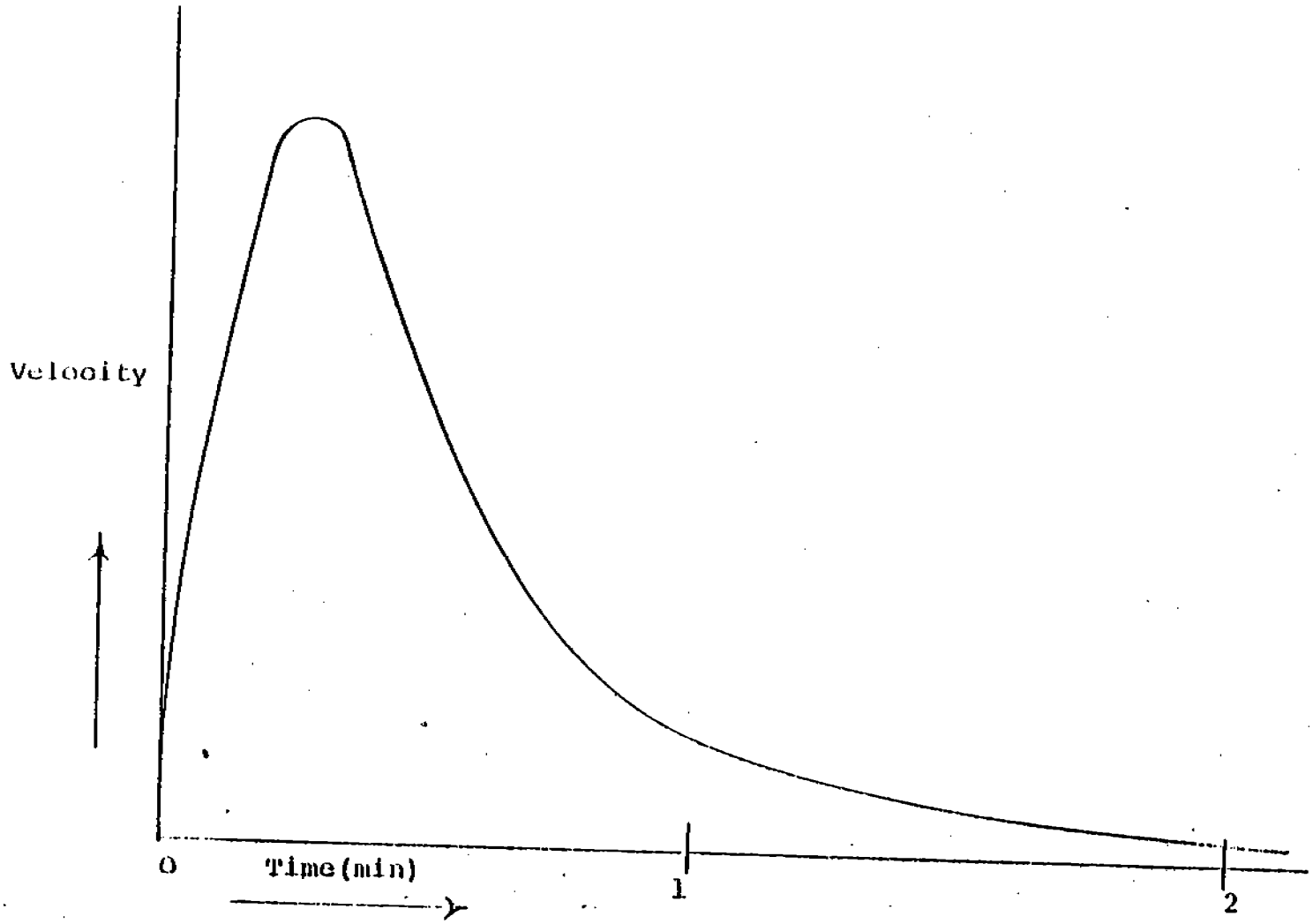
In June, 1976, a plant visit to U. S. Steel Lorain Works revealed a circular brick tower of 120 feet with no internal buttressing. The tower was fitted with a row of baffles located approximately 16 feet from the top of the coke car. Observations of the plume and of fugitive emissions from the base of the tower were taken and compared with those from a short rectangular tower. Based on these comparisons and the fact that the circular tower's sump could be switched from contaminated to clean water, it was decided to conduct a velocity profile program on circular tower No. 1.

A sampling level was selected 100 feet up the tower. Four 90° opposed sampling ports were installed, as well as scaffolding for workers. Thirty-six (36) points at this level were sampled for two quenches each with a Hastings-Raydist velocity meter. A continuous strip chart recorder was connected to the Hastings meter to record the velocity head pressure (Δp). The unit operated with air continually purging the pitot lines, thus preventing stack gas from entering the unit. The instrument allowed accurate measurement of the flow in the steam plume even though large diameter solids (coke breeze) and water droplets were present.

Results from these preliminary tests showed that velocity profiles were more structured than the estimates shown in Figures 3-1 and 3-2, with more pronounced and longer plateaus (See Figure 3-3).

When profiles were taken in sequence (within a 1 hour period), obtainable reproducibility was in the two to three percent range of the total flow rate.

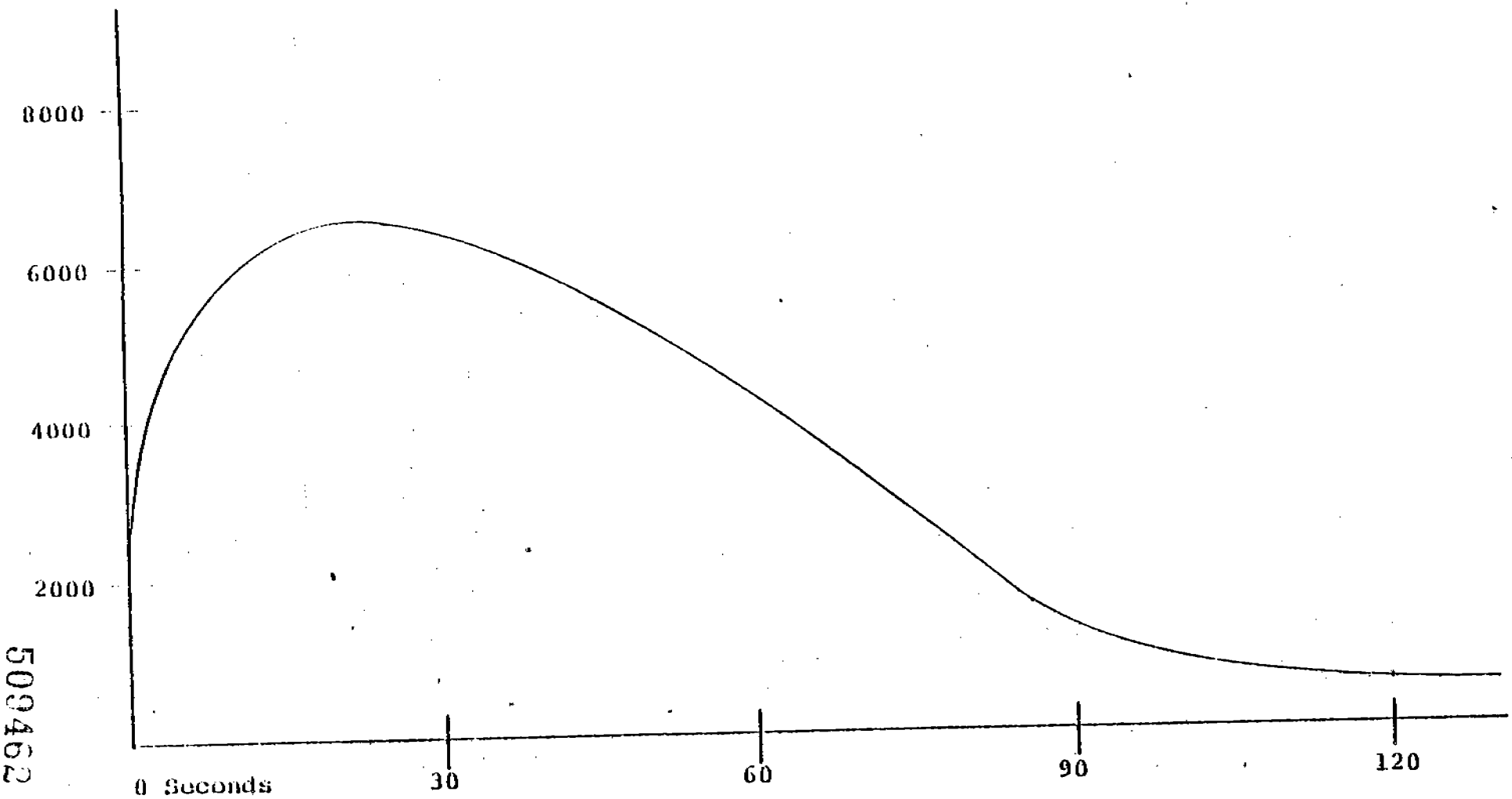
509460



CONCEPTUAL VELOCITY PROFILE

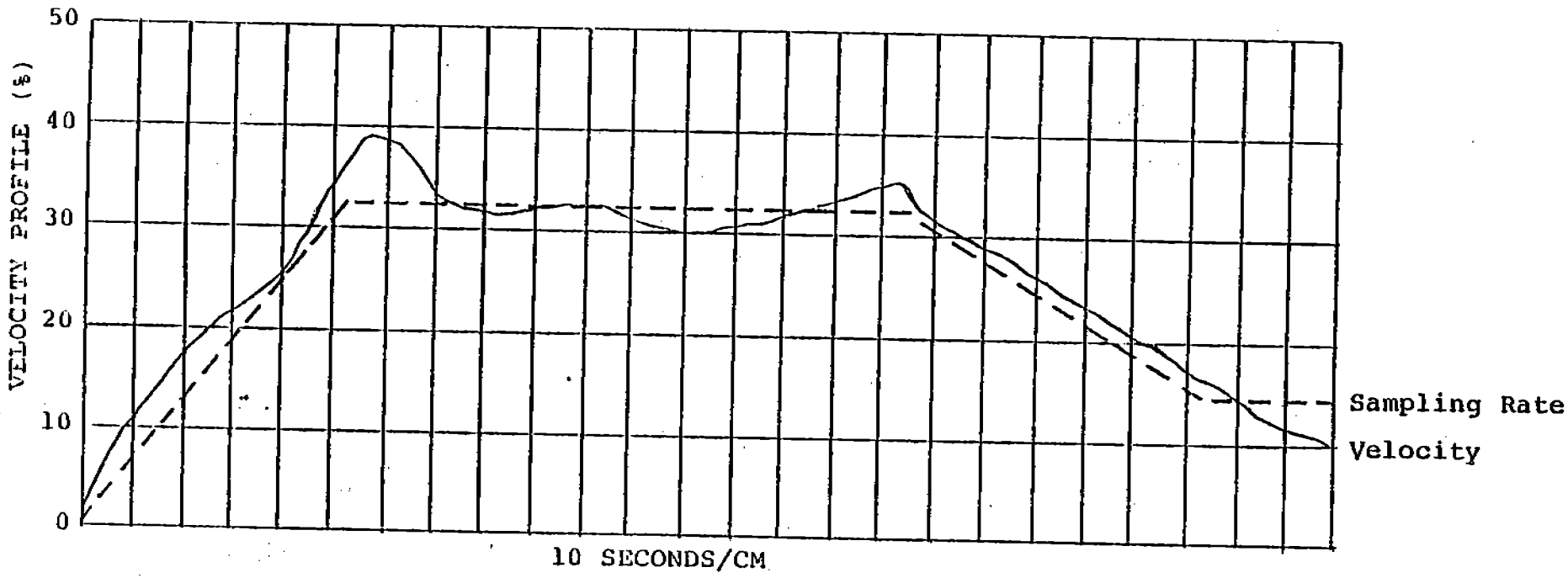
FIGURE 3-1

509461



CONCEPTUAL VELOCITY PROFILE

509462



TYPICAL VELOCITY AND SAMPLING RATE PROFILES

Figure 3-3

509463

3.2 Field Tests

Subsequent to review of the preliminary field work, a sampling rate approach was determined to obtain isokinetic sampling. The problem was to maintain the correct orifice rate over the entire quench period (from car-in to car-out), allowing for the rise and fall of both the velocity head (Δp) and the stack temperature.

As discussed in 2.3.3, the profile was sectionalized into ramp-up, plateau, and ramp down. Each section was analyzed for average Δp and temperature. An appropriate sampling rate (ΔH) was then determined.

Since velocity results were reproducible within a time frame of approximately one hour, profiles were taken preceding each test run to determine sampling rates for the test.

Sampling rates for an average test profile are shown in Figure 3-3.

If a major velocity variation occurred during sampling, (10-20% change from velocity profile) a new sampling rate was determined and implemented within 5-10 seconds.

3.3 Data Analysis

The area under the profile curve was not used to determine sample rates required during field tests. Instead, 6-second blocks were averaged to establish the Δp readings and, in turn, the necessary isokinetic sampling rates (ΔH). The averaging method was used to reduce calculation time since a field computer was not available.

Subsequent comparison of this "short-cut" field method with the integration method yielded results within $\pm$ 2%. The comparison

50946

was performed by taking thirty (30) random quenches and applying area under the curve and block averaging techniques to each. The equation used to integrate the area under the velocity curve is as follows:

$$A = \lim_{n \to \infty} \sum_{i=1}^{n} f(x_i) \Delta x_i = \int_b^a f(x)dx$$

These analyses along with the velocity profiles themselves are on file at York Research.

The velocity variation from quench to quench within any given test was less than 2.0% based on data obtained using the area under the curve method.

Variations between separate tests may be as high as 13.3%. This may be due to:

- moisture content of the stack gas
- probe position
- wind speed and direction
- total tonnage of coke quenched
- coke temperature

Multiple regression analysis was performed in an attempt to determine the effect of moisture content, wind direction, and wind speed on the volumetric stack gas flow rate (scfmd). The data record for these parameters was not sufficiently complete to yield significant correlations with gas flow rates.

Table 3-1 is presented as a quick summary of the variations between individual quench tests.

Table 3-2 is a more thorough summary showing the major parameters recorded during the stack tests.

509465

TABLE 3-1

Summary of Variation Between Individual Quench Tests

	ΔP ("H_2O)	SCFM	Vs (fps)	Time (m
Avg.	0.15	187147.	30.92	2.29
Std. Div.	0.00	24902.	4.28	0.23
Range	.088 - .245	152613 - 236107	23.05 - 40.25	1.12 - 3.

TABLE 3-2

Summary of Major Parameters for All Tests

Test	ΔP (Avg)	SCFM	Wind Speed	Wind Dir.	Total Time	Vs	%H_2O
4B20	.20	226225	NA	NA	9.7	35.95	34.8
5B50	.20	201161	17.3	320°	9.6	36.89	43.4
6B80	.095	175087	6.9	230°	7.57	24.52	25.8
7C50	.17	174197	8.0	230°	7.90	34.22	47.1
8C20	.15	167901	6.9	180°	9.05	32.41	46.2
9C80	.19	155652	6.9	180°	6.76	36.06	55.1
10D50	.12	153788	3.4	180°	8.78	29.17	45.1
11D80	.10	161734	6.9	180°	9.10	26.63	36.8
12D20	.17	202294	6.9	190°	9.0	31.40	33
13A50	.11	182456	5.7	210°	8.9	27.12	29.9
14A20	.17	233806	8.0	210°	9.0	32.94	26.3
15A80	.12	166000	6.9	220°	9.2	29.47	41.3
1C31	.15	204452	8.0	170°	9.3	30.24	29.8
3C21	.145	184985	9.2	30°	9.1	30.23	36.2
1B51	.15	199894	9.2	240°	9.8	31.36	34.8
2B21	.17	195338	9.2	110°	9.5	33.85	40.3
3B81	.16	218638	5.7	210°	9.4	32.34	30.4
4D51	.088	157604	5.7	290°	9.6	24.54	34.1
5D21	.12	178030	4.6	210°	9.4	28.35	35.6
6D81	.09	152613	5.7	360°	9.5	24.96	37.3
7A51	.14	207740	17.3	210°	9.7	30.14	28.7
8A81	.08	173289	13.8	210°	9.5	23.05	22.1
9A21	.167	194496	16.11	230°	9.5	33.62	40
10M1	.15	175486	11.5	250°	9.7	33.2	43.4
12M1	.245	236107	8.1	210°	9.2	40.25	39.1

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3.4 Angular Velocities

Observations during pre-survey work in June and August, 1976, revealed the possibility that the flow within quench tower No. 1 was not vertical. Bifurcation of the exit plume may be sympotomatic of this angular flow. Missing plates in the center of the baffle system may have been responsible for this flow pattern.

In order to conduct the velocity traverses and the subsequent mass emission tests within the maximum flow direction; angular flow measurements were taken with a directional probe connected to a standard manometer. Results from these tests were limited due to plugging of the lines with moisture and particulate matter.

Initial readings indicated that the maximum flow existed between 100° and 115° from horizontal.

In order to determine if these preliminary tests were accurate, and if the angle varied as a function of time during the quench process, a device as pictured in Figure 3-4 was constructed. This device was utilized in twelve (12) separate quenches, one at each of the twelve sampling points. Oscillation of the unit during the quenching process did not vary by more than $\pm$ 10 degrees. The average angle of maximum flow was 109 degrees, with a variation of $\pm$ 7 degrees in the twelve tests.

Positioning of the sampling nozzle and pitot tube were subsequently maintained at 110° for all but the two clean water tests run in the center of the tower.

Possible flow patterns for the quench tower are shown in Figures 3-5 and 3-6. The patterns are based on velocity data in feet per second at each of the sampling points utilized in the test program.

509437

ANGULAR FLOW DETECTOR

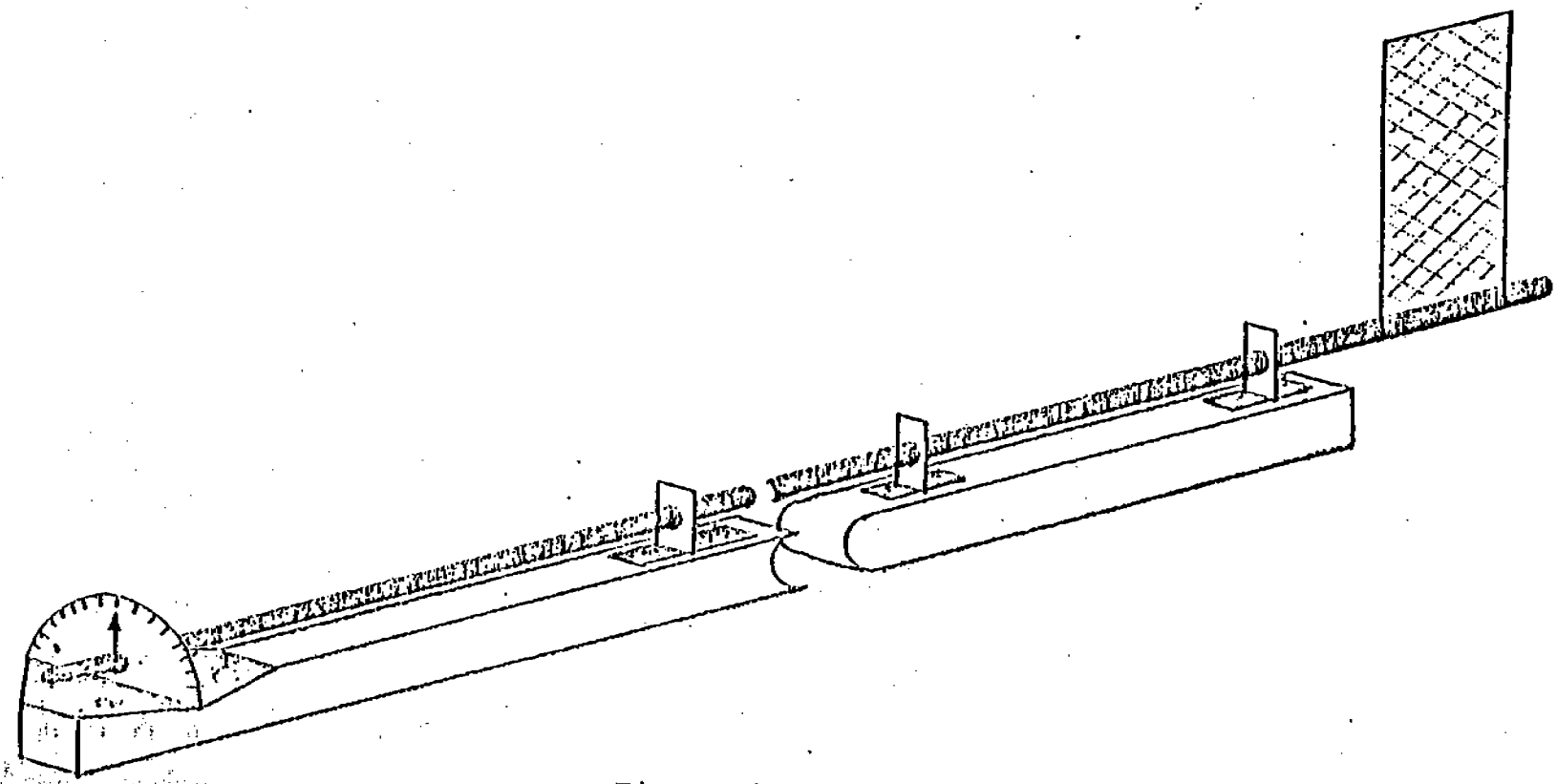

Figure 3-4

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VELOCITY CROSS-SECTION

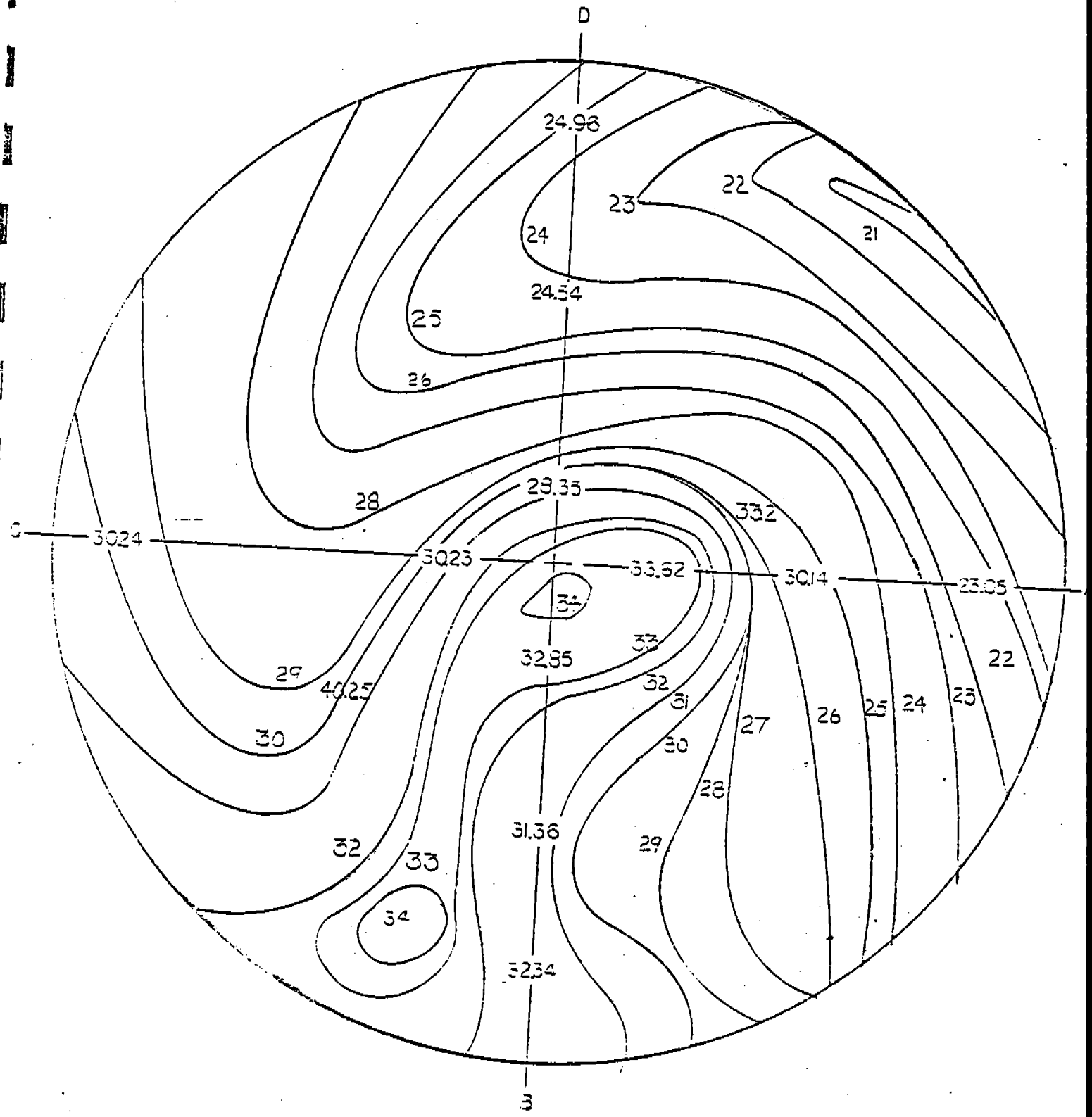

Figure 3-5

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VELOCITY CROSS-SECTION

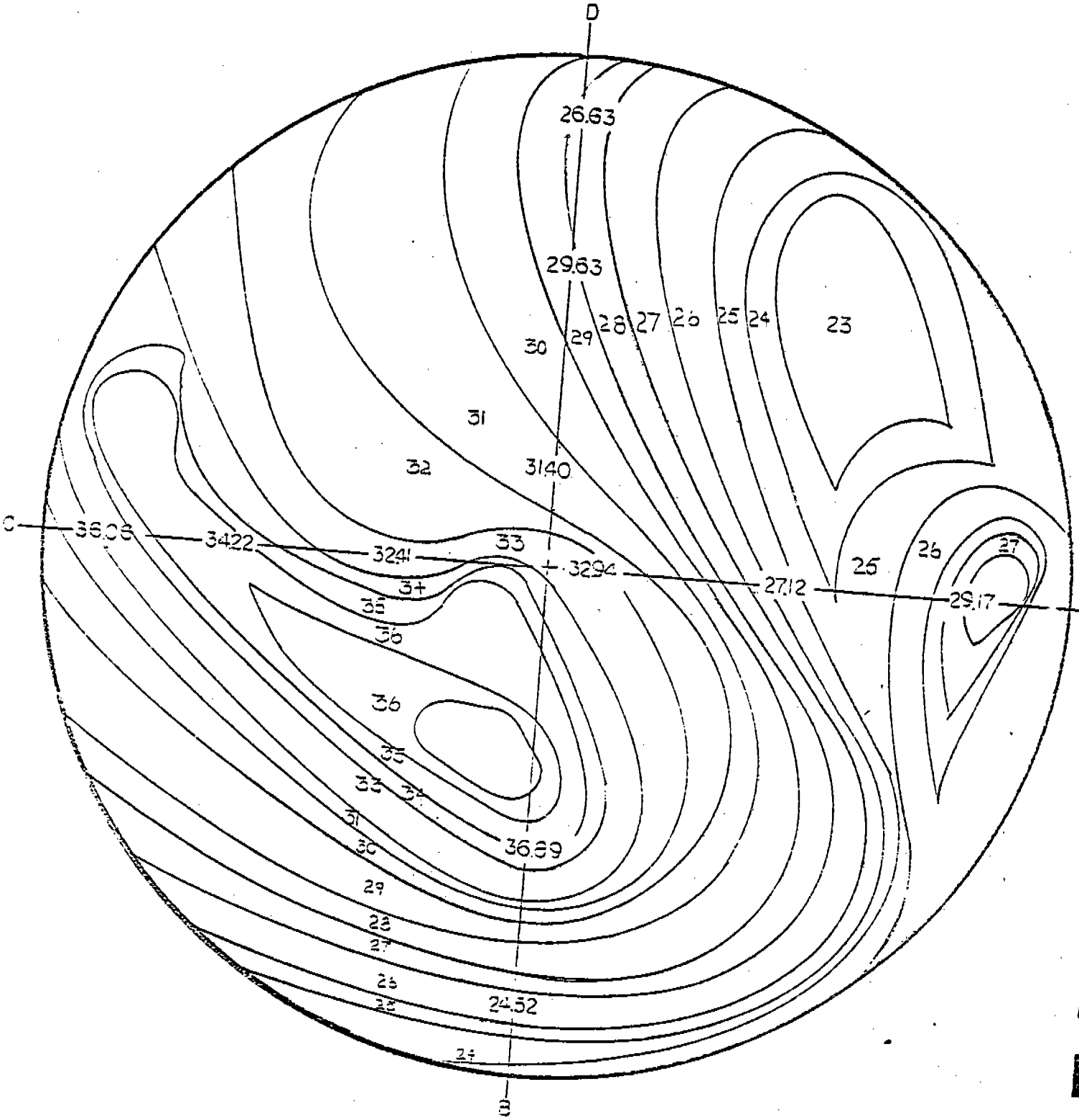

Figure 3-6

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-84-

3.5 Fugitive Emissions

Emissions from the base of Tower No. 1 were classified as fugitive. Frequency and duration of fugitive emissions from the eastern opening of the quench tower were observed from a point located atop the pumphouse roof.

Total test time (sec), fugitive emission duration (sec), wind speed (mph),and wind direction (degrees) are presented in Tables 3-3 through 3-8. Fugitive emission data is presented also in Fiugres 3-7 through 3-19. Fugitive emission time as a percentage of total test time is presented in Table 3-9.

Testing was terminated whenever fugitive emissions occurred for longer than sixty (60) seconds or when wind and emissions caused unsafe working conditions. In this manner, stack samples were obtained which were representative of the total flow. No attempts were made to determine the volume of the fugitive emissions.

TABLE 3-3. FUGITIVE EMISSIONS

Ref. Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind* Vel.	Wind* Dir.
5B50	9/10	0001	H-16	132	55		
		0006	H-26	153	Excessive		
		0012	H-36	150	40		
		0017	G-19	150	30		
		0022	G-29	138	30		
				723	155	17.3	320
6B80	9/11	2004	I-56	141	15		
		2014	G-5	138	10		
		2027	G-15	108	10		
		2100	H-8	67	15		
				454	50	6.9	240
7C50	9/11	2345	G-29	138	5		
		2357	I-58	108	5		
		2408	H-1	108	10		
		2417	H-11	120	5		
				474	25	8.0	230
8C20	9/12	2016	G-15	132	30		
		2030	G-25	138	35		
		2035	I-41	132	30		
		2040	H-51	141	25		
				543	120	6.9	180
9C80	9/12	2140	I-13	103	35		
		2145	I-23	107	30		
		2150	I-33	103	05		
		2210	G-17	97	N/A		
				410	70	8.9	180

* Velocity in meter per hour and direction in degrees

509472

TABLE 3-4. FUGITIVE EMISSIONS

Ref. Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind Vel.	Wind Dir.
10D50	9/12	2323	I-53	131	35		
		2327	I-63	137	30		
		2335	H-64	109	20		
		2342	H-5	155	35		
				532	120	3.5	180
11D80	9/13	1959	I-55	137	10		
		2005	I-65	135	5		
		2008	G-5	143	10		
		2015	G-15	132	10		
				547	35	6.9	180
12D20	9/13	2115	G-25	133	0		
		2150	G-17	138	0		
		2155	G-27	131	0		
		2158	G-9	135	0		
				537	0	6.9	190
13A50	9/13	2324	H-23	131	2		
		2330	H-64	132	10		
		2337	H-59	135	10		
		2345	I-9	135	5		
				533	27	5.8	210
14A20	9/14	2016	H-12	135	5		
		2022	H-32	138	0		
		2052	H-42	136	0		
		2057	G-7	131	0		
				540	5	8.1	210

509473

TABLE 3-5. FUGITIVE EMISSIONS

Ref Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind Vel.	Wind Dir.
15A80	9/14	2315	I-62	138	20		
		2325	H-4	141	10		
		2330	H-14	144	30		
		2337	H-23	137	0		
				560	60	6.9	220

509474

TABLE 3-6. FUGITIVE EMISSIONS

Ref. Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind Vel.	Wind Dir.
1B51	10/29	1855	G	150	20		
		1902	G	146	15		
		1907	G	147	20		
		1915		144	20		
				587	75	9.2	240
2B21	10/30	1805	G-13	142	10		
		1815	I-1	139	15		
		1820	I-11	144	5		
		1825	I-21	141	10		
				566	40	9.2	110
3B81	10/30	0115	G-29	141	10		
		0120	G-39	139	5		
		0125	H-5	144	10		
		0130	H-15	141	10		
				565	35	5.8	210
4D51	11/01	1720	H-37	144	15		
		1725	H-47	150	15		
		1730	H-57	141	30		
		1740	G-21	139	20		
				574	80	5.8	290
5D21	11/05	2335	I-6	138	15		
		2340	I-16	141	20		
		2345	I-26	141	15		
		2355	I-46	145	10		
				565	60	4.6	210

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TABLE 3-7. FUGITIVE EMISSIONS

Ref. Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind Vel.	Wind Dir.
6D81	11/01	0105	G-2	141	10		
		0110	G-8	150	10		
		0115	G-18	138	5		
		0125	G-28	141	20		
				570	45	5.8	360
7A51	11/02	1710	H-57	144	15		
		1715	G-21	146	20		
		1720	G-31	155	15		
		1725	G-41	139	15		
				584	65	17.3	210
8A81	11/02	1925	I-18	138	5		
		1930	I-28	143	5		
		1935	I-38	145	5		
		1940	I-48	144	5		
				580	20	13.8	210
9A21	9/02	2055	G-17	139	20		
		2100	G-27	144	10		
		2105	H-1	143	5		
		2110	H-11	140	10		
				566	45	16.1	230
10M1	11/03	1645	G-31	143	15		
		1650	G-41	145	10		
		1655		149	10		
		1745	G-3	144	30		
				581	65	11.5	250

509476

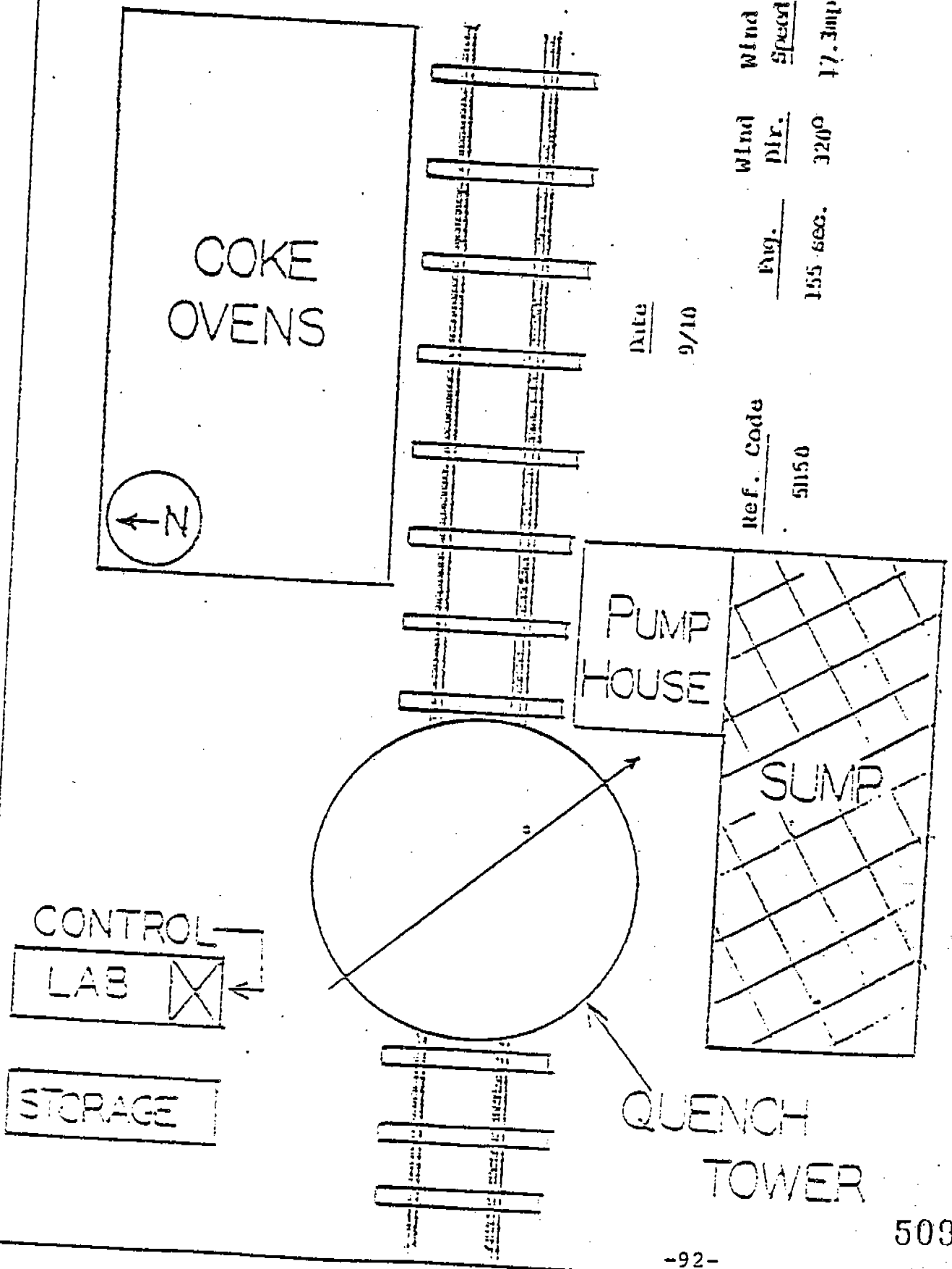
TABLE 3-8. FUGITIVE EMISSIONS

Ref. Code	Date	Time	Oven No.	Seconds of Observation	Seconds Fugitive	Wind Vel.	Dir.
11MP1	11/03	1945	G-37	140	35		
		1950	G-27	141	25		
		1955	G-	138	40		
				419	100	5.9	250
12M1	11/03	2140	G-17	141	15		
		2145	G-27	139	35		
		2150	G-37	137	20		
		2210	H-5	138	40		
				555	110	8.1	210
13A5P1	11/03	0055		149	30		
		0100	G-2	154	20		
		0110	G-	181	15		
1C81	10/05	2125	H-29	140	10		
		2130	H-39	138	10		
		2135	H-49	144	5		
		2150	G-9	135	10		
				557	35	12.7	180
3C21	10/07	1900	I-64	144	30		
		1907	G-23	134	10		
		1914	G-33	135	30		
		1920	H-6	133	15		
				546	85	12.7	40

509477

Report No. Figure 3-7

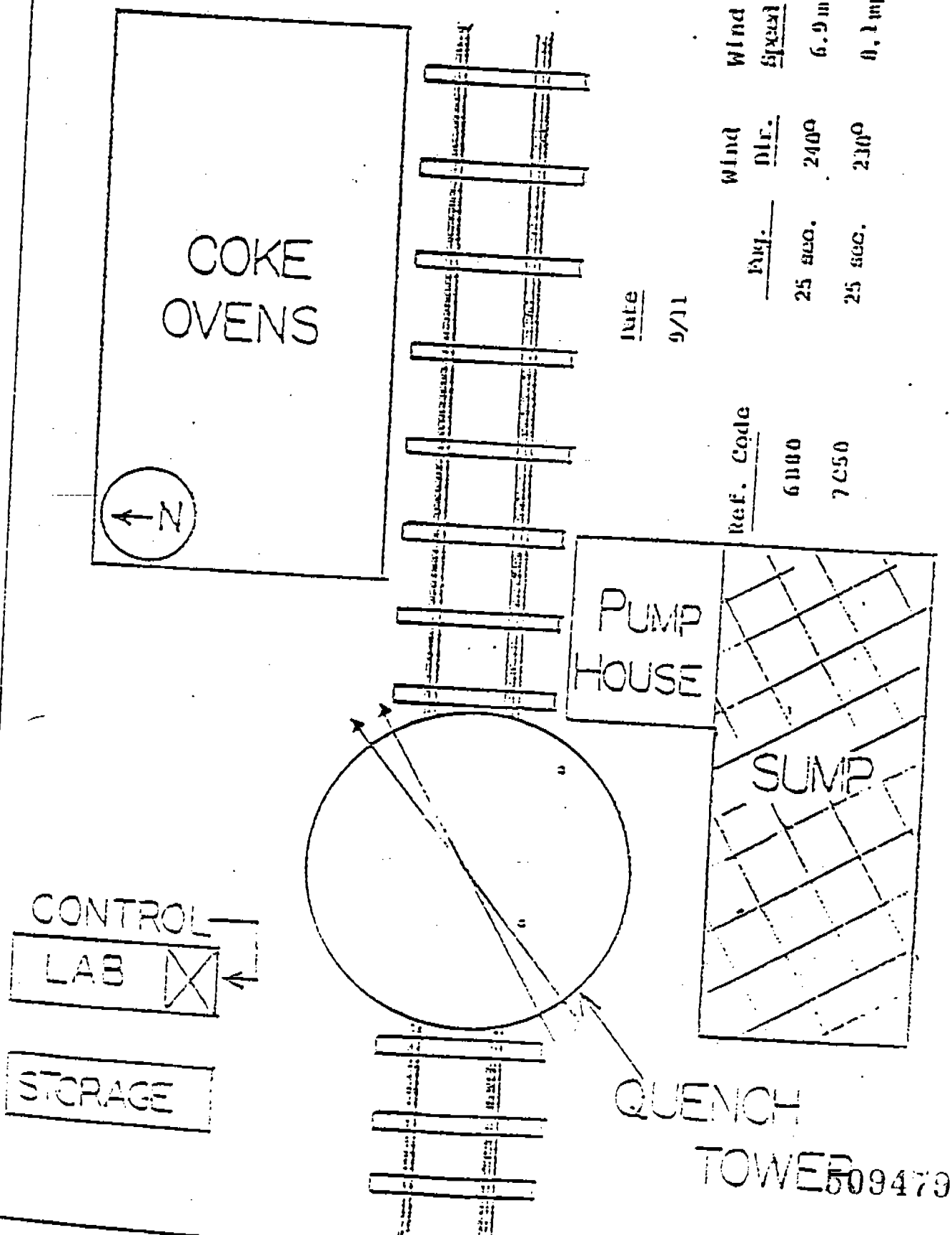
QUENCH TOWER LAYOUT



Ref. Code	Date	Beg.	Wind Dir.	Wind Speed
5150	9/10	155 sec.	320°	17.3mph

FIGURE ~~2.4-2~~ 3-8

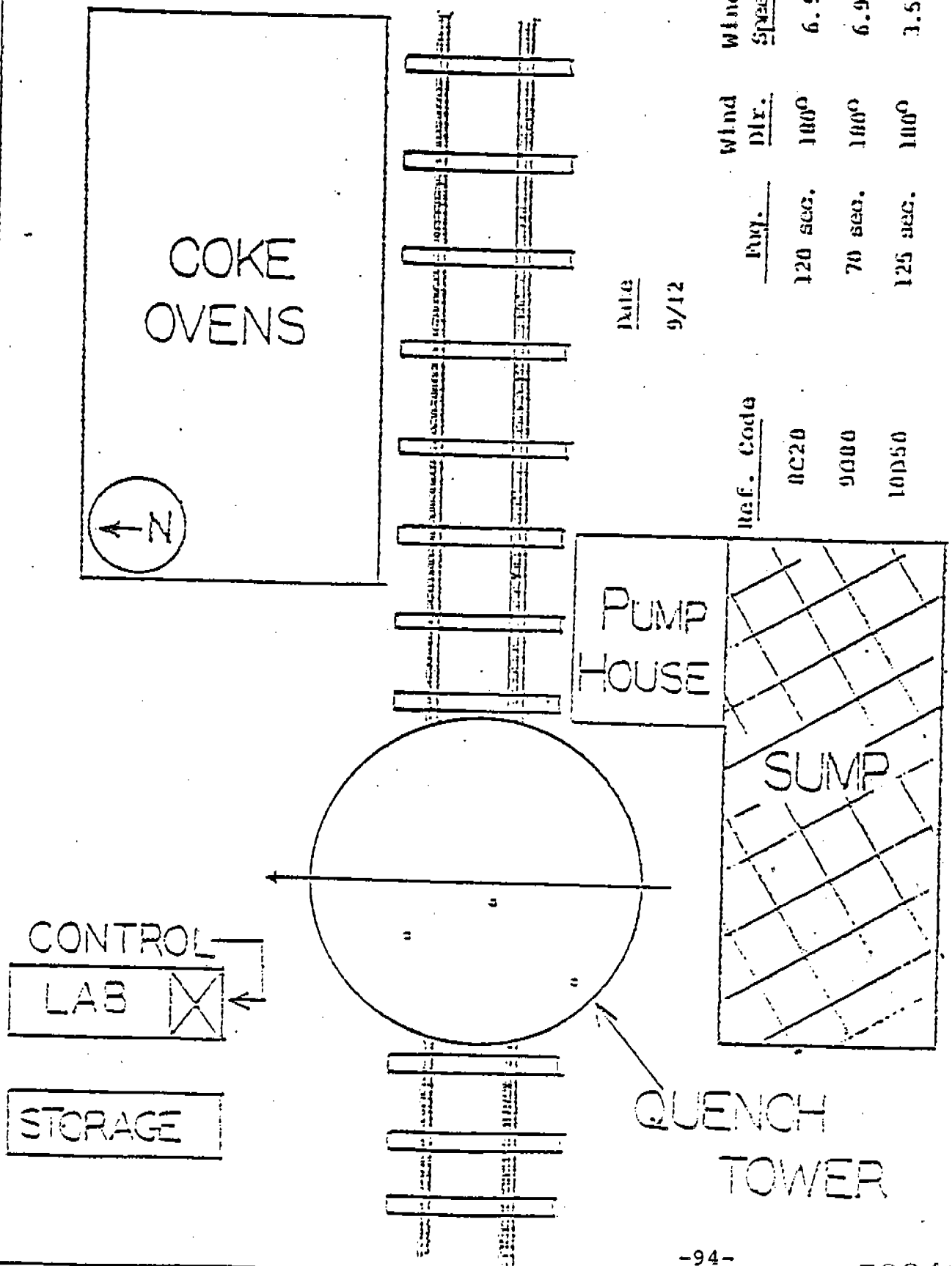
QUENCH TOWER LAYOUT



Ref. Code	Date	Dur.	Wind Dir.	Wind Speed
6080	9/11	25 sec.	240°	6.9 mph
7050		25 sec.	230°	8.1 mph

Figure 3-9

QUENCH TOWER LAYOUT



Ref. Code	Dur.	Wind Dir.	Wind Speed
8C20	120 sec.	180°	6.9 mph
9080	70 sec.	180°	6.9 mph
10050	125 sec.	180°	3.5 mph

Date 9/12

509460
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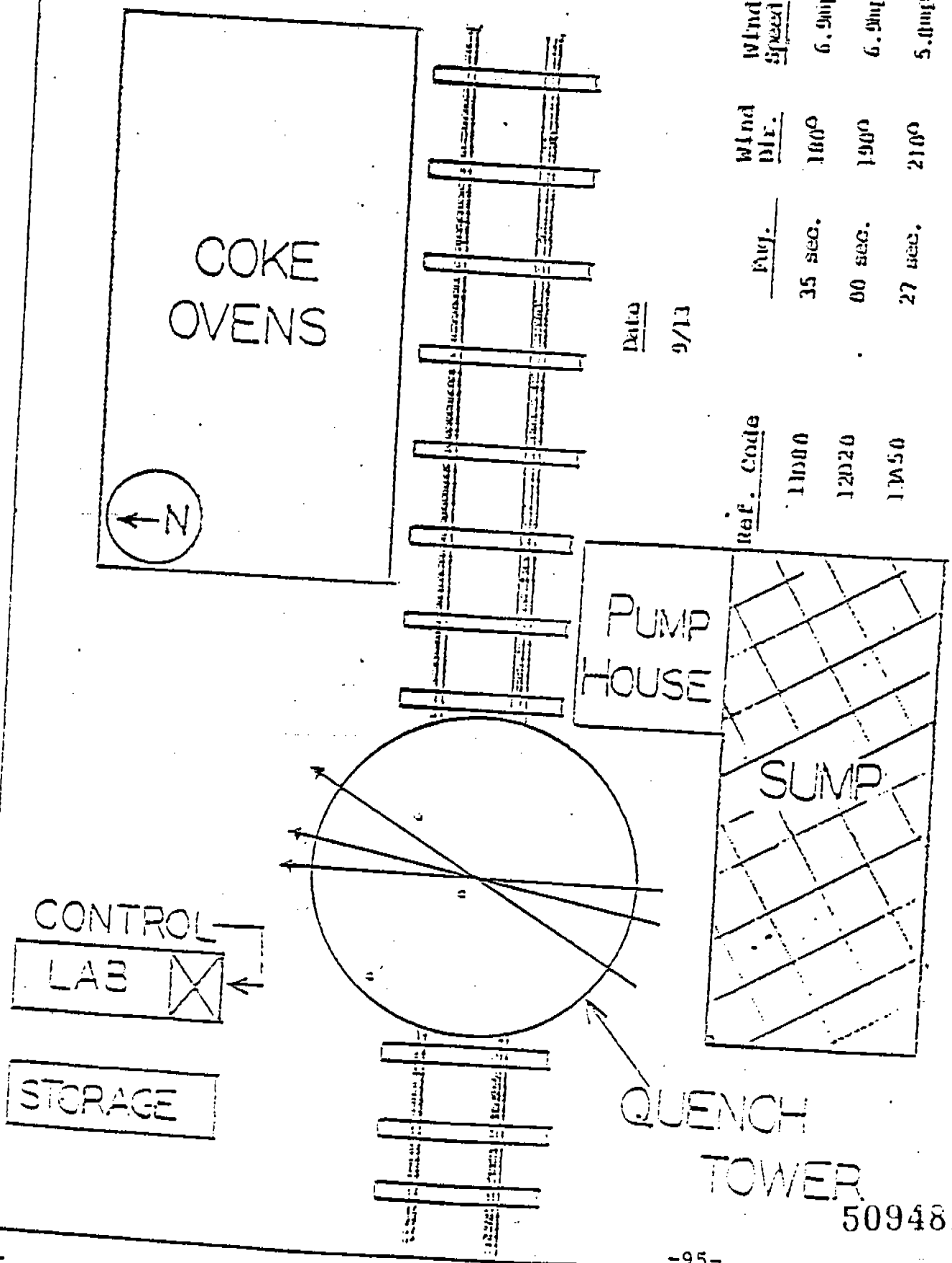
FIGURE ~~2.1.4~~ 3-10

QUENCH TOWER LAYOUT



Ref. Code	Avg.	Wind Dir.	Wind Speed
11000	35 sec.	1800	6.9mph
12020	00 sec.	1960	6.9mph
13450	27 sec.	2100	5.0mph

Date 9/13

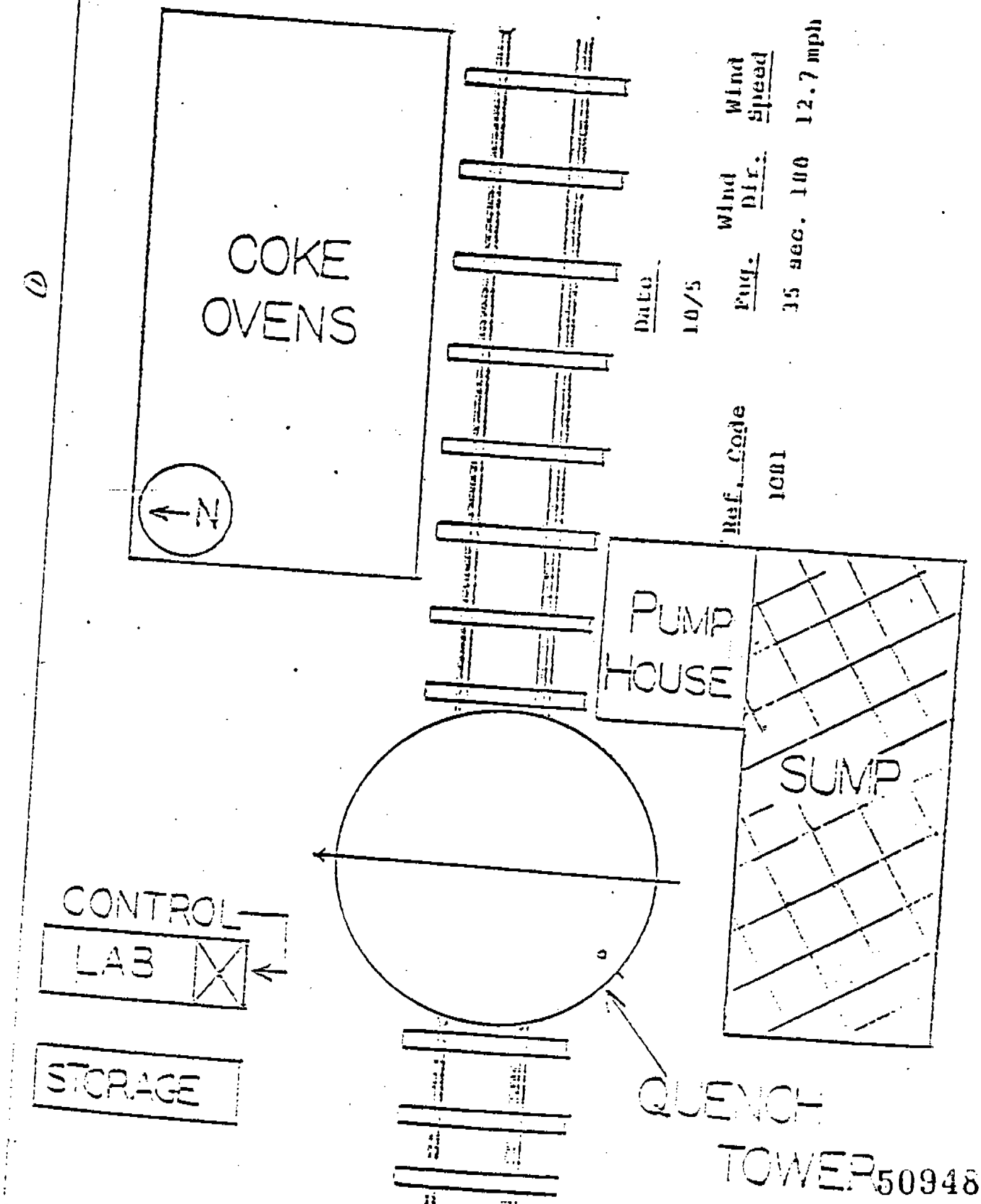
509481

FIGURE ~~2.4-3~~ 3.11

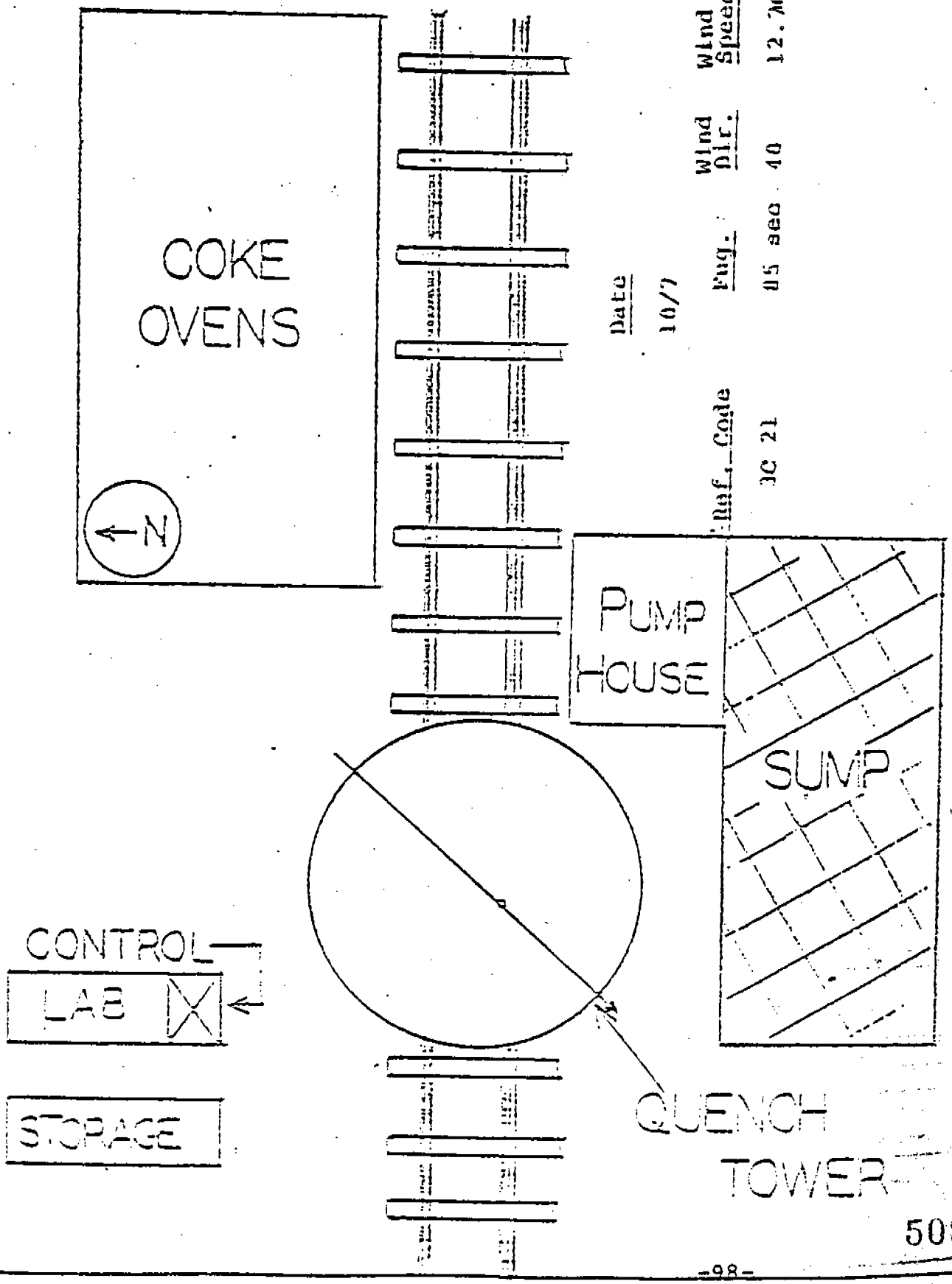
QUENCH TOWER LAYOUT

Date	Ref. Code	Avg.	Wind Dir.	Wind Speed
9/14	14A20	5 sec.	210°	8. mph
	15A00	60 sec.	220°	6.9mph

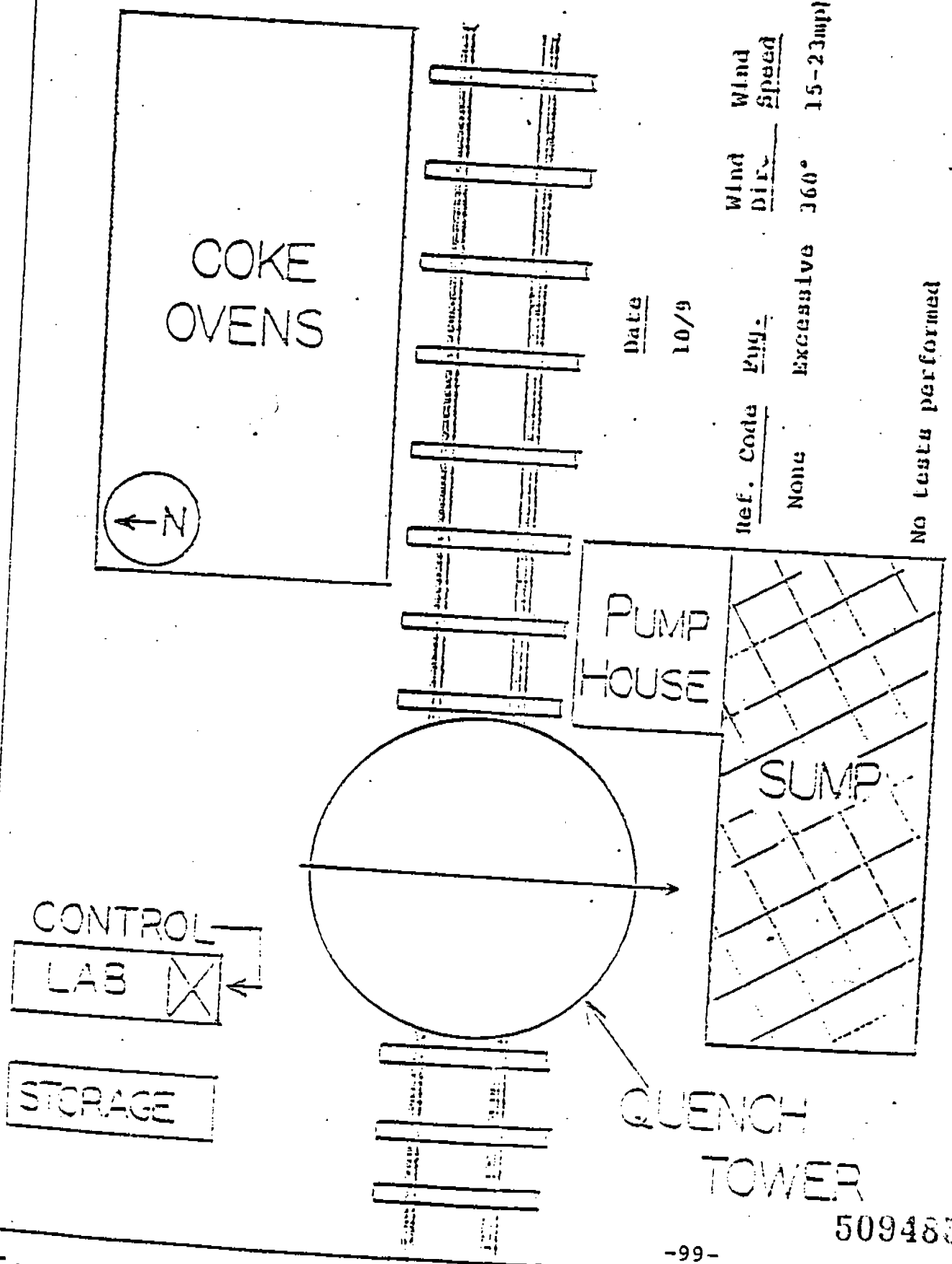
QUENCH TOWER LAYOUT



QUENCH TOWER LAYOUT



QUENCH TOWER LAYOUT

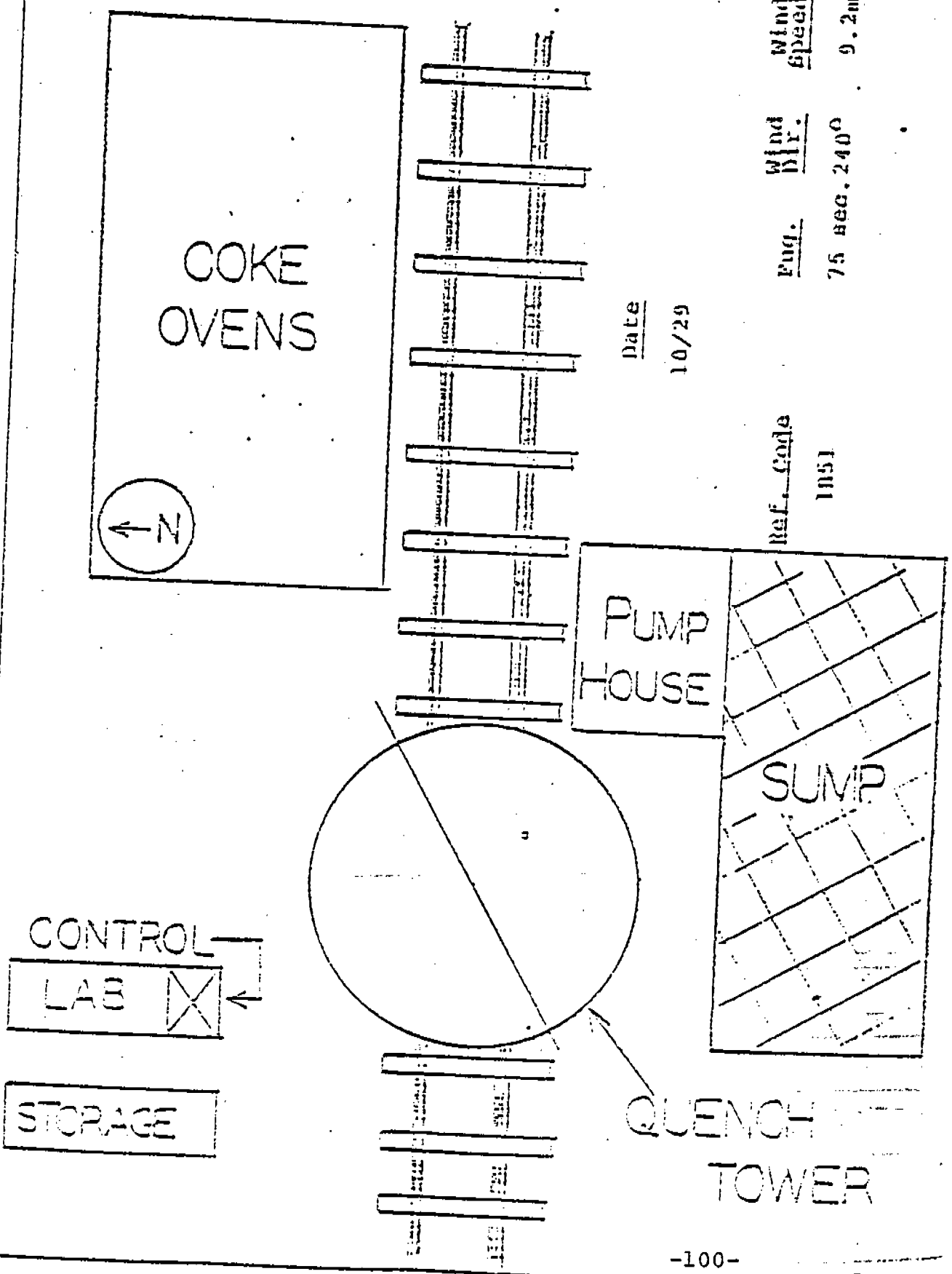


Date	Ref. Code	Pop.	Wind Dir.	Wind Speed
10/9	None	Excessive	360°	15-23mph

No tests performed

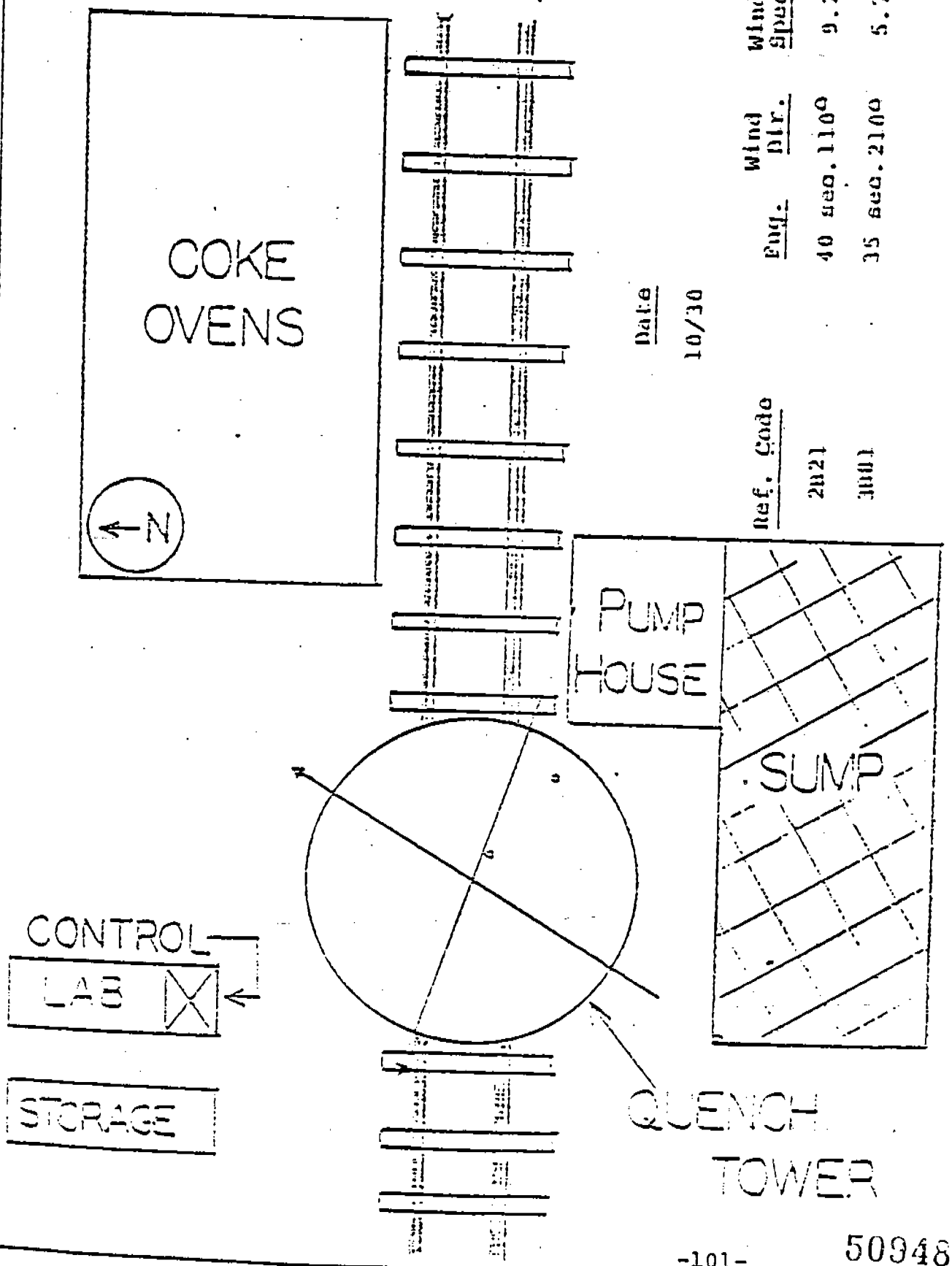
509485

QUENCH TOWER LAYOUT



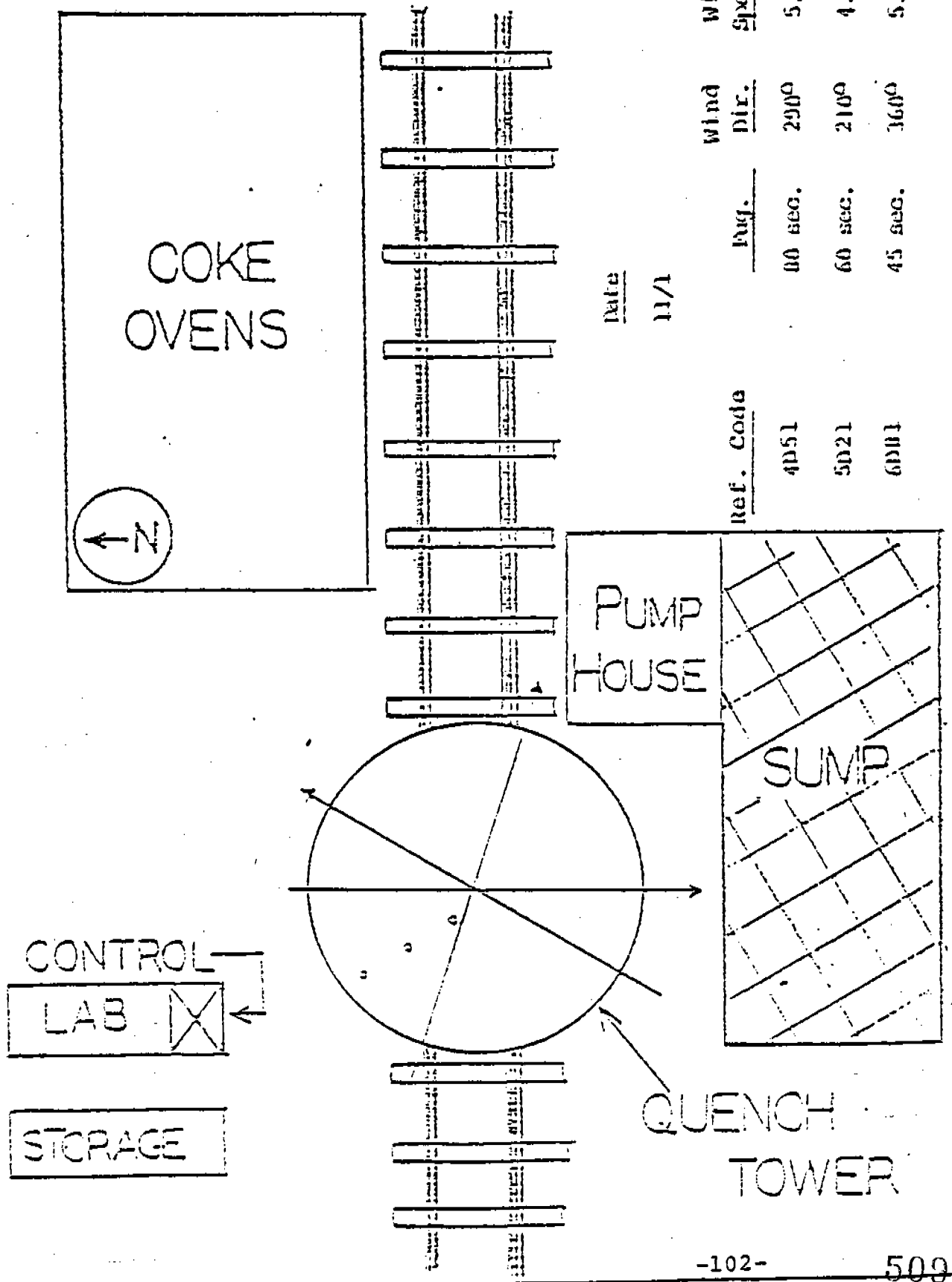
Wind Speed 9.2mph
Wind Dir. 75 sec. 240°
Fug.
Date 10/29
Ref. Code 1851

QUENCH TOWER LAYOUT



509487

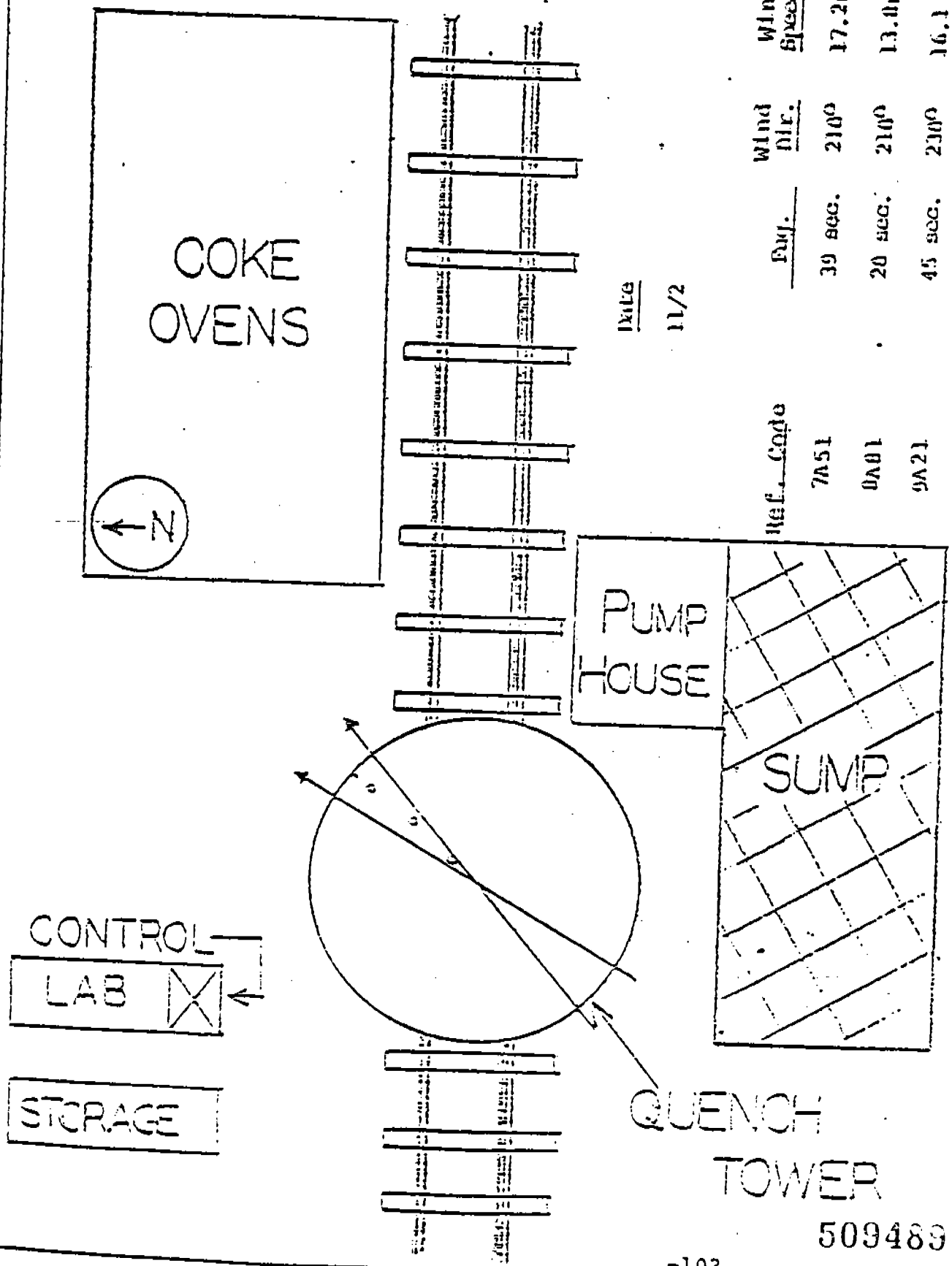
QUENCH TOWER LAYOUT



Ref. Code	Date	Pug.	Wind Dir.	Wind Speed
4051	11/1	00 sec.	290°	5.7mph
5021		60 sec.	210°	4.6mph
6081		45 sec.	360°	5.7

509488

QUENCH TOWER LAYOUT

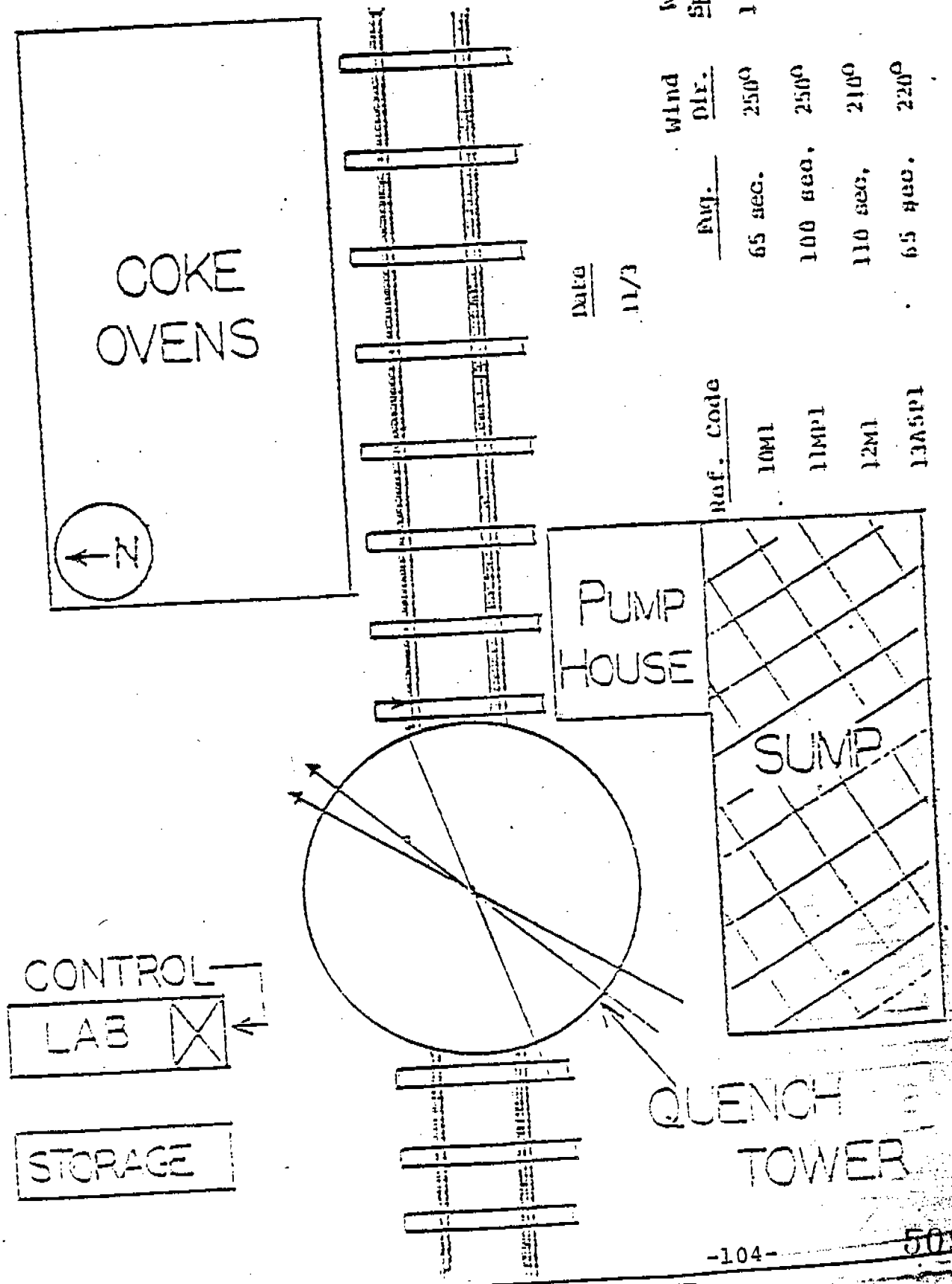


Ref. Code	Date	Dur.	Wind Dir.	Wind Speed
7A51	11/2	39 sec.	210°	17.2mph
8A01		20 sec.	210°	13.0mph
9A21		45 sec.	230°	16.1

509489

FIGURE ~~2.4-13~~ 3-19

QUENCH TOWER LAYOUT



Ref. Code	Date	Dur.	Wind Dir.	Wind Speed
10M1	11/3	65 sec.	250°	11.5mph
11MP1		100 sec.	250°	6.9mph
12M1		110 sec.	210°	8.1mph
13A5P1		65 sec.	220°	6.9

TABLE 3-9. FUGITIVE EMISSIONS TIME PERCENTAGE

Test No.	Percent	Test No.	Percent	Test No.	Percent of Total Time
5B50	21	1C81	6	10M1	11
6B80	11	3C21	16	11MP1	24
7C50	5	1B51	13	12M1	20
8C20	22	2B21	7	13A5P1	13
9C80	17	3B81	6		
				Avg. Clean	11
10D50	23	4D51	14	Contaminated	11
11D80	6	5D21	11		
12D20	0	6D81	8		
13A50	5	7A51	11		
14A20	1	8A81	3		
15A80	11	9A21	8		

509491

3.6 Ambient Weather Conditions

Weather readings obtained by telephone from the Lorain County Municipal Airport were utilized in determining barometric pressure, relative humidity, dew point, and wind speed. The distance from the plant to the weather station is approximately 1.4 miles. Wind direction was recorded also by means of a directional wind vane located at the stack sampling location.

Ambient weather data are presented in Table 3-10.

509432

TABLE 3-10. AMBIENT CONDITIONS

Date	Ref. Code	Time Taken	Position	Windspeed	Dir.	Temp.	Dew Pt.	Rel. Hum.	Bar. Press	Dry Bulb
9/10/76	5B50	11:55	B-5	17.3 mph	120°	61°F	48°F	62%	29.14	61°F
9/11/76	6B80	20:55	B-8	6.9 mph	240°	60°F	51°F	72%	29.15	60°F
9/11/76	7C50	21:55	C-5	8.1 mph	230°	55°F	50°F	83%	29.19	55°F
9/12/76	8C20	20:55	C-2	6.9 mph	180°	63°F	57°F	81%	29.40	63°F
9/12/76	9C80	21:55	C-8	6.9 mph	180°	62°F	57°F	84%	29.41	62°F
9/12/76	10D50	23:55	D-5	3.5 mph	180°	59°F	55°F	87%	29.42	59°F
9/13/76	11D80	19:55	D-8	6.9 mph	180°	68°F	58°F	71%	29.45	68°F
9/13/76	12D20	21:55	D-2	6.9 mph	190°	64°F	57°F	78%	29.45	64°F
9/13/76	13A50	23:55	A-5	5.8 mph	210°	60°F	56°F	87%	29.45	60°F
9/14/76	14A20	20:55	A-2	8.1 mph	210°	71°F	62°F	73%	29.33	71°F
9/14/76	15A80	23:55	A-8	6.9 mph	220°	68°F	61°F	79%	29.31	68°F

509433

TABLE 3-10. (Continued)

Date	Ref. Code	Time Taken	Position	Windspeed	Dir.	Temp.	Dew Pt.	Rel. Hum.	Bar. Press	Dry Bulb
10/29/76	1B51	18:55	B-5	9.2 mph	240°	42°F	27°F	55%	29.34	42°F
10/30/76	2B21	17:55	B-2	9.2 mph	110°	44°F	33°F	65%	29.04	44°F
10/30/76	3B81	00:55	B-8	5.7 mph	210°	38°F	23°F	54%	29.33	38°F
11/01/76	4D51	17:55	D-5	5.7 mph	290°	40°F	23°F	50%	29.43	40°F
11/01/76	5D21	23:55	D-2	4.6 mph	210°	29°F	22°F	75%	29.42	29°F
11/01/76	6D81	00:55	D-8	5.7 mph	360°	39°F	27°F	62%	29.34	39°F
11/02/76	7A51	16:55	A-5	17.2 mph	210°	51°F	29°F	43%	29.16	51°F
11/02/76	8A81	18:55	A-8	13.8 mph	210°	50°F	30°F	46%	29.17	50°F
11/02/76	9A21	20:55	A-2	16.1 mph	230°	50°F	30°F	46%	29.16	50°F
11/03/76	10M1	16:55	A-C	11.5 mph	250°	44°F	15°F	31%	29.05	44°F
11/03/76	11MP1	17:55	A-5	6.9 mph	250°	39°F	15°F	37%	29.07	39°F
11/03/76	12M1	21:55	A-C	8.1 mph	210°	35°F	16°F	46%	29.07	35°F
11/03/76	13A5P1	00:55	A-C	6.9 mph	220°	42°F	34°F	73%	29.13	42°F

509431

4.0 STACK EMISSION RESULTS

Mass Rate and Concentration

Flow conditions and mass rate of stack emissions for clean water and contaminated water tests are summarized in Table 4-1.

Physical Characteristics

- Particulate matter in quench emissions is not primarily large sized. Based on size distribution analysis, 99% of the particulate matter collected was below 35 microns in diameter. The weight of larger aerosols collected by the initial cyclone was only 33% of the total weight emitted when quenching with contaminated water and 17% of the "clean" water quench emissions. The average size of the particles in the plume aerosol is less than 4 microns.
- During "clean" water tests, the greatest weight fraction (71%) of particulate was recovered from the probe/nozzle washes. During contaminated tests, particulate matter was found to be distributed more evenly throughout the probe/nozzle and cyclone washes (33% in each). Particles collected in the probe averaged about 3 microns in size. Overall, the greatest amount of particulate was found in the probe and nozzle washings.
- The amount of particulate recovered from the probe/nozzle water washes was less in the "clean" tests than in contaminated tests. However, the amount of particulate in the acetone wash was greater in the "clean" tests than in the dirty tests. The reason for this observation is not known at present. It would appear that this fraction of the quench emissions does not correlate with the known

509463

TABLE 4-1. SUMMARY OF QUENCH EMISSION TEST RESULTS

(Obtained from 13 "clean" and 12 contaminated test runs; ranges of values are shown in parenthesis.)

PARAMETER	USING "CLEAN" MAKE-UP WATER	USING CONTAMINATED MAKE-UP WATER
FLOW CONDITIONS		
PERCENT ISOKINETIC SAMPLING RATE (%)	99.0 (92.8 to 109.2)	99.4 (91.1 to 109.5)
VOLUMETRIC FLOW RATE (10^3 dscfm)	190.7 (152.6 to 236.1)	183.3 (153.8 to 233.5)
PERCENT MOISTURE (%)	34.8 (22.1 to 43.4)	38.7 (25.8 to 55.1)
PARTICULATE EMISSIONS (IN POUNDS PER QUENCH)		
• Cyclone (~20μm , 50% cut size)	1.72(0.51 to 3.23)	2.78 (1.24 to 10.35)
- Filterable Solids	1.72 (0.51 to 3.23)	2.78 (1.24 to 10.35)
- Dissolved Solids	1.99 (0.73 to 3.65)	12.54 (7.09 to 19.75)
Subtotal	3.71 (1.24 to 6.88)	15.32 (8.91 to 21.93)
• Probe		
- Water Wash	4.72 (1.83 to 8.70)	6.93 (4.25 to 10.27)
- Acetone Wash	10.60 (0.44 to 15.83)	8.19 (1.08 to 20.10)
Subtotal	15.32 (3.85 to 23.72)	15.12 (6.11 to 30.37)
• Filter	0.20 (0.00 to 0.95)	5.89 (3.82 to 9.72)
TOTAL FRONT HALF OF SAMPLING TRAIN CATCH	19.32 (8.83 to 26.98)	36.33 (22.86 to 58.88)
TOTAL BACK HALF OF SAMPLING TRAIN CATCH (Impingers)	2.04 (0.62 to 4.22)	10.63 (4.57 to 23.05)
TOTAL QUENCH TOWER PARTICULATE EMISSIONS	21.27 (9.93 to 30.95)	46.96 (27.46 to 78.23)

509496

composition of the quench water. It may be derived from some other source, such as the coke being quenched.

- There was a striking reduction in quantity of emissions when the switch was made from contaminated to "clean" quench water. The greatest reduction was in the amount of particulate collected on the filter. Most of the material collected on the filters was smaller than 3 microns and larger than 0.3 microns.
- More than 20% of the total particulate collected during the contaminated water series was collected in the impinger. This was reduced to 10% in the "clean" tests.

Droplets

- About 300 to 400 gallons of water per quench (out of a total of 1800 gallons in the aerosol) was entrained in the aerosol as water droplets larger than 10 microns and smaller than 150 to 200 microns. The balance of the water was present in the aerosol mostly as vapor with a small amount as an aerosol less than 10 microns in size. The larger water droplets were probably formed directly and mechanically from the water as it left the nozzles and was sprayed onto the coke.
- Larger droplets increase in size as the plume rises inside the tower. This is because the larger droplets travel slower than the smaller drops, allowing the smaller drops to overtake and collide with the larger ones. This results in some overall growth.
- Analysis of clean and clean and contaminated cyclone and filter particulates indicate that, aside from carbon, chloride is the primary chemical constituent of filter particulates and sulfate is the primary chemical constituent of cyclone particulates. These materials are present in amounts consistent with previous test results reported on other quench towers.

509497

Chemical Characteristics

- Those elements at high concentrations in the filter are in relatively low concentrations in the cyclone. Conversely, those in high concentration in the cyclone are not detected at all in the filter (except for sulfur which is in much higher concentration throughout). Sodium, magnesium, and silicon seem to be associated with large particles or with the water and, therefore, are deposited in the cyclone whereas the calcium, chloride, barium, and potassium are associated with finer fractions of the aerosol and are carried through to the filter.

- Substantial chemical constituents of the particulate and droplet phase of the aerosol seem to be:

Cl^-	Ba
SO_4 or S	K
Ca	Sr

  Chloride, sulfate, and calcium are introduced by contaminated and clean make-up water and incandescent coke.

Gaseous Emissions

- The results indicate a definite correlation between the composition of gaseous emissions and the quality of quench water used. These chemicals which are concentrated in quench water are also found to be concentrated in the gaseous emissions from contaminated quenches. Relative to clean water, the concentration of contaminants in contaminated water is as follows: phenol increases about 500 times, ammonia about 50 times, cyanide about 40 times. This pattern of concentration is exactly followed in the gaseous emissions.

- Substantial concentrations of phenol and ammonia are found in emissions when contaminated quench water is used. These values can be compared with those from previous tests at other coke quench towers. The results for the Lorain Quench tower agree quite well with the rest.

509493

TABLE 4-2. GASEOUS EMISSIONS (Averages)

	Contaminated		Clean	
	ppmw	lbs/quench	ppmw	lbs/quench
SO_2	187	6.0	2.2	0.07
Phenol	92	2.9	1.6	0.05
Ammonia	134	4.3	11	0.35
Cyanide	4.1	0.13	0.90	0.029
Sulfide	.003		0.003	
Oxygen	115,402	3693		
Carbon dioxide	16,806	538		
Carbon monoxide	681	22		
Hydrogen	49	1.6		
Total Hydrocarbon	12 (by volume)			

$$\frac{\text{ppmw} \times 32{,}000}{1{,}000{,}000} \text{ lbs/quench avg. stack flow} = \text{lbs/quench}$$

509499

- The concentrations of chemical contaminants in the gaseous emissions are greatly increased when contaminated water is used instead of clean water. The approximate rise in concentration for each chemical in the gaseous emission is as follows:

Phenol	60 times
Ammonia	12
Cyanide	4
Sulfide	1

Organic Emissions

A special testing scheme was conducted to determine the amount and character of organic pollutants being emitted from the tower during quench operations. The conclusions from this testing are as follows:

- The organic emissions from a coke quenching tower are substantial. (Range between 15-115 lbs per quench)
- The chemical nature of these emissions is primarily aromatic.
- The amount of organic emission is probably more dependent on the coke and its processing conditions, or on other factors than it is on the quality of the water used for quenching.

509500

TABLE 4-3. COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS

LBS/TON OF COAL

	YRC Tests at USS Lorain Plant Contam. Water	(1) Contam. Water	(2) Contam. Water	(3) Contam. Water
Ammonia	0.328	0.029	6.5 free and fixed	0.0251
Phenol	0.221	0.13	0.34 as C_6H_5 OH	0.348
Cyanide	0.010	0.001	0.054 as HCN	0.021 as Hydrocyanic Acid
Sulfide	0.001		0.70 as H_sS	0.170 as H_2S
Total Hydrocarbon		0.012		

TABLE 4-4. COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS

LBS/TON OF COAL

	YRC Tests at: USS Lorain Plant Clean Water	(3) "Cleaner" Water
Ammonia	0.027	0.001
Phenol	0.004	0.002
Cyanide	0.002	0.002
Total Hydrocarbons	NA	0.047

Numbers in () refer to references

509501

4.1 Mass Rate and Concentration

In the course of this test program, 29 mass determinations or particulate tests were performed on quench tower stack emissions. Gaseous pollutants such as sulfur dioxide, ammonia, phenol, cyanide, hydrocarbons, and sulfide were also measured. Water and coke samples were taken periodically during these tests to complete the emission data obtained. In order to correlate all of these data and tests, a reference code has been established to identify the mass train samples (see Table 4-5).

Tests performed between September 8 and September 15, 1976, were conducted while contaminated water was being used in the quenching operations. Contaminated water is the term used for water contaminated with flushing liquor and blow down from various processes. Tests on the quench tower during the use of "clean water" or service water, were performed during the period of October 5th to November 4th, 1976.

The sample point location for each test was determined as indicated in Figure 4-1. Sample point locations are included in Table under the Position column and, also, as part of the Reference Code.

The flow conditions and mass rates of stack emissions for clean water and contaminated water tests are summarized in Table 4-5. The individual test results are listed in Tables 4-7 through 4-35.

509502

TABLE 4-5.

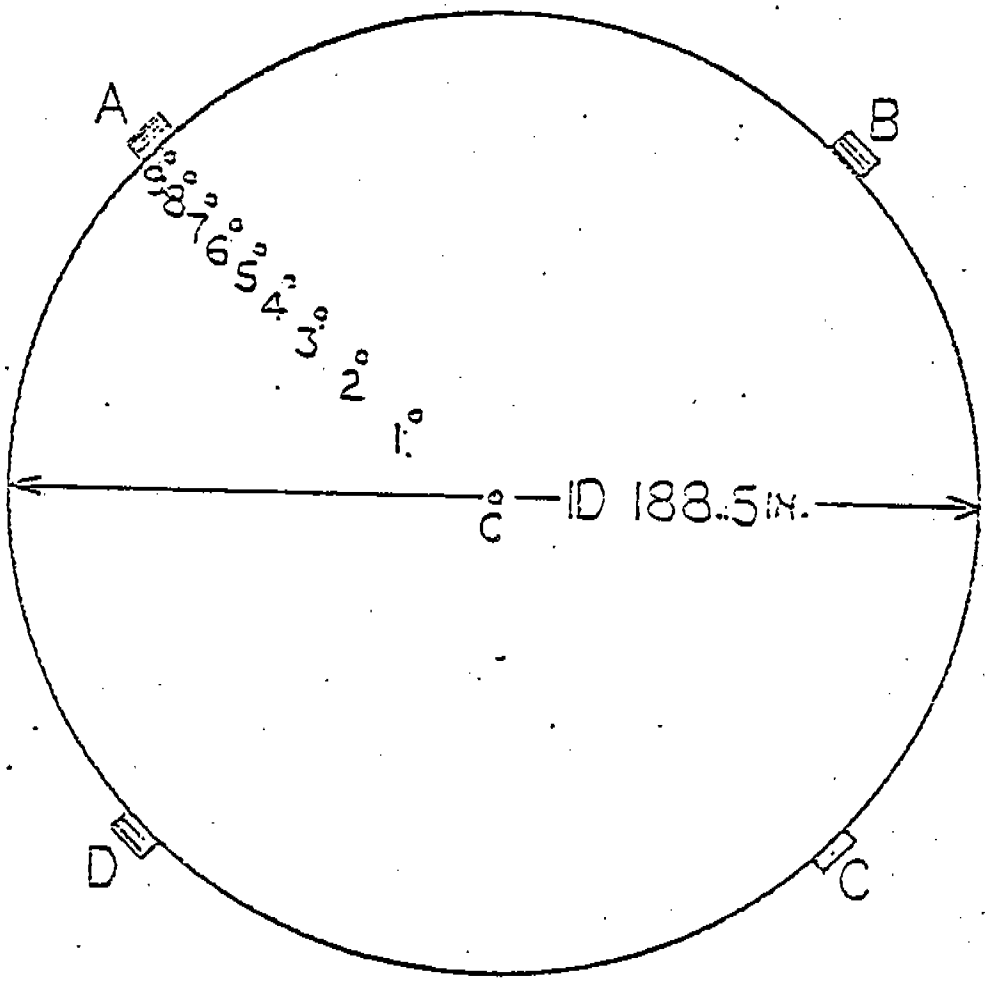
KEY TO REFERENCE CODING SYSTEM

MASS DETERMINATION TESTING					REFERENCE CODE
DATE	TIME	TEST NO.	POSITION	WATER	
9/09/76	2131-2205	4	B2	DIRTY	4B20
9/10/76	2317-0013	5	B5	DIRTY	5B50
9/11/76	2004-2101	6	B8	DIRTY	6B80
	2345-2419	7	C5	DIRTY	7C50
9/12/76	2016-2043	8	C2	DIRTY	8C20
	2140-2212	9	C8	DIRTY	9C80
	2323-2345	10	D5	DIRTY	10D50
9/13/76	1959-2017	11	D8	DIRTY	11D80
	2115-2200	12	D2	DIRTY	12D20
	2324-2347	13	A5	DIRTY	13A50
9/14/76	2017-2059	14	A2	DIRTY	14A20
	2316-2340	15	A8	DIRTY	15A80
9/15/76	2140-2157	16	C5	DIRTY	16C5P0
10/05/76	2125-2150	1	C8	CLEAN	1C81
10/07/76	1900-1920	3	C2	CLEAN	3C21
10/29/76	1855-1915	1	B5	CLEAN	1B51
10/30/76	1805-1825	2	B2	CLEAN	2B21
10/31/76	0115-0130	3	B8	CLEAN	3B81
11/01/76	1720-1740	4	D5	CLEAN	4D51
	2335-2355	5	D2	CLEAN	5D21
11/02/76	0105-0125	6	D8	CLEAN	6D81
	1710-1745	7	A5	CLEAN	7A51
	1925-1940	8	A8	CLEAN	8A81
	2055-2110	9	A2	CLEAN	9A21
11/03/76	1645-1745	10	MID	CLEAN	10M1
	1945-1955	11	MID	CLEAN	11MP1
	2140-2210	12	MID	CLEAN	12M1
11/04/76	0055-0110	13	A5	CLEAN	13A5P1

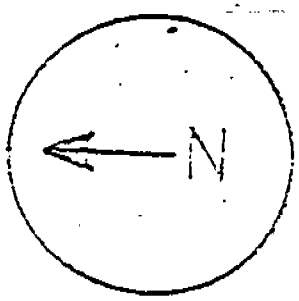
509503

FIGURE 4-1

SAMPLE POINT LOCATION



PT. NO.	INCHES FROM STACK WALL
1	71.60
2	55.60
3	44.40
4	35.40
5	27.50
6	20.50
7	14.10
8	18.25
9	12.65
0	9.425



50950 INGP

TABLE 4-6. SUMMARY OF QUENCH EMISSION TEST RESULTS

(Obtained from 13 "clean" and 12 contaminated test runs; ranges of values are shown in parenthesis.)

PARAMETER	USING "CLEAN" MAKE-UP WATER	USING CONTAMINATED MAKE-UP WATER
FLOW CONDITIONS		
PERCENT ISOKINETIC SAMPLING RATE (%)	99.0 (92.8 to 109.2)	99.4 (91.1 to 109.5)
VOLUMETRIC FLOW RATE (10^3 dscfm)	190.7 (152.6 to 236.1)	183.3 (153.8 to 233.5)
PERCENT MOISTURE (%)	34.8 (22.1 to 43.4)	38.7 (25.8 to 55.1)
PARTICULATE EMISSIONS (IN POUNDS PER QUENCH)		
o Cyclone (20 , 50% cut size)	1.72(0.51 to 3.23)	2.78 (1.24 to 10.35)
- Filterable Solids	1.72 (0.51 to 3.23)	2.78 (1.24 to 10.35)
- Dissolved Solids	1.99 (0.73 to 3.65)	12.54 (7.09 to 19.75)
Subtotal	3.71 (1.24 to 6.88)	15.32 (8.91 to 21.93)
o Probe		
- Water Wash	4.72 (1.83 to 8.70)	6.93 (4.25 to 10.27)
- Acetone Wash	10.60 (0.44 to 15.83)	8.19 (1.08 to 20.10)
Subtotal	15.32 (3.85 to 23.72)	15.12 (6.11 to 30.37)
o Filter	0.20 (0.00 to 0.95)	5.89 (3.82 to 9.72)
TOTAL FRONT HALF OF SAMPLING TRAIN CATCH	19.32 (8.83 to 26.98)	36.33 (22.86 to 58.88)
TOTAL BACK HALF OF SAMPLING TRAIN CATCH (Impingers)	2.04 (0.62 to 4.22)	10.63 (4.57 to 23.05)
TOTAL QUENCH TOWER PARTICULATE EMISSIONS	21.27 (9.93 to 30.95)	46.96 (27.46 to 78.23)

509503

TABLE 4-7.

TEST NO 4B20

DATE/TIME PERIOD OF TEST: 9/8 / 2131-2205

POSITION IN STACK: B-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 98.4
Angle of Flow 110°
Mean Vertical Velocity 35.95 (ft/min)
Mean Stack Temperature 180.5 (°F)
Mean Volumetric Flow 226225 (scfm)
% Moisture By Volume 34.8 %
Molecular Weight of Stack Gas 25.04
Mole Fraction of Dry Gas 0.625

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	130.8	0.132	10.35
-Dissolved Solids	89.3	0.090	7.09
PROBE/NOZZLE-Acetone Wash	40.8	0.041	3.24
-Water Wash	112.4	0.114	8.94
FILTER -	122.5	0.124	9.72
IMPINGER -	290.6	0.294	23.05
TOTAL SOLIDS	786.4	0.796	62.41

509503

TABLE 4-7.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .50 inches / .196 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 15.21 (scfd)

Volume of Water Collected:

Cyclone 75 (ml)

Impinger 171 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.7 (min.)

IV. SITE CONDITIONS

Ambient Temperature NA

Ambient Humidity NA

Ambient Pressure NA

Wind Direction NA

Wind Velocity NA

Weather Conditions NA

509507

TABLE 4-8.

TEST NO 5850

DATE/TIME PERIOD OF TEST: 9/10 / 2317-0013

POSITION IN STACK: B-5

NUMBER OF QUENCHES SAMPLED: 5

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 109.2
Angle of Flow 110°
Mean Vertical Velocity 36.89 (ft/min)
Mean Stack Temperature 180.3 (°F)
Mean Volumetric Flow 201161 (scfm)
% Moisture By Volume 43.4 %
Molecular Weight of Stack Gas 24.12
Mole Fraction of Dry Gas 0.566

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quenc
CYCLONE-Filterable Solids	79.75	0.052	3.68
-Dissolved Solids	351.75	0.229	16.10
PROBE/NOZZLE-Acetone Wash	35.38	0.024	1.63
-Water Wash	97.38	0.064	4.48
FILTER -	134.63	0.087	6.19
IMPINGER -	391.13	0.255	17.95
TOTAL SOLIDS	1090.02	0.711	50.03

509503

TABLE 4-8.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 23.59 (scfd)

Volume of Water Collected:*

Cyclone 100 (ml)

Impinger 304.8 (ml)

Silica Gel 76.2 (mg)

Net Sampling Time* 9.6 (min.)

IV. SITE CONDITIONS

Ambient Temperature 61 °F

Ambient Humidity 62 RH

Ambient Pressure 29.14 mm Hg

Wind Direction 320°

Wind Velocity 17.3

Weather Conditions SCT

*Adjusted

509503

TABLE 4-9.
Table 4.9

TEST NO 6B80

DATE/TIME PERIOD OF TEST: 9/11 / 2004-2101

POSITION IN STACK: B-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 97.7
Angle of Flow 110°
Mean Vertical Velocity 24.52 (ft/min)
Mean Stack Temperature 180.7 (°F)
Mean Volumetric Flow 175087 (scfm)
% Moisture By Volume 25.8 %
Molecular Weight of Stack Gas 26.01
Mole Fraction of Dry Gas 0.742

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	52.0	0.057	2.71
-Dissolved Solids	160.1	0.175	8.31
PROBE/NOZZLE-Acetone Wash	70.0	0.077	3.64
-Water Wash	84.2	0.092	4.38
FILTER -	73.4	0.080	3.82
IMPINGER -	87.8	0.096	4.57
TOTAL SOLIDS	527.5	0.577	27.46

509510

TABLE 4-9.
(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 / .303
inches square inches

Pitot Tube Correction Factor 1.0
Volume of Dry Gas Sampled 14.06 (scfd)
Volume of Water Collected:

Cyclone 70 (ml)
Impinger 103 (ml)
Silica Gel 0.0 (mg)

Net Sampling Time 7.57 (min.)

IV. SITE CONDITIONS

Ambient Temperature 60 °F
Ambient Humidity 72 RH
Ambient Pressure 29.19 mm Hg
Wind Direction 230°
Wind Velocity 6.9
Weather Conditions CLR

509511

TABLE 4-10.

TEST NO 7C50

DATE/TIME PERIOD OF TEST: 9/11 / 2345-2419

POSITION IN STACK: C-5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 96.6
Angle of Flow 110°
Mean Vertical Velocity 34.22 (ft/min)
Mean Stack Temperature 181 (°F)
Mean Volumetric Flow 174197 (scfm)
% Moisture By Volume 47.1 %
Molecular Weight of Stack Gas 23.72
Mole Fraction of Dry Gas 0.529

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	31.1	0.033	1.62
-Dissolved Solids	174.7	0.186	9.12
PROBE/NOZZLE-Acetone Wash	21.1	0.023	1.10
-Water Wash	145.2	0.155	7.60
FILTER -	112.6	0.120	5.88
IMPINGER -	174.7	0.186	9.12
TOTAL SOLIDS	659.4	0.703	34.44

509512

TABLE 4-10.
(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1
Volume of Dry Gas Sampled 14.45 (scfd)
Volume of Water Collected:

Cyclone 30 (ml)
Impinger 271 (ml)
Silica Gel 0.0 (mg)

Net Sampling Time 7.9 (min.)

IV. SITE CONDITIONS

Ambient Temperature 55 °F
Ambient Humidity 83 RH
Ambient Pressure 29.19 mm Hg
Wind Direction 230°
Wind Velocity 8.0
Weather Conditions CLR

509513

Table 4-11

TEST NO 8C20

DATE/TIME PERIOD OF TEST: 9/12 / 2016-2043

POSITION IN STACK: C-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 101.7
Angle of Flow 110°
Mean Vertical Velocity 32.41 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 167901 (scfm)
% Moisture By Volume 46.2 %
Molecular Weight of Stack Gas 23.81
Mole Fraction of Dry Gas 0.538

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	21.6	0.031	1.65
-Dissolved Solids	193.3	0.274	14.79
PROBE/NOZZLE-Acetone Wash	20.9	0.030	1.60
-Water Wash	76.6	0.108	5.83
FILTER -	88.53	0.125	6.75
IMPINGER -	133.6	0.189	10.20
TOTAL SOLIDS	534.5	0.757	40.82

509514

TABLE 4-11.
(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .50 / .196
inches square inches

Pitot Tube Correction Factor 1
Volume of Dry Gas Sampled 10.88 (scfd)
Volume of Water Collected:

Cyclone 65 (ml)
Impinger 197 (ml)
Silica Gel 0.0 (mg)

Net Sampling Time 9.05 (min.)

IV. SITE CONDITIONS

Ambient Temperature 63 °F
Ambient Humidity 81 RH
Ambient Pressure 29.4 mm Hg
Wind Direction 180°
Wind Velocity 6.9
Weather Conditions THIN OVC

509515

TABLE 4-12.

TEST NO 9C80

DATE/TIME PERIOD OF TEST: 9/12 / 2140-2212

POSITION IN STACK: C-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 95.2
Angle of Flow 110°
Mean Vertical Velocity 36.06 (ft/min)
Mean Stack Temperature 181.2 (°F)
Mean Volumetric Flow 155652 (scfm)
% Moisture By Volume 55.1 %
Molecular Weight of Stack Gas 22.85
Mole Fraction of Dry Gas 0.449

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	26.1	0.037	1.39
-Dissolved Solids	141.4	0.200	7.52
PROBE/NOZZLE-Acetone Wash	199.1	0.282	10.60
-Water Wash	80.1	0.113	4.25
FILTER -	129.5	0.183	6.88
IMPINGER -	159.0	0.225	8.46
TOTAL SOLIDS	735.2	1.040	39.10

509516

TABLE 4-12.

(cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 10.88 (scfd)

Volume of Water Collected:

Cyclone 20 (ml)

Impinger 282 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 6.76 (min.)

IV. SITE CONDITIONS

Ambient Temperature 62 °F

Ambient Humidity 84 RH

Ambient Pressure 29.4 mm Hg

Wind Direction 180°

Wind Velocity 6.9

Weather Conditions THIN OVC

509517

TABLE 4-13.

TEST NO 10D50

DATE/TIME PERIOD OF TEST: 9/12 / 2323-2345

POSITION IN STACK: D5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 105.3
Angle of Flow 110°
Mean Vertical Velocity 29.17 (ft/min)
Mean Stack Temperature 181.5 (°F)
Mean Volumetric Flow 153788 (scfm)
% Moisture By Volume 45.1 %
Molecular Weight of Stack Gas 23.93
Mole Fraction of Dry Gas 0.549

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	45.2	0.045	2.18
-Dissolved Solids	408.6	0.408	19.75
PROBE/NOZZLE-Acetone Wash	339.1	0.338	16.37
-Water Wash	190.9	0.190	9.20
FILTER -	104.2	0.104	5.04
IMPINGER -	137.7	0.137	6.63
TOTAL SOLIDS	1,225.7	1.222	59.08

509518

TABLE 4-13.
(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 / .303
inches square inches

Pitot Tube Correction Factor 1
Volume of Dry Gas Sampled 15.44 (scfd)
Volume of Water Collected:

Cyclone 110 (ml)
Impinger 268 (ml)
Silica Gel 0.0 (mg)

Net Sampling Time 8.78 (min.)

IV. SITE CONDITIONS

Ambient Temperature 59 °F
Ambient Humidity 87 RH
Ambient Pressure 29.4 mm Hg
Wind Direction 180°
Wind Velocity 3.4
Weather Conditions SCT

509519

TABLE 4-14.

TEST NO 11D80

DATE/TIME PERIOD OF TEST: 9/13 / 19:55-2010

POSITION IN STACK: D-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 100.0
Angle of Flow 110°
Mean Vertical Velocity 26.63 (ft/min)
Mean Stack Temperature 181 (°F)
Mean Volumetric Flow 161734 (scfm)
% Moisture By Volume 36.8 %
Molecular Weight of Stack Gas 24.82
Mole Fraction of Dry Gas 0.632

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	24.6	0.024	1.24
-Dissolved Solids	270.4	0.259	13.64
PROBE/NOZZLE-Acetone Wash	223.1	0.214	11.27
-Water Wash	84.5	0.081	4.28
FILTER -	82.3	0.079	4.17
IMPINGER -	101.0	0.097	5.12
TOTAL SOLIDS	785.9	0.754	39.72

509520

TABLE 4-14.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 16.02 (scfd)

Volume of Water Collected:

Cyclone 110 (ml)

Impinger 197 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.1 (min.)

IV. SITE CONDITIONS

Ambient Temperature 68 °F

Ambient Humidity 71 RH

Ambient Pressure 29.4 mm Hg

Wind Direction 180°

Wind Velocity 6.9

Weather Conditions CLR

509521

TEST NO 12D20

DATE/TIME PERIOD OF TEST: 9/13 / 2115-2200

POSITION IN STACK: D-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 92.8
Angle of Flow 110°
Mean Vertical Velocity 31.40 (ft/min)
Mean Stack Temperature 181 (°F)
Mean Volumetric Flow 202294 (scfm)
% Moisture By Volume 33 %
Molecular Weight of Stack Gas 25.24
Mole Fraction of Dry Gas 0.670

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quenc
CYCLONE-Filterable Solids	25.3	0.021	1.36
-Dissolved Solids	184.1	0.151	9.82
PROBE/NOZZLE-Acetone Wash	189.9	0.156	10.14
-Water Wash	89.7	0.074	4.81
FILTER -	119.4	0.098	6.37
IMPINGER -	152.2	0.125	8.13
TOTAL SOLIDS	760.6	0.625	40.63

509522

TABLE 4-15.
(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1
Volume of Dry Gas Sampled 18.78 (scfd)
Volume of Water Collected:

Cyclone 50 (ml)
Impinger 195 (ml)
Silica Gel 0.0 (mg)

Net Sampling Time 9.0 (min.)

IV. SITE CONDITIONS

Ambient Temperature 64 °F
Ambient Humidity 78 RH
Ambient Pressure 29.4 mm Hg
Wind Direction 190°
Wind Velocity 6.9
Weather Conditions CLR

509523

TABLE 4-16.

TEST NO 13A50

DATE/TIME PERIOD OF TEST: 9/13 / 2324-2347

POSITION IN STACK: A-5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 94.6
Angle of Flow 110°
Mean Vertical Velocity 27.12 (ft/min)
Mean Stack Temperature 182 (°F)
Mean Volumetric Flow 182456 (scfm)
% Moisture By Volume 29.9 %
Molecular Weight of Stack Gas 25.57
Mole Fraction of Dry Gas 0.701

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	34.3	0.032	1.84
-Dissolved Solids	186.3	0.172	9.97
PROBE/NOZZLE-Acetone Wash	20.1	0.019	1.08
-Water Wash	167.2	0.155	8.99
FILTER -	75.5	0.070	4.05
IMPINGER -	91.2	0.084	4.89
TOTAL SOLIDS	574.6	0.532	30.82

509524

TABLE 4-16.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 16.65 (scfd)

Volume of Water Collected:

Cyclone 60 (ml)

Impinger 150 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 8.9 (min.)

IV. SITE CONDITIONS

Ambient Temperature 60 °F

Ambient Humidity 87 RH

Ambient Pressure 29.4 mm Hg

Wind Direction 210°

Wind Velocity 5.7

Weather Conditions CLR

509525

TABLE 4-17.

TEST NO 14A20

DATE/TIME PERIOD OF TEST: 9/14 /2017-2059

POSITION IN STACK: A-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 96.3
Angle of Flow 110°
Mean Vertical Velocity 32.94 (ft/min)
Mean Stack Temperature 181.2 (°F)
Mean Volumetric Flow 233506 (scfm)
% Moisture By Volume 26.3 %
Molecular Weight of Stack Gas 25.96
Mole Fraction of Dry Gas 0.737

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	38.0	0.041	3.09
-Dissolved Solids	182.0	0.197	14.79
PROBE/NOZZLE-Acetone Wash	215.6	0.233	17.49
-Water Wash	124.9	0.135	10.14
FILTER -	63.9	0.069	5.19
IMPINGER -	124.9	0.135	10.14
TOTAL SOLIDS	749.3	0.810	60.83

509526

TABLE 4-17.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .50 inches / .196 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 14.24 (scfd)

Volume of Water Collected:

Cyclone 50 (ml)

Impinger 107 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.0 (min.)

IV. SITE CONDITIONS

Ambient Temperature 71 °F

Ambient Humidity 73 RH

Ambient Pressure 29.33 mm Hg

Wind Direction 210°

Wind Velocity 8.0

Weather Conditions OVC

509527

TABLE 4-18.

TEST NO 15A80

DATE/TIME PERIOD OF TEST: 9/14 / 2316-2340

POSITION IN STACK: A-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 105.4
Angle of Flow 110°
Mean Vertical Velocity 29.47 (ft/min)
Mean Stack Temperature 182.5 (°F)
Mean Volumetric Flow 166000 (scfm)
% Moisture By Volume 41.3 %
Molecular Weight of Stack Gas 24.34
Mole Fraction of Dry Gas 0.587

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	31.5	0.043	2.32
-Dissolved Solids	264.4	0.360	19.56
PROBE/NOZZLE-Acetone Wash	271.9	0.370	20.10
-Water Wash	139.2	0.189	10.27
FILTER -	89.6	0.122	6.63
IMPINGER -	262.0	0.356	19.34
TOTAL SOLIDS	1,058.6	1.440	78.23

509528

TABLE 4-18.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .50 inches / .196 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 11.32 (scfd)

Volume of Water Collected:

Cyclone 90 (ml)

Impinger 168 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.2 (min.)

IV. SITE CONDITIONS

Ambient Temperature 68 °F

Ambient Humidity 79 RH

Ambient Pressure 29.3 mm Hg

Wind Direction 220°

Wind Velocity 6.9

Weather Conditions BRKN

509529

TABLE 4-19.

TEST NO 16C5PO

DATE/TIME PERIOD OF TEST: 9/15/76/

POSITION IN STACK: 110

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 108.6
Angle of Flow 110°
Mean Vertical Velocity 1728.36 (ft/min)
Mean Stack Temperature 205 (°F)
Mean Volumetric Flow 2656.33 (scfm)
% Moisture By Volume 9.6 %
Molecular Weight of Stack Gas 27.76
Mole Fraction of Dry Gas 0.904

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids			
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash			
-Water Wash			
FILTER -			
IMPINGER -			
TOTAL SOLIDS			

509580

TABLE 4-19.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: 0.31 inches / .075 square inches

Pitot Tube Correction Factor 1

Volume of Dry Gas Sampled 6.66 (scfd)

Volume of Water Collected:

Cyclone N/A (ml)

Impinger 15 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.2 (min.)

IV. SITE CONDITIONS

Ambient Temperature 68 °F

Ambient Humidity 79% RH

Ambient Pressure 29.31 ins. mm Hg

Wind Direction 220°

Wind Velocity 6.906 mph

Weather Conditions

509531

TABLE 4-20.

TEST NO 1C81

DATE/TIME PERIOD OF TEST: 10/5 / 2125-2150

POSITION IN STACK: C-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 97
Angle of Flow 110°
Mean Vertical Velocity 30.24 (ft/min)
Mean Stack Temperature 180.0 (°F)
Mean Volumetric Flow 204452 (scfm)
% Moisture By Volume 29.8 %
Molecular Weight of Stack Gas 25.58
Mole Fraction of Dry Gas .702

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	45.22	0.043	2.91
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash	246.00	0.233	15.83
-Water Wash	91.27	0.086	5.87
FILTER -	7.51	0.007	0.48
IMPINGER -	42.51	0.040	2.74
TOTAL SOLIDS	432.51	0.409	27.82

509532

TABLE 4-20.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / .246 square inches

Pitot Tube Correction Factor 1.00
Volume of Dry Gas Sampled 16.26 (scfd)
Volume of Water Collected:

Cyclone 40 (ml)
Impinger 135 (ml)
Silica Gel 10.6 (mg)

Net Sampling Time 9.3 (min.)

IV. SITE CONDITIONS

Ambient Temperature 54 °F
Ambient Humidity 56 RH
Ambient Pressure 29.92 mm Hg
Wind Direction 170°
Wind Velocity 8.0
Weather Conditions CL

509533

TABLE 4-21.

TEST NO data not available

DATE/TIME PERIOD OF TEST: _____ / _____

POSITION IN STACK: _____

NUMBER OF QUENCHES SAMPLED: _____

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic _____
Angle of Flow _____
Mean Vertical Velocity _____ (ft/min)
Mean Stack Temperature _____ (°F)
Mean Volumetric Flow _____ (scfm)
% Moisture By Volume _____ %
Molecular Weight of Stack Gas _____
Mole Fraction of Dry Gas _____

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids			
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash			
-Water Wash			
FILTER -			
IMPINGER -			
TOTAL SOLIDS			

509534

TABLE 4-21.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: _____/_____
inches square inches

Pitot Tube Correction Factor _____
Volume of Dry Gas Sampled _____ (scfd)
Volume of Water Collected:

Cyclone _____ (ml)
Impinger _____ (ml)
Silica Gel _____ (mg)

Net Sampling Time _____ (min.)

IV. SITE CONDITIONS

Ambient Temperature _____
Ambient Humidity _____
Ambient Pressure _____
Wind Direction _____
Wind Velocity _____
Weather Conditions _____

509535

TABLE 4-22.

TEST NO 3C21

DATE/TIME PERIOD OF TEST: 10/7 / 1900-1920

POSITION IN STACK: C-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 92.6
Angle of Flow 110°
Mean Vertical Velocity 30.23 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 184985 (scfm)
% Moisture By Volume 36.2 %
Molecular Weight of Stack Gas 24.89
Mole Fraction of Dry Gas .638

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	42.0	0.038	2.27
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash	233.4	0.210	12.61
-Water Wash	67.4	0.061	3.64
FILTER -	8.1	0.007	0.43
IMPINGER -	19.2	0.017	1.04
TOTAL SOLIDS	370.1	0.333	19.98

509536

TABLE 4-22.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 17.14 (scfd)

Volume of Water Collected:

Cyclone 55 (ml)

Impinger 205 (ml)

Silica Gel -0.3 (mg)

Net Sampling Time 9.1 (min.)

IV. SITE CONDITIONS

Ambient Temperature 48 °F

Ambient Humidity 57 RH

Ambient Pressure 29.79 mm Hg

Wind Direction 30°

Wind Velocity 9.2

Weather Conditions CL

509537

TABLE 4-23.

TEST NO 1B51

DATE/TIME PERIOD OF TEST: 10/29 / 1855-1915

POSITION IN STACK: B-5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 109.5
Angle of Flow 110°
Mean Vertical Velocity 31.36 (ft/min)
Mean Stack Temperature 177 (°F)
Mean Volumetric Flow 199894 (scfm)
% Moisture By Volume 34.8 %
Molecular Weight of Stack Gas 25.04
Mole Fraction of Dry Gas .652

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	24.9	0.020	1.42
-Dissolved Solids	29.7	0.024	1.69
PROBE/NOZZLE-Acetone Wash	263.9	0.215	15.02
-Water Wash	152.8	0.124	8.70
FILTER -	2.0	0.002	0.12
IMPINGER -	26.3	0.021	1.50
TOTAL SOLIDS	499.6	.406	28.44

509533

TABLE 4-23.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 / .240
inches square inches

Pitot Tube Correction Factor 1.0
Volume of Dry Gas Sampled 18.93 (scfd)
Volume of Water Collected:

Cyclone 29.2 (ml)
Impinger 209 (ml)
Silica Gel 4.1 (mg)

Net Sampling Time 9.8 (min.)

IV. SITE CONDITIONS

Ambient Temperature 42 °F
Ambient Humidity 55 RH
Ambient Pressure 29.34 mm Hg
Wind Direction 240°
Wind Velocity 9.2
Weather Conditions CL

509559

TABLE 4-24.

TEST NO 2B21

DATE/TIME PERIOD OF TEST: 10/30 / 1805-1825

POSITION IN STACK: B-2.

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 91.1
Angle of Flow 110°
Mean Vertical Velocity 33.85 (ft/min)
Mean Stack Temperature 181 (°F)
Mean Volumetric Flow 195338 (scfm)
% Moisture By Volume 40.3 %
Molecular Weight of Stack Gas 24.44
Mole Fraction of Dry Gas .597

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	9.2	0.008	0.51
-Dissolved Solids	13.1	0.011	0.73
PROBE/NOZZLE-Acetone Wash	242.8	0.204	13.49
-Water Wash	121.5	0.102	6.75
FILTER -	17.0	0.014	0.95
IMPINGER -	28.2	0.024	1.57
TOTAL SOLIDS	431.8	0.363	23.99

509540

TABLE 4-24.
(cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 18.37 (scfd)

Volume of Water Collected:

Cyclone 15.0 (ml)

Impinger 252 (ml)

Silica Gel 9.9 (mg)

Net Sampling Time 9.5 (min.)

IV. SITE CONDITIONS

Ambient Temperature 44 °F

Ambient Humidity 65 RH

Ambient Pressure 29.04 mm Hg

Wind Direction 110°

Wind Velocity 9.2

Weather Conditions CLDY

509541

TABLE 4-25.

TEST NO 3B81

DATE/TIME PERIOD OF TEST: 10/30 / 0115-0130

POSITION IN STACK: B-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 105.3
Angle of Flow 110°
Mean Vertical Velocity 32.34 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 218638 (scfm)
% Moisture By Volume 30.4 %
Molecular Weight of Stack Gas 25.51
Mole Fraction of Dry Gas .696

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	54.7	0.044	3.23
-Dissolved Solids	61.8	0.050	3.65
PROBE/NOZZLE-Acetone Wash	224.0	0.180	13.23
-Water Wash	111.5	0.090	6.58
FILTER -	5.0	0.004	0.29
IMPINGER -	67.2	0.054	3.97
TOTAL SOLIDS	524.2	0.422	30.95

509542

TABLE 4-25.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 19.14 (scfd)

Volume of Water Collected:

Cyclone 49.3 (ml)

Impinger 173 (ml)

Silica Gel 3.6 (mg)

Net Sampling Time 9.4 (min.)

IV. SITE CONDITIONS

Ambient Temperature 38 °F

Ambient Humidity 54 RH

Ambient Pressure 29.33 mm Hg

Wind Direction 210°

Wind Velocity 5.7

Weather Conditions CLDY

509543

TABLE 4-26.

TEST NO 4D51

DATE/TIME PERIOD OF TEST: 11/1 / 1720-1740

POSITION IN STACK: D-5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 108.4
Angle of Flow 110°
Mean Vertical Velocity 24.54 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 157604 (scfm)
% Moisture By Volume 34.1 %
Molecular Weight of Stack Gas 25.11
Mole Fraction of Dry Gas .659

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS (lbs [illegible])
CYCLONE-Filterable Solids	30.9	.027	1.4[illegible]
-Dissolved Solids	36.4	.032	1.[illegible]
PROBE/NOZZLE-Acetone Wash	208.8	.181	9.[illegible]
-Water Wash	76.0	.066	3.5[illegible]
FILTER -	4.4	.004	0.[illegible]
IMPINGER -	90.1	.078	4.[illegible]
TOTAL SOLIDS	446.6	.388	20.3[illegible]

509544

TABLE 4-26.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 17.75 (scfd)

Volume of Water Collected:

Cyclone 37.5 (ml)

Impinger 192 (ml)

Silica Gel 2.1 (mg)

Net Sampling Time 9.6 (min.)

IV. SITE CONDITIONS

Ambient Temperature 40 °F

Ambient Humidity 50 RH

Ambient Pressure 29.43 mm Hg

Wind Direction 290°

Wind Velocity 5.7

Weather Conditions CLR

509545

TABLE 4-27.

TEST NO 5D21

DATE/TIME PERIOD OF TEST: 11/1 / 2335-2355

POSITION IN STACK: D-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 101.1
Angle of Flow 110°
Mean Vertical Velocity 28.35 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 178030 (scfm)
% Moisture By Volume 35.6 %
Molecular Weight of Stack Gas 24.95
Mole Fraction of Dry Gas .644

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	24.6	.021	1.23
-Dissolved Solids	28.2	.024	1.41
PROBE/NOZZLE-Acetone Wash	188.5	.158	9.42
-Water Wash	52.7	.044	2.63
FILTER -	1.2	.001	0.06
IMPINGER -	12.4	.010	0.62
TOTAL SOLIDS	307.6	.258	15.36

509546

TABLE 4-27.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 18.42 (scfd)

Volume of Water Collected:

Cyclone 41.7 (ml)

Impinger 210 (ml)

Silica Gel 4.9 (mg)

Net Sampling Time 9.4 (min.)

IV. SITE CONDITIONS

Ambient Temperature 29 °F

Ambient Humidity 75 RH

Ambient Pressure 29.42 mm Hg

Wind Direction 210°

Wind Velocity 4.6

Weather Conditions L RAIN

509547

TABLE 4-28.

TEST NO 6D81

DATE/TIME PERIOD OF TEST: 11/1 / 0105-0125

POSITION IN STACK: D-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 97.9
Angle of Flow 110°
Mean Vertical Velocity 24.96 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 152613 (scfm)
% Moisture By Volume 37.3 %
Molecular Weight of Stack Gas 24.77
Mole Fraction of Dry Gas .627

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	22.8	0.019	0.95
-Dissolved Solids	26.1	0.021	1.08
PROBE/NOZZLE-Acetone Wash	197.6	0.162	8.18
-Water Wash	44.3	0.037	1.83
FILTER -	*		-
IMPINGER -	14.3	0.018	0.89
TOTAL SOLIDS	305.1	0.257	12.93

*an unknown negative balance

509548

TABLE 4-28.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / .246 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 18.81 (scfd)

Volume of Water Collected:

Cyclone 56.1 (ml)

Impinger 230 (ml)

Silica Gel 6.0 (mg)

Net Sampling Time 9.5 (min.)

IV. SITE CONDITIONS

Ambient Temperature 39 °F

Ambient Humidity 62 RH

Ambient Pressure 29.34 mm Hg

Wind Direction 360°

Wind Velocity 5.7

Weather Conditions CLDY

509540

TABLE 4-29.

TEST NO 7A51

DATE/TIME PERIOD OF TEST: 11/2 /1710-1745

POSITION IN STACK: A-5

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 101.5
Angle of Flow 95°
Mean Vertical Velocity 30.14 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 207740 (scfm)
% Moisture By Volume 28.7 %
Molecular Weight of Stack Gas 25.70
Mole Fraction of Dry Gas .713

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	14.4	.012	0.88
-Dissolved Solids	19.7	.017	1.20
PROBE/NOZZLE-Acetone Wash	251.4	.214	15.38
-Water Wash	64.8	.055	3.97
FILTER -	-1.9	-.002	-0.12
IMPINGER -	70.1	.060	4.29
TOTAL SOLIDS	418.5	.360	25.60

509550

TABLE 4-29.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 18.12 (scfd)

Volume of Water Collected:

Cyclone 17.5 (ml)

Impinger 147 (ml)

Silica Gel 6.9 (mg)

Net Sampling Time 9.7 (min.)

IV. SITE CONDITIONS

Ambient Temperature 51 °F

Ambient Humidity 43 RH

Ambient Pressure 29.16 mm Hg

Wind Direction 210°

Wind Velocity 17.3

Weather Conditions

509551

TABLE 4-30.

TEST NO 8A81

DATE/TIME PERIOD OF TEST: 11/2 / 1925-1940

POSITION IN STACK: A-8

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 93.5
Angle of Flow 110°
Mean Vertical Velocity 23.05 (ft/min)
Mean Stack Temperature 181 (°F)
Mean Volumetric Flow 173289 (scfm)
% Moisture By Volume 22.1 %
Molecular Weight of Stack Gas 26.41
Mole Fraction of Dry Gas .779

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	41.9	0.039	2.27
-Dissolved Solids	50.1	0.046	2.71
PROBE/NOZZLE-Acetone Wash	8.1	0.008	0.44
-Water Wash	63.0	0.058	3.41
FILTER -	-1.6	-.002	-0.09
IMPINGER -	21.8	0.020	1.18
TOTAL SOLIDS	183.3	0.169	9.93

509552

TABLE 4-30.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 16.72 (scfd)

Volume of Water Collected:

Cyclone 43.5 (ml)

Impinger 93 (ml)

Silica Gel 7.1 (mg)

Net Sampling Time 9.5 (min.)

IV. SITE CONDITIONS

Ambient Temperature 50 °F

Ambient Humidity 46 RH

Ambient Pressure 29.17 mm Hg

Wind Direction 210°

Wind Velocity 13.8

Weather Conditions

509553

TABLE 4-31.

TEST NO 9A21

DATE/TIME PERIOD OF TEST: 11/2 / 2055-2110

POSITION IN STACK: A-2

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 91.9
Angle of Flow 110
Mean Vertical Velocity 33.62 (ft/min)
Mean Stack Temperature 182 (°F)
Mean Volumetric Flow 194496 (scfm)
% Moisture By Volume 40 %
Molecular Weight of Stack Gas 24.48
Mole Fraction of Dry Gas .600

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	17.7	0.015	0.98
-Dissolved Solids	25.2	0.021	1.39
PROBE/NOZZLE-Acetone Wash	100.7	0.085	5.58
-Water Wash	100.1	0.084	5.54
FILTER -	- .7	-.001	-0.04
IMPINGER -	29.8	0.025	1.65
TOTAL SOLIDS	272.8	0.229	15.11

509554

TABLE 4-31.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .621 inches / .303 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 18.36 (scfd)

Volume of Water Collected:

Cyclone 33.7 (ml)

Impinger 248 (ml)

Silica Gel 9.9 (mg)

Net Sampling Time 9.5 (min.)

IV. SITE CONDITIONS

Ambient Temperature 50 °F

Ambient Humidity 46 RH

Ambient Pressure 29.165 mm Hg

Wind Direction 230°

Wind Velocity 16.11

Weather Conditions

509555

TABLE, 4-32.

TEST NO 10 M1

DATE/TIME PERIOD OF TEST: 11/3 / 1645-1745

POSITION IN STACK: MIDPOINT

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 94.6
Angle of Flow 90°
Mean Vertical Velocity 175486 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 175486 (scfm)
% Moisture By Volume 43.4 %
Molecular Weight of Stack Gas 24.11
Mole Fraction of Dry Gas .566

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	33.3	0.036	2.19
-Dissolved Solids	46.6	0.051	3.07
PROBE/NOZZLE-Acetone Wash	105.2	0.114	6.93
-Water Wash	33.9	0.037	2.23
FILTER -	-2.0	-.002	-0.13
IMPINGER -	27.5	0.030	1.82
TOTAL SOLIDS	244.5	.266	16.11

509556

TABLE 4-32.

(cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / .246 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 14.21 (scfd)

Volume of Water Collected:

Cyclone 35 (ml)

Impinger 230 (ml)

Silica Gel 0.0 (mg)

Net Sampling Time 9.7 (min.)

IV. SITE CONDITIONS

Ambient Temperature 44 °F

Ambient Humidity 31 RH

Ambient Pressure 29.05 mm Hg

Wind Direction 250°

Wind Velocity 11.5

Weather Conditions

509557

TABLE 4-33.

TEST NO 11 MP1

DATE/TIME PERIOD OF TEST: 11/3 / 1945-2000

POSITION IN STACK: MIDPOINT

NUMBER OF QUENCHES SAMPLED: 3

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 107.2
Angle of Flow 110°
Mean Vertical Velocity 30.93 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 251822 (scfm)
% Moisture By Volume 15.5 %
Molecular Weight of Stack Gas 27.13
Mole Fraction of Dry Gas .845

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids			
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash			
-Water Wash			
FILTER -			
IMPINGER -			
TOTAL SOLIDS			

509553

TABLE 4-33.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .375 inches / .0031 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 7.46 (scfd)

Volume of Water Collected:

Cyclone NA (ml)

Impinger 8 (ml)

Silica Gel 20.8 (mg)

Net Sampling Time 7.0 (min.)

IV. SITE CONDITIONS

Ambient Temperature 39 °F

Ambient Humidity 37 RH

Ambient Pressure 29.07 mm Hg

Wind Direction 250°

Wind Velocity 6.9

Weather Conditions

509550

TABLE 4-34.

TEST NO 12 M1

DATE/TIME PERIOD OF TEST: 11/3 / 2140-2210

POSITION IN STACK: MIDPOINT

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 103
Angle of Flow 110°
Mean Vertical Velocity 40.25 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 236107 (scfm)
% Moisture By Volume 39.1 %
Molecular Weight of Stack Gas 24.58
Mole Fraction of Dry Gas .609

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids	33.7	0.026	2.02
-Dissolved Solids	54.1	0.042	3.26
PROBE/NOZZLE-Acetone Wash	197.2	0.153	11.86
-Water Wash	110.8	0.086	6.66
FILTER -	-2.2	-.002	-0.13
IMPINGER -	25.6	0.020	1.54
TOTAL SOLIDS	419.2	.325	25.22

509560

TABLE 4-34.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .56 inches / 246 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 19.86 (scfd)

Volume of Water Collected:

Cyclone 26.5 (ml)

Impinger 262 (ml)

Silica Gel 7.1 (mg)

Net Sampling Time 9.2 (min.)

IV. SITE CONDITIONS

Ambient Temperature 35 °F

Ambient Humidity 46 RH

Ambient Pressure 29.07 mm Hg

Wind Direction 210°

Wind Velocity 8.06

Weather Conditions

509561

TABLE 4-35.

TEST NO 13A5P1

DATE/TIME PERIOD OF TEST: 11/3 / 0055-0110

POSITION IN STACK: A-5

NUMBER OF QUENCHES SAMPLED: 3

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic 101.3
Angle of Flow 90°
Mean Vertical Velocity 21.75 (ft/min)
Mean Stack Temperature 180 (°F)
Mean Volumetric Flow 186110 (scfm)
% Moisture By Volume 13.2 %
Molecular Weight of Stack Gas 27.38
Mole Fraction of Dry Gas N/A

II. SUMMARY RESULTS - TOTAL PARTICULATE EMISSIONS

	SAMPLE WEIGHT (mg)	CONCENTRATION (gr/scfd)	MASS RATE (lbs/quench)
CYCLONE-Filterable Solids			
-Dissolved Solids			
PROBE/NOZZLE-Acetone Wash			
-Water Wash			
FILTER -			
IMPINGER -			
TOTAL SOLIDS			

509562

TABLE 4-35.

(Cont.)

III. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross sectional area: .44 inches / .152 square inches

Pitot Tube Correction Factor 1.0

Volume of Dry Gas Sampled 7.82 (scfd)

Volume of Water Collected:

Cyclone N/A (ml)

Impinger 12 (ml)

Silica Gel 13 (mg)

Net Sampling Time 8.1 (min.)

IV. SITE CONDITIONS

Ambient Temperature 42 °F

Ambient Humidity 73 RH

Ambient Pressure 29.13 mm Hg

Wind Direction 220°

Wind Velocity 69

Weather Conditions

509563

Ambient air sampling was performed on November 9 and 10, 1976, in order to determine background levels of particulate matter. A high volume sampler set up near the entrance to the quench tower was used for this sampling. Damages to equipment incurred during shipment prevented ambient air sampling before this date.

Results from the two (2) twelve hour tests and the one (1) 105 minute test are shown below:

Date	Test No.	Time	gr/scf
11/9/76	1	2130-2315	3.92×10^{-5}
11/10/76	2	2130-0930	5.9×10^{-4}
11/10/76	3	1100-2300	6.8×10^{-4}

	mg/cm
1	21.6
2	32.6
3	37.9

The average amount of particulate matter introduced by the ambient air background is 1.22×10^{-4} lbs per quench. This amount is insignificant compared to the total particulate emissions up the stack, which averaged 20.95 lbs per quench for "clean" water and 46.96 lbs per quench for contaminated water.

4.2 Chemical and Physical Composition

A full characterization of the aerosol from a coke quench tower involves consideration of chemical and physical properties. In this section, physical characteristics such as size distribution of water droplets and particulate are described. This is followed by a discussion of the chemical composition of these phases.

4.2.1 Physical Characteristics

Particle Size Distribution

For the purpose of this test program, a number of modifications were made to the standard EPA particulate sampling train (see Section 2.3.2). The major reason for the modifi-

509564

cations was to minimize sampling error. An added benefit was that the in-stack cyclone, which was part of the modification, provided some indication of the size distribution of the emissions.

The quench tower plume consists of visible aerosols in the form of steam. Such aerosols are known to range from 1 or 2 microns in size to about 100 microns.[11] The largest cyclone used in these tests was designed with a 50 percent cut size of about 10 microns. This cyclone measured 16 cm overall and was 25 cm high including the collection cup. This is the practical size limit for a cyclone to be inserted into a stack under the prevailing conditions at the top of a quench tower.

Two smaller cyclones, with 50 percent cut sizes of approximately 1 micron and 3 microns were also used. These were designed for lower flow rates and were used when flow rates through the sampling train were reduced during the "Level I Organic" (PAH) tests. See Section 4.3 for discussion of these results.

The samples collected in the cyclones were filtered, weighed, and dried. Weights of dissolved solids, filterable solids, and liquid were taken. These measurements provided an indication of large droplet and grit emissions. The probe and nozzle assembly was washed first with water, then acetone. These rinses were dried and the residues weighed.

The sampling train filter was weighed and the amount of filtered particulate determined. Liquid collected in the impinger train was measured, then evaporated and the residue was weighed.

The weight fractions (%) of each particulate component collected for each test are listed in Table 4-36. The weight fractions (%) of each particulate component averaged over the 13 clean water tests and the 12 contaminated water tests are presented at the bottom of Table 4-36. The large drops, over 10 microns in size, contained dissolved solids which were included in the

509565

cyclone catch. In order to estimate the size distribution of the grit portion of the aerosol, these dissolved solids in the cyclone catch were not included in Table 4-37. Table 4-37 presents the combined average size distribution of the grit particles in the aerosol. These size estimates were made using the sampling train as a size classification device.

The following observations on coke quench emission characteristics are based on the Tables and Figures presented in this report:

1. Particulate matter in quench emissions is not primarily large sized. Based on Coulter[12] size distribution analysis, 99 percent of the particulate matter collected was below 35 microns in diameter. The weight of larger aerosols collected by the initial cyclone was only 33 percent of the total weight emitted when quenching with contaminated water and 17 percent of the "clean" water quench emissions. Figure 4-2 indicates that the average size of the plume aerosol is less than 4 microns.

2. During "clean" water tests, the greatest weight fraction (71 percent) of particulate was recovered from the probe/nozzle washes. During contaminated tests, particulate matter was found to be distributed more evenly throughout the probe/nozzle and cyclone washes (33 percent in each). Particles collected in the probe averaged about 3 microns in size. Overall, the greatest amount of particulate was found in the probe and nozzle washings.

3. The amount of particulate recovered from the probe/nozzle water washes was less in the "clean" tests than in contaminated tests. However, the amount of particulate in the acetone wash was greater in the "clean" tests than in the dirty tests (see Table 4-6). The reason for this observation is not known at present. It would appear that this fraction of the quench emissions does not correlate with the known composition of the quench water. It may be de-

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rived from some other source, such as the coke being quenched.

4. There was a striking reduction in quantity of emissions when the switch was made from contaminated to "clean" quench water. The greatest reduction was in the amount of particulate collected on the filter. This particulate was made up partly of whatever large (> 3 micron) diameter aerosols passed through the cyclone and probe. Most of the material collected on the filters was smaller than 3 microns and larger than 0.3 microns. (These filters have a 99 percent efficiency for sizes above 0.3 microns.) Some of the filters in the "clean" water tests developed holes, as discussed in Section 6. This decreased the total amount of material found on the filters during "clean" water tests.

5. As indicated in Table 4-36, more than 20 percent of the total particulate collected during the contaminated water series, was collected in the impinger. This was reduced to 10 percent in the "clean" tests. The amount collected in the impinger during the "clean" tests probably would have been even smaller if no holes had developed in the filters. Because of these holes, some particles collected in the impinger were larger than 0.3 microns in size.

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TABLE 4-36. WEIGHT FRACTION (%) OF EACH PARTICULATE COMPONENT COLLECTED IN SAMPLING TRAIN (EPA METHOD 5)

Test No.	Impinger	Filter	Probe/Nozzle Water	Probe/Nozzle Acetone	Sub Total	Cyclone Dissolved Solids	Cyclone Filterable Solids	Cyclone Sub Total
4 B20	36.9	15.6	15.6	5.0	20.6	11.3	16.6	27.9
5 B50	35.9	12.4	9.0	3.2	12.2	32.2	7.3	39.5
6 B80	16.6	13.9	16.0	13.3	29.3	30.3	9.8	40.1
7 C50	26.5	17.1	22.0	3.2	25.2	26.5	4.7	31.2
8 C20	25.0	16.6	14.4	4.0	18.4	36.2	4.0	40.2
9 C80	21.6	17.6	10.9	27.1	38.0	19.2	3.6	22.8
10 D50	11.2	8.5	15.6	27.7	43.3	33.3	3.7	37.0
11 D80	12.9	10.5	10.8	28.4	39.2	34.4	3.1	32.5
12 D20	20.0	15.7	11.8	25.0	36.8	24.2	3.3	27.5
13 A50	15.9	13.1	29.1	3.5	32.6	32.4	6.0	38.4
14 A20	16.7	8.5	16.7	28.8	45.5	24.3	5.0	29.3
15 A80	24.7	8.5	13.1	25.7	38.8	25.0	8.0	28.0
16 C5P0	(1)							
1 C81	9.8	1.7	21.1	56.9	78.0		10.5	10.5
3 C21	5.2	2.2	18.2	63.1	81.3		11.3	11.3
1 B51	5.3	.04	30.6	52.9	83.5	5.9	5.0	10.9
2 B21	6.5	3.9	28.1	56.2	84.3	3.0	2.1	5.1
3 B81	12.8	.9	21.2	42.7	63.9	11.8	10.4	22.2
4 D51	20.2	.9	17.0	46.8	63.8	8.1	6.9	15.0
5 D21	4.0	.3	17.1	61.2	78.3	9.2	7.9	17.1
6 D81	4.6		14.5	64.8	79.3	8.5	7.5	16.0
7 A51	16.7	0	15.4	59.8	75.2	4.7	3.42	8.12
8 A81	11.8	0	34.1	4.4	38.5	27.1	22.7	49.8
9 A21	10.9	0	36.6	36.9	73.5	9.2	6.5	15.7
10 M1	11.2	0	13.8	42.7	56.5	18.9	13.5	32.4
11 MP1	(2)							
12 M1	6.1	0	26.3	46.8	73.1	12.8	8.0	20.8
13 A5P1	(3)							
Summary (4) Contaminated sump makeup water	21	12	15	18	33	28	5	33
Clean sump makeup water	10	2	22	49	71	9	8	17

(1) (2) (3) Special "PAH" Tests - weights not available
(4) Summary from Table 4-2 (Particulate Emission Test Results)

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The quench tower stack gases had an average moisture content close to saturation. During peak flows early in the quench period, stack gases were assumed to be saturated. In addition, substantial mechanical entrainment of water droplets were expected. A significant issue involved in evaluation of the stack gases was possible change in physical characteristics as the gases moved up the tower. For instance, would there be changes in the size of the aerosol? There would be a tendencey for larger particles (and droplets) to rise more slowly than smaller particles. This is due to the effect of the frictional drag of air on smaller particles off-setting the pull of gravity. Smaller particles and droplets would tend to overtake large ones. This would provide opportunity for agglomeration to take place, creating a larger sized aerosol.

A further question has to do with what other interactions might take place between particle and droplet. The observed fog or the mechanically entrained water droplets of larger size might serve to "clean" particulate matter from the stack gas as in a gravitational spray tower or scrubber. A dimensionless number describing the target efficiency of a droplet and a particle may be utilized to determine the likelihood of impact between droplets and particulate matter in the aerosol. Such a separation number may be stated as:

$$N_s = \frac{D_p^2 \ \rho_s \ V_o}{18 \ \mu \ D_b} \qquad (6)$$

where:
- D_p is the particle diameter
- D_b is the droplet diameter
- μ is the viscosity of the aerosol
- ρ_s is the density of the solid particles
- V_o is the average velocity of particle laden aerosols relative to the collecting droplet

The larger the separation number in this equation, the greater the

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impaction efficiency. High values of relative velocity and small droplet sizes would lead to high impaction rates. The effective value of V_o in a quench tower is the difference between the gravitational free-falling speeds of the particulate and the droplet. When the particulate is very small compared to the size of droplet, V_o may be taken as equal to the free-falling speed of the droplet. The two requirements for high impact efficiency of a given particulate; namely a small obstacle (droplet) and a high relative velocity, are mutually exclusive. Impaction of small particulate upon small drops is negligible because of the low relative velocity between the two phases of the aerosol. Particulat e matter smaller than 2 or 3 microns would be practically unaffected by droplets less than 100 microns in size. Fog, which is generally considered to be below 100 microns in size, would have little effect. 500 micron droplets, the optional size, would impact on less than 5 to 20 percent of the 2 to 3 micron size particles. The average droplet size in the quench tower is in the range of 10 to 50 microns, as determined later in this section. The scrubbing efficiency of these droplets would be minimal, even on 10 micron sized particulate. Since 96 percent of the quench particulate was below 10 microns in size, it is unlikely that there was significant scrubbing action by water droplets in the coke quench.

The size of particles collected by the cyclones was affected by the wet walls of the cyclone and by the presence of water droplets. Agglomeration of particles resulted in the removal of some particles smaller than the calibrated cut size. Therefore, the weight fraction collected in the cyclones included some material smaller than the cut size. The percent weight fractions in the particle size distribution reported for the individual tests would therefore tend to be falsely skewed toward the larger particle sizes.

When calculating the combined size distribution data for all 25 runs (Table 4-37), an effort was made to correct for this effect.

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Two of the large cyclone catches were analyzed by Coulter counter techniques. This analysis was used to determine the weight fractions of the 10 micron cyclone catch larger than 10 microns, and the weight fractions smaller than 10 microns. The combined results of these calculations for all 25 tests are summarized in Table 4-37 and in Figures 4-2 and 4-3. For this purpose, the D_{50} cut size of the "In-Stack" cyclones at test conditions was calculated for each test as shown in Table 4-37.

The D_{50} cut size of any given cyclone is determined by a number of variables. These variables include gas density, gas viscosity, gas inlet velocity, particle density, and particle size and shape. The value of the gas density is so small relative to particle density that, in most cases, variation in gas density will have a negligible effect on cyclone separation efficiency or calibration. For a given set of conditions in which particle density, gas density, and gas viscosity are assumed to be fixed, the D_{50} cut size of a given cyclone is determined largely by the gas inlet velocity and the particle size and shape.

Design and calibration data for a series of cyclone devices similar to those used in this test program is available in the literature.[13] Calibration data for this series of SASS cyclones has been utilized to construct Figure 4-4. This graph relates flow in actual cubic feet per minute to the D_{50} cut size in microns for the three sizes of cyclones used. ACFM is, in this case, used as a convenient indication of inlet gas velocity. It is an average value based on the measured amount of dry gas recorded by the dry gas meter (Table 4-37, Column 3), the elapsed time of the test (Table 4-37, Column 2), and the volume of water vapor. These values are corrected to actual stack conditions at the temperature of the test (Table 4-37, Column 4). Following the determination in ACFM of the gas flow for each test (Table 4-37, Column 11), the D_{50} cut size in microns is read from Figure 4-4. Since the inlet velocity was an average, the D_{50} cut size is also an average.

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TABLE 4-37. WEIGHT FRACTION OF PARTICULATE COLLECTED FROM COKE QUENCH EMISSIONS BY MODIFIED EPA METHOD 5 SAMPLE TRAIN - COMBINED AVERAGE FOR ALL TESTS (DISSOLVED SOLIDS IN THE CYCLONE LIQUID NOT INCLUDED)

	lbs/quench	Weight Fraction(%)	Cumulative Weight Fraction(%)	Nominal Size Range (Microns)
		12 Contaminated Tests		
Impinger	10.6	30.8	30.8	0.3
Filter	5.9	17.2	48.0	0.3-2.6
Probe	15.1	43.9	91.9	2.6-10.2
Cyclone	2.8	8.1	100.0	10.2
TOTALS	34.4	100.0	100.0	-
		13 Clean Tests		
Impinger	2.1	10.9	10.9	0.3
Filter	0.2	1.0	11.9	0.3-2.9
Probe	15.3	79.3	91.2	2.9-10.5
Cyclone	1.7	8.8	100.0	10.5
TOTALS	19.3	100.0	100.0	-

509572

TABLE 4-37. (Continued)

	Average	Coulter Tests*	Combined	Weight Fraction (%)	Cumulative Weight Fraction (%)	Nominal Size Range (Microns)
Impinger	6.2	-	6.2	23.3	23.3	0.3
Filter	2.9	0.6	3.5	13.2	36.5	0.3-2.8
Probe	15.2	0.7	15.9	59.8	96.3	2.8-10.4
Cyclone	2.3 =	0.4	0.4	1.5	97.8	10.4-20
		0.3	0.3	1.0	98.8	20-30
		0.1	0.1	0.4	99.2	30-40
		0.1	0.1	0.4	99.6	40-50
		0.1	0.1	0.4	100.0	50
TOTALS	26.6	2.3	26.6	100.0	100.0	-

* Size distribution (from Coulter analysis) of the particulate collected in the cyclone for two dirty water tests was used to estimate the overall distribution of the combined results (size distribution of cyclone catch was not available for clean tests). Since some of the cyclone material was smaller than the 10 micron cyclone cut size, these smaller fractions were included in the probe and filter fractions as indicated above. The Coulter analysis of 4B20 and 10D50 was combined and graphed in the Appendix. The cyclone size distribution data was obtained from this graph.

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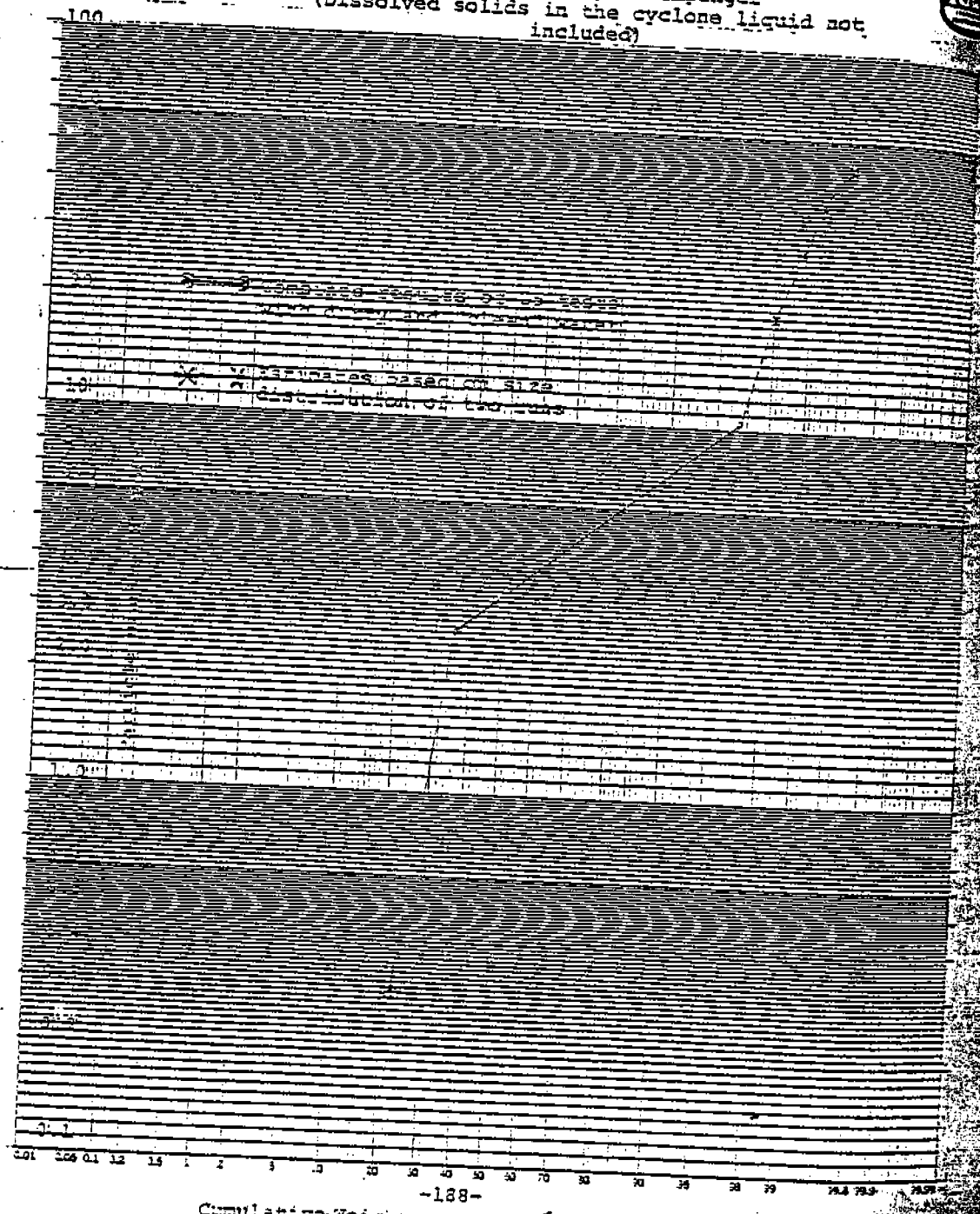
Figure 4-2

Size distribution of particles collected by cyclone, probe, filter, and impinger (Dissolved solids in the cyclone liquid not included)



Cumulative Weight percent ≤ stated size

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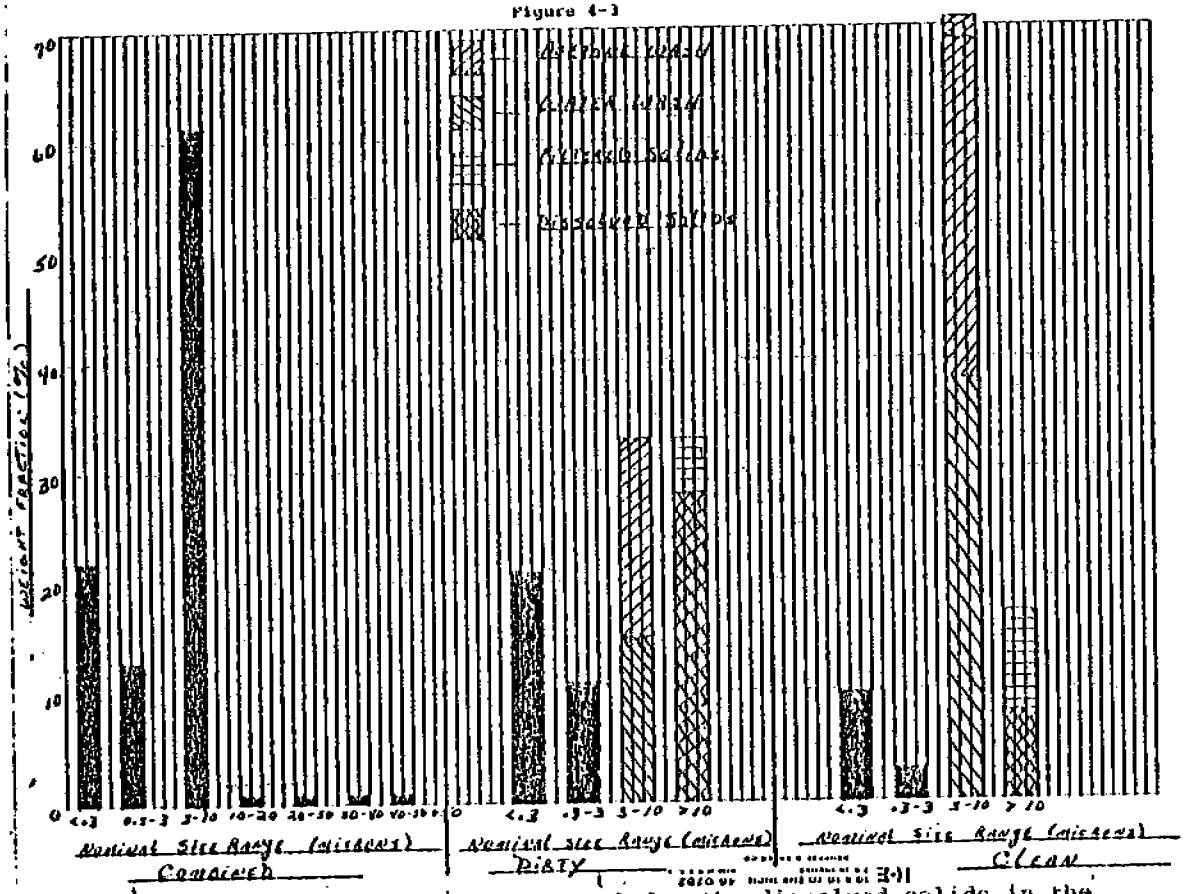
Comparing Size Distribution of Particles Collected by Cyclone, Probe, Filter, and Impinger During "Dirty" Water Tests vs "Clean" Water Tests and Combined Results

Figure 4-3



Data for clean and dirty tests combined.

Includes the dissolved solids in the cyclone catch.

Ace. W. = Acetone Wash
H_2O W. = Water Wash

F.S. = Filtered Solids
D.S. = Dissolved Solids

Data from Table 4-33. Dissolved solids in the cyclone liquid not included.

5093?3

TABLE 4-38. CUT SIZE OF "IN STACK" CYCLONE AT TEST CONDITIONS

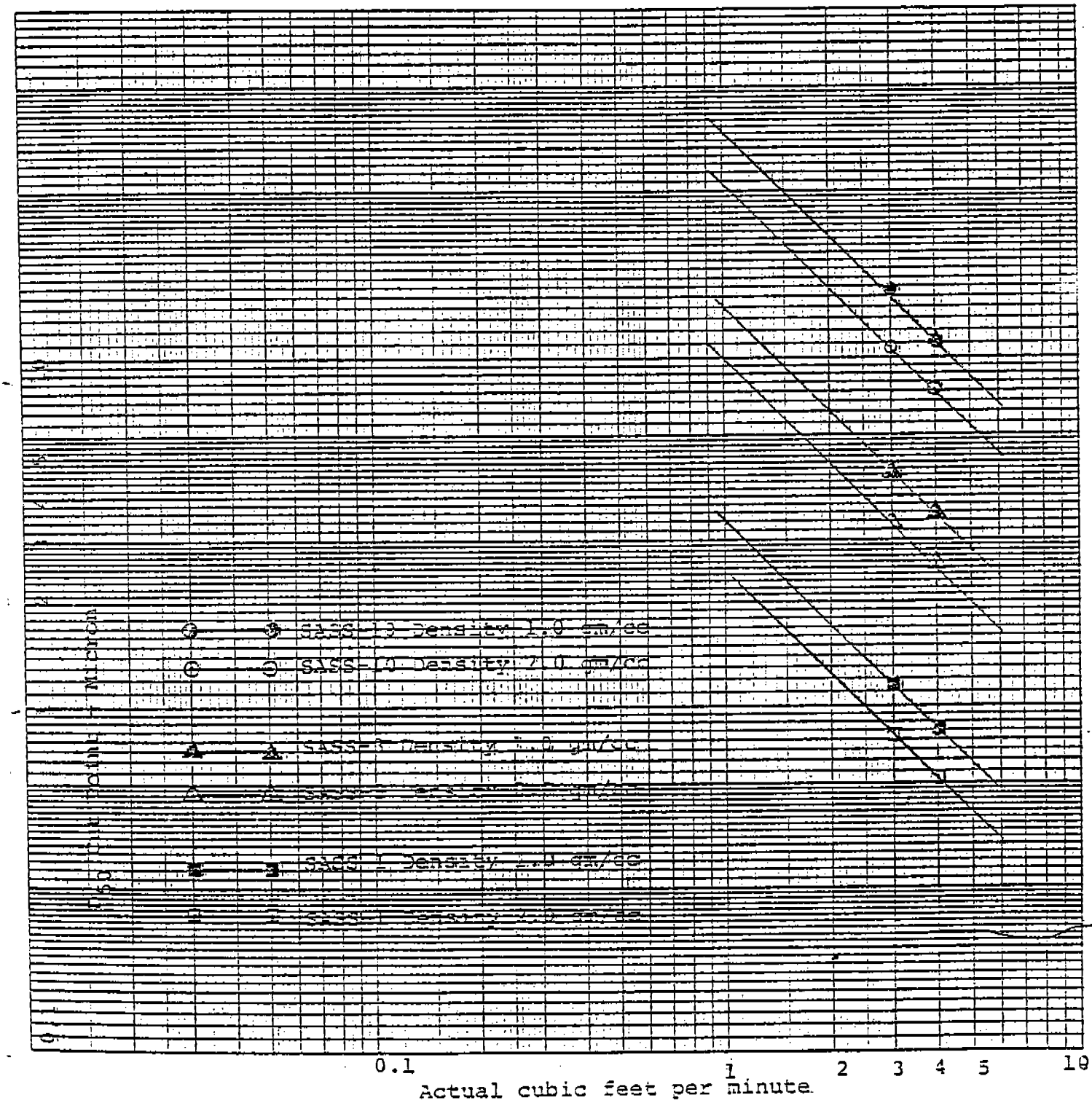
(1) REF CODE	TEST TIME/MIN (2) CAR IN CAR OUT	GAS (3) DSCF PER TEST PERIOD (METER DATA)	GAS (4) STACK TEMPERATURE °F	GAS (5) LBS DRY GAS DURING TEST PERIOD	WATER (6) IMP. ML. DATA	WATER (7) CYCLONE ML. DATA	(8) LBS H_2O/LBS DRY GAS IN SAMPLE AFTER CYCLONE	VOL. OF MIXTURE DRY GAS + IMPINGER WATER AT STACK TEMP. (9) ACF PER LB.	(10) ACF	(11) FLOW OF MIXTURE ACFM	CYCLONE SASS MODEL	CYCLONE (12) D_{50} CUT SIZE MICRONS
4B20	9.7	15.21	180.5	1.140	171	75.0	0.33	24.62	28.07	2.09	10	11
5B50	9.6	23.59	180.0	1.760	305	100.0	0.38	25.91	45.81	4.77	10	7
6B80	7.6	14.06	180.7	1.054	103	70.0	0.21	22.37	23.5	3.10	10	10
7C50	7.9	14.45	181.0	1.083	271	30.0	0.55	30.29	32.80	4.15	10	8
8C20	9.0	10.88	180.0	0.815	197	65.0	0.53	29.54	24.07	2.62	10	12
9C80*	6.8	10.88	181.2	0.815	282	20.0	0.76	34.01*	27.72	4.10	10	8
10D50	8.9	15.44	181.5	1.157	260	110.0	0.51	30.05	34.77	3.91	10	8
11D80	9.1	16.82	181.0	1.201	197	110.0	0.36	26.18	31.44	3.45	10	9
12D20	9.0	18.78	181.0	1.408	195	50.0	0.31	23.86	33.59	3.73	10	8
13A50	8.9	16.65	182.0	1.248	150	60.0	0.26	23.57	29.42	3.31	10	10
14A20	9.0	14.24	181.2	1.067	107	50.0	0.22	27.07	28.88	3.21	10	12
15A80	9.2	11.32	182.5	.848	160	90.0	0.44	27.52	23.34	2.54	10	13
16C5P0	9.2	6.66	205.0	.499	15	N/A	0.07	18.62	9.29	1.01	3	8
1C81	9.3	16.26	180.0	1.219	135	40.0	0.24	22.29	27.17	2.92	10	11
3C21	9.1	17.14	180.0	1.285	205	55.0	0.35	25.11	32.27	3.55	10	9
1B51	9.8	18.93	177.8	1.419	209	29.2	0.32	24.23	34.38	3.51	10	9
2B21	9.5	18.37	181.0	1.377	252	15.0	0.40	26.43	36.39	3.83	10	8
3B81	9.4	19.14	180.0	1.435	173	49.3	0.27	23.06	33.09	3.52	10	9
4B51	9.6	17.75	180.0	1.330	192	37.5	0.32	24.34	32.37	3.37	10	9
5B21	9.4	18.42	180.0	1.381	210	41.7	0.33	24.60	33.97	3.61	10	9
6B81	9.5	18.81	180.0	1.410	230	56.1	0.36	25.37	35.77	3.77	10	8
7A51	9.7	18.12	180.0	1.358	147	17.5	0.24	22.29	30.27	3.12	10	10
8A81	9.5	16.72	181.0	1.253	93	43.5	0.16	20.23	25.35	2.67	10	12
9A21	9.5	18.36	182.0	1.376	248	33.7	0.40	26.47	36.42	3.83	10	8
10M1	9.7	14.21	180.0	1.065	230	35.0	0.48	27.16	28.93	2.98	10	11
11MP1	7.0	7.46	180.0	0.559	8	N/A	0.03	16.90	9.45	1.35	3	6
12M1	9.2	19.06	180.0	1.409	262	26.5	0.39	26.14	38.92	4.23	10	7
13A5P1	8.1	7.82	180.0	0.586	12	N/A	0.05	17.15	10.05	1.24	1	2

* Saturated

5095576

FIGURE 4-4

D_{50} CUT POINT IN MICRONS VS. CUBIC FEET PER MINUTE FOR 3 SIZES OF CYCLONES



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Example

In the following example, the D_{50} cut size is determined for Test 10D50 (Table 4-9):

15.44 dscf x 0.07495 lbs/cf = 1.157 lbs dry gas during test period.

The volume of water collected in the impinger (Table 4-38, Column 6) is converted to pounds of water vapor per pound of dry gas (Table 4-38, Column 8), as follows:

$$\frac{268 \text{ ml } H_2O}{454 \text{ ml/lb } H_2O \times 1.157 \text{ lbs dry gas}} = 0.51 \text{ lbs water/lb dry gas}$$

This value (the absolute humidity) is used with reference tables to determine the ACF/lb of the mixture of dry gas and water vapor. The water collected in the cyclone is included in Table 4-38 for reference, but is not used in these calculations.

ACF per pound (Table 4-38, Column 9) is converted to ACF (Table 4-38, Column 10):

30.05 ACF/lb x 1.157 = 34.77 ACF,

ACF of mixture is converted to ACF per minute (Table 4-38, Column 11) by dividing the elapsed time of the test (Table 4-38, Column 2):

$$\frac{34.77 \text{ ACF}}{8.90 \text{ min.}} = 3.91 \text{ ACFM (Table 4-38, Column 11).}$$

This actual cubic feet per minute value is entered on the ordinate of Figure 4-4. By use of the appropriate graph, in this case SASS-10, and an assumed density of 2.0 gm cm^{-3}, the D_{50} cut size for conditions of test 10D50 is read as 8 microns. The D_{50} cut sizes for each test are tabulated in Table 4-38. The equivalent mass diameters for the clean and dirty tests are as follows:

Equivalent mass diameter - Dirty	10.5 microns
Equivalent mass diameter - Clean	10.2 microns

The weight of dissolved solids later recovered from the cyclone water was not used in calculating these equivalent mass diameters. If it wereused, the average would be about 0.5 microns smaller.

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The basic calibration of 50 percent cut size was based primarily on cyclone design and gas volume. In addition, the size distribution of the particulate caught in the cyclone was determined by Coulter analysis. The results of several tests are reported in Figure 4-5 through 4-9.

The D_{50} cut sizes as determined above were compared with the D_{50} cut size as determined by Coulter analysis. This comparison is summarized in the following Table:

TABLE 4-39. CUT SIZE COMPARISONS

Test Number	Cyclone Model Number	Calculated D_{50} Cut Size in Microns	Actual D_{50} Cut Size of Collected Sample Analyzed by Coulter Counter-Microns
4B20	SASS #10	11	16
10D50	SASS #10	8	5
16D5PO	SASS #3	8	4
11MP1	SASS #3	6	27
13A5P1	SASS #1	2	19

The 10 micron cyclones were used for most of the tests to knock out the larger water droplets. It was not physically possible to suspend 3 cyclones in series. However, the 3 micron or 1 micron cyclone was substituted in those tests where sample rate was reduced.

There are a number of possibilities for the poor correlation in cut size for Tests 11MP1 and 13A5P1. When the smaller cyclone sizes were used (as in these tests), the test train included a special (PAH) adsorberunit (see Section 4.3). With this configuration, the overall flow resistance of the train limited the gas volume sampled to about 1/3 of that sampled with the larger cyclones. In addition, the sample collected during the "PAH" runs had to be handled in a special manner. Therefore, the weight of particulate caught in various parts of the train is not available for these runs. Also, the small cyclones were probably overloaded in these tests with the combination of water droplets and large grit particles. This resulted in particle agglomeration

509579

FIGURE 4-5

REF 16D5PO SASS II CYCLONE

2527A

COULTER COUNTER® Model T+TA — PARTICLE SIZE ANALYSIS

ORGANIZATION: York Research (Art Stewart)

OPERATOR: Mayra Bisnow

COMPANY: TA II

SAMPLE: 69377 ICFM — ELECTROLYTE: Isoton — DISPERSANT: IA, 60 sec. U.S.

MIED. CYC/MB

9/15/96 Test #16

Job # 4-8479F-29

APER. SIZE	SERIAL		PART DIA.	M	Δ IA	A	DIA.	M	Δ IA	A
400		Microspheres	18.04	6	3.2	151	20.2	6	3.2	108
140	37367	Microspheres	9.69	8	3.2	131	10.1	8	3.2	116
30	32695	Latex	2.02	7	.8	117	2.0	7	.8	121

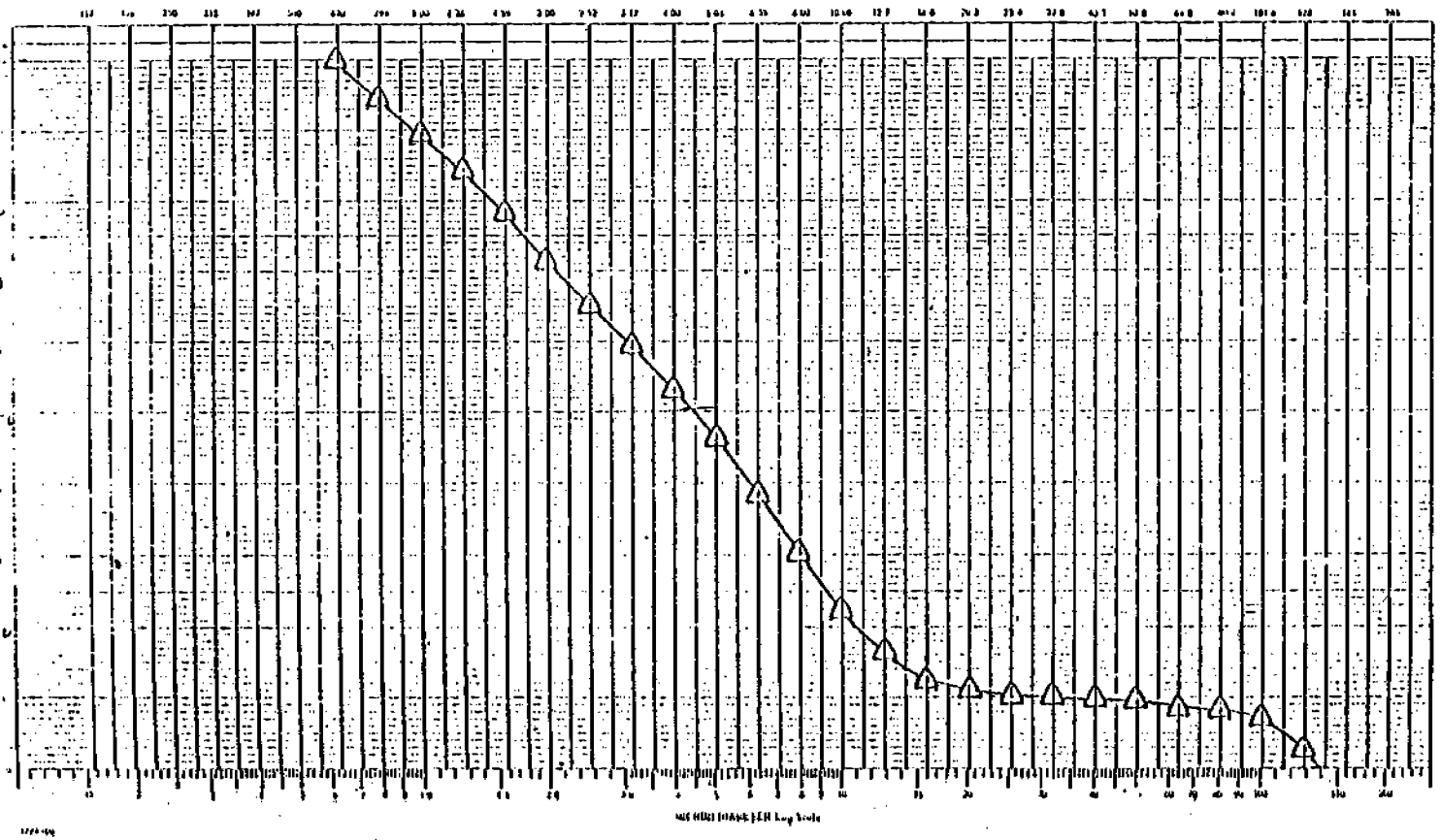

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FIGURE 4-6
REF. 4820 SASS #10 CYCLONE

25778

COULTER COUNTER® Model T&TA

PARTICLE SIZE ANALYSIS

DESCRIPTION York Research (Art Stewart)

OPERATOR Mayra Bisnow

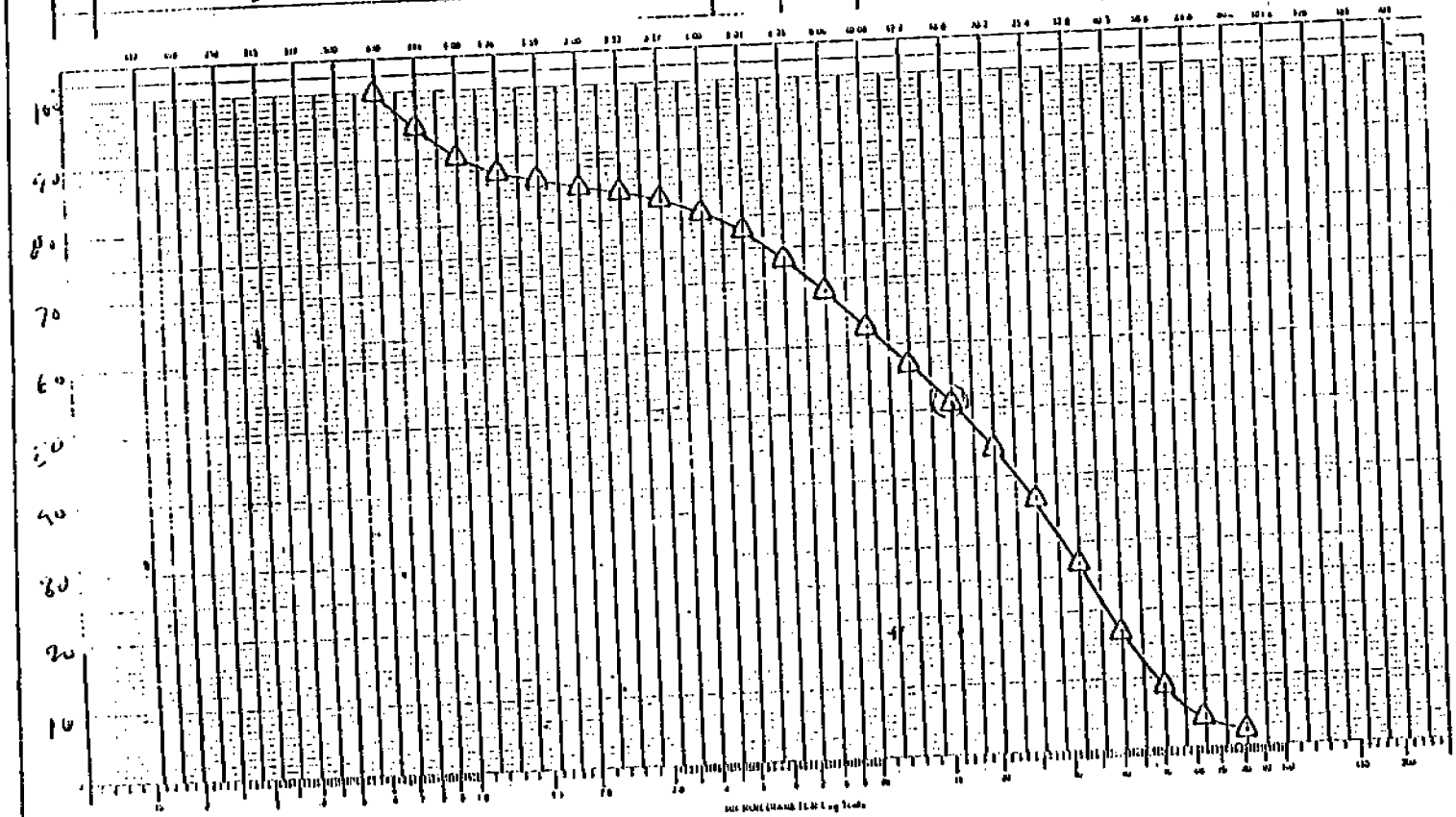
EQUIPMENT TA II

SAMPLE 68858 20 ELECTROLYTE Isoton DISPERSANT IA, 60 sec. U.S.

ML. Aliquot

APER. SIZE	SERIAL		PART DIA.	N	Δ	A
400		Microspheres	16.04	6	3.2	151
140	37367	Microspheres	9.69	8	3.2	131
30	32695	Latex	2.02	7	.8	117

DIA.	N	Δ	A
20.2	6	3.2	10
10.1	8	3.2	11
2.0	7	.8	12



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2527 C

FIGURE 4-7
REF: P10D50 SASS #10 CYCLONE

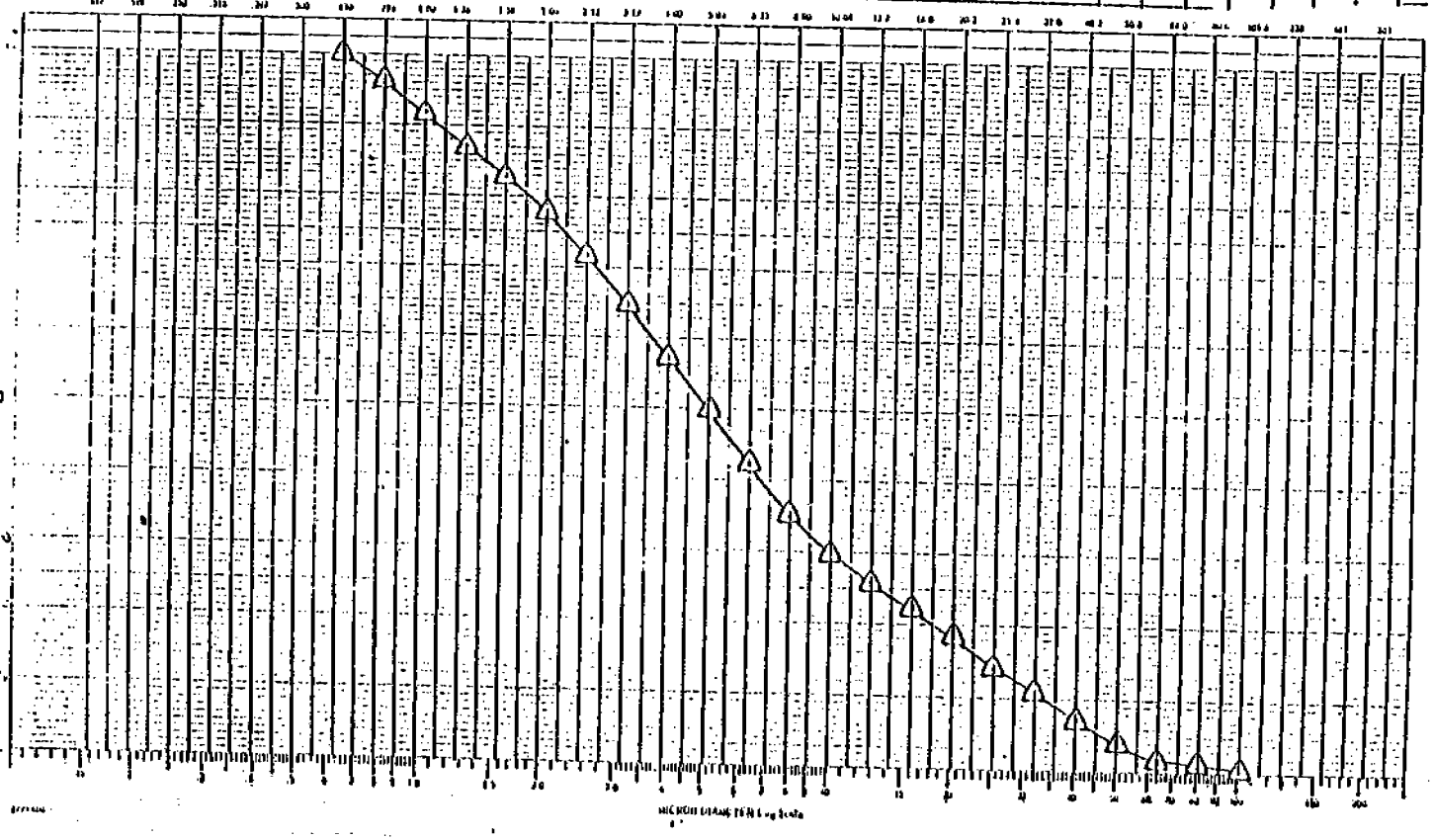
COULTER COUNTER® Model T & TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

ORGANIZATION: York Research (Art Stewart)
OPERATOR: Mayra Bisnow
EQUIPMENT: TA II
SAMPLE: 69058 20 HC. Aliquot
ELECTROLYTE: Isoton
DISPERSANT: IA, 60 sec. U.S.

$b = d\sqrt[3]{\frac{\pi}{6}}$ FOR MODEL T; $\frac{\Delta b}{\Delta t} = \left(\frac{\Delta t}{\Delta t}\right)^3$ when $M_t = V_t$; $\frac{\Delta b}{\Delta t} = \left(\frac{\Delta t}{\Delta t}\right)^3$ when $M_t = V_t$ FOR MODEL TA

APER. SIZE	STRIAE		PART DIA.	N	Δ ln	A	SAMPLE SETTINGS DIA.	N	Δ ln	A
400		Microspheres	18.04	6	3.2	151	20	6	3.2	100
140	37367	Microspheres	9.69	8	3.2	131	10	8	3.2	116
30	32695	Latex	2.02	7	.8	117	2.0	7	.8	121



509582

FIGURE 4-8

REF. 11MP1 SASS #3 CYCLONE

2567-7

COULTER COUNTER® Model T & TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

ORGANIZATION: York Research

OPERATOR: Mayra Bisnow

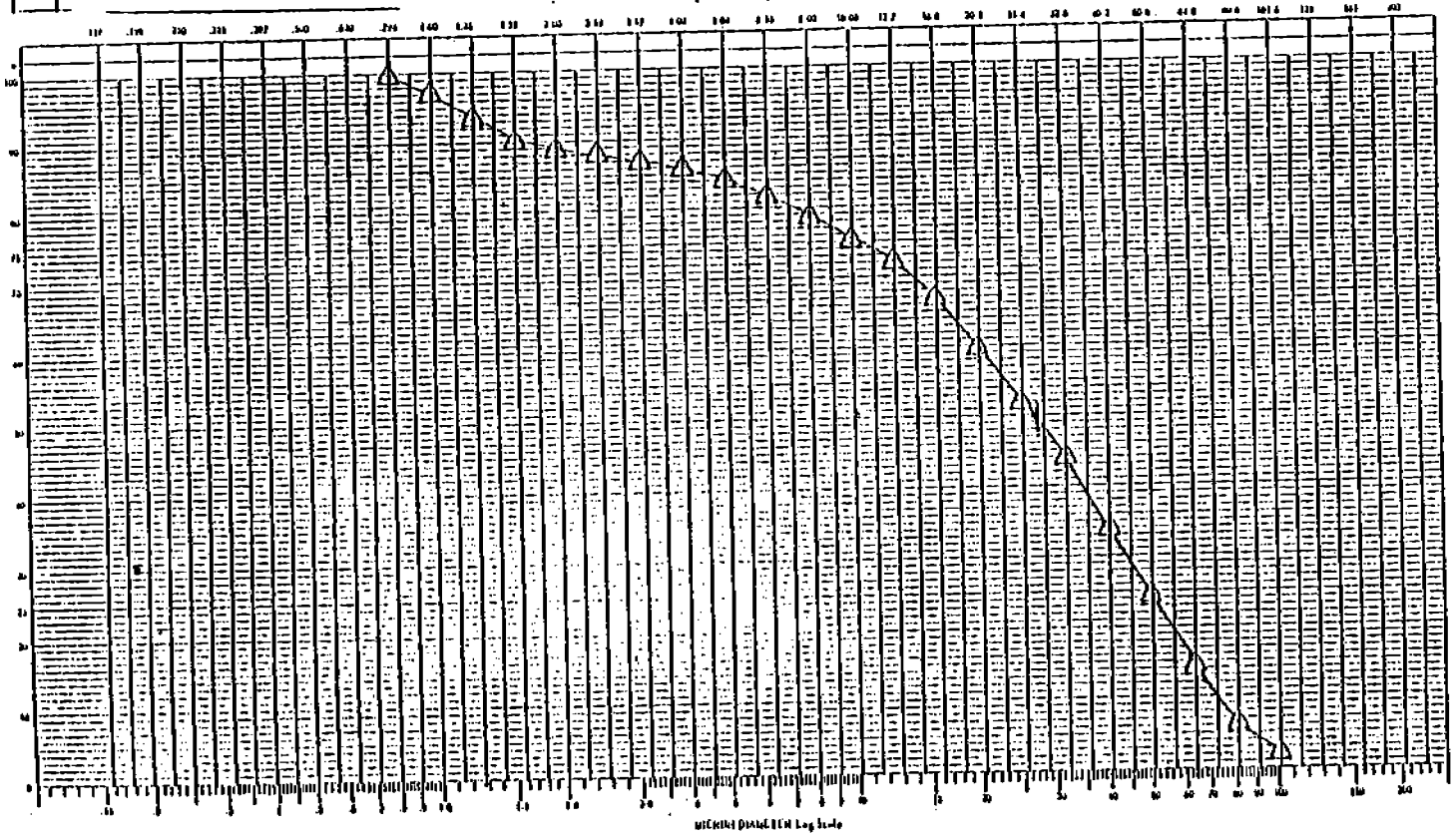
EQUIPMENT: TA II

SAMPLE: 11-3-76 Test 11a

ELECTROLYTE: Isoton

DISPERSANT: IA, 60 sec. U.S.

APRX. SIZE	SERIAL		PART DIA.	M	Δ	Δ	DIA.	M	Δ	Δ
400		Microspheres	19.86	7	3.2	206	20.2	7	3.2	197
140	23155	Microspheres	10.11	9	3.2	202	10.08	9	3.2	204
30	44597	Latex	2.02	7	.8	145	2.00	7	.8	150



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2567-8

FIGURE 4-9
REF. 13A5P1 SASS #1 CYCLONE

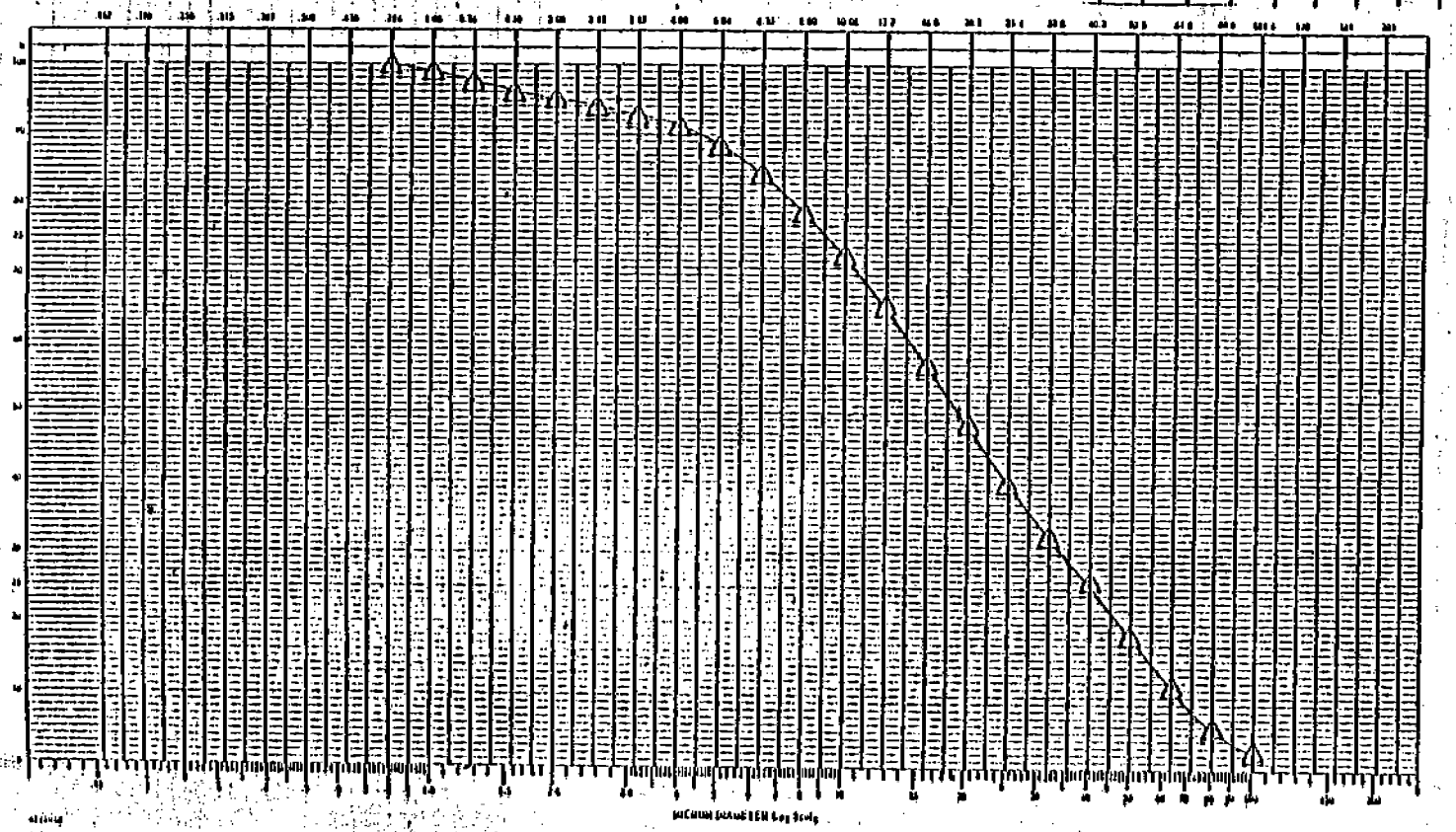
COULTER COUNTER® Model T+TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

DESIGNATION	York Research
OPERATOR	Mayra Bisnow
EQUIPMENT	TA II
SAMPLE	11-3-76
ELECTROLYTE	Tauton
DISPERSANT	IA, 60 sec. U.S.
	Test 13a

$\frac{d_1}{d_2} = \left(\frac{d_1}{d_2}\right)^2$ FOR MODEL T; $\frac{d_1}{d_2} = \left(\frac{d_1}{d_2}\right)^2$ FOR MODEL TA

APER. SIZE	SERIAL		PART DIA.	N	Δ	Δ	SAMPLE ASSEMBLY DIA.	N	Δ	Δ
400		Microspheres	19.80	7	1.2	206	20.2	7	1.2	197
140	23155	Microspheres	10.11	9	1.2	202	10.00	9	1.2	20[illegible]
30	44597	Latex	2.02	7	.8	145	2.00	7	.8	50



50958

and some increase in the observed size of particles.

A final possibility for the poor correlation between the two test methods in the smaller cyclone sizes is that the Coulter analyses were performed on small samples. There may have been some difficulty in obtaining a representative sample from the small amount of liquid and suspended particles caught in the cyclones.

The Coulter results of Tests 4B20 and 10D50 tend to confirm the design D_{50} cut size. The calculated cut size and the weight fractions for the 25 tests as reported in this section have been used in estimating the average size of the quench emissions.

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Droplet Size Distribution

The plume of the coke quench tower was observed to contain large quantities of steam. In previous efforts to measure particulates, the moisture content of aerosol had caused plugging of the pitot tubes and filters. There was visual evidence indicating the plume approached saturation at peak periods of water flow, for instance the inside surfaces of thick masonry walls of the areas were wet and dripping; and there was an obvious fallout of drizzle and particulate from the plume as it passed over any given area.

There has been some effort to measure drizzle from quench operation. The most recent reported intense drizzle with a median droplet size of 450 microns. However, very little if anything has been reported that would aid in identifying the size distribution of water droplets passing up the stack of a coke quench tower.

Within the quench tower itself is a set of baffles designed to cover a 19'2" square area above the quench car. A series of 6 individual boxes measuring 9'6" x 6'3½", comprise the entire unit, which rests on a 1'2" wide concrete encased I-beam. (see Section 6.4).

These baffles are designed in such a way as to cause larger water droplets entrained in the quenching gases, rising into the stack, to impact on 2" x 10" pressure creosoted boards inclined at 45°. Because of the high moisture content of quench emissions, water droplets can be seen collecting on and falling from the baffles during quench operations.

The baffles remove approximately 85 percent of the droplets above 150 microns in diameter and about 40 percent of the droplets above 50 microns diameter. These estimates are based on the probable impaction of certain sizes under quench tower conditions as predicted by the separation number N_s :[15]

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where $N_s = \frac{D_p^2 \; V \quad P}{18 \quad D_b}$

and

N_s = separation number dimensionless

Detailed calculations supporting this statement and an analysis of the effect of the baffles on the aerosol is included in Section 6.4. This analysis of the baffles' effect on droplets and particulate matter concludes that, under quench conditions, baffles would be effective only on large sizes, such as water droplets 100 to 150 microns and larger.

As the plume rises in the tower, droplets impact, adhere, and collect, forming larger drops and fall back down the tower. Above the baffles average air velocities would be so low that any such impaction would not have the energy to create many smaller drops requiring higher surface energies. Below the baffles, however, the violent jets and turbulence would be expected to create droplets mechanically as the water left the distributing nozzles.

If any jets of steam blasted up through the baffles without being mixed or cooled by induced air, the separation number would be affected. The increase in velocity would increase N_s. However, the viscosity of the mixture would be increased which would tend to decrease the separation number. The velocity would probably be the greater effect and, therefore, the jets and turbulence we observed probably increased the efficiency of impaction at that point for a short period.

To obtain further data on whether the drops would grow or change in size or even be created after the water vapor passed through the baffles, several temperature profiles of the tower were recorded. The profiles do reflect the rising plume of steam with each quench but they do not indicate how much any given portion of plume is cooling or heating as it rises. However, the heat and mass balance presented in Section 5.0 indicates:

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- there was more than enough water found in the stack gases as vapor to account for the cooling of the coke.
- there is not enough heat to account for the droplets of water to have originally been vaporized.
- nor is there any evidence of heat being released by any large amount of vapor condensing to droplets on the way up the stack.

The liquid collected in the cyclone would represent the amount of water contained in droplets above 5-15 microns in size. If there were, in fact, few droplets above 100 to 150 microns rising inside the tower, the size range of the water droplets caught in the cyclone could be better defined. In an effort to obtain more information about drop size distribution, the paper sizing techniques described by Martin[16] and Chilton and Lowe[17] were adopted for use in the quench tower environment. However, the exposure time was so short that early attempts involving the insertion and withdrawal of a shaped surface were abandoned. Instead, the sliding shutter shown in Figure 4-10 was constructed.

By attaching the paper to a plate, placing it inside a sealable plastic bag, and passing the connecting handle through a second open plastic bag, it was possible to position the apparatus within the stack at a given point and have it remain dry and unaffected. When a sample was to be taken, the handle connected to the plate was pulled outward causing the sealed bag to open. The paper was then exposed for the desired time period and pulled into the second bag. The movement was continuous and the paper was exposed for about one-tenth of a second.

The data collected with this apparatus is limited. Many of the test papers were unusable because of over exposure. However, three areas "approximately 2" x 2" were counted on two of these test papers and the results combined and plotted as Figure 4-11.

A D_{50} size of approximately 170 microns is indicated. This is

509588

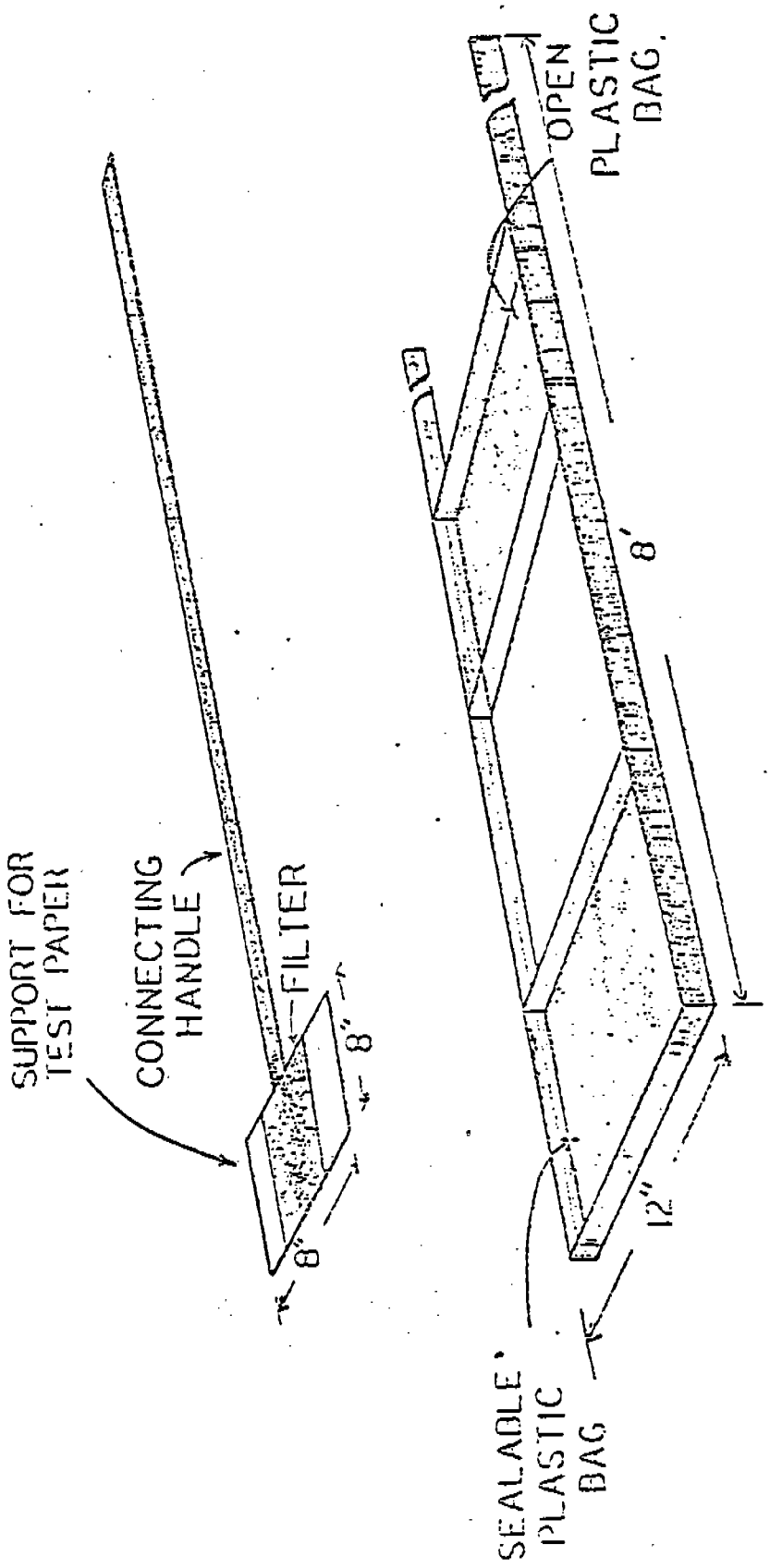
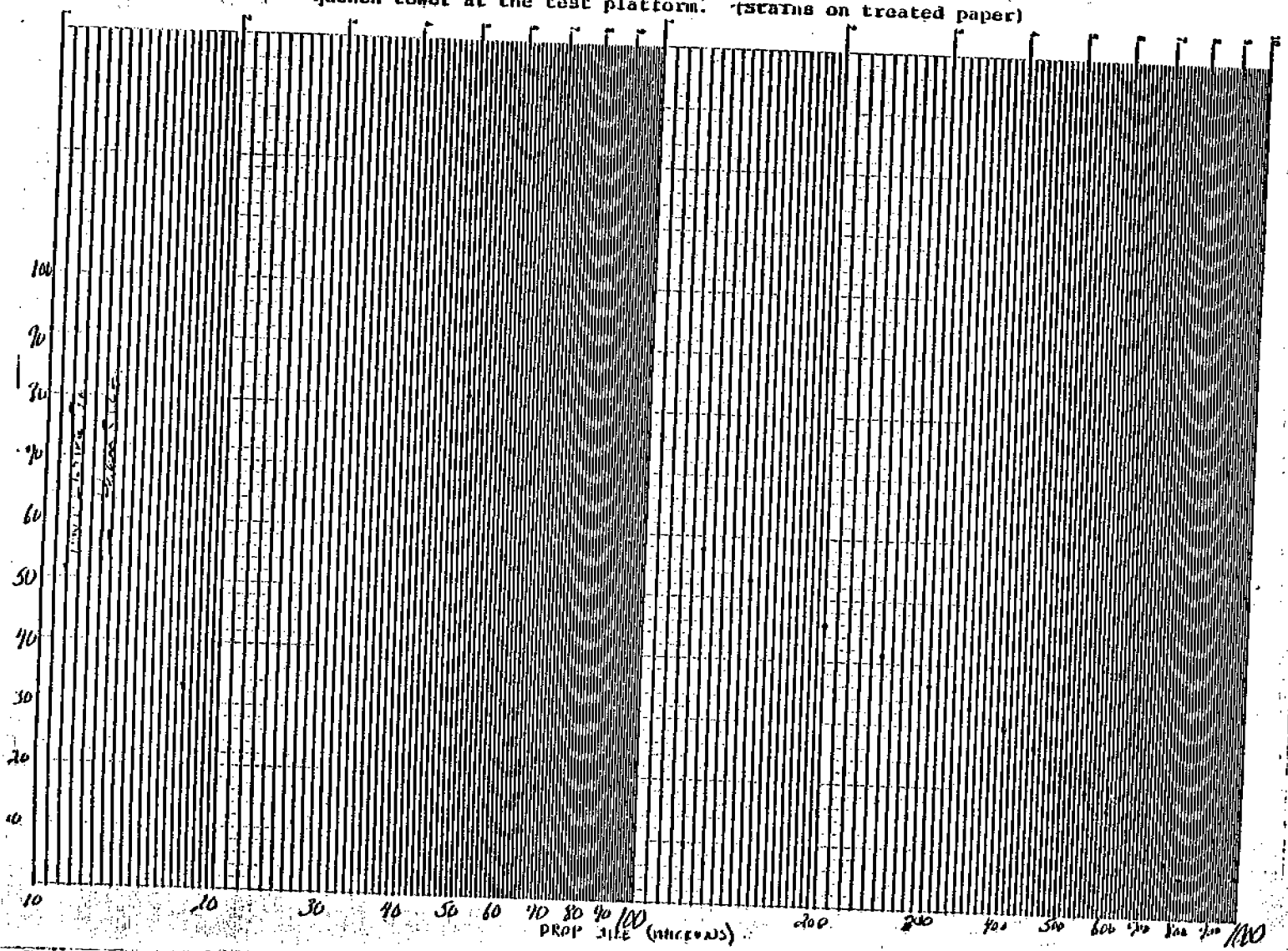


FIGURE 4-10.
SHUTTER APPARATUS TO EXPOSE SENSITIVE PAPER TO THE DROPLETS RISING IN THE QUENCH TOWER.

509583

Figure 4-11 Droplet measurement inside the quench tower at the test platform. (stains on treated paper)



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somewhat larger than would be indicated by the baffle design and considerations based on the separation number N_s. Since the fine drops would follow the air flow around the flat plate and not impinge, the resultant average size would be biased towards the larger drops. The flat plate was a first effort in development and should be followed by an improved design built to accomodate an air foil shape as required in order to allow the impingement of the finer droplets. The droplets were also measured by use of the KLD[18] counter on October 9th, 1976. The weather conditions, i.e., wind from the north (15-20 knots), caused excessive fugitive emissions at the base of the quench tower, and, therefore, this was not a regular test day. The results of two measurements were combined into one graph (Figure 4-12). The average droplet size is indicated as 3 microns. A third test recorded 8,000 out of 10,000 drops as less than one micron in diameter. This test was disregarded since there was some possibility of instrument problems due to rain and drizzle.

Visual observation of the aerosol moving up the tower confirmed the presence of large drops and suggested that if the cloud or fog of smaller droplets follows the usual sizing found for such formations, the individual drops would range in size from about 2 or 3 microns and larger.

The induction of outside air causes much rapid violent cooling and mixing at the base of the tower. This cooling no doubt continues to some small extent a few diameters beyond the baffles. However, no significant cooling would be expected as the plume rises in the tower.

At least one other possible mechanism for the formation of larger droplets in the rising plume inside the tower should be mentioned. The larger droplets are traveling slower than the smaller drops. The smaller drops then tend to overtake and collide with those slightly larger, resulting in some overall growth.

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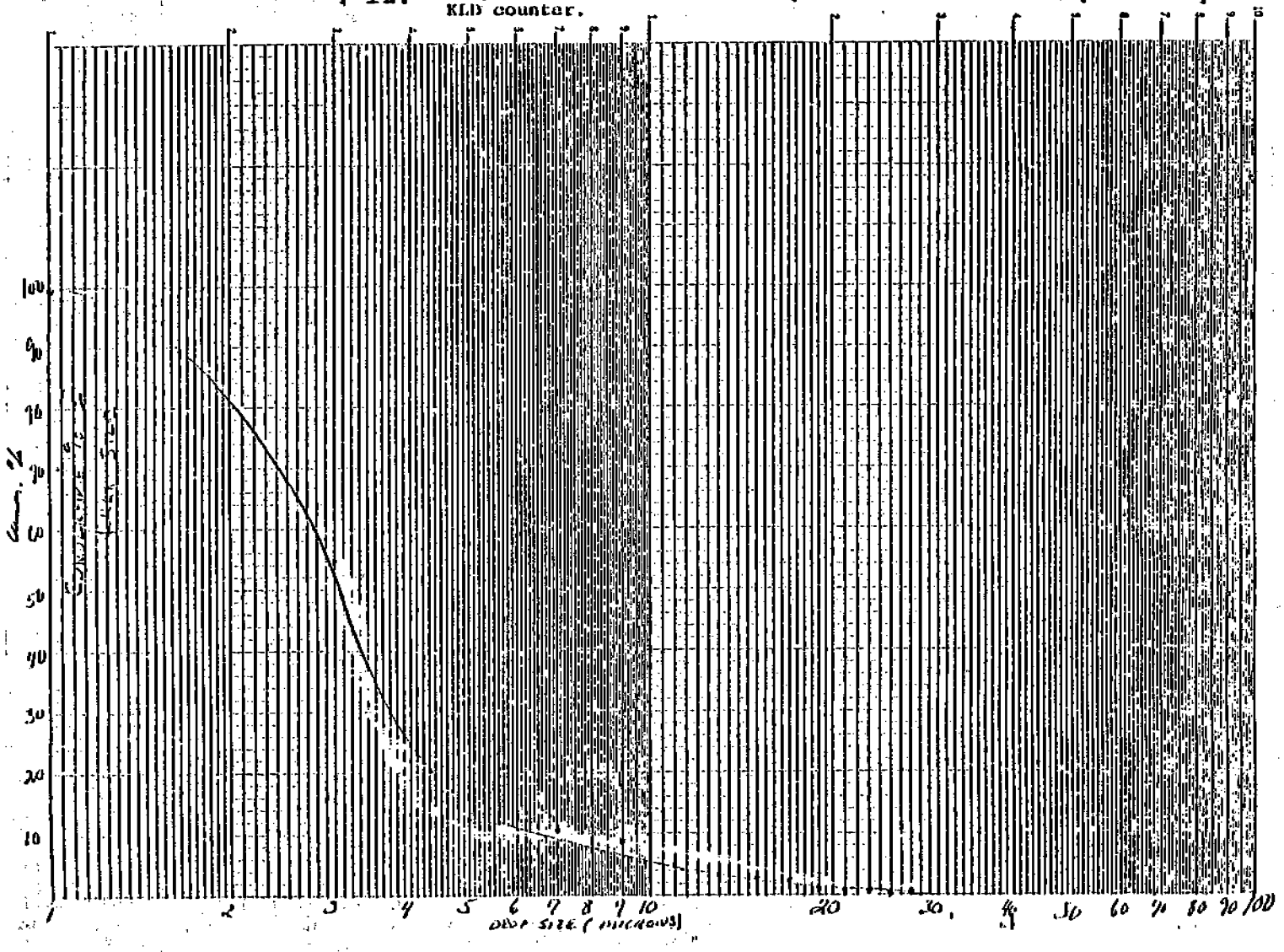
Figure 4-12. Droplets measured inside the quench tower at the test platform by KLD counter.



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The thermodynamic heat balance (Section 5.1.3) indicates that the water droplets removed from the aerosol by the cyclone were probably originally formed directly and mechanically from water as it left the nozzles and sprayed onto the coke from the water nozzle. The cyclone catch was equivalent to 370 gallons per quench. About 250 gallons of this was caught as drizzle in a test conducted by IITRI . The droplets at that point had an average size of 450 microns. These drops had a definite dissolved salt content which would be expected if they were mechanically entrained from initial spray and not formed entirely from condensation of water vapor.

509533

The efficiency of the baffles to impact large diameter water droplets over 150 microns is somewhat greater than 90 percent as shown in Table 6-32. These large droplets were probably formed directly by mechanical action during the spraying operation. Therefore very few of these would be expected in the steam plume inside the stack.

Based on thermodynamic considerations, it is likely that no droplets were formed in the tower due to condensation but larger rather from the action of small, faster travelling, droplets colliding with larger, slower moving droplets. Paper sizing techniques were of limited usefulness, yielding data only on larger size droplets. The KLD counter results were consistently low. More work is needed in this area to further define the average size of the aerosol in the tower. Best available data at this time indicates an average size in the 10 to 150 micron range.

50955

The size distribution data discussed thus far have been based on the weight fractions of droplets and particulate matter collected in the stack cyclone, and on the subsequent Coulter counter analysis. The probe and the filter operated as two additional pieces of sizing equipment.

A large amount of particulate material was recovered from the probe and nozzle washings. In an effort to characterize the flow regime in the probe, the dimensionless ratio known as the Reynolds Number was calculated. For the purposes of this application, the Reynolds Number is defined as:

$$\frac{V, D\ \rho_g}{\mu}, \text{ where:}$$

V_1, velocity $= \dfrac{\text{ACFM} \times 28320\ \text{cm}^3/\text{ft}^3}{60\ \text{sec/min} \times A_o}$, A_o = cross-sectional area of probe in cm^2

D = diameter of probe

ρ_g = density of gas in gm cm^{-3},

μ = viscosity of gas, essentially constant for all tests

Velocity, density, and viscosity were determined as follows, using Test 10D50 as an example:

$$V_1 = \frac{3.91\ \text{ACFM} \times 28320\ \text{cm}^3/\text{ft}^3}{60\ \text{sec min}^{-1} \times 0.665\ \text{cm}^2} = 2806\ \text{cm sec}^{-1}$$

$$D = 0.92\ \text{cm}$$

$$g = \frac{1}{30.05\ \text{ACF}\ 16^{-1} \times 28320\ \text{cm}^3\ \text{ft}^{-3} \times 116 \times 454\ g^{-1}} =$$

$$5.33 \times 10^{-4}\ g\ \text{cm}^{-3}$$

$$= 180 \times 10^{-6}\ \text{poise}$$

The Reynolds number for this example is:

$$\frac{2806 \times 0.92 \times (5.33 \times 10^{-4})}{180 \times 10^{-6}} = 7.64 \times 10^3$$

509595

The boundary between laminar and turbulent flow patterns is considered to be at a Reynold's value of 2,000. In Table 4-40 the Reynolds number for each test has been tabulated. The Reynold's number in these tests varied from 5,000 to 10,000; well above the transition to turbulent flow.

Net gas flow velocities in the probe ranged from 1800 cm sec^{-1} to 3300 cm sec^{-1}. These velocities were high enough to suspend small droplets and particulate matter that passed through the cyclone. However, despite the presence in the probe of this turbulent flow regime, some droplets and particulates were deposited in the probe; generally remaining there until removed in the water and acetone wash. An analysis of the friction values[19] and Reynold's conditions in the system indicates how this deposition is possible despite the turbulent flow. The radial resolute of the gas fluctuation velocity imparts sufficient inertia to entrained droplets and particles to project them through the flow boundary layer. These droplets and particles impinge on the heated probe surface. Many of them adhere to this surface; remaining there until removed in the water and acetone washes. These washes were evaporated to leave a precipitate of the dissolved solids and small suspended particulate. Because individual particles would tend to agglomerate during precipitation, no Coulter analysis was performed on the probe collection.

The average flow velocity in the horizontal sampling probe was 20 to 30 meters per second. The settling rate of particles less than 20 microns in diameter is considerably less than the vertical component of the mean eddy velocity due to turbulence. Such particles therefore, would be deposited in a relatively uniform distribution over the entire section of the tube.

The basic equation defining a coefficient of mass transfer , K, which would apply to the deposition of particulate in the probe may be stated as follows:

509596

Table 4-40.

Actual gas velocity and Reynolds number-entering the probe

1 Test	2 V_1 (cm-sec^{-1})	3 ρ_g (gr-cm^{-3})	4 Reynolds No.
4B20	2048	6.5×10^{-4}	6×10^3
5B50	3385	6.18 "	10.6×10^3
6B80	2204	7.16 "	8.06 "
7C50	2941	5.12 "	7.69 "
8C20	1885	5.42 "	5.22 "
9C80	2905	4.71 "	6.99 "
10D50	2806	5.33 "	7.64 "
11D80	2445	6.11 "	7.63 "
12D20	2643	6.91 "	9.33 "
13A50	2338	6.79 "	8.11 "
14A20	1856	5.91 "	5.6 "
15A80	1800	6.27 "	5.76 "
1C81	2069	7.18 "	5.59 "
3C21	2515	6.38 "	8.20 "
1B51	2487	6.61 "	8.40 "
2B21	2714	6.06 "	8.40 "
3B81	2494	6.94 "	8.84 "
4D51	2388	6.58 "	8.47 "
5D21	2558	6.51 "	8.51 "
6D81	2664	6.31 "	8.59 "
7A51	2211	7.18 "	8.11 "
8A81	1892	7.91 "	7.64 "
9A21	2714	6.05 "	8.39 "
10M1	2112	5.89 "	6.35 "
12M1	2998	6.12 "	9.37 "

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$$j = dn/dt\ (1/A) = K\ \Delta C,$$

where j, the mass flux per unit area, is an expression for the transfer of N moles through an area, A, during time t. This may also be expressed as a mass transfer coefficient, K, with dimensions of (length) x $(\text{time})^{-1}$ times a concentration difference, ΔC.

The mass transfer coefficients, K, for the 25 tests have been calculated as follows and are reported in Table 4-41.

$$K\ (\text{cm min}^{-1}) = \frac{j}{\Delta C} = \frac{\frac{M_p}{A \times t}}{\frac{Mav}{Va}} = \frac{M_p}{A \times t} \times \frac{Va}{Mav}$$

Example based on test number 10D50:

M_p	= Mass in probe	0.53 g Reference Table 4-41.
A	= Surface area of probe	996 cm^2
t	= Time of test	8.78 min, Table 4-13.
Mav	= Mass in gas stream, average	.506 g, see below

$$Mav = Filt + Imp + \frac{M_p}{2}, \text{ where:}$$

Filt	= Particulate mass on filter	.104 g, Table 4-13.
Imp	= Particulate mass in impinger	.138 g, Table 4-13.

$$Mav = 0.104 + 0.138 + \frac{0.530}{2}$$

$$= 0.506 \text{ g}$$

Va	= Actual volume of gas mixture thru probe during test	9.85×10^5 cm^3, Table 4-40.

Continuing with 10D50 as an example:

$$K = \frac{0.530}{996 \times 8.78} \times \frac{9.85 \times 10^5}{0.506} = 118.0 \text{ cm min}^{-1}$$

The net rate of deposition depends on both the rate of transport of the particles to the wall and the rate of re-entrainment. The effect of re-entrainment is considered to be negligible since the wet particulate matter tended to adhere to the heated surface of the probe.

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TABLE 4-41.

MASS TRANSFER COEFFICIENT K

1 Test	2 Mp Mass deposited in Probe (g)	3 Mav Ave. Mass Thru Probe(g)	4 Mass Transfer Coefficient, K ($cm\text{-}min^{-1}$)
4B50	.153	.488	26.0
5B50	.132	.591	30.3
6B80	.154	.238	57.2
7C50	.166	.370	53.0
8C20	.097	.270	27.1
9C80	.279	.428	76.0
10D50	.530	.505	117.9
11D80	.307	.337	90.0
12D20	.279	.410	72.2
13A50	.187	.259	67.8
14A20	.341	.358	70.8
15A80	.411	.558	53.2
1C81	.337	.218	128.4
3C21	.300	.177	171.0
1B51	.417	.236	176.0
2B21	.364	.228	173.0
3B81	.335	.240	139.0
4D51	.285	.237	115.0
5D21	.241	.134	184.0
6D81	.242	.135	181.0
7A51	.316	.228	123.0
8A81	.071	.058	94.8
9A21	.20	.130	171.0
10M1	.139	.096	122.0
12M1	.308	.180	205.0

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An average particle diameter was calculated for the material deposited in the probe in each test using the methodology of Friedlander and Johnstone, 1957.[20] The calculations were performed using the mass transfer coefficient, K, and assuming the Reynolds analogy to hold in the turbulent core. In this case, the friction factor , f, can be determined graphically from the Reynolds number. A rearrangement of Friedlander and Johnstone's Equation 13 yields a value for the stopping distance, S^+, in a dimensionless form:

$$S^+ = \sqrt{\frac{1525}{V_2 \quad \sqrt{f/2} \quad \frac{1}{f/2} + 50.6}}$$

Using 10D50 as an example:

V_2 =	Velocity	168,384 cm min^{-1}	Table 4-40
K =	Mass transfer coefficient	118.0 cm min^{-1}	Table 4-41
f =	Friction factor	8.1×10^{-3}	Table 4-42

$$S^+ = \sqrt{\frac{1525}{\frac{168,384 \quad \left(\frac{8.1 \times 10^{-3}}{2}\right)^{\frac{1}{2}}}{118.0} - \frac{1}{\left(\frac{8.1 \times 10^{-3}}{2}\right)^{\frac{1}{2}}} + 50.6}}$$

$S^+ = 3.5$

S^+ values are tabulated in Table 4-38.

The diameter of the particles in microns is related by Friedlander to S^+ as follows:

$$d_p \text{ (microns)} = \frac{S^+ \cdot 18 \; u^2}{0.9 \; V_2^2 \cdot f/2 \cdot \quad p \cdot \quad g}$$

Where the units are as previously described:

ρ_p = density of the particle, assumed to be 2.0 gram cm^{-3}.

The above relationship applies when S^+ is less than 5; that is, when the stopping distance is less than the thickness of the sub-layer. However, the mass transfer coefficient is somewhat

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increased by the mass of dissolved solids from the wet aerosol, especially in the dirty tests, and the calculated S^+ for these tests did not exceed 5 by more than 10 percent. Therefore, this limitation need not be strictly enforced.

Continuing with 10D50 as an example:

$$d_p = \frac{3.5 \times 18\ (180 \times 10^{-6})^2}{0.9 \times 2806 \times \frac{8.1 \times 10^{-3}}{2} \times 2 \times 5.3 \times 10^{-4}}$$

$$d_p = 2.6 \times 10^{-4} \text{ cm or } 2.6 \text{ microns}$$

The calculated diameter, dp, of the particles deposited in the probe in each test are tabulated in Table 4-42. The equivalent mass diameter was calculated to be 2.6 microns for the dirty tests, and 2.9 microns for the clean tests. The average equivalent mass diameter for all 25 tests was 2.7 microns.

The preceding calculations have been developed from the work of Friedlander and Johnstone (1957). Davies[19] in 1966 points out that Friedlander's assumption that the deposition or radial velocity is equal to 0.9 of the friction velocity, is not applicable to very large particles which never attain the friction velocity or to very small particles which are influenced by Brownian diffusion. Other factors, such as probe roughness and rotation of the aerosol about the axis of the probe, would increase the radial resolute or deposition component of the gas velocity.

Material collected in the probe contained solids precipitated from some of the small water droplets which passed through the cyclone and impinged on the walls of the probe. Deposits in the nozzle and connecting elbows which were added to the probe material, also increased the weight collected in the probe. Therefore, the weight fraction calculated for the test probes is larger than the fraction actually deposited in the probe.

For the "clean" water tests, the greatest weight fraction of particulate was removed from the probe/nozzle washes. A smaller

TABLE 4-42.

CALCULATED DIAMETER OF PARTICULATE DEPOSITED IN PROBE

Test	V_2 (cm-min^{-1})	Fraction Factor, f	S+ dimensionless	dp(microns)	Equivalent Mass Diameter Microns
4B20	122886	8.6×10^{-3}	2.1	2.4	
5B50	203136	7.5 "	1.8	1.5	
6B80	132240	8.0 "	2.9	2.6	
7C50	176466	8.2 "	2.5	2.1	
8C20	113106	9.0 "	2.2	2.9	
9C80	174342	8.5 "	2.9	2.4	
10D50	168384	8.1 "	3.5	2.6	
11D80	146700	8.1 "	3.3	2.7	
12D20	15864	7.8 "	3.0	2.3	
13A50	140322	7.9 "	3.0	2.6	
14A20	111408	9.0 "	3.3	3.4	
15A80	108000	8.9 "	3.0	3.3	
Dirty Average					Avg. 2.6
1C81	124164	8.3 "	3.9	2.8	
3C21	150948	8.0 "	4.1	2.7	
1B51	149250	7.9 "	4.2	2.8	
2B21	162858	7.9 "	4.0	3.0	
3B81	149676	7.8 "	3.8	2.7	
4D51	143298	7.9 "	3.7	2.6	
5D21	153504	7.9 "	4.2	3.1	
6D81	159882	7.9 "	4.1	3.3	
7A51	132666	8.0 "	3.9	2.7	
8A81	113532	8.4 "	3.6	3.2	
9A21	162840	8.9 "	3.9	2.4	
10M1	126720	8.6 "	3.4	2.9	
12M1	179880	7.8 "	4.1	2.9	
Clean Average					Avg. 2.9
			25 Tests Combined		Comb. Avg. 2.7

509602

weight fraction was found in these washes in the contaminated water tests. Overall, the greatest amount of particulate was found in the probe and nozzle washings. The amount of particulate recovered from the probe/nozzle water wash was less in the "clean" tests than in the contaminated tests. However, the amount of particulate in the acetone wash increased in the "clean" tests. This fraction of the quench emissions does not appear to correlate with the known composition of the quench water. It is probable that it is derived, and in fact comes from the coke itself, and possibly other sources. Additional analysis of organic materials as suggested in Level I Survey Methods is reported separately. It has been determined that most of the acetone wash (95 percent in the contaminated test and 65 percent in the clean water test) is soluble in benzene and appears to be an oil liquid. The source of this material may be the #2 fuel oil which is sprayed on the coal (for density purposes) prior to the coking process. Other contributing sources may be the quench water, river water, etc. Preliminary laboratory work indicates that this oil contains aromatic hydrocarbons. Additional work is required.

Some recent work by Elder[21] tends to confirm that a large fraction of the quench aerosols would be collected in the nozzle and the probe. In the three aerosols reported by Elder, this weight fraction varied from about 10 percent with 2.0 microns fly ash to 77 percent with 3.0 microns fly ash. Larger aerosols, 13 micron glass beads, were deposited by gravitational force in the probe, however the Reynolds number was only barely turbulent, less than 3000 compared to well over 5000 in the 25 quench tower tests.

As reported by Elder, many of these aerosols were deposited in the nozzle at joints and diameter changes. In the case of the quench tower work, the field conditions did not permit any quantitative examination to differentiate areas of significant deposition. However, since the probe velocities were generally higher during the coke quench tests than in Elders work (1800 cm sec^{-1} to 3300 cm sec^{-1} compared to 1550 cm sec^{-1}), and the Reynolds number was

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at least double in the quench tests, and particles greater than 10 microns were almost entirely removed by the cyclone; Elder's work would seem to support consideration of the probe as another size classifying device.

FILTER

After passing through the probe, another classification took place on the filter. The spectrograde type AF glass fiber filter normally has an efficiency of 99.99 percent for particles smaller than 0.3 microns. Since the probe and the filter were heated at 250°F, any remaining water would be evaporated and any dissolved solids with a low vapor pressure would be deposited along with other particulate matter.

Some of the filters developed holes during the clean tests. This reduced the amount of particulate collected on the filter and increased the amount collected in the impingers. Some of the Coulter analyses of impinger particulate reflects these larger particles. Some of the analyses indicates particles larger than 10 microns in the impinger liquid. These may be pieces of the fiber glass filter. As shown in Table 4-36, particularly the summary at the bottom of that Table, there was a striking reduction in emissions when the switch was made from contaminated to "clean" quench water. The greatest reduction was the amount of particulate collected on the filter. This particulate was composed of whatever large diameter aerosols passed through the cyclone and, of course, the smaller sizes.

Dissolved solids were associated with some of the aerosol. As the water evaporated (the filter was at 250°F), dissolved solids stable at that temperature were deposited.

It is unlikely that any significant amount of material larger than 15 or 20 microns would have passed through the cyclone; cyclones of this type in this size range are normally very efficient, (90 percent removal in a small diameter range when the cyclone is properly designed and only a few inches in diameter).

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The probe also would remove any large particles so it would seem reasonable to expect the filter weight to be generally in the 5 micron to submicron range.

IMPINGER

The final collection point was in the impinger. The material collected there should have been smaller than 0.3 microns except for the effect of any holes as previously noted. All of these weights have been summarized in Table 4-32. More than 20% of the total particulate was collected in the impinger during the contaminated water series. This was reduced to 10 percent in the "clean" tests.

Several samples of impinger water from the clean tests were analyzed for particles by the Coulter technique. The D_{50} cut size varied from a little over a micron to as high as 40 microns. The filter holes developed during some clean tests (for readons noted in Section 2.3.6) are noted. Other samples also contained some large particles; possibly from very small holes which were not apparent to the eye or from some agglomeration or growth may have taken place in the sample before it was counted.

The D_{50} cut size as observed is reported below:

TABLE 4-43. D_{50} CUT SIZES

Sample	Ref. Code	Average D_{50} Cut Size Microns
Impinger Water	1B51	40
Impinger Water	2B21 & 3B81 comb.	10
Impinger Water	4D51, 5D21 & 6D81 Comb.	1.3
Impinger Water	11MP1 & 13A5P1 Comb.	1.5

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2567-1

FIGURE 4-13
REF. 1051 IMPINGER WATER

COULTER COUNTER® Model T&TA — PARTICLE SIZE ANALYSIS

Organization: York Research
Operator: Mayra Bisnow
Company: TA II
Sample: 10/29/76 Tuton IA, 60 sec. U.S.
Test 1a

Aper. size	Serial		Pore dia.	d	Δ	Δ	Dia.	d	Δ	Δ
400		Microspheres	19.86	7	1.2	206	20.2	7	1.2	197
140	23155	Microspheres	10.11	9	1.2	202	10.08	9	1.2	20[illegible]
30	44597	Latex	2.03	7	.8	145	2.00	7	.8	150

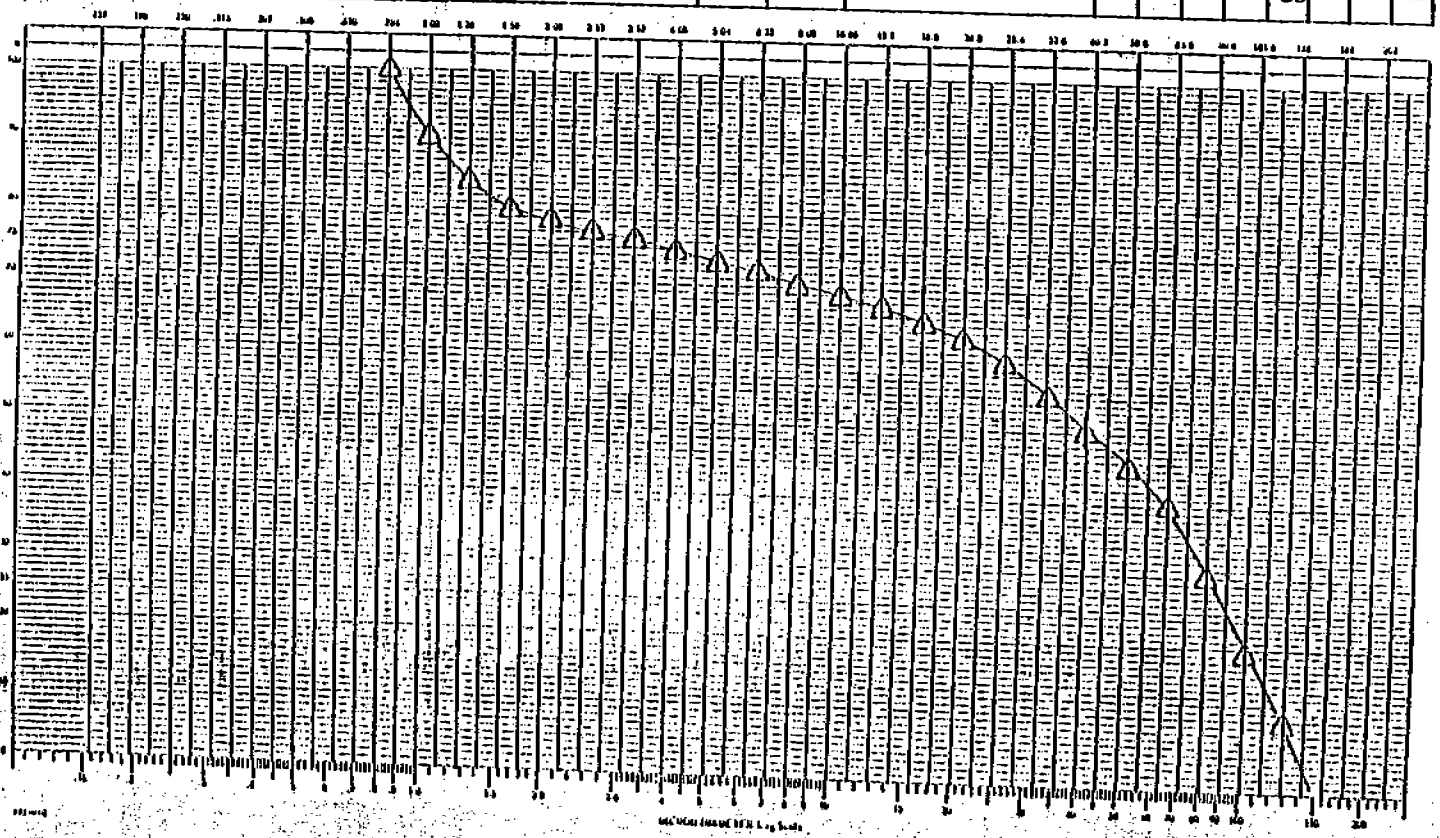

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FIGURE 4-14

RED. 2B21 & 3B51 COMBINED IMPINGER WATER

2567-2

COULTER COUNTER® Model T&TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

ORGANIZATION: York Research

OPERATOR: Mayra Bisnow

EQUIPMENT: TA II

SAMPLE: 10/30/76 — Tsoton — IA, 60 sec. U.S.

Test 2a - 3a

APER. SIZE	SERIAL		PART DIA.	N	ΔIA	A	DIA.	N	ΔIA	A
400		Microspheres	19.86	7	1.2	206	20.2	7	1.2	192
140	23155	Microspheres	10.11	9	1.2	202	10.08	9	1.2	204
30	44597	Latex	2.02	7	.8	145	2.00	7	.8	150

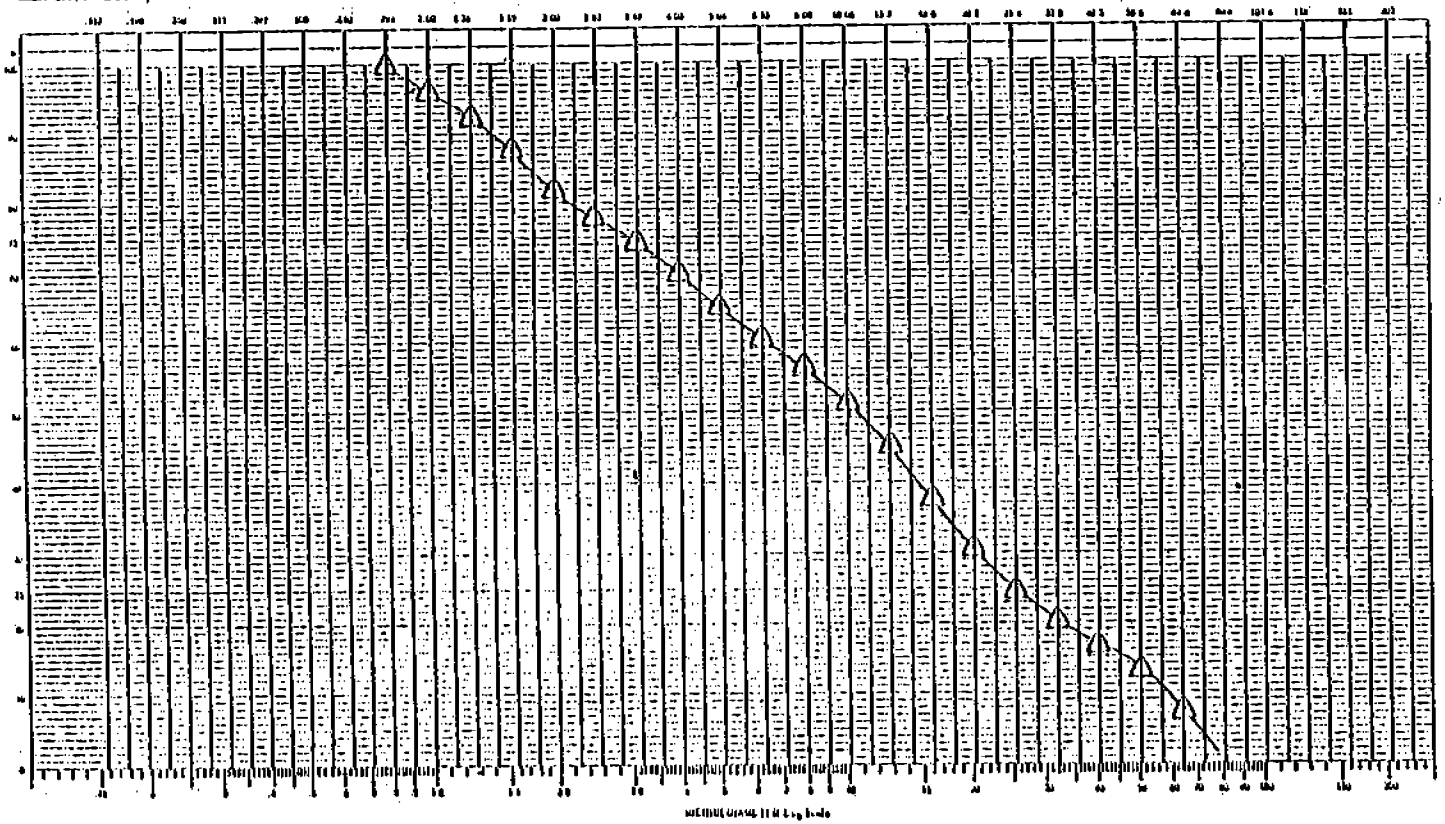

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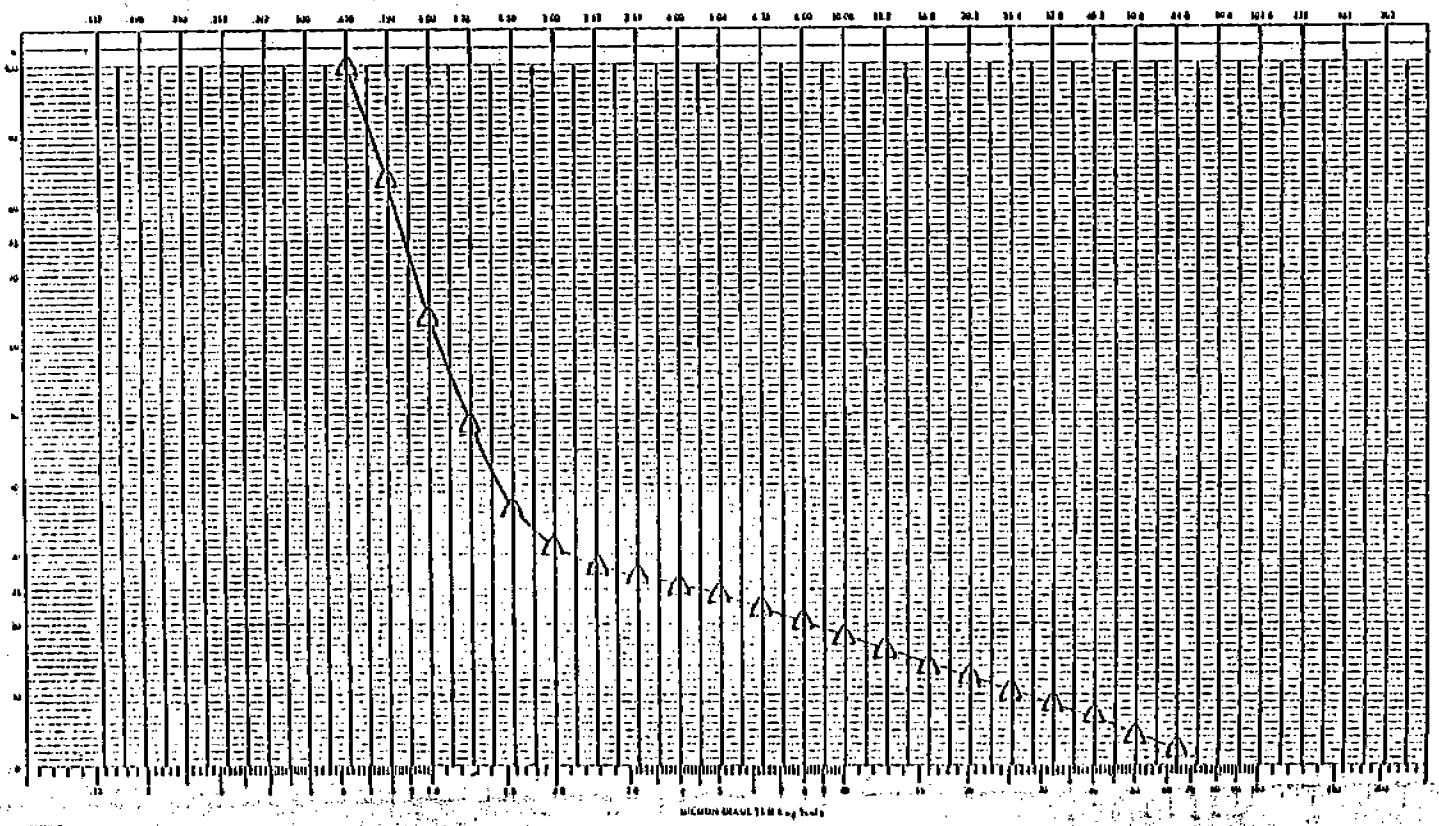
FIGURE 4-15

2567-3 REF: 4D51, 5D21 & 6D81 COMBINED IMPINGER WATER

COULTER COUNTER® Model T&TA PARTICLE SIZE ANALYSIS

ORGANIZATION	York Research
OPERATOR	Mayra Bisnow
EQUIPMENT	TA II
SAMPLE	11-1-76
ELECTROLYTE	Isoton
DISPERSANT	IA, 60 sec. U.S.
	Test 4a-5a-6a

APER. SIZE	SERIAL		FAST DIA.	M	ΔM	Δ	DIA.	M	ΔM	Δ
400		Microspheres	19.86	7	1.2	206	20.2	7	1.2	197
140	23155	Microspheres	10.11	9	1.2	202	10.08	9	1.2	204
30	44597	Latex	2.02	7	.8	145	2.00	7	.81	50



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2567-4

FIGURE 4-16

REF. 7A51, 8A81, & 9A21 COMBINED IMPINGER WATER

COULTER COUNTER® Model T&TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

ORGANIZATION: York Research

OPERATOR: Mayra Bisnow

EQUIPMENT: TA II

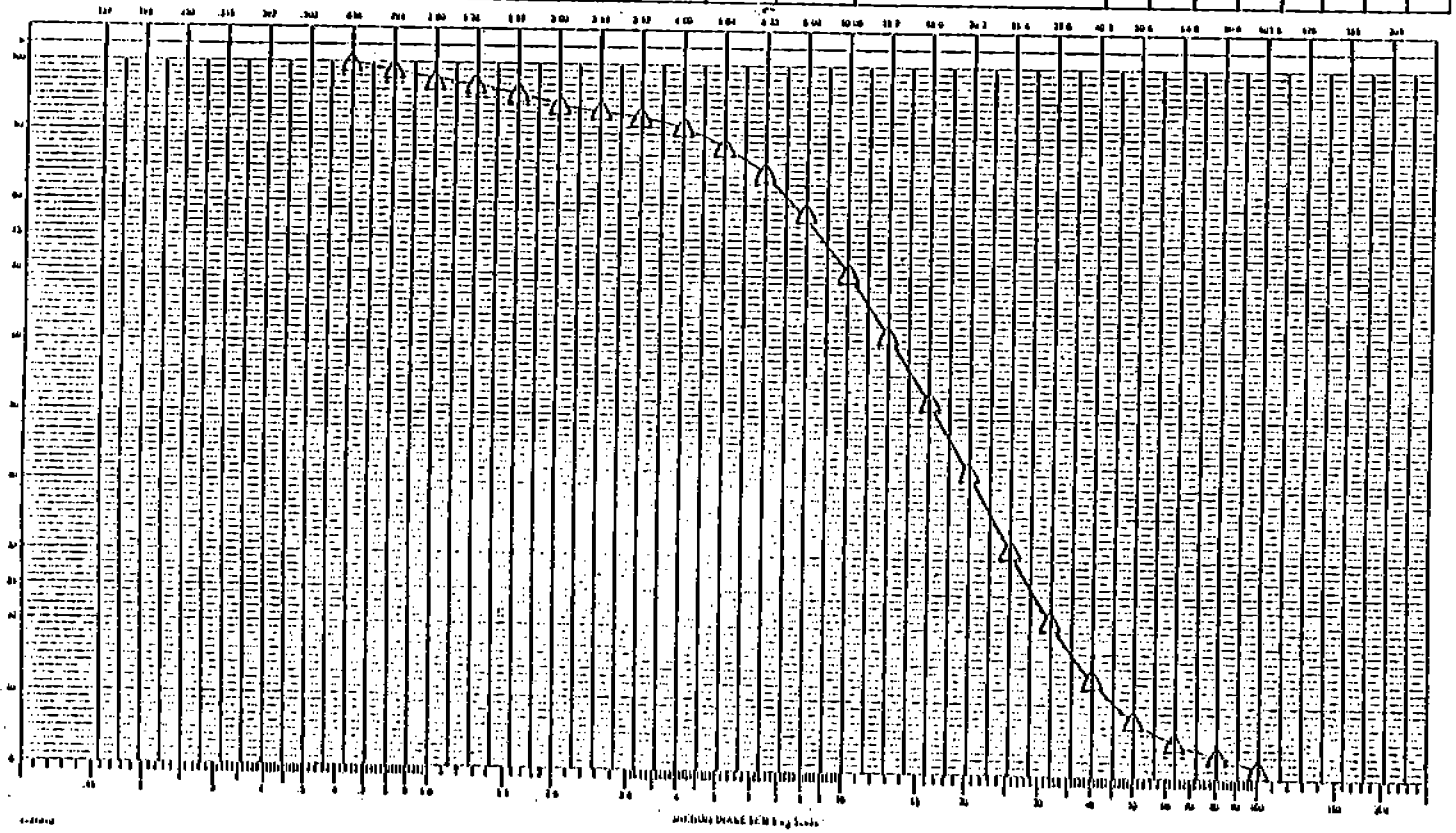
SAMPLE: 11/2/76 — ELECTROLYTE: Isoton — DISPERSANT: IA, 60 sec. U.S.

TEST 7a - 8a - 9a

$L = d\sqrt{\frac{\pi}{2}}$ FOR MODEL T; $\frac{dL}{dt} = \left(\frac{dL}{dt}\right)^2$ when $V_t = V_s$; $\frac{dL}{dt} = \left(\frac{dL}{dt}\right)^2$ when $V_t = V_s$ FOR MODEL TA

SAMPLE SETTINGS

APER. SIZE	SERIAL		PART DIA.	M	Δ	A	DIA.	M	Δ	A
400		Microspheres	19.86	7	1.2	206	20.2	7	1.2	197
140	23155	Microspheres	10.11	9	1.2	202	10.08	9	1.2	204
30	44597	Latex	2.02	7	.8	145	2.00	7	.8	150



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2567-5

2567-5

FIGURE 4-17
REF. 11MP1 & 13A5P1 COMBINED IMPINGER WATER

COULTER COUNTER® Model TA TA — PARTICLE SIZE ANALYSIS

TA II

SAMPLE 11-3-76	ELECTROLYTE Isoton	IA, 60 sec. U.S.	APER. SIZE	TOTAL		PART SIZE	M	Δ SA	Δ	SIZE	M	Δ SA	Δ
Test 11a + 13a			400		Microspheres	19.86	7	1.2	206	20.2	7	1.2	197
			140	23155	Microspheres	10.11	9	1.2	202	10.00	9	1.2	204
			30	44597	Latex	2.02	7	.8	145	2.00	7	.8	150

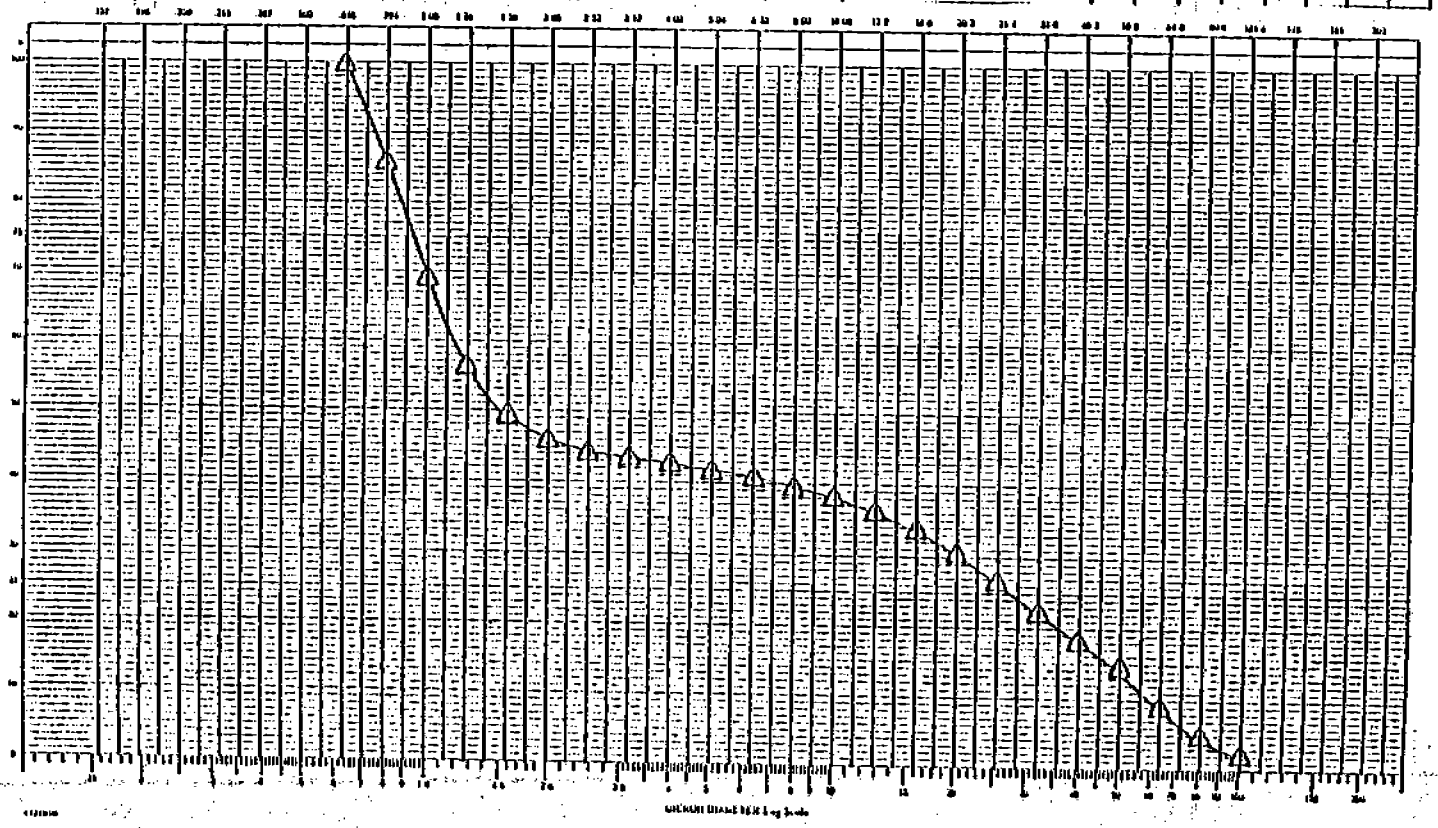

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FIGURE 4-18

REF. 10M1 & 12M1 COMBINED IMPINGER WATER

2567-6

COULTER COUNTER® Model T&TA — PARTICLE SIZE ANALYSIS

COULTER ELECTRONICS INC.

ORGANIZATION: York Research

OPERATOR: Mayra Bisnow

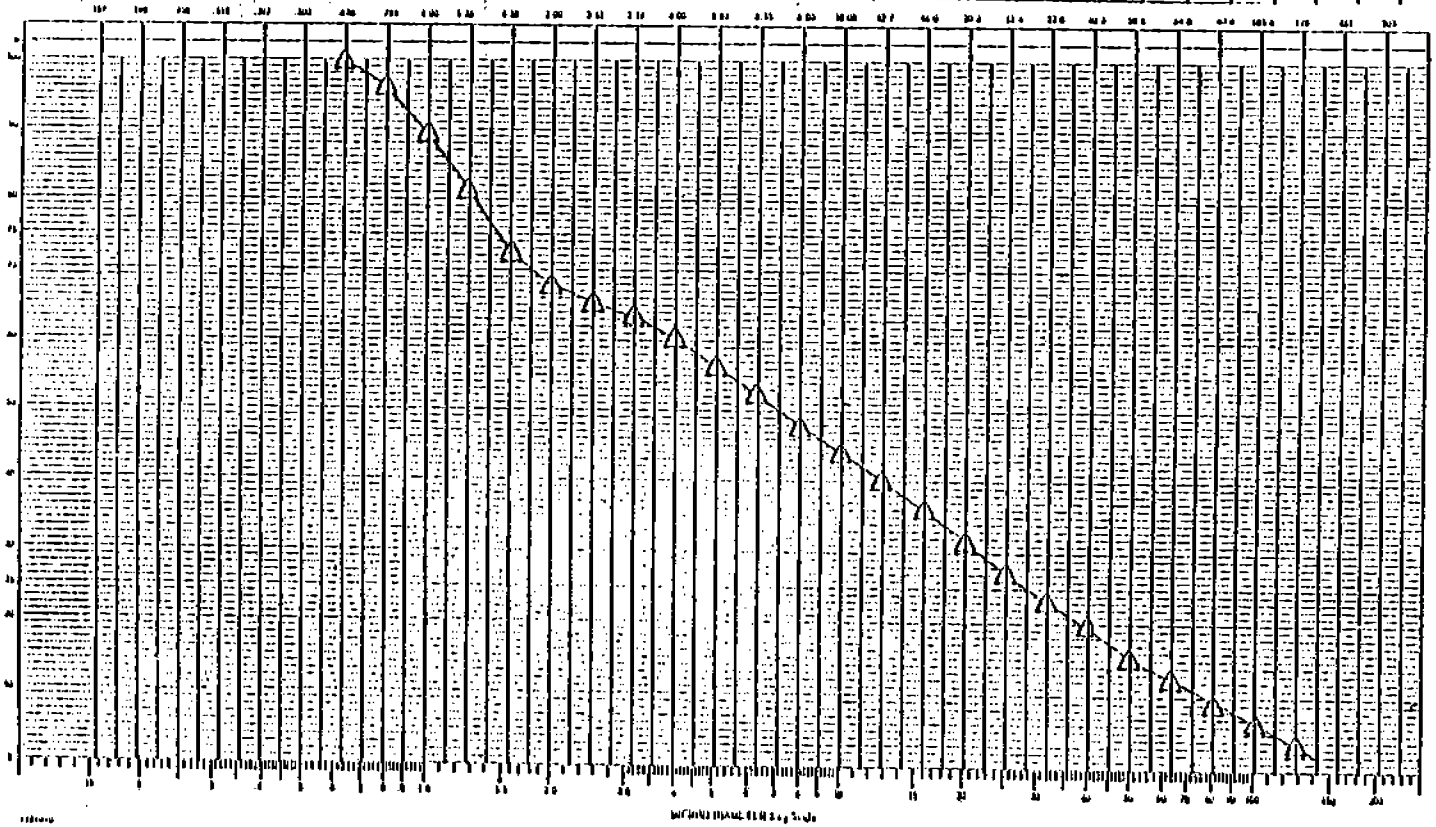
COMPANY: TA II

SAMPLE: 11-3-76 — ELECTROLYTE: Isoton — DISPERSANT: IA, 60 sec. U.S.

Test 10a + 12a

$k = d\sqrt[3]{2^n}$ FOR MODEL T; $\frac{dk}{dt} = \left(\frac{dt}{dk}\right)^2$ when $M_2 = M_1$; $\frac{dk}{dt} = \left(\frac{dt}{dk}\right)^2$ when $M_2 = M_1$ FOR MODEL TA

APER. SIZE	SERIAL		FAST DIA.	M	Δ Sa	A	SAMPLE SETTINGS DIA.	M	Δ Sa	A
400		Microspheres	19.86	7	4.2	206	20.2	7	4.2	197
140	23155	Microspheres	10.11	9	4.2	202	10.08	9	4.2	20[illegible]
30	44597	Latex	2.02	7	.8	145	2.00	7	.8	150



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4.2.2 Chemical Characteristics

The chemical characteristics of the aerosol will be discussed in relation to particulate, gaseous, and overall stack emissions.

Particulate Emissions

The chemical composition of the particulate emissions was determined by analysis for chloride, fluoride, calcium, sulfate, and trace elements.

York Research performed the analyses on clean and contaminated cyclone and filter particulates as seen in Table 4-44. The constituents present at the highest levels (other than carbon) are chlorides for filter particulates and sulfates for cyclone particulates. These are in the range reported in previous tests on other quench towers as shown in Table 4-45.

TABLE 4-44. CHEMICAL COMPONENTS OF PARTICULATE EMISSIONS

	Filter				Cyclone			
	Clean		Contaminated		Clean		Contaminated	
	ppm	lb quench	ppm	lb quench	ppm	lb quench	ppm	lb quench
Cl^-	NA	NA	292,500	1.62	5,100	0.019	67,600	1.02
F^-	NA	NA	1,100	0.006	2,900	0.011	600	0.009
SO_4	NA	NA	33,200	0.184	83,600	0.310	86,500	1.31
Ca	NA	NA	15,900	0.088	28,100	0.104	5,600	0.085

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TABLE 4-45. COMPARISON OF LORAIN DATA TO THAT FROM OTHER QUENCH TOWERS

PARTICULATE STACK EMISSIONS
Lbs/Ton of Coal

Reference Source	USS Lorain Plant Contaminated Water	USS Lorain Plant Clean Water	(5) Contam. Water	(7) Contam. Water
Sulfate	0.11	0.025	0.31	0.159
Chloride	0.20	0.006	0.91	0.062

Analyses for trace elements in a filter composite and a cyclone composite (clean and contaminated water in use) were performed by Battelle-Columbis Labs. The results appear in Tables 4-46 and 4-47. The following elements are in high concentration on the filter:

TABLE 4-46. TRACE ELEMENTS (High Concentrations)

	ppm
Calcium	30,000
Chlorine	19,000
Barium	18,000
Potassium	5,000
Sulfur	1,500
Strontium	900

Trace elements are at a much lower concentration level in cyclone particulates and are given in parts per billion. Among the most concentrated here are:

TABLE 4-47. TRACE ELEMENTS (Low Concentrations)

	ppb
Magnesium	10,000
Sodium	5,000
Sulfur	2,000
Silicon	1,000

TABLE 4-43. MASS SPECTROGRAPHIC ANALYSES OF FILTER SAMPLES (ppmw)

Element	Filter Blank	Filter Composite Sample	Composite Sample Less Blank
Li	20	50	30
Be	0.03	0.1	0.07
B	2000	2000	--
F	300	500	200
Na	~10%	~10%	--
Mg	~3%	~3%	--
Al	~2%	~2%	--
Si	20%	~20%	--
P	5	30	25
S	500	2000	1500
Cl	1000	~2%	19000
K	5000	~1%	5000
Ca	~2%	~5%	~3%
Sc	2	2	--
Ti	20	100	80
V	0.5	2	1.5
Cr	10	50	40
Mn	30	30	--
Fe	1000	1000	--
Co	3	5	2
Ni	50	100	50
Cu	50	100	50
Zn	30	10	--
Ga	<1	<1	--
Ge	<1	<3	--
As(a)	≤5	<5	--
Se(a)	<50	<50	--
Br	20	200	180
Rb	5	10	5
Sr	100	1000	900
Y	1	5	4
Zr	50	100	50
Nb	0.5	2	1.5
Mo	2	5	3
Ru	<0.3	<0.5	--
Rh	<0.5	<0.5	--
Pd	<2	<2	--
Ag	<2	<1	--
Cd	<0.3	<1	--
In(a)	2	<2	--
Sn	2	1	--
Sb	1	5	4
Te	<0.2	<0.5	--
I	<50	<2	--
Cs	<1	<1	--
Ba	2000	~2%	18000

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TABLE 4-48. (Continued)

Element	Filter Blank	Filter Composite Sample	Composite Sample Less Blank
La	<0.5	5	5
Ce	0.2	10	9.8
Pr	<0.5	1	1
Nd	<0.5	<3	--
Sm	<1	<1	--
Eu	<0.3	<1	--
Gd	<0.5	<1	--
Tb	<0.2	<0.3	--
Dy	<0.5	<1	--
Ho	<0.1	<0.5	--
Er	<0.3	<0.5	--
Tm	<0.2	<0.5	--
Yb	<2	<2	--
Lu	<0.2	<1	3
Hf	<0.5	3	--
Ta	<0.2	<1	--
W	<0.3	<0.3	--
Re	<0.2	<0.2	--
Os	<0.2	<0.3	--
Ir	<0.2	<0.3	--
Pt	<0.3	<0.5	--
Au	<0.1	<0.1	--
Hg	<0.3	<0.3	--
Tl	<0.1	<0.3	--
Pb(a)	<10	<0.2	--
Bi	<0.1	<0.1	--
Th	<0.1	<0.1	--
U	<2	<2	--

(a) Memory from previous sample.

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TABLE 4-49. MASS SPECTROGRAPHIC ANALYSIS OF CYCLONE SAMPLE (ppbs)

Element	Cyclone	Element	Cyclone
Li	3	La	<2
Be	<0.1	Ce	2
B	30	Pr	<2
F	<3	Nd	<3
Na	5000	Sm	<3
Mg	10000	Eu	<3
Al	≤500	Gd	<10
Si	≤1000	Tb	<3
P	30	Dy	<10
S	2000	Ho	<3
Cl	300	Er	<10
K	200	Tm	<20
Ca	500	Yb	<5
Sc	<3	Lu	<3
Ti	≤200	Hf	<10
V	30	Ta	<5
Cr	30	W	<3
Mn	50	Re	<20
Fe	500	Os	<20
Co	30	Ir	<3
Ni	30	Pt	<20
Cu	200	Au	<3
Zn	100	Hg	<20
Ga	<10	Tl	<20
Ge	<20	Pb(a)	<100
As(a)	<300	Bi	<3
Se(a)	<300	Th	3
Br	100	U	<30
Rb	3		
Sr	3		
Y	<3		
Zr	<10		
Nb	<3		
Mo	<5		
Ru	<5		
Rh	<3		
Pd	<20		
Ag	<20		
Cd	10		
In	<30		
Sn	≤50		
Sb	2		
Te	<5		
I	10		
Cs	<10		
Ba	<30		

(a) Memory from previous sample

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According to the mass spectrometry data, those elements at high concentrations in the filter are in relatively low concentrations in the cyclone. Conversely, those in high concentrations in the cyclone are not detected at all in the filter (except for sulfur which is in much higher concentration throughout). Sodium, magnesium, and silicon seem to be associated with larger particles or with the water and therefore are deposited in the cyclone whereas the calcium, chloride, barium and potassium are associated with finer fractions of the aerosol and are carried through to the filter.

Substantial chemical constituents of the particulate and droplet phase of the aerosol seem to be:

Cl^-	Ba
SO_4 or S	K
Ca	Sr

Chloride, sulfate, and calcium are introduced by contaminated and clean make-up water (Table 5-13) and incandescent coke. No tests were conducted for potassium, barium, and strontium in water but these elements are found in large quantities in incandescent coke.

GASEOUS EMISSIONS

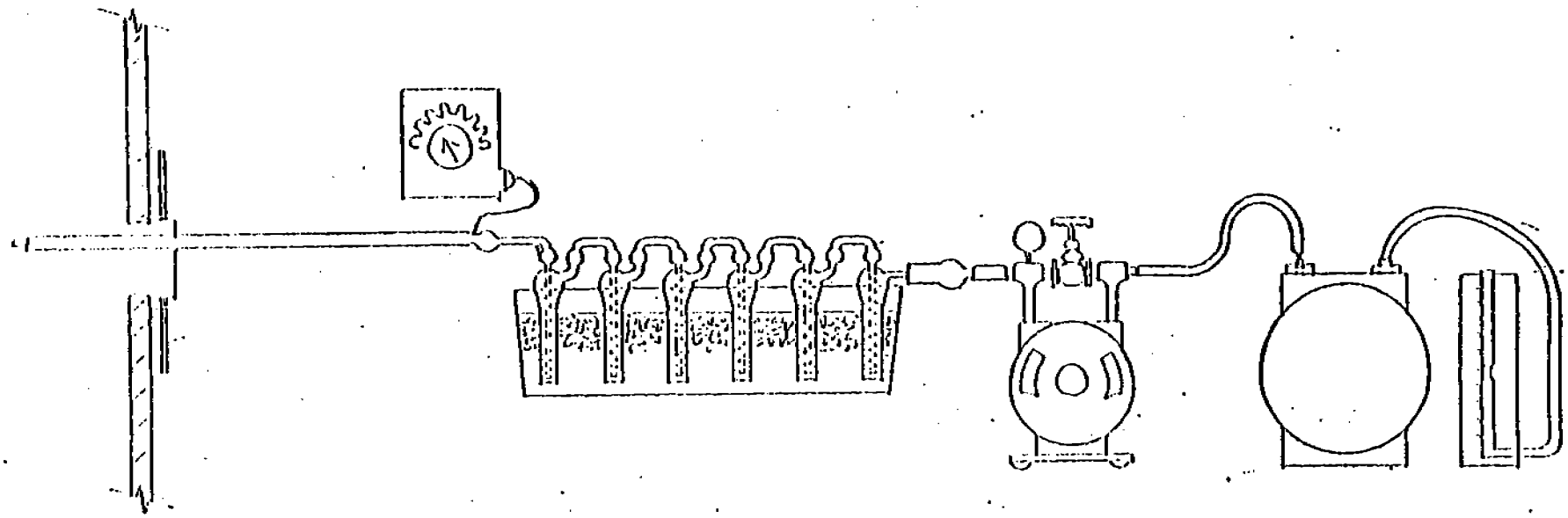
Sampling methods for gaseous emissions are different than the EPA Method 5 train used in particulate sampling. Gaseous emissions testing is described below.

Tests conducted for the following parameters:

Cyanide	Sulfide
Ammonia	Sulfur Dioxide
Phenol	

were performed utilizing the EPA Method 6 (Determination of Sulfur Dioxide Emissions from Stationary Sources) sample train configuration with two (2) additional impingers (see Figure 4-19).

509617



GASEOUS EMISSION TRAIN
EPA METHOD # 6 AS MODIFIED

FIG. 4-19

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Samples were taken from the time the car entered the tower until the car exited the tower. The total sample volume for each test was about three cubic feet. Approximately thirteen quenches were needed to satisfy the sample volume requirements.

Insertion depth for the probes used ranged from three to five feet. The six impingers, which were placed in an ice bath during testing, were connected to each other and to the heated glass probe with glass fittings.

The first two impingers were left empty and acted as traps to knock out entrained moisture, the next three were filled with fifteen milliliters of adsorbing reagent.

Contaminant to be determined	Reagent
Total Sulfur	3% Hydrogen Peroxide
Sulfide	Aqueous suspension of cadmium hydroxide
Ammonia	0.1 Normal Sulfuric Acid
Phenols and Cyanides	0.1 Normal Sodium Hydroxide

The last impinger was left blank as a knock-out, followed by a drying tube containing silica gel to protect the dry gas meter.

Vacuum hose was utilized to connect the drying tube with a leakless pump; and the pump to the dry gas meter which could be read to 0.001 cubic feet.

Results for sulfide during the contaminated phase are not available as the concentration was not high enough to be detected by the indicated reagent. Rough calculations show that sulfide concentrations of greater than 0.003 lbs/quench were possible.

EVACUATED FLASK SAMPLING

Samples were taken mid-morning on 1/12/77, when contaminated water was used, to be analyzed for:

Carbon Monoxide
Carbon Dioxide
Total Hydrocarbon
Hydrogen
Oxygen

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TABLE 4-50. GASEOUS EMISSIONS (Averages)

	Contaminated		Clean	
	ppmw	lbs/quench	ppmw	lbs/quench
SO_2	187	6.0	2.2	0.07
Phenol	92	2.9	1.6	0.05
Ammonia	134	4.3	11	0.35
Cyanide	4.1	0.13	0.90	0.029
Oxygen	115,402	3693		
Carbon Dioxide	16,806	538		
Carbon Monoxide	681	22		
Hydrogen	49	1.6		
Total Hydrocarbon	12 (by volume)			

$\frac{\text{ppmw}}{1,000,000}$ x 32,000 lbs/quench avg. stack flow - lbs/quench

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GASE EMISSIONS

TABLE ~~[illegible]~~ ~~4-47~~ 4-48

SULFUR DIOXIDE

TABLE 4-51

TEST NO.	DATE OF SAMPLING	REF. CODE	STACK FLOW RATE (scfmd)	NUMBER OF QUENCHES	NET SAMPLING TIME/MIN	NET VOLUME SAMPLED (scfd)	EMISSIONS AMOUNT SAMPLED mg	EMISSIONS CONCENTRATION ppm (volume)	EMISSIONS LBS/* QUENCH
1	9/13	12D20	202294	13.47	30.3	3.03	19.22	86	6.4
2	9/14	14A20	233506	13.20	29.1	2.97	17.30	78	6.0
3	9/14	14A20	233506	13.69	30.0	3.08	20.19	88	7.6
1	10/30	2H21	195330	12.59	30.0	3.0	0.3	1	.1
2	11/1	4D51	157604	13.22	31.5	3.15	< 0.3	1	.1
3	11/1	4D51	157604	12.64	30.1	3.01	< 0.3	1	.1

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GAS[illegible] EMISSIONS

TABLE 2. ~~4-38-44~~

PHENOLS

TABLE 4-52

TEST NO.	DATE OF SAMPLING	REF. CODE	STACK FLOW RATE (scfmd)	NUMBER/ OF QUENCHES	NET SAMPLING TIME/MIN.	NET VOLUME SAMPLED (scfd)	EMISSIONS AMOUNT SAMPLED mg	EMISSIONS CONCENTRATION ppm (volume)	EMISSIONS LBS/* QUENCH	
1	9/13	11D80	161734	13.64	38.7	3.07	13.25	10	~~.95~~	3.46
2	9/13	11D80	161734	13.69	30.0	3.08	5.50	4	~~.39~~	1.46
1	10/30	2B21	195330	12.72	30.3	3.03	.00	>0.5	.02	✓
2	10/30	2B21	195330	12.85	30.6	3.06	.05	>0.5	.01	✓
1	10/30	2B21	195330	13.31	31.7	3.17	.06	>0.5	.02	✓

509622

GAS[illegible] EMISSIONS

TABLE [illegible]

CYANIDE

TABLE 4-53

TEST NO.	DATE OF SAMPLING	REF. CODE	STACK FLOW RATE (scfmd)	NUMBER OF QUENCHES	NET SAMPLING TIME/MIN.	NET VOLUME SAMPLED (scfd)	AMOUNT SAMPLED mg	EMISSIONS CONCENTRATION ppm (volume)	EMISSIONS LBS/* QUENCH
1	9/11	11D00	161734	13.64	30.7	3.07	0.68	7	.10
2	9/11	11D00	161734	13.69	30.8	3.08	0.20	2	.04
1	10/30	2B21	191428	12.72	30.6	3.06	0.07	<1	.02
2	10/30	2B21	191428	12.85	30.6	3.06	0.07	<1	.02
3	10/30	2B21	191428	13.31	31.7	3.17	0.07	<1	.02

*using 2.25 min/quench

-237-

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GASEOUS EMISSIONS

TABLE ~~4-50~~ 4-51

AMMONIA

TABLE 4-54

TEST NO.	DATE OF SAMPLING	REF. CODE	STACK FLOW RATE (scfm)	NUMBER OF QUENCHES	NET SAMPLING TIME/MIN.	NET VOLUME SAMPLED (scfd)	EMISSIONS: AMOUNT SAMPLED mg	EMISSIONS: CONCENTRATION PPM (volume)	EMISSIONS: LBS/* QUENCH	
1	9/12	8C20	167901	11.69	30.8	3.08	230.81	4	3.62	64.71
2	9/12	8C20	130267	11.61	25.9	2.59	189.96	8	~~3.17~~	43.72
3	9/14	14A20	233506	13.07	29.4	2.94	252.75	4120 8	~~3.46~~	99.35
1	11/1	4D51	157604	12.00	30.5	3.05	8.93	14	.22	✓
2	11/1	5D21	170030	13.40	32.1	3.21	1.24	10	.32	✓
3	11/1	5D21	152613	10.96	26.1	2.61	1.39	25	.30	✓

*using 2.25 min/quench

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GASE. EMISSIONS

Table 2. 4-54, 4-52

SULFIDE

TABLE 4-55

TEST NO.	DATE OF SAMPLING	REF. CODE	STACK FLOW RATE (scfmd)	NUMBER OF QUENCHES	NET SAMPLING TIME/MIN.	NET VOLUME SAMPLED (scfd)	EMISSIONS AMOUNT SAMPLED mg	CONCENTRATION ppm (volume)	LBS/# QUENCH
1	11/1	3C21	251022	13.42	30.2	3.02	0	0	0
2	11/3	3C21	236107	12.53	20.2	2.02	0	0	0
3	11/3	3C21	106110	13.73	30.9	3.09	0	0	0

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These samples were collected using the ASME (PTC-19.10 - Flue and Exhaust Gas Analysis) gas collection method.

The sample train was evacuated to a vacuum of less than 25 mm of mercury, measured on a mercury manometer. After purging the probe and flask, the sample was aspirated and the sample container sealed off. After transportation, the samples were analyzed by gas chromatography.

ORSAT SAMPLES

Integrated gas samples were extracted from the quench tower at each sampling point utilizing EPA Method 3 (Gas Analysis for Carbon Dioxide, Excess Air, and Dry Molecular Weight) and analyzed with an Orsat analyzer.

After the probe was inserted in the stack and purged, the sample bag was evacuated and connected to the probe making sure there were no leaks. Gas was then drawn through the probe at a rate proportional to the stack gas velocity. The bag was then disconnected and the sample analyzed with a Hays Orsat instrument.

Results of dirty and clean tests (averaged) are listed in a summary form in the gaseous section.

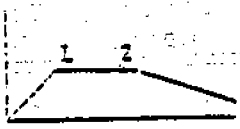
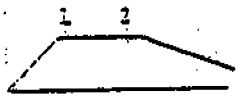
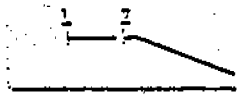
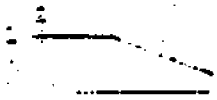
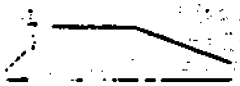
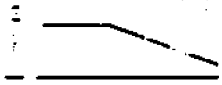
The chemical analysis of quench tower gaseous emissions is presented in Table 4-50. Individual test data and results sheets are found in Tables 4-51 - 4-55. Substantial concentrations of sulfur dioxide, phenol, and ammonia are found in emissions when contaminated quench water is used. These values can be compared with those from previous tests (see Tables 4-57 and 4-58) at other coke quench towers. The results for the Lorain quench tower agree quite well with the earlier tests.

The concentrations of all the chemicals (except for sulfide) are greatly increased when contaminated water is used instead of clean

509623

EVACUATED FLASK SAMPLING

TABLE 5-56

Velocity Profile	Concentration (ppm)
	**HC**
	1 10.88
	2 12.50
	**NO_x**
	1 1384.8
	2 1424.5
	**O_2**
	1 207,200
	2 203,245
	**CO**
	1 760.
	2 640.
	**CO_2**
	1 12,600.
	**SO_2**
	2 940.

509627

TABLE 4-57. COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS

LBS/TON OF COAL

	YRC Tests at USS Lorain Plant Contam. Water	(4) Contam. Water	(5) Contam. Water	(7) Contam. Water
Ammonia	0.328	0.029	6.5 free and fixed	0.0251
Phenol	0.221	0.13	0.34 as C_6H_5 OH	0.348
Cyanide	0.010	0.001	0.054 as HCN	0.021 as Hydrocyanic Acid
Sulfide	0.001		0.70 as H_sS	0.170 as H_2S
Total Hydrocarbon		0.012		

TABLE 4-58. COMPARISON OF GASEOUS EMISSIONS FROM U.S. STEEL LORAIN QUENCH TOWER TO EMISSIONS FROM OTHER TOWERS

LBS/TON OF COAL

	YRC Tests at: USS Lorain Plant Clean Water	(4) "Cleaner" Water
Ammonia	0.027	0.001
Phenol	0.004	0.002
Cyanide	0.002	0.002
Total Hydrocarbons	NA	0.047

Numbers in () refer to references

509623

water. The approximate rise in concentration for each chemical is as follows:

TABLE 4-59. INCREASES WHEN CONTAMINATED QUENCH WATER WAS USED

SO_2	80 times
Phenol	60
Ammonia	12
Cyanide	4
Sulfide	1

When contaminated water is used, the sulfur dioxide concentration becomes the largest contaminant constituent, its concentration in the stack gas increasing eighty times the amount for clean quench water. When clean quench water is used, ammonia is the largest constituent of the gaseous emission.

These results indicate a definite dependence of the composition of gaseous emissions on the quality of quench water. And the chemicals concentrated in gaseous emissions do, in fact, reflect those found concentrated in quench water as discussed in Section 5.2.2. For contaminated water quenches, the concentration in the stack gases of phenol increases about 500 times, ammonia about 50 times, cyanide about 40 times, over the levels when clean water is used. Sulfide remains about the same. This pattern of relative concentration exactly follows that for gaseous emissions. The only exception here is sulfur dioxide. Sulfide and sulfate concentrations were similar in clean water and in contaminated water.

509627

A major source of chemicals in gaseous emissions is the quench water. Another source of contaminants is the coke. Coke oven gas is cooled by water (flushing liquor, which then becomes contaminated water) and chemicals from the coke are then carried by water to the quench tower.

Carbon monoxide, carbon dioxide, hydrogen, oxygen, and total hydrogen were sampled only while contaminated water was in use. Oxygen is a primary component of the earth's atmosphere. Its concentration here is no higher than it is in normal air. Carbon dioxide is also a major component of air. Its concentration is normally around 4,500 ppm. CO_2 concentration is substantially increased in the gaseous emissions (by 3 to 4 times). Burning coke produces CO_2; this is the probable source of CO_2 in gaseous emissions. It would derive either directly from the coke in the quench tower or from water used to cool oven gases and later used as make-up water.

Hydrogen and carbon monoxide exist in very small concentrations in air. Their concentrations here are higher than normal. Some hydrogen release could be due to the reaction of water and ammonia on the coke.

See Section 5.2.2 for explanation of hydrogen release - ammonia, water.

It was found that emissions from the coke quench tower are largely composed of sulfur dioxide and sulfate. Values are as high as 187 ppm SO_2 and 86,500 ppm SO_4. Several mechanisms exist for the oxidation of SO_2 to SO_4 as listed in Table 4-60. These reactions are not well understood but they are the determining factor for the rate of formation of sulfate and its final form (as SO_4^{--} or H_2SO_4...). [22]

At Lorain, all five mechanisms of sulfate formation are possible. The most probable is No. 3, "Air Oxidation in Liquid Droplets". Water droplets are heavily concentrated in the quench tower plume.

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TABLE 4-60.

MECHANISMS BY WHICH SULFUR DIOXIDE IS CONVERTED TO SULFATES

Mechanism	Overall reaction	Factors on which sulfate formation primarily depends
1. Direct photo-oxidation.	$SO_2 \xrightarrow[\text{water}]{\text{light, oxygen}} H_2SO_4$	Sulfur dioxide concentration, sunlight intensity.
2. Indirect photo-oxidation.	$SO_2 \xrightarrow[\text{organic, oxidants, hydroxyl radical (OH)}]{\text{smog, water, } NO_x} H_2SO_4$	Sulfur dioxide concentration, organic oxidant concentration, OH, NO_x.
3. Air oxidation in liquid droplets.	$SO_2 \xrightarrow{\text{liquid water}} H_2SO_3$ $NH_3 + H_2SO_3 \xrightarrow{\text{Oxygen}} NH_4^+ + SO_4^=$	Ammonia concentration.
4. Catalyzed oxidation in liquid droplets.	$SO_2 \xrightarrow[\text{heavy metal ions}]{\text{oxygen, liquid water}} SO_4^=$	Concentration of heavy metal (Fe, V, Mn) ions.
5. Catalyzed oxidation on dry surfaces.	$SO_2 \xrightarrow[\text{carbon, particulate}]{\text{oxygen, water}} H_2SO_4$	Carbon-particle concentration (surface area).

taken from "Sulfates in the Atmosphere", p.4

509631

Ammonia concentration is high as evidenced by the gas emission data.

It is possible that sulfur dioxide contributes to sulfate emissions at Lorain though the rate of conversion of sulfur dioxide to sulfate aerosol is probably so low near the point of emission as to make this contribution insignificant. Discussion of the SO_2 to SO_4 reactions are important, however, because as stack emissions mix with the ambient air the rate of reaction increases to several percent. Stack height influences sulfate formation since lower heights tent to allow SO_2 removal by mixing with the ground surface but taller stacks allow more time for SO_2 to mix with ambient air and form sulfate. The sulfate then can be carried as far as several hundred miles and pollute air which is quite far from the true (polluting) source.

Sulfate is suspected of being toxic to human beings as indicated by epidemiological and laboratory studies.[23,24] It may be that sulfate is even more harmful than sulfur dioxide or total suspended particulates. In addition, sulfates have been named as a cause of "tropospheric haze".[25]

OVERALL STACK EMISSIONS

In order to gain a new perspective on the chemical make-up of the aerosol (aside from direct analysis of gaseous and particulate emissions) a normal ratio method of analysis was applied to inlet and return water concentrations. Calculation of enrichment factors based on the normal ratios indicates enrichment or loss of certain chemicals (relative to the ratio base) within the quench tower system. A loss may be interpreted as loss to the atmosphere or loss through association with another chemical.

A "normal ratio " is defined as the ratio of each substance considered within a particular medium (i.e., inlet water) to one particular chemical in the medium. The "enrichment factor" is the ratio of a chemical's normal ratio in one medium to its

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normal ratio in another medium. Here, an enrichment factor would be:

$$\frac{\text{ammonia/chloride in Return Water}}{\text{ammonia/chloride in Inlet Water}}$$

A factor greater than one indicates enrichment, less than one is a loss, and equal to one is stable (in comparison to chloride). This method allows the dynamics of a system to be shown relative to a constant component and reveals anomalies (due to sampling error, change in conditions, etc.). Also, results are compared on a test by test basis which may either verify conclusions drawn using test averages or produce new information.

Due to the fluctuation in inlet/return water concentration ratios for calcium (see Table 4-61), a normal ratio analysis was attempted based on chloride. Chloride is expected to be volatile and is not as stable an element base as desired but is the next best choice after calcium. Chloride does have a fairly stable inlet/return concentration ratio and therefore the percent loss of Cl remains constant. There is a greater concentration of chloride in contaminated water than in clean, as expected.

The chemical concentrations in inlet and return water (clean and contaminated) were utilized so that any losses to the atmosphere or to coke could be observed. The contaminants used are ammonia, phenol, sulfate, cyanide, calcium, total organic carbon (T.O.C.), dissolved solids (D.S.), suspended solids (S.S.), and volatile solids (V.S.). The ratios of these substances to chloride and their enrichment factors are listed in Tables 4-62 through 4-69. There are nine tests for clean water in use and six tests for contaminated water in use. These tests were considered because they are the ones used to generate the average chemical concentration values in inlet and return water for the overall quench study.

A graph of the enrichment factors for each test was made to compare substances within each test and the tests themselves (see

509633

TABLE 4-61. FLUCTUATION OF WATER CONCENTRATION RATIOS (Calcium)

Calcium Clean Water Tests	Ca Inlet / Ca Return	ppm Ca makeup water
1C81	0.975	28
3C21	1.03	27.5
3B81	0.905	36.5
10M1/11MP1	1.08	38.5
12M1/13A5P1	0.998	39.0
7A51	0.928	37.9
8A81	1.72	65.0
9A21	1.03	38.4
4D51/5D21/6D81	1.08	38.8
Contam. Water Tests		
8C20	0.776	12.7
9C80/10D50	.875	12.8
14A20	5.03	7.7
15A80	0.603	13.1
11D80	0.593	14.4
12D20/13A50	1.25	14.3

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Table 4-62.

CLEAN WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 1C81	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.0186	.0257	1.3
Phenol	.000958	.00136	1.4
Sulfate			
Cyanide	.0001197	.0001509	1.3
Calcium	.0231	.0298	1.3
T.O.C.	.0120	.00906	.75
T.S.	.754	1.63	2.2
T.D.S.	.717	.952	1.3
S.S.	.0369	.682	18.5
V.S.	.0448	.0298	.67
Test 3C21	**Inlet**	**Return**	**Enrichment Factor**
Chloride	1	1	
Ammonia	.0146	.0190	1.3
Phenol	.0006363	.0006896	1.1
Sulfate			
Cyanide	.000182	.000276	1.5
Calcium	.035	.0517	1.5
T.O.C.	.000909	.0359	39.5
T.S.	1.014	2.97	2.9
T.D.S.	.934	1.25	1.3
S.S.	.0797	1.718	21.6
V.S.	.0541	.0648	1.2

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Table 4-63.

CLEAN WATER TESTS - NORMAL RATIOS BASED ON CHLORIDE

Test 3B81	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.0324	.0340	1.05
Phenol	.000588	.000556	.95
Sulfate	.402	.389	.97
Cyanide	.000441	.000417	.95
Calcium	.0963	.101	1.1
T.O.C.	.0176	.00833	.47
T.S.	1.48	1.83	1.2
T.D.S.	1.37	1.51	1.1
S.S.	.0662	.382	5.8
V.S.	.03	.0353	1.2
Test 4D51/5D21 6B81			
Chloride	1	1	
Ammonia	.0236	.0196	.83
Phenol	.000625	.000612	.98
Sulfate	.424	.292	.69
Cyanide			
Calcium	.0935	.0708	.76
T.O.C.	.00625	.00612	.98
T.S.	1.37	1.83	1.3
T.D.S.	.407	1.17	2.9
S.S.	.102	.556	5.5
V.S.	.023	.0229	.99

509636

Table 4-64.

CLEAN WATER TESTS - NORMAL RATIOS BASED ON CHLORIDE

Test 7A51	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.0306	.0229	.75
Phenol	.000833	.000833	1
Sulfate	.433	.452	1.04
Cyanide	.000417	.000417	1
Calcium	.0951	.1025	1.1
T.O.C. (not used in ave.)			
T.S.	1.471	1.968	1.3
T.D.S.	1.45	1.56	1.1
S.S.	.0468	.379	8.1
V.S.	.0314	.0396	1.3
Test 8A81			
Chloride	1	1	
Ammonia	.0303	.0474	1.6
Phenol	.00121	.00172	1.4
Sulfate	.476	.443	.93
Cyanide	.000303	.000345	1.1
Calcium	.103	.0681	.66
T.O.C.	.0227	.0293	1.3
T.S.	1.67	1.998	1.2
T.D.S.	1.58	1.62	1.03
S.S.	.110	.365	3.3
V.S.	.0389	.0429	1.1

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Table 4-65.

CLEAN WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 9A21	Inlet	Return	Envirhment Factor
Chloride	1	1	
Ammonia	.025	.0410	1.6
Phenol	.00113	.00125	1.1
Sulfate	.378	.430	1.1
Cyanide	.00025	.000417	1.7
Calcium	.0854	.0917	1.1
T.O.C.	.0125	.0153	1.2
T.S.	1.48	1.729	1.2
T.D.S.	1.38	1.539	1.1
S.S.	.0838	.303	3.6
V.S.	.0328	.0335	1.0
Test 10M1/11MP1			
Chloride	1	1	
Ammonia	.00813	.0471	5.8
Phenol	.000281	.00145	5.2
Sulfate	.0881	.382	4.3
Cyanide	.0000625	.000484	7.7
Calcium	.0204	.0979	4.8
T.O.C.	.00313	.0194	6.2
T.S.	.326	1.737	5.3
T.D.S.	.0116	.226	19.5
S.S.	.321	1.526	4.8
V.S.	.00575	.0429	7.5

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Table 4-66.

CLEAN WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 12M1/13A5P1	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.0117	.0365	3.1
Phenol	.000267	.000694	2.6
Sulfate	.199	.416	2.1
Cyanide	.000133	.000556	4.2
Calcium	.04	.0835	2.1
T.O.C.	.00667	.0236	3.5
T.S	no info this test		
T.D.S.	no info this test		
S.S.	no info this test		
V.S.	.0159	.0311	1.95

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Table 4-67.

CONTAMINATED WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 8C20	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.207	.0672	.32
Phenol	.0592	.0202	.34
Sulfate	.0409	.0244	.60
Cyanide			
Calcium	.00496	.00368	.74
T.O.C.	.151	.0732	.48
T.S.	2.076	.764	.37
T.D.S.	1.406	.742	.53
S.S.	.0183	.0670	3.7
V.S.	.0143	.00812	.57
Test 9C80/10D50			
Chloride	1	1	
Ammonia	.127	.109	.86
Phenol	.0398	.0311	.78
Sulfate	.0275	.0266	.97
Cyanide			
Calcium	.00301	.00322	1.07
T.O.C.	.106	.101	.95
T.S.	.978	1.048	1.07
T.D.S.	.948	1.069	1.1
S.S.	.0152	.0184	1.2
V.S.	.00965	.00891	.92

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Table 4-48.

CONTAMINATED WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 11D80	Inlet	Return	Enrichment Factors
Chloride	1	1	
Ammonia	.0609	.0593	.97
Phenol	.0310	.0359	1.2
Sulfate	.0207	.0268	1.3
Cyanide	.0006357	.000935	1.5
Calcium	.00195	.00597	3.1
T.O.C.	.0842	.142	1.7
T.S.	.702	1.58	2.3
T.D.S.	.668	1.36	2.04
S.S.	.0199	.0704	3.5
V.S.	.00676	.0122	1.8
Test 12D20/13A50			
Chloride	1	1	
Ammonia	.0714	.153	2.1
Phenol	.0212	.0493	2.3
Sulfate	.0238	.0335	1.4
Cyanide	.000712	.000880	1.2
Calcium	.00252	.00305	1.2
T.O.C.	.09288	.148	1.6
T.S.	.854	1.33	1.6
T.D.S.	.731	.942	1.3
S.S.	.0134	.0221	1.6
V.S.	.00718	.0113	1.6

509641

Table 4-69.

CONTAMINATED WATER TESTS - NORMAL RATIOS BASED ON Cl

Test 14A20	Inlet	Return	Enrichment Factor
Chloride	1	1	
Ammonia	.0682	0.123	1.8
Phenol	.0235	.0414	1.8
Sulfate	.0254	.0315	1.2
Cyanide	.000986	.000516	.5
Calcium	.00280	.000822	.29
T.O.C.	.0884	.131	1.5
T.S.	.790	1.34	1.7
T.D.S.	.702	1.14	1.6
S.S.	.0128	.0317	2.5
V.S.	.00739	.0109	1.5
Test 15A80			
Chloride	1	1	
Ammonia	.204	.157	.77
Phenol	.0232	.0359	1.6
Sulfate	.0197	.0384	1.95
Cyanide	.000509	.000787	1.6
Calcium	.00235	.00711	3.03
T.O.C.	.0781	.142	1.8
T.S.	.672	1.35	2.0
T.D.S.	.937	1.34	1.4
S.S.	.00977	.0157	1.6
V.S.	.00654	.0116	1.8

509642

Figures 4-20 through 4-34). It is difficult to compare all of the substances to chloride. Ammonia, cyanide, phenol, sulfate, and T.O.C. may be compared because these are volatile (as is chloride) and may act similarly to chloride in this way. However, calcium is a metal and is non-volatile as are the dissolved and suspended solids.

Two of the clean water tests, 8A81 and 10M1/11MP1 (Figures 4-25 and 4-27), show unusual enrichment for all substances. In these tests the inlet/return water ratio for chloride is unusually high and this carried the other values up with it.

$$NR = \frac{X}{Y} \text{ inlet or } \frac{X}{Y} \text{ return}$$

$$EF = (NR) \text{ ret.}/(NR) \text{ inlet}$$

where: NR - normal ratio
EF- enrichment factor

$$= \frac{\frac{\text{ret}}{\text{ret cl}}}{\frac{\text{inlet}}{\text{inlet Cl}}} = \frac{\text{inlet Cl}}{\text{return Cl}} \times \frac{\text{return}}{\text{inlet}} = EF$$

if $\frac{\text{inlet Cl}}{\text{return Cl}}$ is unusually high

then the EF will also be high.

As seen in the graphs, ammonia, phenol, cyanide, sulfate, and T.O.C. show an enrichment factor close to one (1) in 2/3's of the tests. Therefore, these substances usually remain at a constant level of concentration relative to chloride and are not lost to association or reaction with another substance. These compounds exist in set proportions to chloride in the inlet water and the proportions do not change as the compounds move up the stack, into the coke, or remain in return water. Whatever percentage of chloride is lost to the atmosphere (average about 35 percent), approximately the same percentage of each of the other substances goes up the stack too.

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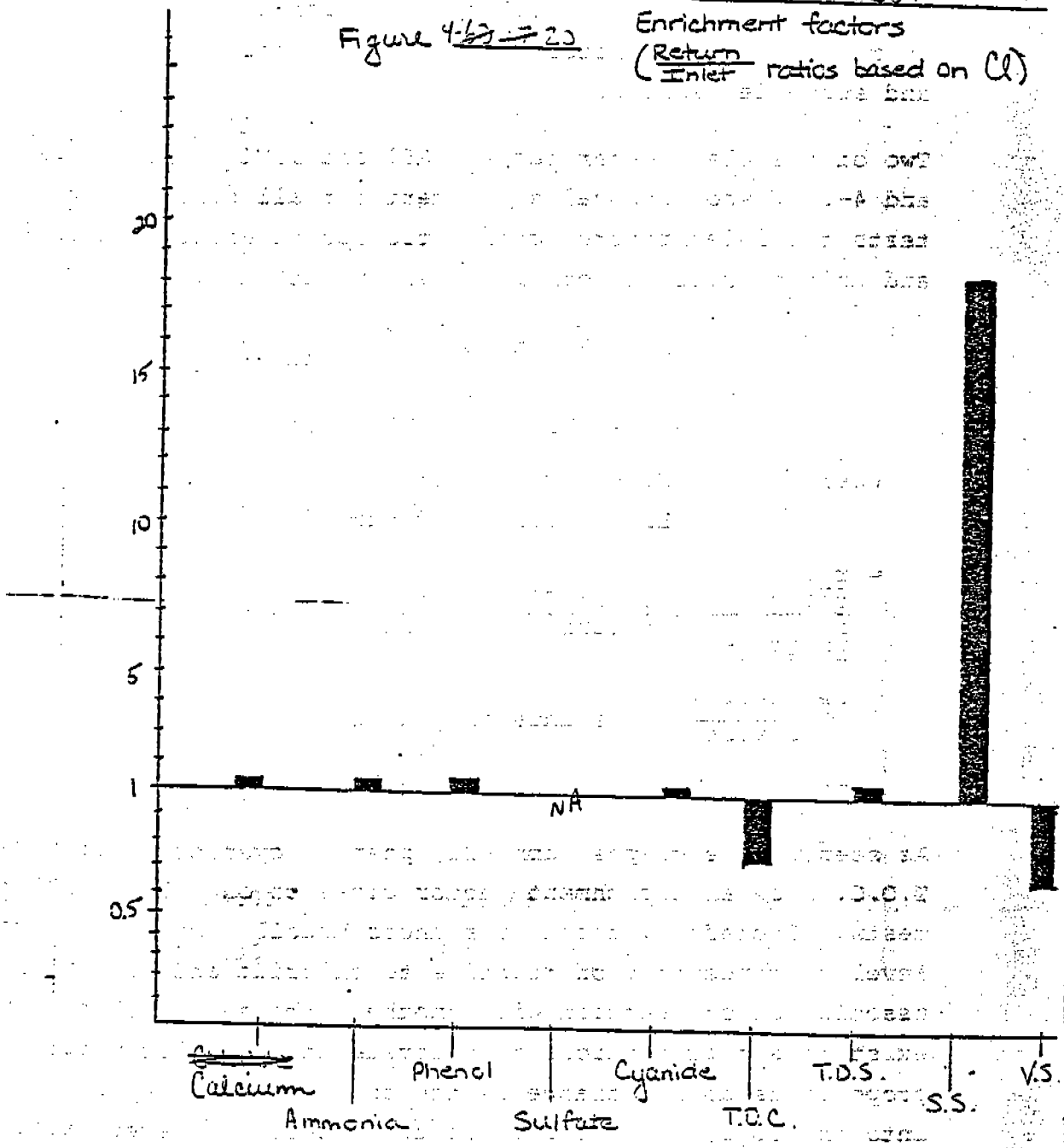
Clean Water Test
1C81

Figure 4-~~63~~ 20 Enrichment factors
(Return/Inlet ratios based on Cl)

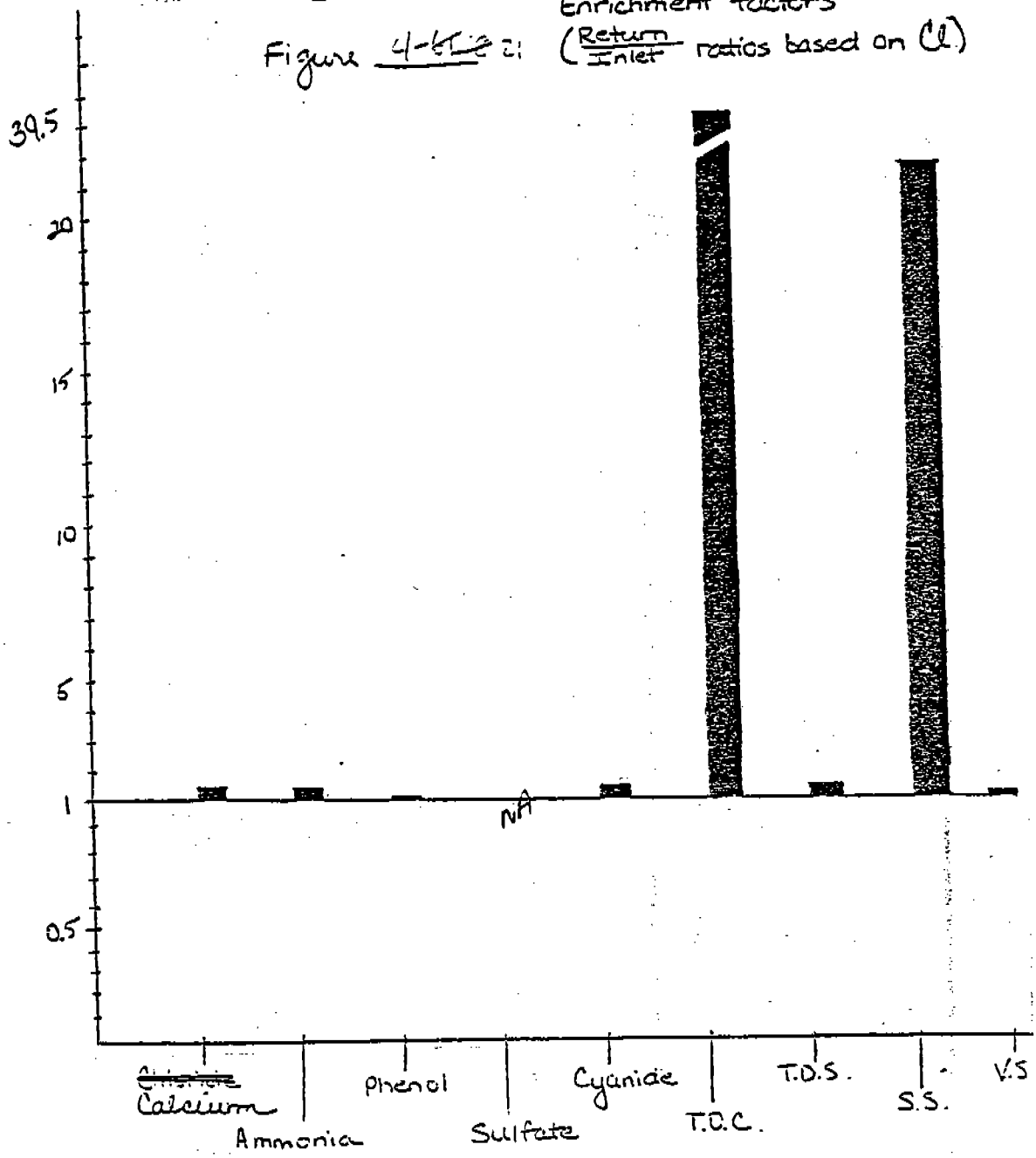


509644

Clean Water Test
3C21

Enrichment factors

Figure 4-~~6~~ 21 (Return/Inlet ratios based on Cl)



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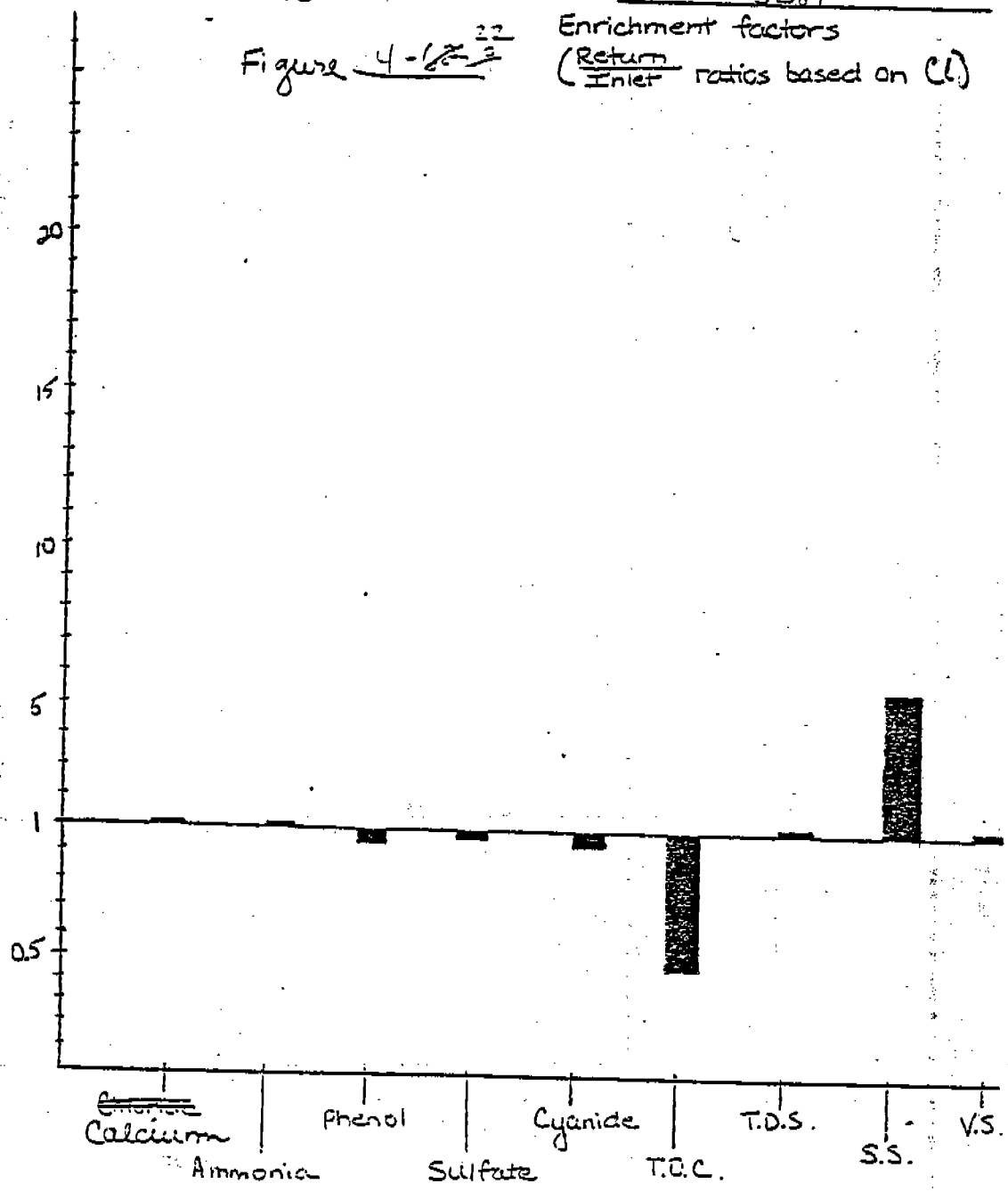
Clean Water Test
3B81

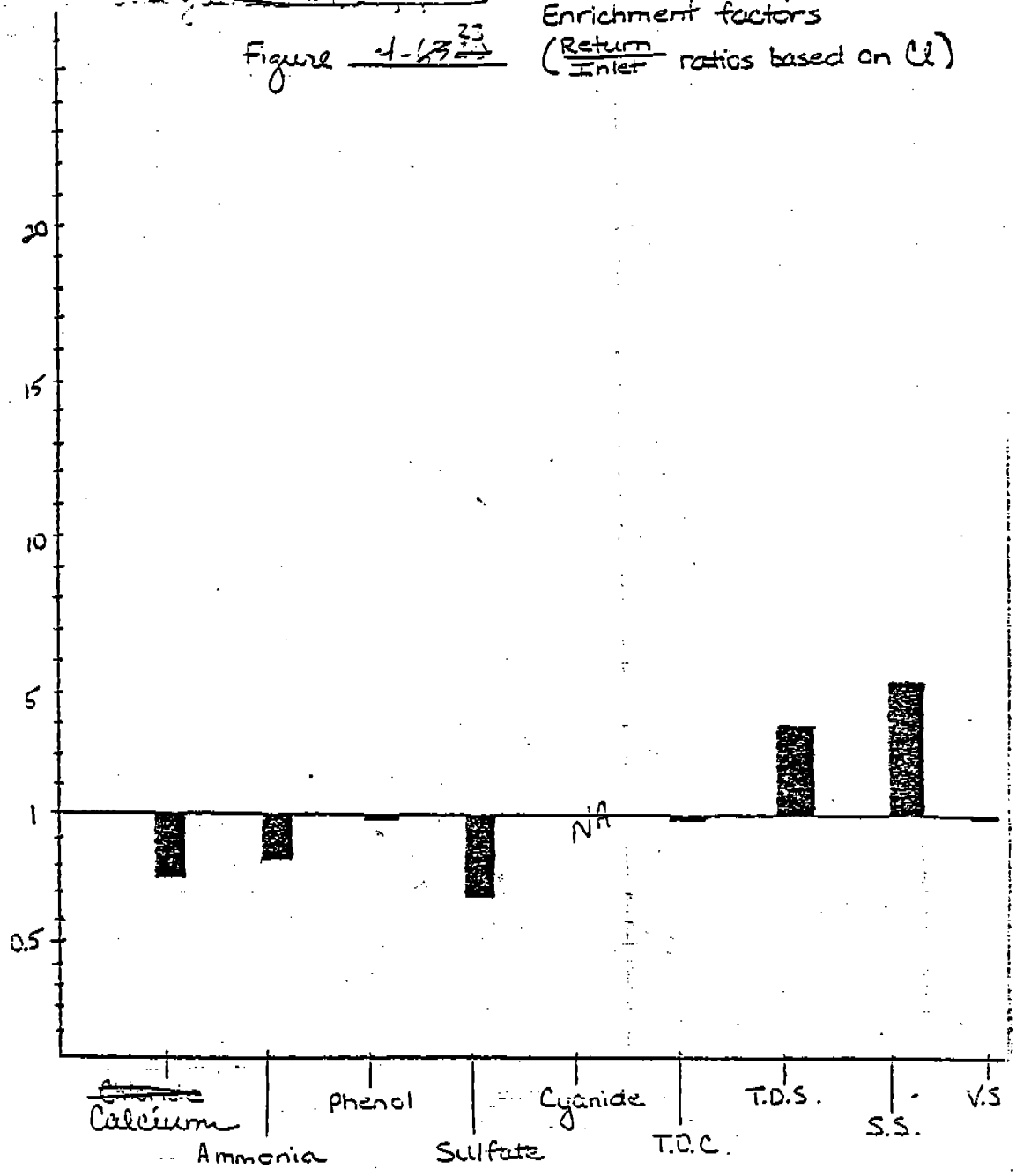
Figure 4-~~6~~ 22 Enrichment factors
(Return/Inlet ratios based on Cl)



509646

Clean Water Test
4057/5D21/6D81

Figure 4-23 Enrichment factors (Return/Inlet ratios based on Cl)



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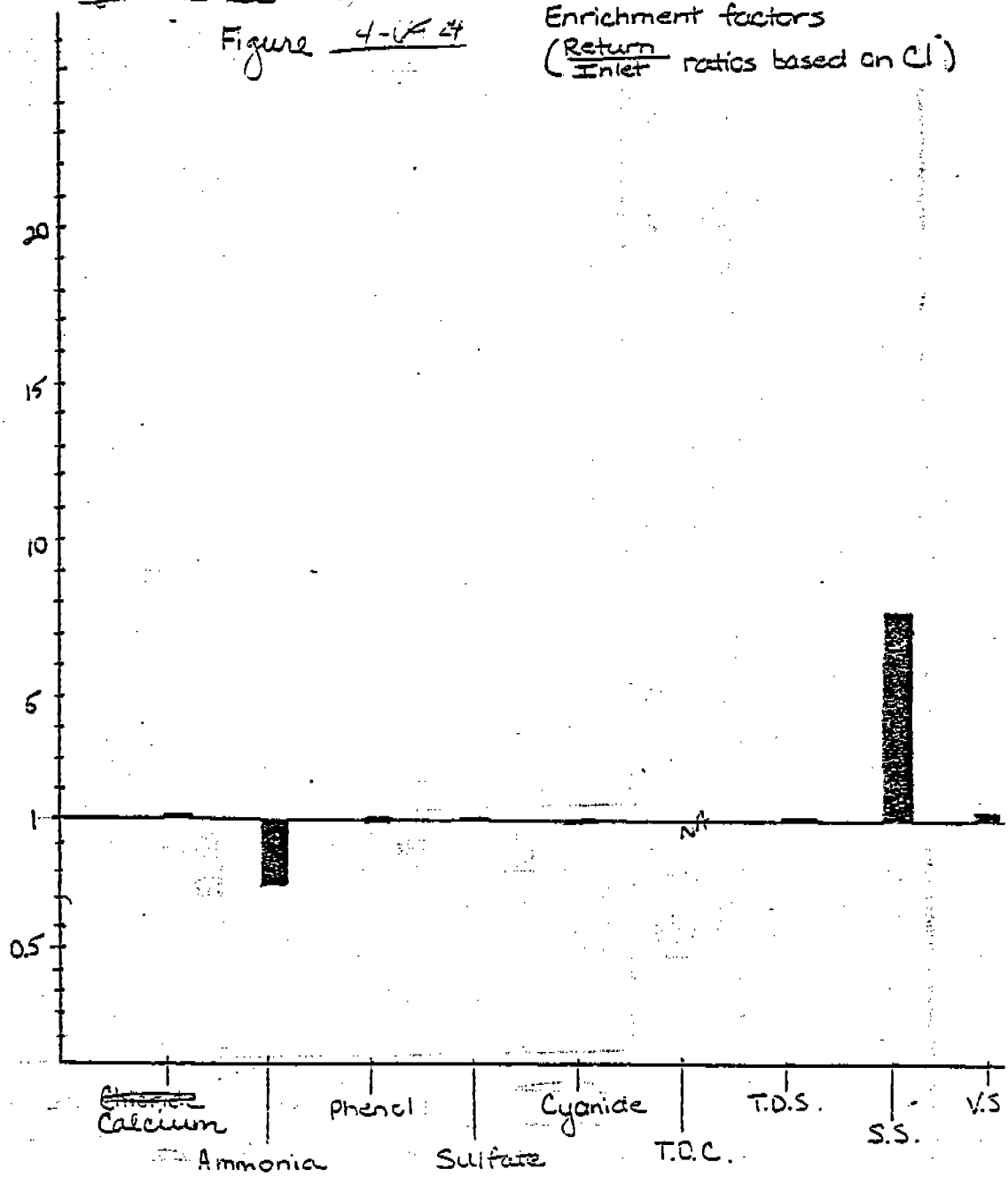
Clean Water Test

7A51

Enrichment factors

(Return/Inlet ratios based on Cl⁻)

Figure 4-VF 4



509648

Clean Water Test
8A81

Figure 4-~~65~~ 25 Enrichment factors
(Return/Inlet ratios based on Cl)

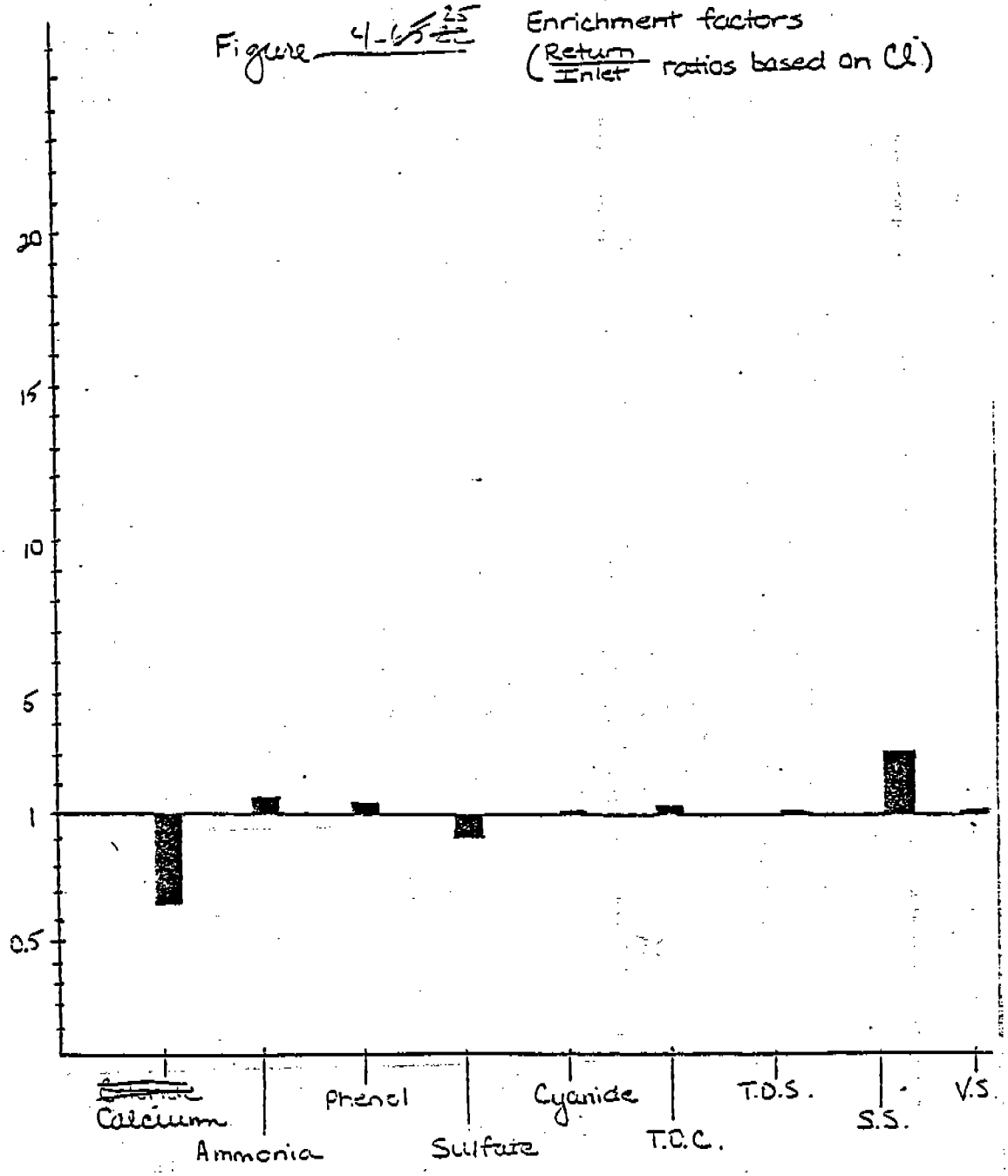


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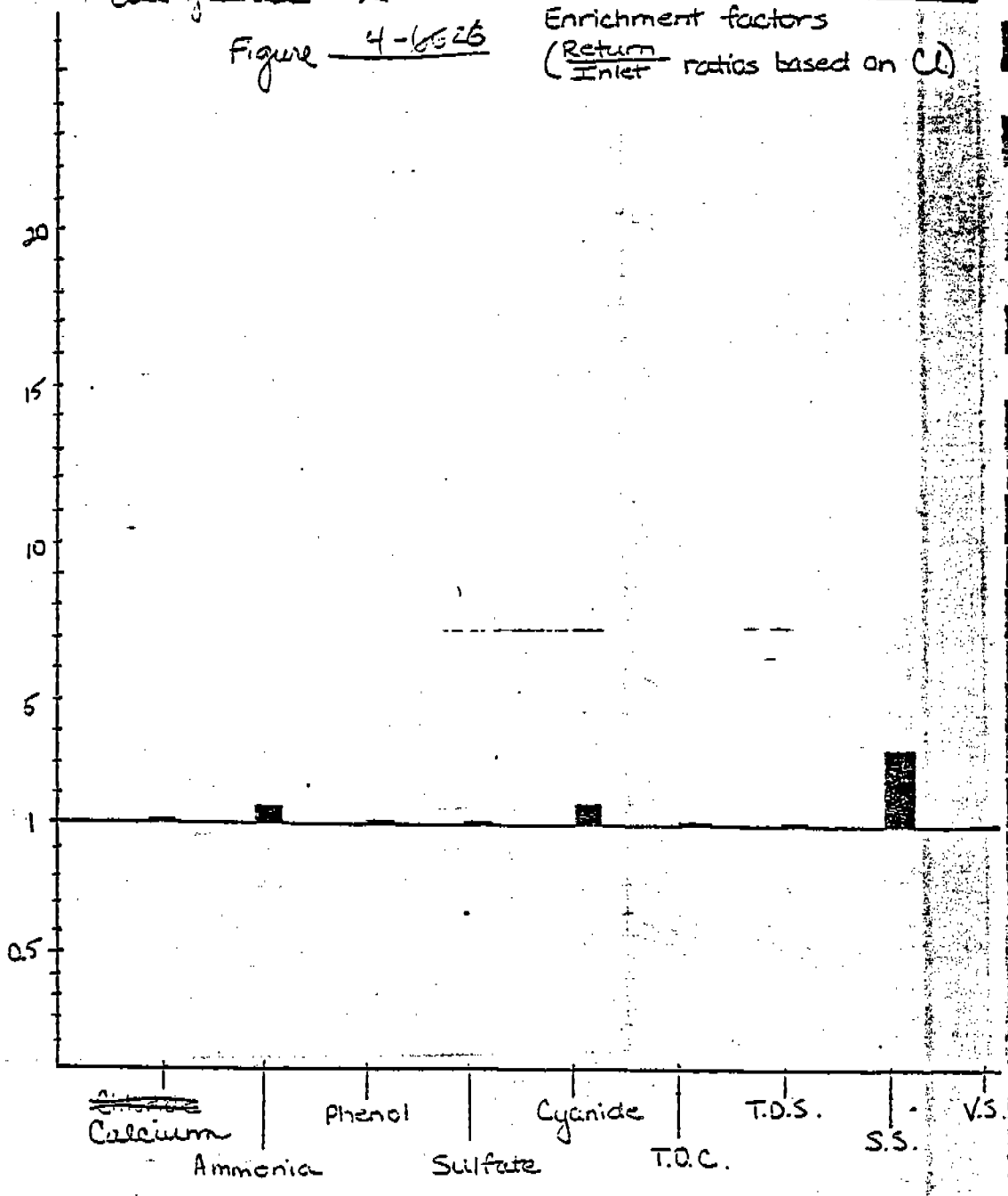
Figure 4-1626

Clean Water Test
9A21

Enrichment factors
(Return/Inlet ratios based on Cl)



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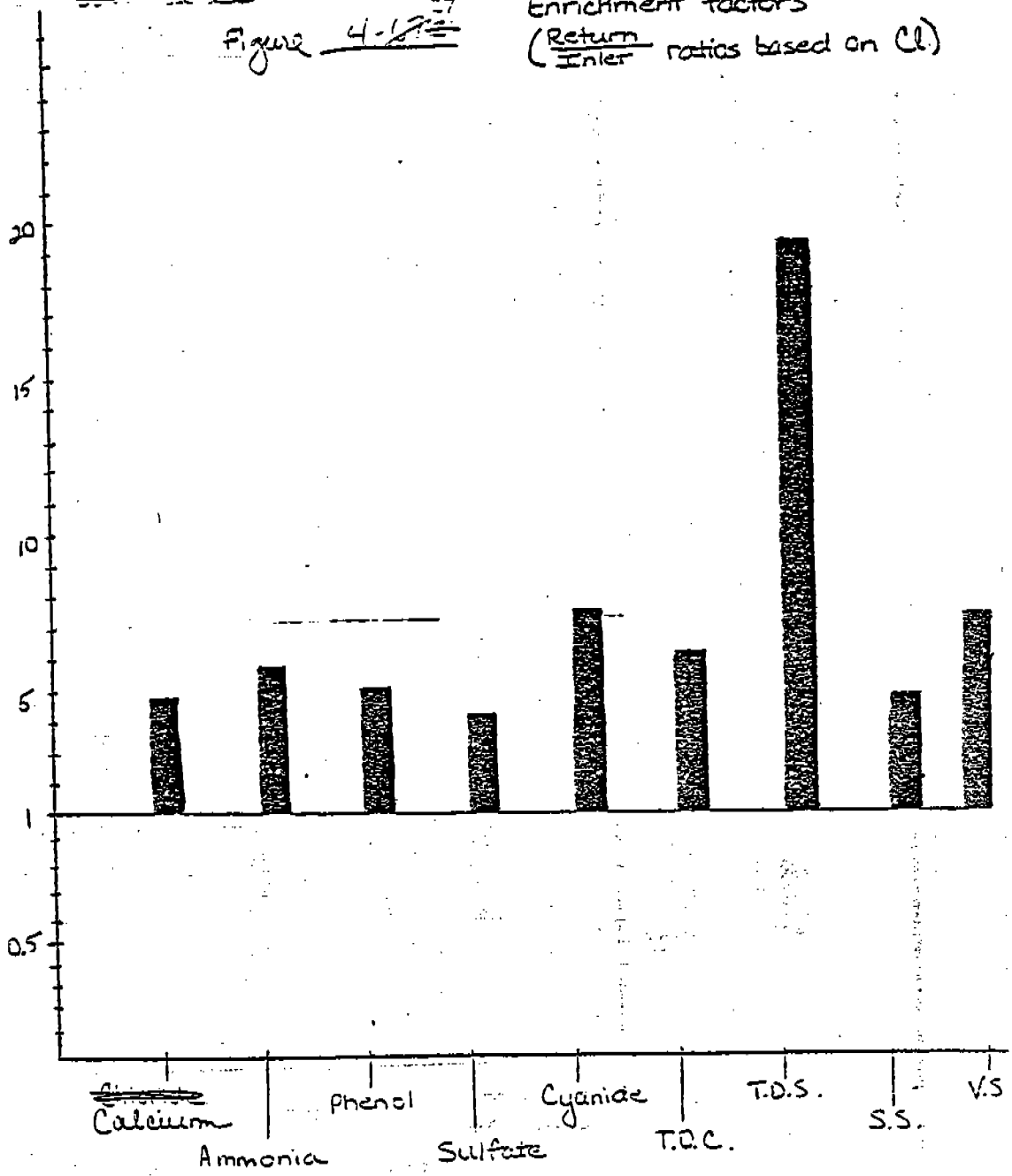
Clean Water Test
10 M1 / 11 MP1

Figure 4-17

Enrichment factors
($\frac{\text{Return}}{\text{Inlet}}$ ratios based on Cl)



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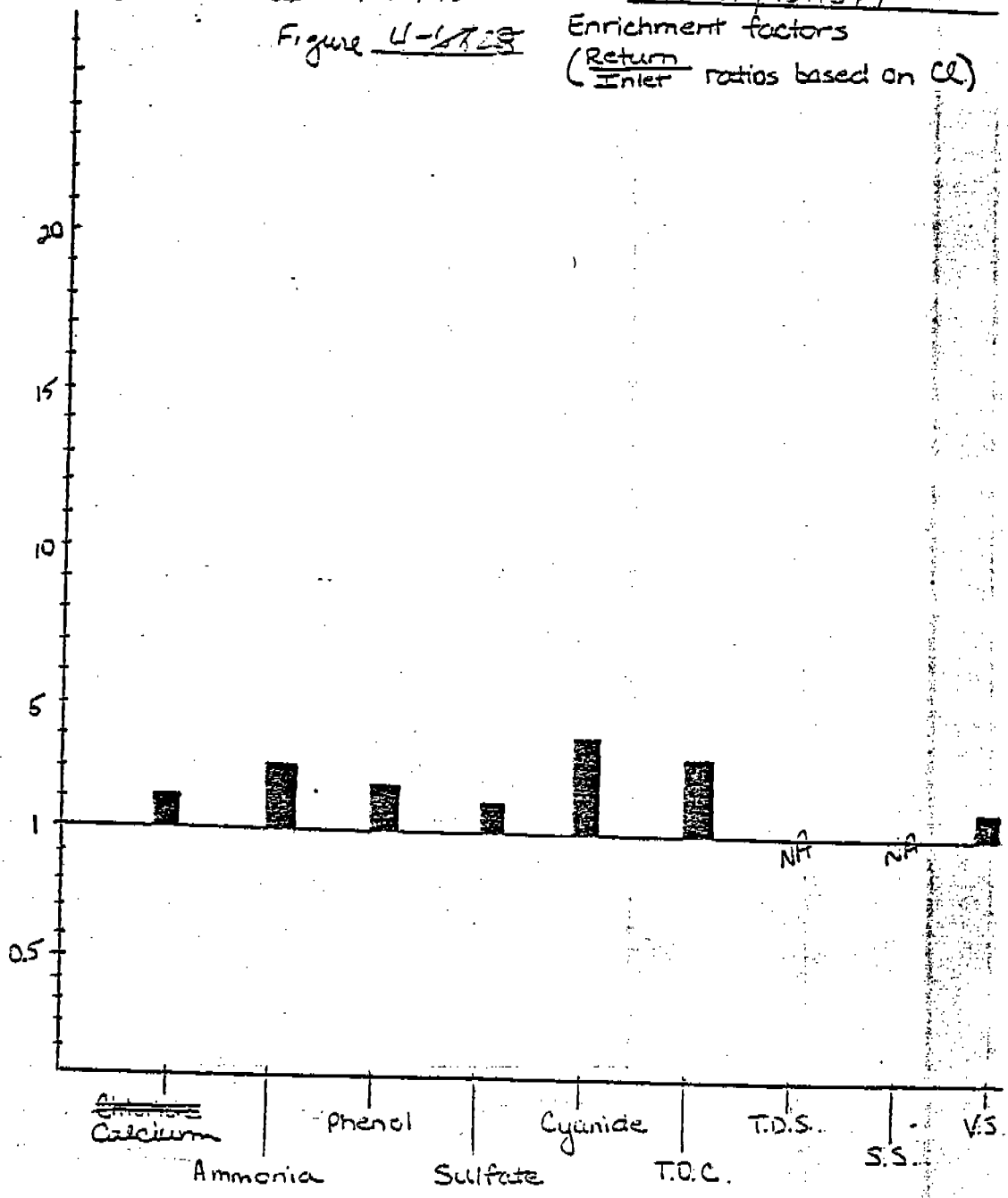
Clean Water Test
12M1 / 13A5P1

Figure 4-[illegible]

Enrichment factors
(Return / Inlet ratios based on Cl)



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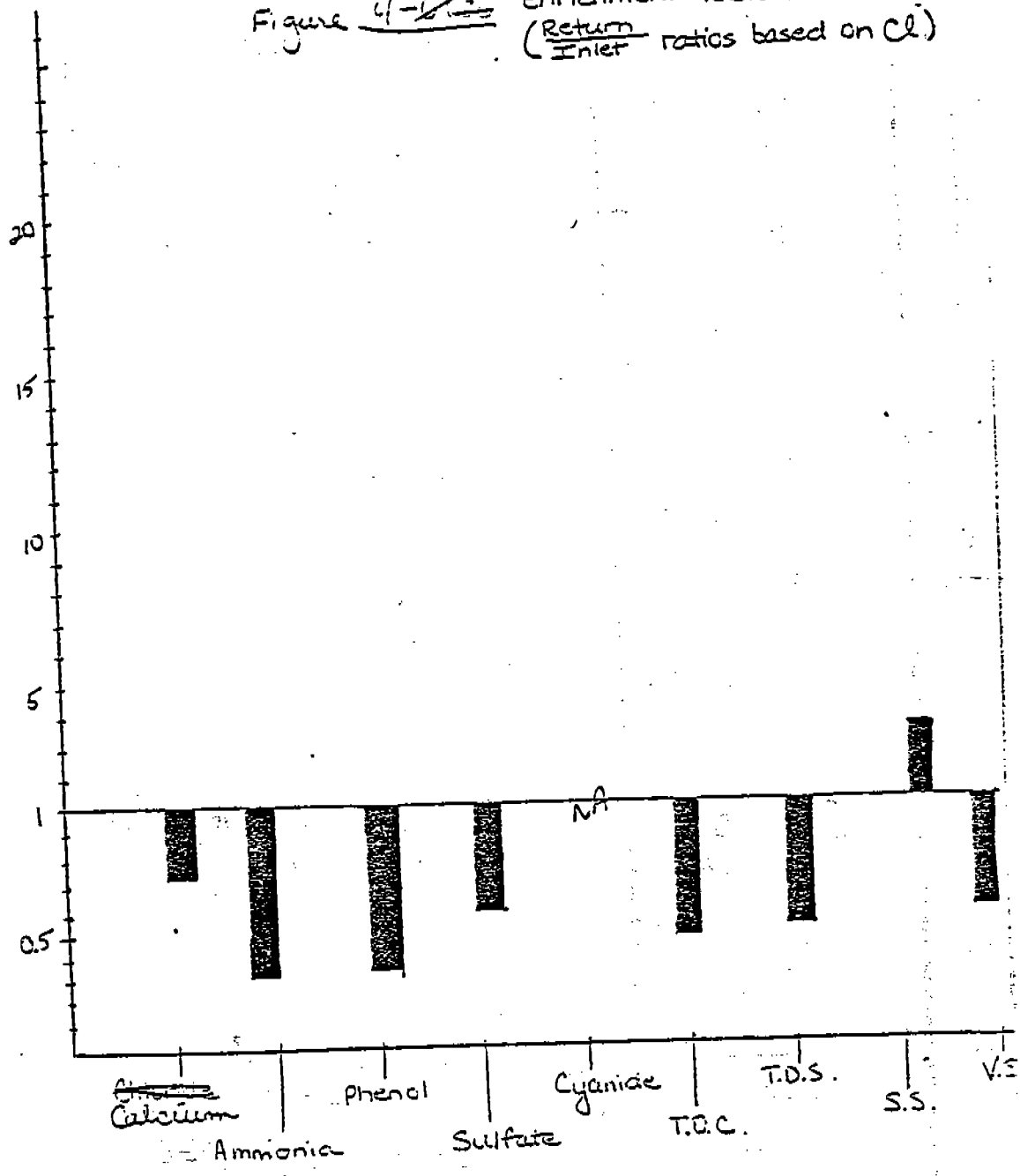
Contaminated Water Test
SC20

Figure 4-12 Enrichment factors
(Return/Inlet ratios based on Cl)



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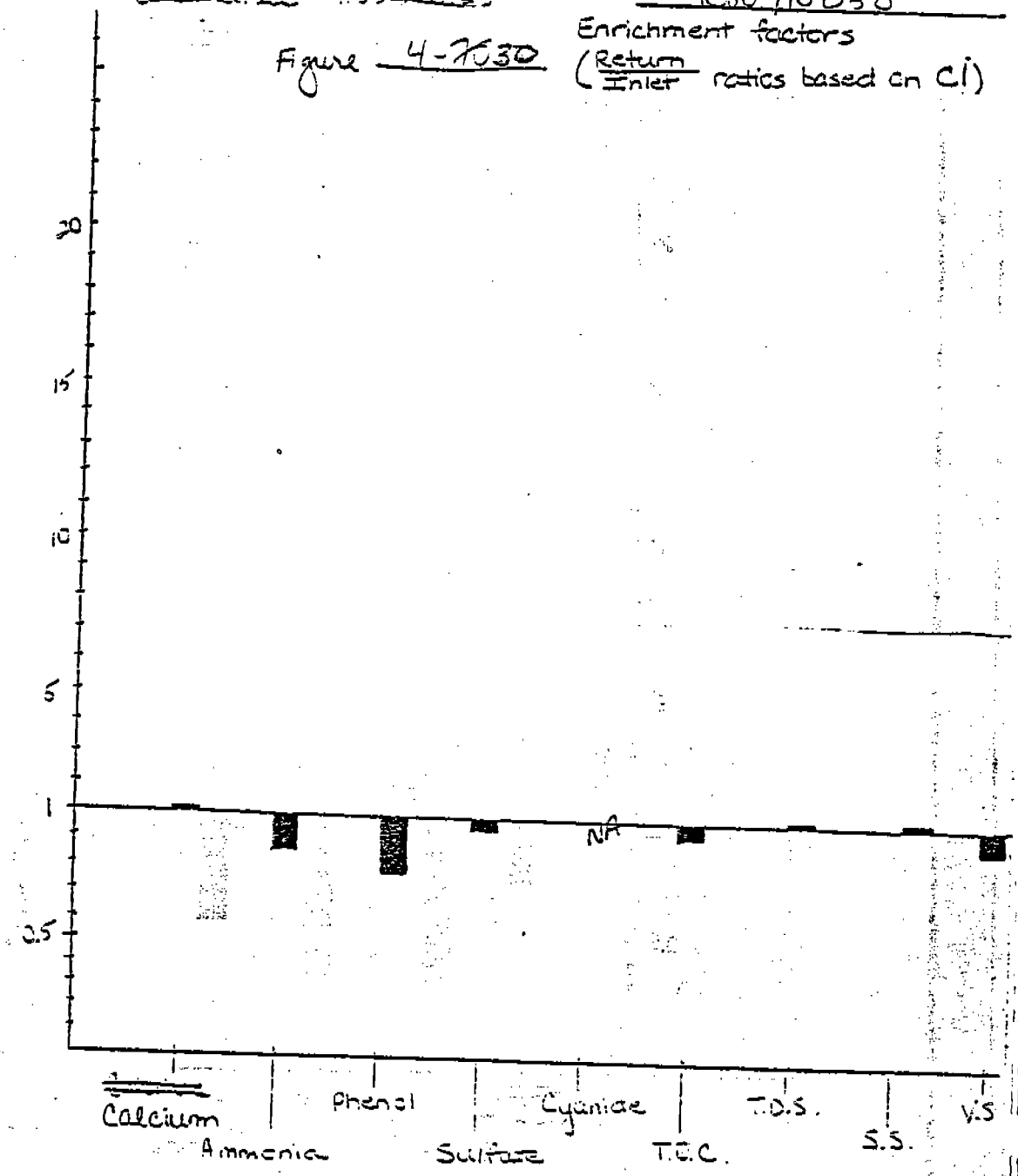
Contaminated Water Test
9C80 / 10D50
Enrichment factors
(Return / Inlet ratios based on Cl)

Figure 4-7030



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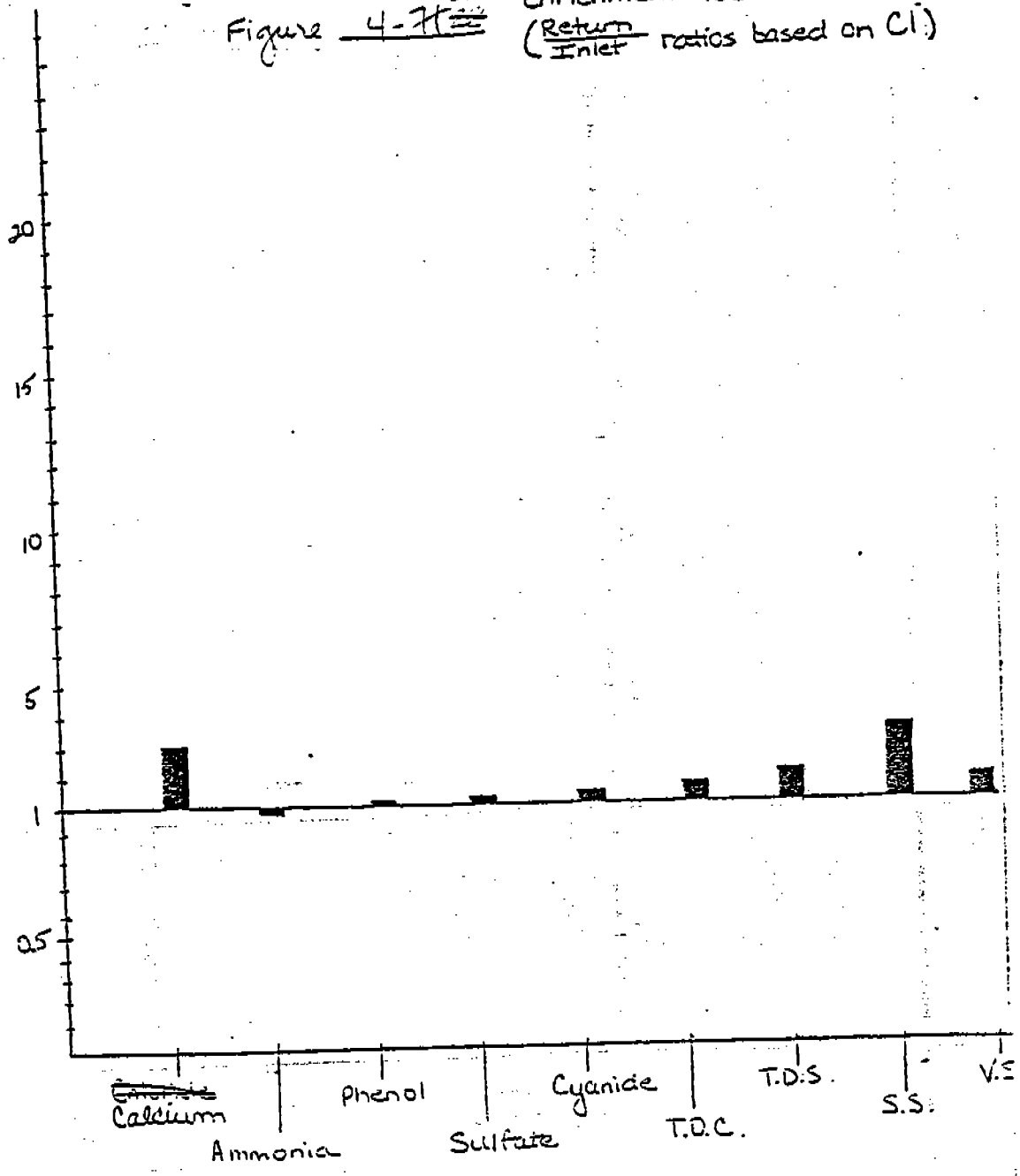
Contaminated Water Test
11D80

Figure 4-7 31 Enrichment factors ($\frac{\text{Return}}{\text{Inlet}}$ ratios based on Cl⁻)



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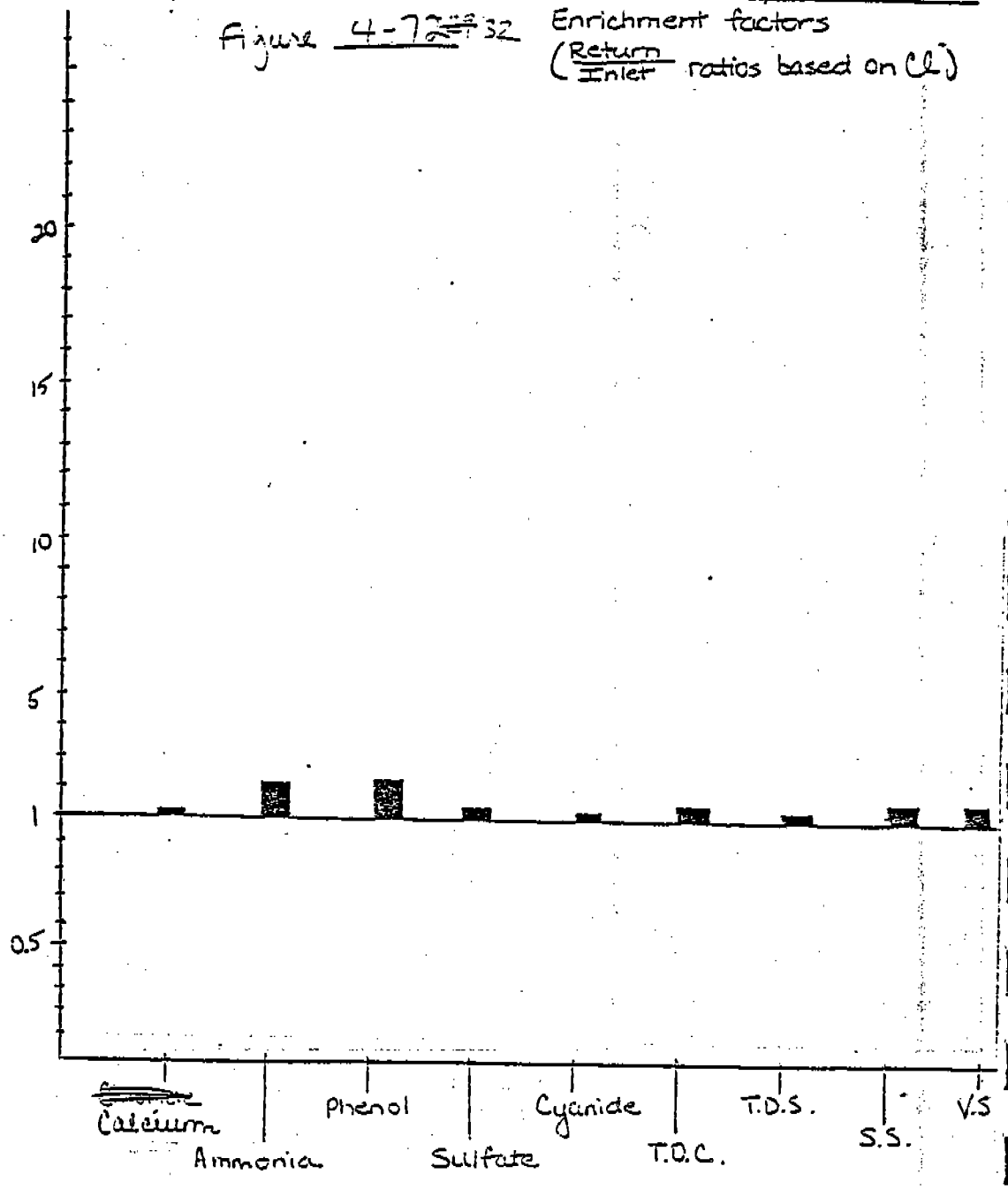
Contaminated Water Test
12D20 / 13A50

Figure 4-72 32 Enrichment factors
(Return/Inlet ratios based on Cl⁻)



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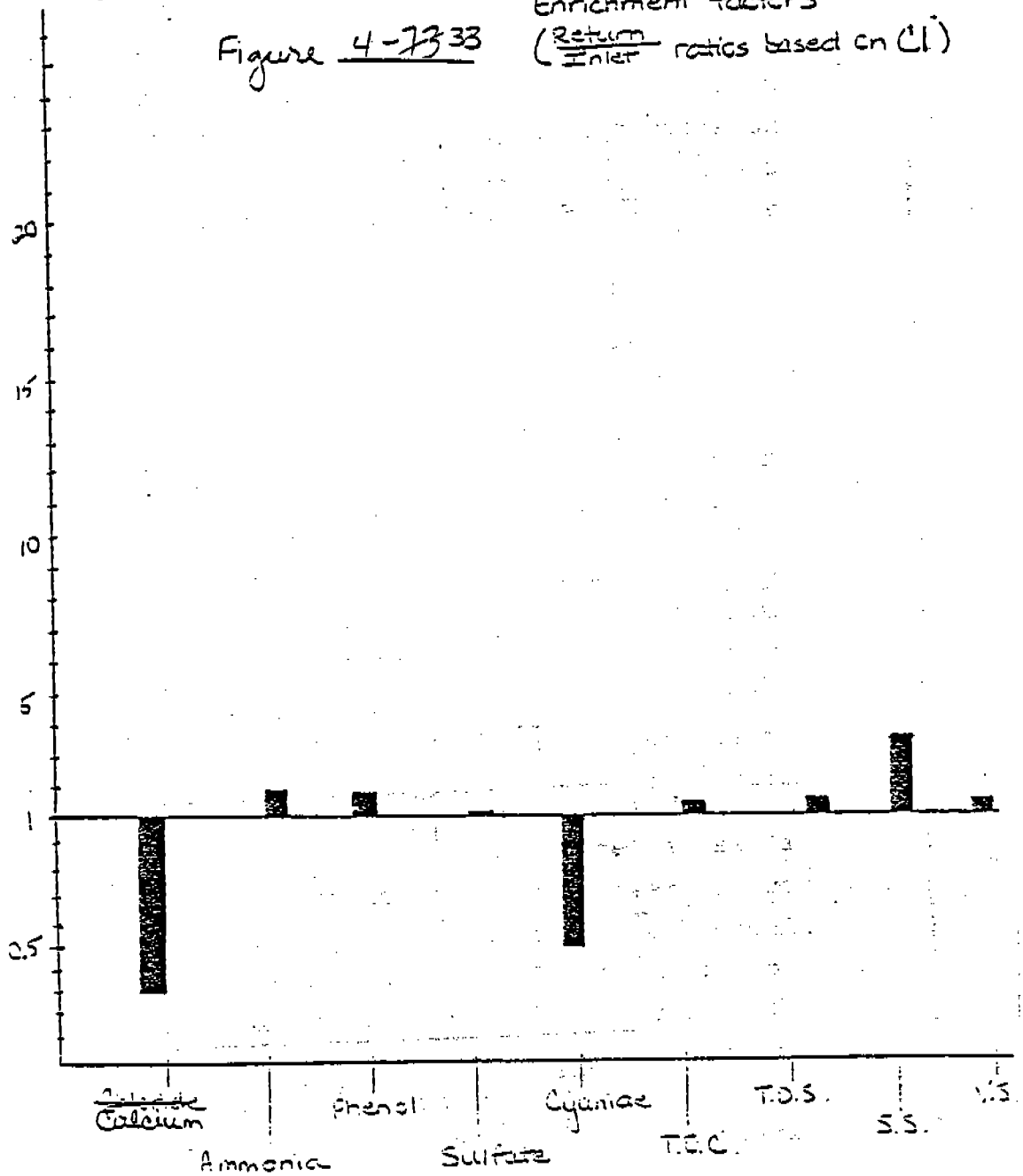
Contaminated Water Test
14A20

Figure 4-7733

Enrichment factors
($\frac{\text{Return}}{\text{Inlet}}$ ratios based on Cl)



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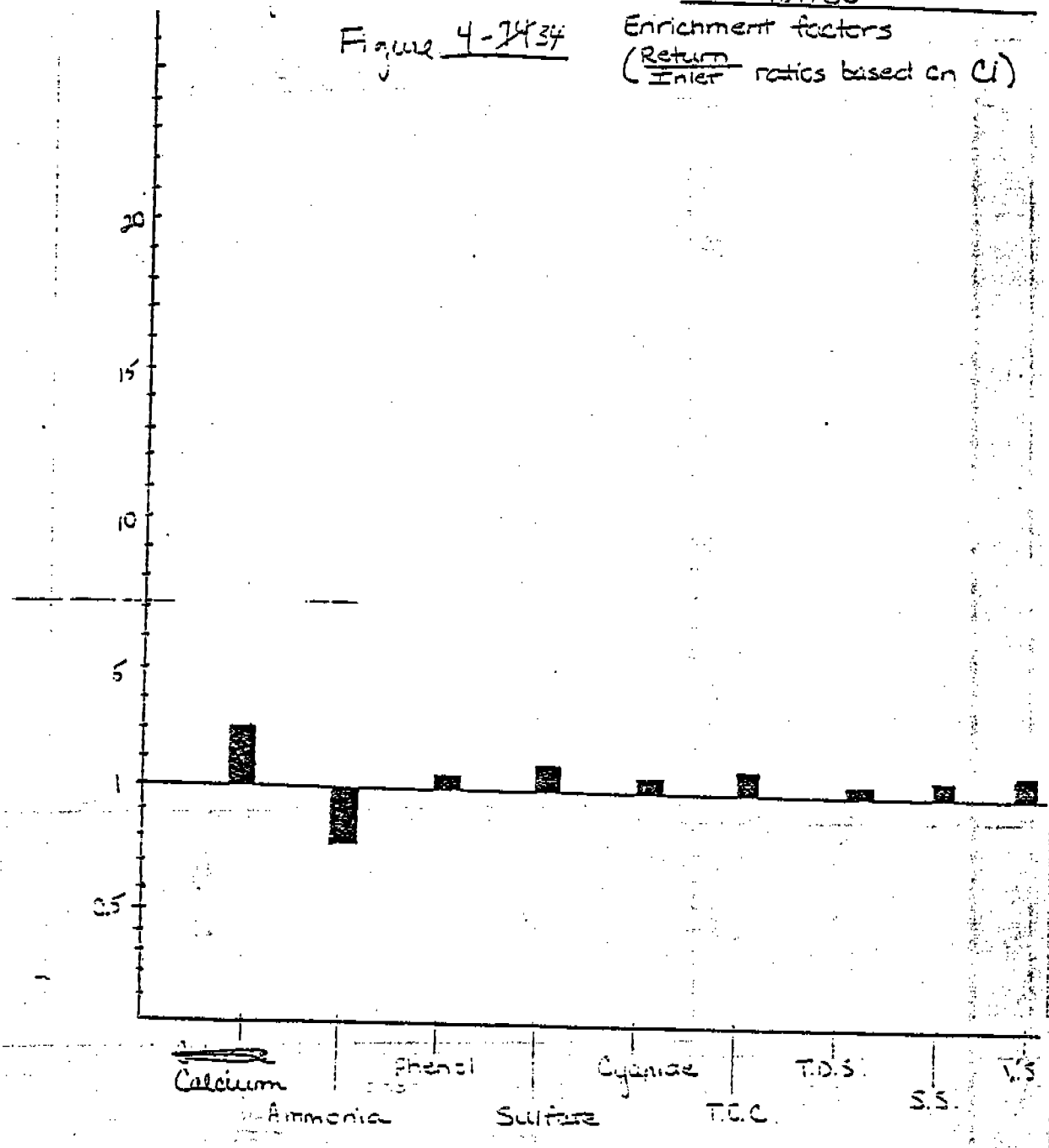
Contaminated Water Test
15A80

Figure 4-7434 Enrichment factors
(Return/Inlet ratios based on Cl)



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The suspended solids never go down in concentration level and usually are substantially enriched. As previously mentioned, S.S. is difficult to compare on a chloride basis, but the resulting enrichment factors show such a consistent pattern that this data should not be ignored. Also, enrichment of suspended solids is expected because of the large quantity of particles lost to the return water by the coke. Physical factors such as the temperature of the quench water, change in the force of the quench water spray, etc., will affect how much coke is lost to S.S.

The normal ratio analysis of individual inlet and return quench water tests did not give definite indications as to the behavior of each chemical but did serve to uphold the results of the chemical analysis of stack emissions discussed previously.

Based on chloride, the normal ration analysis revealed that ammonia, phenol, cyanide, sulfate, and T.O.C. tend to follow a similar pattern of movement in the quench tower. Some portion of these contaminants, along with chloride, is lost from the inlet water to the atmosphere. Suspended solids, however, remain within the system and become more concentrated in the return water.

Test averages corresponding to the individual tests used above basically agree with these conclusions. Inlet averages compared to return averages for contaminated water show that ammonia, phenol, cyanide, sulfate, and T.O.C., all decreased in concentration in return water and S.S. increased. For clean water, only sulfate decreased in concentration and S.S. increased. The other chemicals remained at about the same concentrations. However, phenol, ammonia, and cyanide were actually present in stack emissions during both clean and contaminated water use.

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4.3 Sampling and Analysis of Organic Emissions

4.3.1 Summary

A special testing scheme (26) was conducted to determine the amount and character of the organic material being emitted from the tower during quenching operations. In order to obtain the stack sample necessary, a modification was made to the Hi-Volume Aerotherm train used for particulate testing. This consisted of a water-cooled adsorber trap which was filled with a porous polymer placed downstream of the heated filter box and upstream of the first impinger. Chemical analyses were performed on the combined extracts obtained from each component of the train. Only four tests were planned since it was thought that the organic emissions would be minimal. Two tests were to be conducted while clean water was being used for quenching and two when contaminated water was employed. One of the later tests was discarded due to excessive plugging in the sampling train.

The analysis scheme which is described in detail in Section 4.3.5 consisted of a liquid chromatographic separation of the concentrated extracts from the train which were later characterized by infrared spectroscopy. In addition, a separate mass spectroscopy scan for polynuclear aromatic hydrocarbons was performed.

Grab samples of the water (clean and contaminated) and coke were analyzed in a similar manner in order to obtain correlations between quench emissions and possible source material.

4.3.2 Conclusions

Several conclusions can be made from the results of this test scheme.

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1. The organic emissions from a coke quench tower are substantial. (Range between 13-115 lbs material per quench.)

2. The chemical nature of most of this material is aromatic.

3. The amount of the organic material which is emitted during a quench is probably more dependent on the coke, its processing conditions, or some other factor than it is on quality of quench water used.

4.3.3 Results

The values given for the various types of organic compounds have been derived from the infrared scans and fraction weights which appear in Section 4.3.4. This method of reporting the data includes an assessment of the relative amounts of each type of material present. However, the overall picture minimized areas of potantial misinterpretation of the infrared data as defined by the analytical techniques used for Level I data.

Compounds which appear in conventional liquid chromatographic fractions frequently do not fall in such clearly defined fractions when an actual environmental sample is injected. This is apparent in the case of these analyses as it is observed that some compounds appear in as many as six fractions in one test. Consequently, it was necessary to report the data by selecting weights from the gravimetric results and applying them to compound classes as observed in the infrared scans . The results of this effort appear in these tables and are presented in pounds per quench and in concentrations.

These values indicate that the great majority of the organic material collected by this method is aromatic in nature and associated with heterocarbons such as oxygen and nitrogen.

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TABLE 4-~~44~~ 70

CONTAMINATED WATER IN USE

TYPES OF ORGANIC COMPOUNDS	STACK EMISSIONS		INLET WATER		RETURN WATER		MAKE UP LIQUOR		COKE-QUENCHED	
	lb/quench	mg/m³	lb/quench	mg/l	lb/quench	mg/l	lb/quench	mg/l	lb/quench	mg/gram
ALIPHATIC HYDROCARBONS	0.490	14.29	0.0398	0.52	0.0219	0.36	0.0076	0.48	0.777	0.041
AROMATIC HYDROCARBONS	ND	ND	0.0705	0.92	ND	ND	ND	ND	ND	ND
NON-AROMATIC HETEROCARBONS (ESTERS, ALCOHOLS)	0.056	1.64	ND	ND	0.0131	0.22	0.0028	0.18	ND	ND
AROMATIC HETEROCARBONS (PHENOLS, NITRILES, PHTHALATE, ESTERS)	8.895	259.15	7.525	98.24	6.092	100.20	1.5345	97.12	0.106	0.006
ALDEHYDES, ESTERS, CARBOXILIC ACIDS, ACRYLATE POLYMERS	3.282	95.61	3.861	50.40	2.682	44.12	0.4708	29.80	ND	ND
KETONES, AMINE SALTS, PHOSPHINES, ISOTHIOCYANATE	1.126	32.80	0.0858	1.12	0.1021	1.68	0.0164	1.04	0.373	0.020
TOTALS	13.849	403.49	11.582	151.20	8.912	146.58	2.0321	128.62	1.256	0.067

(1) AVERAGE OF 2 TESTS
ND = NOT DETECTED
N/A = DETECTED BUT WEIGHT ATTRIBUTABLE TO THIS COMPOUND NOT AVAILABLE.

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TABLE 4-~~6U~~(CON'T)

CLEAN WATER IN USE

	STACK EMISSIONS (1)		WATER (COMPOSITE) COKE-QUENCHED			
TYPES OF ORGANIC COMPOUNDS	lb/quench	mg/m^3	lb/quench	mg/l	lb/quench	mg/gram
ALIPHATIC HYDROCARBONS	22.503	734.72	0.0919	1.20	0.335	0.018
AROMATIC HYDROCARBONS	N/A	N/A	ND	ND	ND	ND
NON-AROMATIC HETEROCARBONS (ESTERS, ALCOHOLS)	ND	ND	N/A	N/A	ND	ND
AROMATIC HETEROCARBONS (PHENOLS, NITRILES, PHTHALATE, ESTERS)	73.768	2408.57	0.4167	5.44	0.272	0.014
ALDEHYDES, ESTERS, CARBOXILIC ACIDS, ACRYLATE POLYMERS	6.516	212.76	0.3013	3.93	ND	ND
KETONES, AMINE SALTS, PHOSPHINES, ISOTHIOCYANATE	1.369	44.70	0.0225	0.29	0.191	0.010
TOTALS	104.156	3400.75	0.8324	10.86	0.798	0.042

(1) AVERAGE OF 2 TESTS
ND = NOT DETECTED
N/A = DETECTED BUT WEIGHT ATTRIBUTABLE TO THIS COMPOUND NOT AVAILABLE.

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FIGURE ~~GRAPH~~

TOTAL WEIGHT OF ORGANIC EMISSIONS

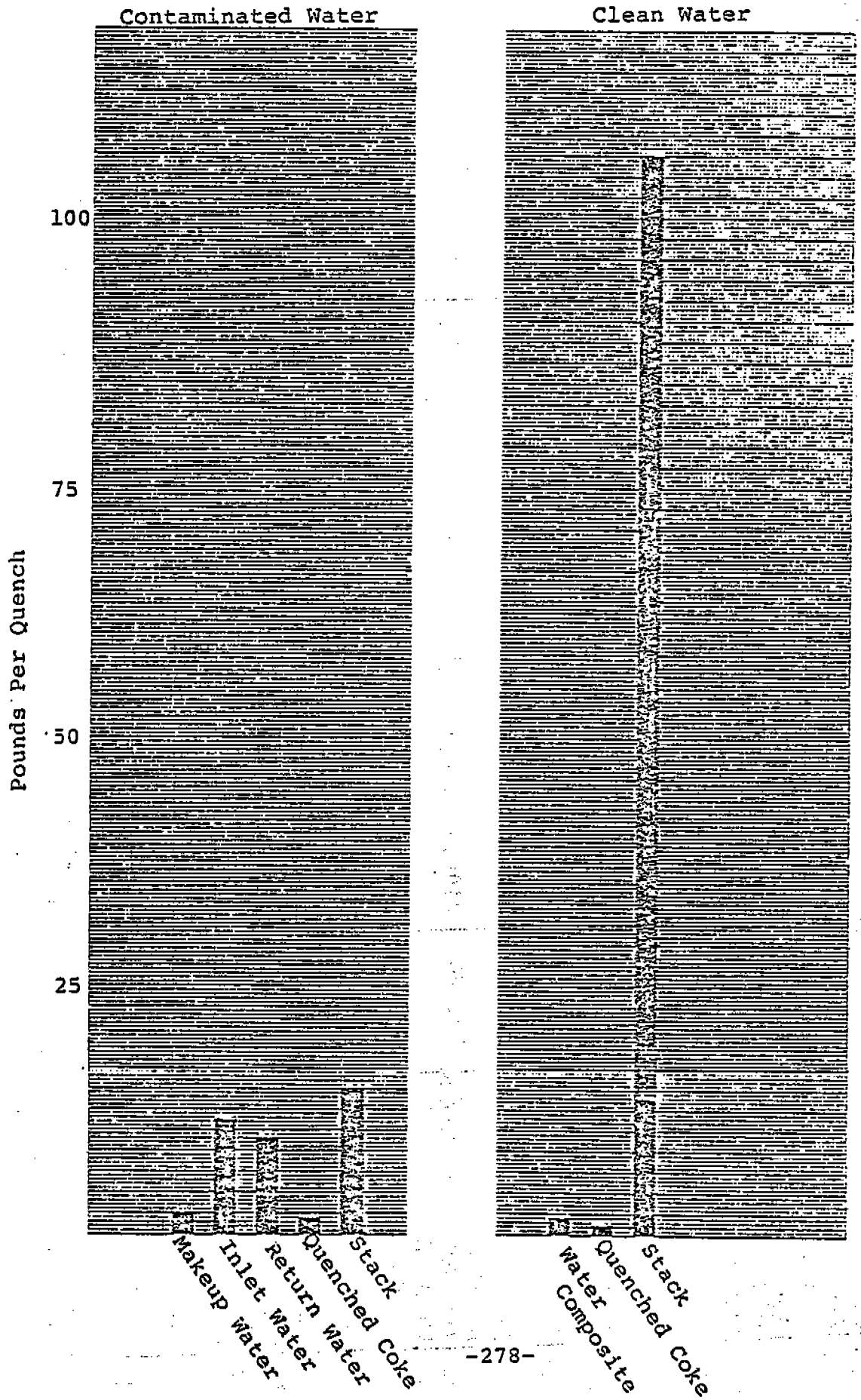

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FIGURE 4-3

STACK EMISSIONS (LBS./QUENCH)

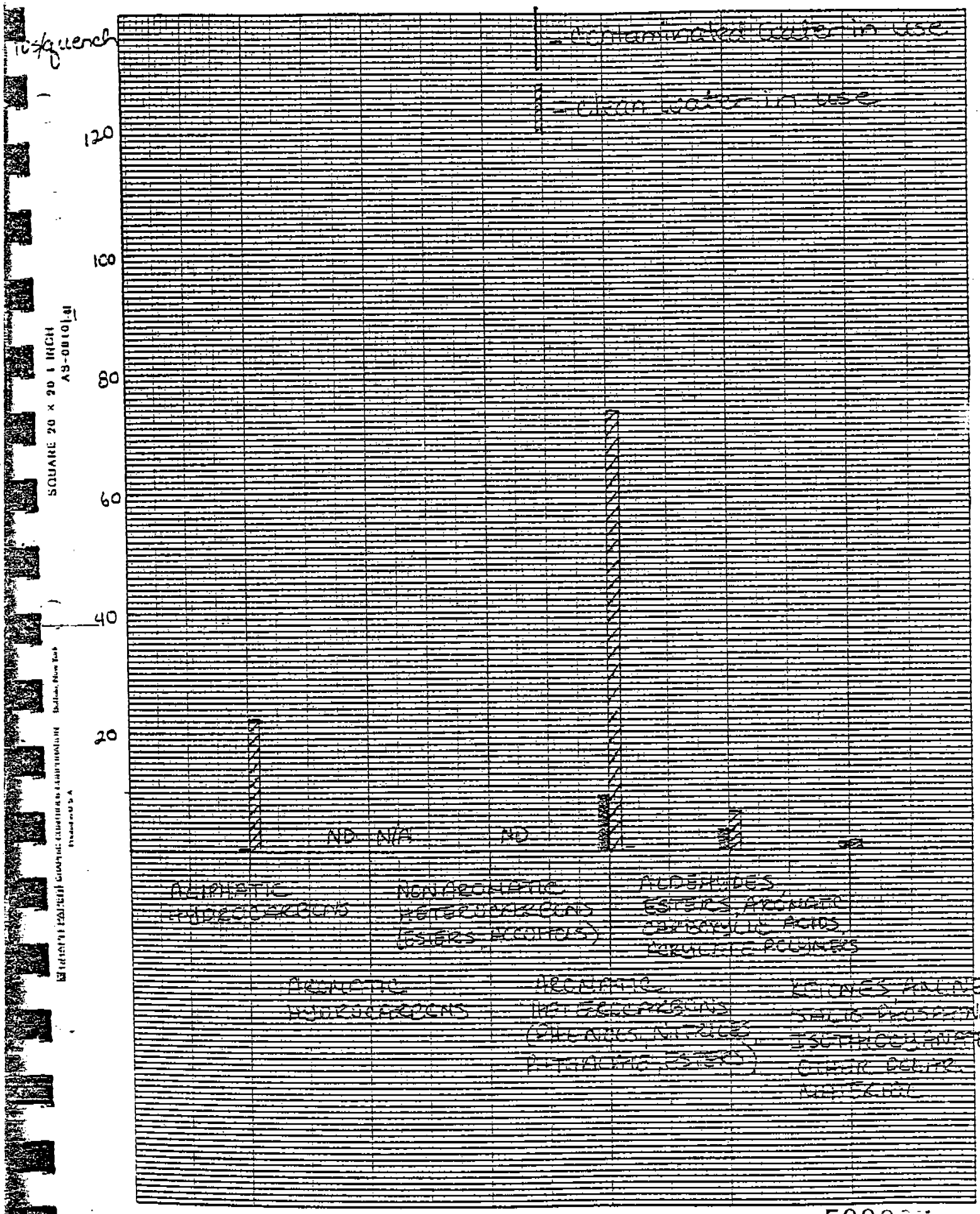

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TABLE 4-71.
POM QUANTIFICATION

CLEAN WATER IN USE

	STACK TEST 11A		STACK TEST 13A		WATER COMPOSITE		COKE-QUENCHED	
Component	lb/quench	ug/m^3	lb/quench	ug/m^3	lb/quench	ug/l	lb/quench	ug/g
Anthracene/ Phenanthrene	2.37×10^{-5}	.673	1.26×10^{-5}	.484	$.419 \times 10^{-5}$	.0547	2.87×10^{-5}	1.5×10^{-3}
Methyl Anthracenes	1.04×10^{-5}	.294	0.706×10^{-5}	.271	$.347 \times 10^{-5}$	.0453	$.383 \times 10^{-5}$	$.2 \times 10^{-3}$
Fluoranthene	1.35×10^{-5}	.384	0.483×10^{-5}	.186	$.358 \times 10^{-5}$	.0467	2.30×10^{-5}	1.2×10^{-3}
Pyrene	0.952×10^{-5}	.270	0.424×10^{-5}	.163	$.337 \times 10^{-5}$	.0440	2.20×10^{-5}	1.15×10^{-3}
Methyl Pyrene Fluoranthene	0.685×10^{-5}	.194	0.436×10^{-5}	.167	$.286 \times 10^{-5}$	.0373		
Benzo (c) phenanthrene	0.869×10^{-5}	.246	0.412×10^{-5}	.158				
Chrysene/ Benz (a) anthracene	0.885×10^{-5}	.251	0.447×10^{-5}	.172	398×10^{-5}	.0520		
Methyl chrysenes	0.067×10^{-5}	.019	0.047×10^{-5}	.018				
Dimethylbenz (a) anthracene	1.00×10^{-5}	.284	0.471×10^{-5}	.181				
Benzo fluoranthenes								
Benz (a) pyrene								
Benz (e) pyrene								
Indene (1,2,3-cd) pyrene								

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TABLE 4-71

POM QUANTIFICATION

CONTAMINATED WATER IN USE

	Stack Test 16A		Inlet Water		Return Water		Makeup Liquor		Coke Quenched	
Component	lb/quench	ug/m^3	lb/quench	ug/l	lb/quench	ug/l	lb/quench	ug/l	lb/quench	ug/g
Anthracene/ Phenanthrene	3.12×10^{-5}	.910	3.52×10^{-5}	.460	$.851\times10^{-5}$	.140	$.246\times10^{-5}$	.156	2.97×10^{-5}	1.55×10^{-3}
Methyl Anthracenes	1.27×10^{-5}	.370	1.04×10^{-5}	.136	$.754\times10^{-5}$	.124	$.253\times10^{-5}$	.160	$.303\times10^{-5}$	$.2\times10^{-3}$
Fluoranthene	1.63×10^{-5}	.476	3.68×10^{-5}	.480	$.705\times10^{-5}$	.116	$.171\times10^{-5}$	.108	2.30×10^{-5}	1.2×10^{-3}
Pyrene	1.22×10^{-5}	.354	2.18×10^{-5}	.284	$.657\times10^{-5}$	.108	$.171\times10^{-5}$	.108	2.30×10^{-5}	1.2×10^{-3}
Methyl Pyrene Fluoranthene	0.93×10^{-5}	.270	1.38×10^{-5}	.180	$.608\times10^{-5}$	.100				
Benzo (c) Phenanthrene	0.98×10^{-5}	.286	$.827\times10^{-5}$	.100	$.097\times10^{-5}$	.016				
Chrysene/Benzo (a) anthracene	1.34×10^{-5}	.392	2.30×10^{-5}	.300	$.851\times10^{-5}$	.140				
Methyl chrysenes			1.16×10^{-5}	.152						
Dimethylbenzo (a) anthracene										
Benzo fluoranthenes			1.56×10^{-5}	.204						
Benzo(a) pyrene			$.337\times10^{-5}$	.044						
Benzo(e) pyrene			$.643\times10^{-5}$	.084						
Indene (1,2,3-cd) pyrene			$.460\times10^{-5}$	.060						
TOTAL	10.49×10^{-5}	3.050	19.087×10^{-5}	2.492	4.523×10^{-5}	0.744	$.841\times10^{-5}$	.532	7.953×10^{-5}	4.15×10^{-3}

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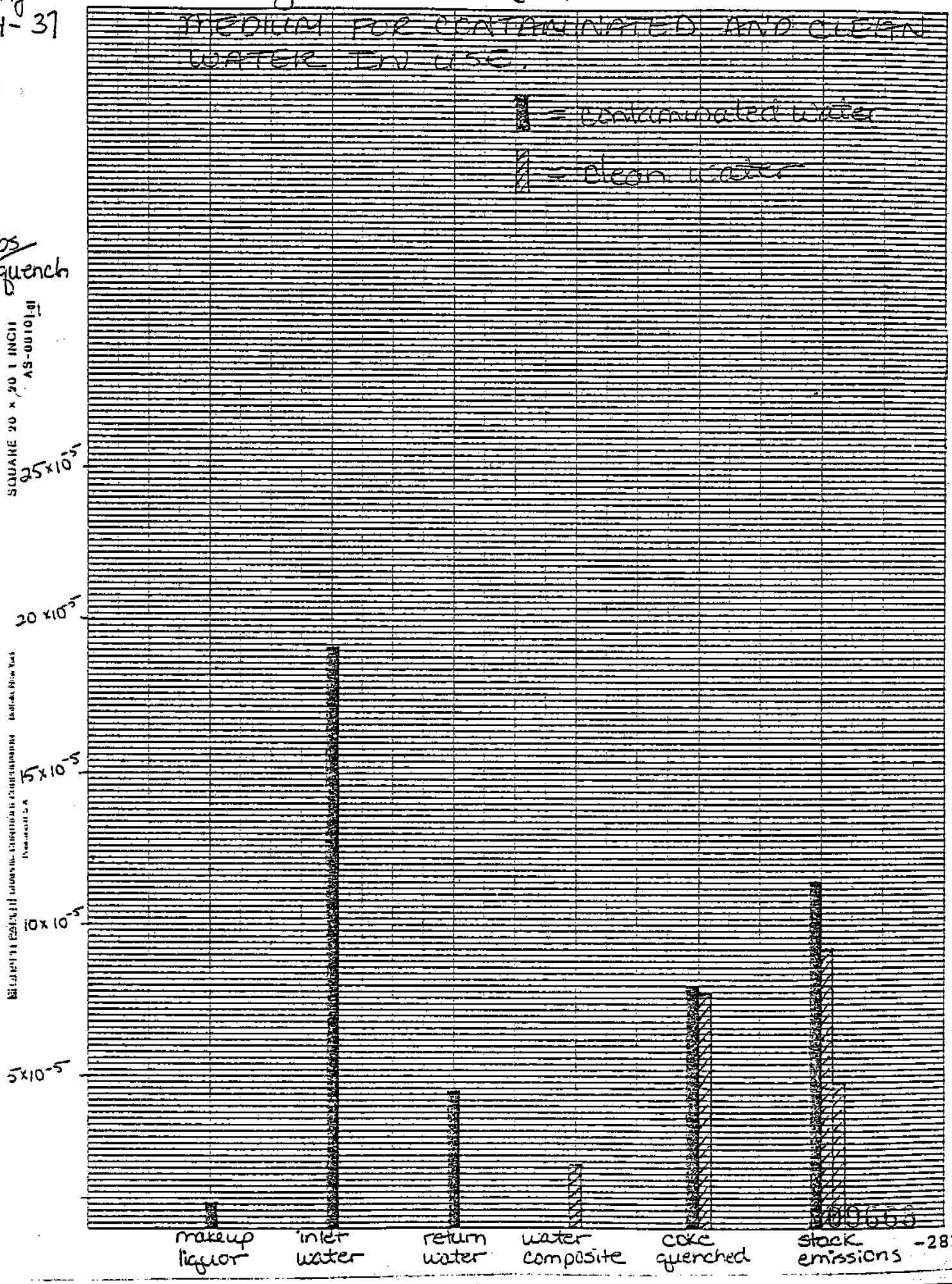
Figure 4-37

Total weight of PON's (LB/QUENCH) IN EACH MEDIUM FOR CONTAMINATED AND CLEAN WATER IN USE.



4.3.4 Data Presentation

The raw data obtained for the stack samples collected appears in Tables 4-73 through 4-75. Sampling statistics, including ambient and weather conditions and general observations on the coke processing parameters, are also included.

The gravimetric analyses of each liquid chromatographic fraction per the Level I scheme appears in Table 4-76. These fractions generally correlate to the polarity of the compound with Fraction 1 being the most non-polar, and Fraction 8 the most polar. These results are in milligrams representing the absolute weight of material collected in that fraction for the entire train (all components).

The infrared spectral analyses is given for each sample in Table 4-77. Silicone is found in some of the stack samples and is presumed to be a contaminant from the grease in the sampling train. The repeated detection of phtalate esters is confusing. No obvious areas for contamination by phtalates were noted in sample collection, storage, or shipping processes. Other Level I type analyses efforts have also detected these compounds. It is possible that they are introduced somewhere in the analytical process. Further work is needed to clarify the origin of these esters.

The data in Table 4-78 represents the absolute weights in the entire samples of the PAH material. The NAS notation refers to the National Academy of Science's classification of carcinogenicity in which the number of asterisks indicates the strength of the carcinogen. Four stars denotes the strongest action on humans.

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Very little aromatic hydrocarbon material was collected. One possible explanation for this result would be that the material caught in the stack gas consists largely of reaction products. Many compounds originally present in the system could have reacted in the catalytic conditions existing in, and immediately above, the hot coke/water interface.

The water samples analyzed show no clear trends in organic content or mass flow. Only one sample each of make-up, inlet and return water, was analyzed. A composite sample of clean water was analyzed.

The coke samples similarly show no cause for the high concentration of some organic materials in the stack emissions. It should be noted that it is quite impossible to obtain a representative sample of the coke due to heat and generally dangerous conditions surrounding the car.

Figure 4-35 illustrates the general order of magnitude of organic emissions contributed by the various media. Again, this must be considered in the framework of small sample numbers (sometimes just one). In addition, the reproducibility of these numbers is unknown. In this case, of the clean water tests at least, factors other than the organic content of the water must be responsible for the air emissions.

Figure 4-36 shows the levels of organics in the various media by compound type. The levels in both cases, contaminated and clean, follow a similar pattern. Aromatic heterocarbons are most prevalent, followed by aliphatic compounds and then by traces of other materials.

Polynuclear Aromatic Hydrocarbons (PAH)

Gas chromatographic separations followed by mass spectrographic analyses were performed on all of the samples; stack, water, and coke, to determine the levels of various polynuclear

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aromatic hydrocarbons. These results are presented in pounds per quench and in concentration in Table 4-67.

Due to the limited number of samples subjected to this lengthy analyses, no clear conclusions on the pathways of these compounds can be drawn. Some interesting observations can be made, but further work will be required to verify these results.

Figure 4-37 depicts the levels of total PAH material found in each medium. The three contaminated water samples do not follow a logical pattern of enrichment or loss from exposure to the quenching process. The high inlet value (which may be an anomaly since each of these represents one isolated grab sample) is quite confusing. One possible explanation could be the leeching of this PAH material out of the coke breeze in the sump sediments. This does not correlate with the relatively high amount found in the coke. Also, this sediment leeching phenomen could possibly account for the presence of any of this material in the clean water composite. However, no conclusions can be clearly drawn from this data.

Table 4-68 lists the findings for the presence of seven serious carcinogens in stack emissions and water samples. Many of these compounds are found in the stack samples even though they were not determined to be present in the water. It is possible that the analytical detection limits for these materials was not reached in the clean water samples.

In the contaminated water tests, only one PAH was present in the stack samples which was not found in the water. No explanation is readily available except that the single water sample determination may not be representative of the inlet water in use during the quench stack test.

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TABLE 4-72. FINDINGS IN STACK AND WATER SAMPLES OF SELECTED POLYNUCLEAR AROMATIC MATERIALS

Test results and their correlation to NAS (National Academy of Sciences) carcinogenicity ratings.

NAS Notation*		Present in: Dirty Water	Clean Water
****	Dimethylbenz(a) anthracene	Stack	Stack
***	Benzo(c) phenanthrene	Stack,inlet,ret	Stack
***	Benzo(a)pyrene	Stack,inlet	Stack
**	Benzo fluoranthenes	Stack,inlet	Stack
*	Chrysene/Benz(a) anthracene	Stack,inlet,ret	Stack,H_2O
*	Methyl Chrysenes	Stack,inlet	Stack
*	Indene (1,2,3-cd) pyrene	Stack,inlet	Stack

These identified carcinogens are all going up stack even when not found in the water.

* 4 stars denote the highest carcinogenicity rating.

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TABLE 4-73.

TEST NO. 16C5PO

DATE/TIME PERIOD OF TEST: 9/15/76

POSITION IN STACK: 110

NUMBER OF QUENCHES SAMPLED: 4

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic: 108.6
Angle of Flow: 110°
Mean Vertical Velocity: 1728.36 (ft/min)
Mean Stack Temperature: 205°F
Mean Volumetric Flow: 244478 scfm
% Moisture by Volume: 9.6%
Molecular Weight of Stack Gas: 27.76
Mole Fraction of Dry Gas: 0.904

II. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross Sectional Area: 0.31 In/0.75 In^2
Pitot Tube Correction Factor: 1
Volume of Dry Gas Sampled: 6.66 scfd
Volume of Water Collected:
Cyclone: N/A
Impinger: 15 ml
Silica Gel: 0.0 mg
Net Sampling Time: 9.2 min

III. SITE CONDITIONS

Ambient Temperature: 68°F
Ambient Humidity: 79% RH
Ambient Pressure: 29.31 mm Hg
Wind Direction: 220°
Wind Velocity: 6.906 mph
Weather Conditions:

IV. COKE PROCESSING CONDITIONS

Oven/Battery: NA
Greenness Rating: NA
Carload: NA

509673

TABLE 4-74.

TEST NO. 13A5P1

DATE/TIME PERIOD OF TEST: 11/3/0055-0110

POSITION IN STACK: A-5

NUMBER OF QUENCHES SAMPLED: 3

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic: 101.3
Angle of Flow: 90°
Mean Vertical Velocity: 21.75 ft/min
Mean Stack Temperature: 180°F
Mean Volumetric Flow: 186110 scfm
% Moisture by Volume: 13.2%
Molecular Weight of Stack Gas: 27.38
Mole Fraction of Dry Gas: NA

II. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross Sectional Area: .44 In/.152 In^2
Pitot Tube Correction Factor: 1.0
Volume of Dry Gas Sampled: 7.82 scfd
Volume of Water Collected:
Cyclone: NA
Impinger: 12 ml
Silica Gel: 13 mg
Net Sampling Time: 8.1 min

III. SITE CONDITIONS

Ambient Temperature: 42°F
Ambient Humidity: 73 RH
Ambient Pressure: 29.13 mm Hg
Wind Direction: 220°
Wind Velocity: 69
Weather Conditions:

IV. COKE PROCESSING CONDITIONS

Process Data - Coke Oven

Ref. Code	Date	Battery #	Oven #	Coking Time
13A5P1	11/03/76			24 Hrs
13A5P1	11/03/76	G	2	24 Hrs
13A5P1	11/03/76	G		24 Hrs

Greenness Rating for Coke Entering Quench Tower

Ref. Code	Date	Time	Oven #	Greeness Rating
13A5P1	11/03/76	00:55	-	1N
	11/03/76	01:00	G-2	1N
	11/03/76	01:10	G	5N

N = Normal Load of Coke in Car
M = More than Normal Amount of Coke
L = Less than Normal Amount of Coke

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TABLE 4-75.

TEST NO. 11MP1

DATE/TIME PERIOD OF TEST: 11/3/1945-2000

POSITION IN STACK: Midpoint

NUMBER OF QUENCHES SAMPLED: 3

I. SUMMARY OF FLOW PARAMETERS

Net % Isokinetic: 107.2
Angle of Flow: 110°
Mean Vertical Velocity: 30.93 ft/min
Mean Stack Temperature: 180°F
Mean Volumetric Flow: 251822 scfm
% Moisture by Volume: 15.5%
Molecular Weight of Stack Gas: 27.13
Mole Fraction of Dry Gas: .845

II. SAMPLING TRAIN PARAMETERS

Nozzle Diameter/Cross Sectional Area: .375 In/.0031 In^2
Pitot Tube Correction Factor: 1.0
Volume of Dry Gas Sampled: 7.46 scfd
Volume of Water Collected:
Cyclone: NA
Impinger: 8 ml
Silica Gel: 20.8 mg
Net Sampling Time: 7.0 min

III. SITE CONDITIONS

Ambient Temperature: 39°F
Ambient Humidity: 37 RH
Ambient Pressure: 29.07 mm Hg
Wind Direction: 250°
Wind Velocity: 6.9
Weather Conditions:

IV. COKE PROCESSING CONDITIONS

Process Data - Coke Oven

Ref. Code	Date	Battery #	Oven #	Coking Time
11MP1	11/03/76	G	37	24 Hrs
11MP1	11/03/76	G	27	24 Hrs
11MP1	11/03/76	G		24 Hrs

Greenness Rating for Coke Entering Quench Tower

Ref. Code	Date	Time	Oven #	Greenness Rating
11MP1	11/03/76	19:45	G-37	1L
	11/03/76	19:50	G-27	1N
	11/03/76	19:55	-	1N

N = Normal Load of Coke in Car
M = More than Normal Amount of Coke
L = Less than Normal Amount of Coke

509675

TABLE 4-76. LEVEL-1 GRAVIMETRIC ANALYSIS OF EACH FRACTION

Sample	Fraction Number, weight in mg								
	1	2	3	4	5	6	7	8	Total
Coke-quenched with Clean Water[1]	0.35	0.030	0.060	0.049	0.069	0.060	0.11	0.090	0.834
Coke-quenched with Contaminated Water[1]	0.79	0.022	0.038	0.973	0.12	0.042	0.19	0.030	1.313
Acetone Wash - Blank[2]	0.14	0.036	11.6	1.38	0.24	0.062	1.52	0.43	15.408
Clean Water Samples (Combined)[2]	0.90	0.19	0.57	0.37	2.72	0.23	2.95	0.22	8.150
Contaminated Water-Inlet[2]	0.13	0.23	2.54	7.74	12.5	1.78	12.6	0.28	37.800
Contaminated Water-Return[2]	0.09	0.054	1.57	1.58	21.0	0.9	11.03	0.42	36.644
Contaminated Water-Makeup Liquor[2]	0.12	0.044	2.8	6.1	13.1	2.28	7.45	0.26	32.154
Stack Test 16C5PO (Contaminated)[3]	2.7	0.31	44.	3.4	1.58	4.77	13.3	6.2	76.260
Stack Test 13A5P1 (Clean)[3]	2.8	422.	335.	34.	11.5	3.25	42.0	10.8	861.350
Stack Test 11MP1 (Clean)[3]	2.1	203.	271.	88.	9.3	2.96	22.9	8.51	607.770

[1] 20 gram sample submitted for analyses
[2] 250 ml sample submitted for analyses
[3] See Collection Data Section 4.3.4

5096/6

TABLE 4.77. LEVEL-1 INFRARED ANALYSIS

Sample No.	Fraction 1	2	3	4	5	6	7	8
Stack Test 13A5P1 (Clean)	aliphatic HC aromatic HC silicone grease		Phthalate(s)(2)		carboxylic acid		Similar to acrylate polymer	crystalline hydrocarbon structure ester (1)
Stack Test 11MP1 (Clean)	aliphatic HC silicone		Phthalate(s)		aldehyde (aliphatic + carboxylic acid + ?	aldehyde + acid + ?	much polar material possible acrylates plus other esters	Same as fraction 7 without phthalate

(1) Surprising to find an ester in Fraction 8, could be introduced during separation.
(2) These phthalates as well as those in the rest of the set seam to be composed of changing amounts of at least three phthalates. The most likely candidates are:
  (a) Butyl benzyl phthalate
  (b) Dimethyl cyclohexyl phthalate
  (c) Mixed alcohol phthalate(s).

Note that some of the fractions such as 16A - 3,4 and 13A - 3,4 had so much of the phthalates that we had to run the spectra as liquid films rather than solvent cast dry films.

509677

TABLE 4-77. (Continued)

Sample No.	Fraction 1	2	3	4	5	6	7	8
Contaminated Water Inlet	aromatic HC (3) aliphatic HC	probably condensed ring aromatic(1)	carbazole and/or indole types		Phenols	Phenols	Carboxylic acid or possible quinone	possible amine HCl salt
					Nitrile or N-H compound	Nitrile or N-H compound		
Contaminated Water Make-Up Liquor	aliphatic Hc	trace ester (normal levels)	carbazole and/or indole types		Phenols	Phenols	Conjugated aromatic carboxylic acid and other C-O	Similar to 7 but with less of acid structure
Clean Water Samples Combined	aliphatic HC	aromatic ester	Aromatic (2) ester W/alcohol group as well	Similar to No. 3 but more aromatic nature	Phenols	Phenols	aromatic carboxylic acids	aromatic carboxylic acids
						Nitrile	Nitrile	ketone, prob. aromatic

(1) I1-2 is most likely a condensed ring aromatic, benzopyrene(s) being a definite possibility.
(2) Note that this could be an aliphatic alcohol and an aromatic ester, or an aromatic ester with an OH on a side chain of the aromatic ring, or be directly on the ring (a phenol).
(3) HC denotes hydrocarbon.

509678

TABLE 4-77. (Continued)

Sample No.	Fraction 1	2	3	4	5	6	7	8
Acetone Blank	Polyethylene[2] Silicone grease	norm ants of aliphatic and aromatic hydrocarbon ester (1)	Phthalate(s) Polyethlene		ester Polyethylene	Phthalate(s)	Aliphatic	ester IV
Coke Quenched with Clean Water	normal aliphatic hydrocarbons	normal aromatic ester I	hydrocarbon ester I (aromatic) Phthalate I	Phthalate I	Phthalate		aliphatic ketone	normal polar materials
Coke Quenched with Contaminated Water	Aliphatic hydrocarbon Silicone grease		Phthalate I	(most in 4)		Phatalate II poss. ester	aliphatic ketone	normal polar materials

(1) Normal means similar in levels to that seen in the BCL tenax washed blanks
Phthalates are the most common spectral feature in these series.
"Phthalate" may indicate more than one phthalate, i.e., a mix of phthalates.

(2) "Polyethylene" does not exclude the possibility of a long chain hydrocarbon(s).

509670

TABLE 4-77. (Continued)

Sample No.	Fraction 1	2	3	4	5	6	7	8
Contaminated Water Return	Aliphatic hydrocarbon (normal levels)	trace ester (normal)	Probable (1) carbazole carbazole indole types	Phenols other C-O compounds	Phenols	cresol? nitrile	Carboxylic acid aromatic possible C≡N compound	amine HCl sa
Stack Test 16C5PO Contaminated	Aliphatic hydrocarbon silicone grease	Phthalate silicone grease	Phthalate(s)		ketone carboxylic acid		carboxylic acid	possible isothiocyanate possible phosphine

(1) We have never seen this in a Level 1 before.

509660

TABLE 4-78. PCM QUANTIFICATION

Component	NAS Notation	Test 11A	Test 13A	Test 16A	Inlet 1	Return 1	Make-up Liquor	Combined Clean H_2O	Dirty Quenched Coke/20g	Clean Quenched Coke/20g
York Research										
Anthracene/Phenanthrene		142 ng	107 ng.	172 ng	115 ng	35 ng	39 ng	41 ng	31 ng	30 ng
Methyl anthracenes		62	60	70	34	31	40	34	4.0	4.0
Fluoranthene		81	41	90	120	29	27	35	24	24
Pyrene		57	36	67	71	27	27	33	24	23
Methyl Pyrene/Fluoranthene		41	37	51	45	25		23		
Benzo(c)phenanthrene	***	52	35	54	27	4.0				
Chrysene/Benz(a)anthracene	*	53	38	74	75	35		39		
Methyl chrysenes	*	4.0	4.0		38					
Dimethylbenz(a)anthracene	****	60	40							
Benzo fluoranthenes	**				51					
Benz(a)pyrene	***				11					
Benz(e)pyrene					21					
Perylene										
Methylbenzopyrenes										
3-Methylcholanthrene	****									
Indeno(1,2,3,-cd)pyrene	*				15					
Benzo(ghi)perylene										
Dibenzo(a,h)anthracene	***									
Dibenzo(c,g)carbazole	***									
Dibenz(ai and ah)pyrenes	***									
Coronene										
TOTAL										

4.3.5 Sampling and Analysis

Sampling of stack emissions was done through the use of the high-volume Aerotherm train as described in Section
A modification in the train, specific to organic sampling, was made at the point just after the heated filter box and before the impinger train (Figure 4-38). The unit employed was a Battelle Adsorbent Sampler.[27] It is a porous polymer adsorbent trap which consists of a water jacket surrounding both a cooling coil and a column of Tenax adsorbent (Figure 4-39). The cooling effect ensures higher adsorbent efficiency. However, the temperature is maintained above dewpoint to prevent water condensation.

One stack test was done while contaminated water was in use for quenching and two while clean water was in use. The sampling location for all three tests was at point ten (10).

For each test the probe and cyclone rinses, filter, and adsorber were sent to Battelle Columbus Laboratories, Columbus, Ohio, where further extractions were combined to yield three samples corresponding to the clean and contaminated tests.

Water samples were taken by grab sampling from the inlet and return (clean and contaminated), liquor, and whart (service) lines several times daily. Each sample was about one gallon and represented a composite of approximately four quenches.

Quenched coke samples were taken by grab sampling once daily. . Each sample represented a composite of approximately 8 to 12 quenches.

The stack, water, and coke samples were extracted with methylene chloride or pentane as prescribed by the Level I scheme. The clean water samples were combined and analyzed as a composite. The various portions of each stack sampling train were also extracted and combined to make one sample per train.

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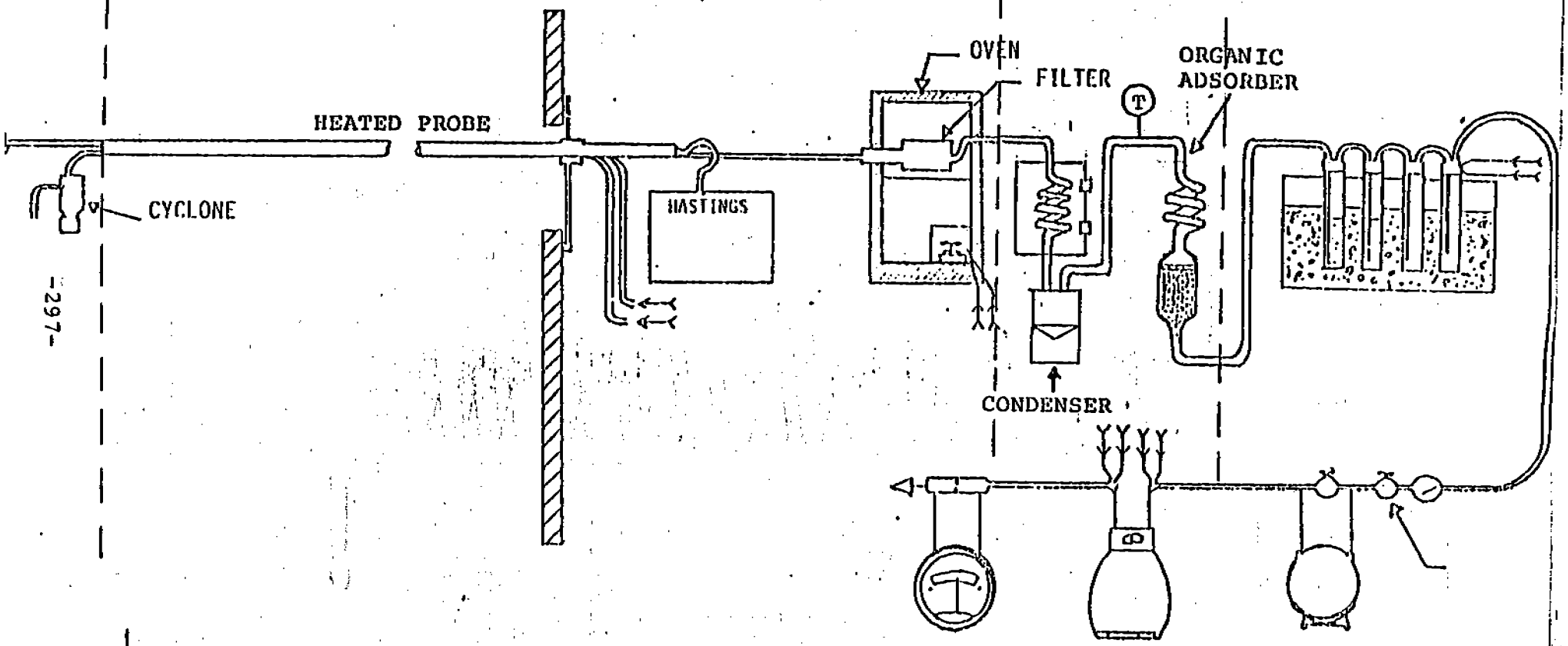
FIGURE 4-38.

SAMPLING TRAIN



= portion of train to be analyzed as a unit

(T) = location of temperature recording device

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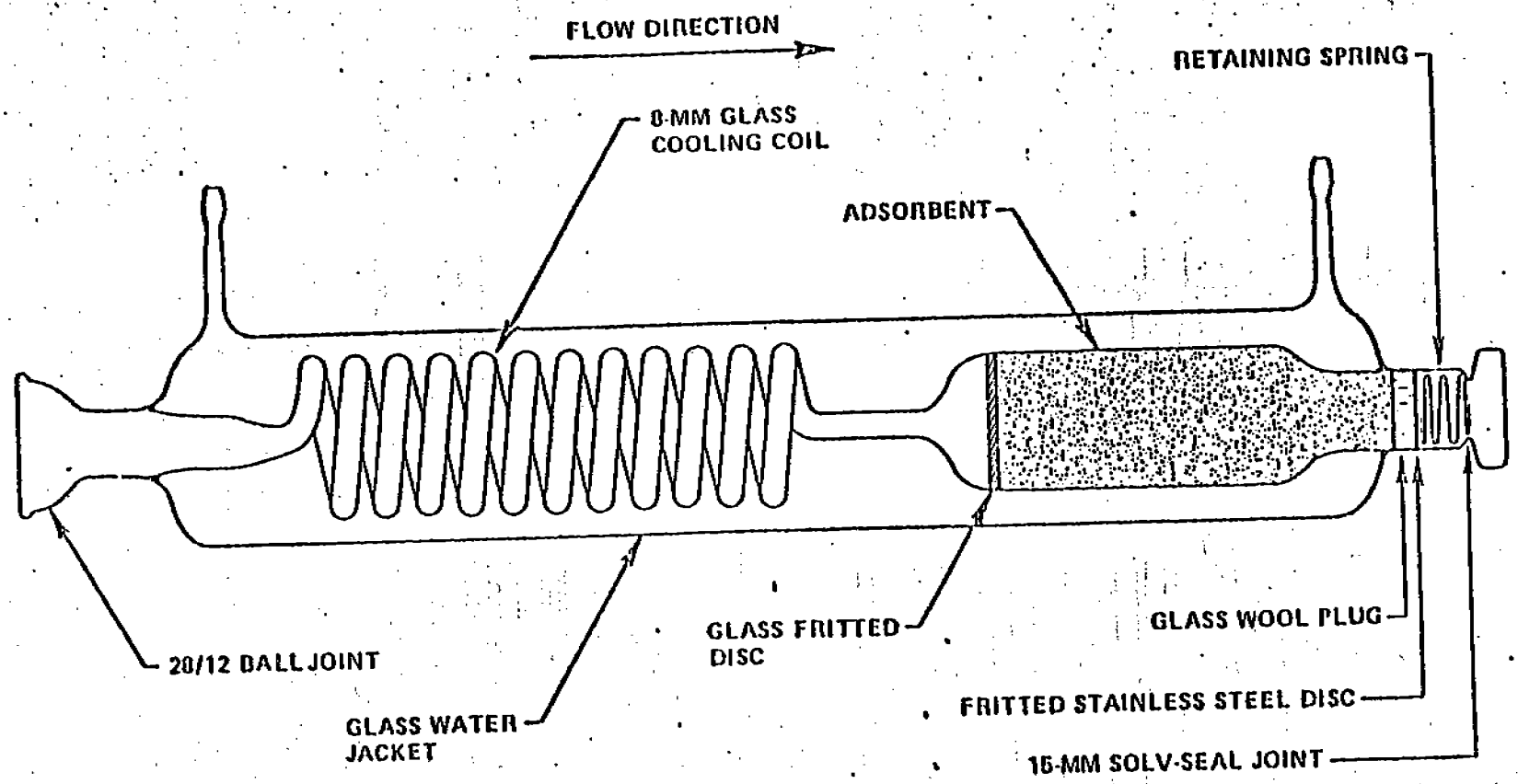

FIGURE 4-39. ADSORBENT SAMPLING SYSTEM

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Following the appropriate extraction procedures for each sample, liquid chromatography was begun. Eluting with solvents and solvent mixtures of increasing polarity on a silica gel column separated the sample into 8 fractions. A gravimetric determination for each fraction was made before further analysis.

The eight fractions representing each sample were analyzed by a Digi-Lab Fourier Transform Infrared Spectrometer Model 14. The organic compound classes detected in each fraction are shown in the infrared results section.

An aliquot of each sample extract was isolated by liquid chromatography using stepwise gradient elution on silica gel. GC-MS analysis of this fraction was done for all detectable PAH species from anthracene through coronene. GC separation was achieved on 3 percent Dexsil 300 column, programmed from 170 to 340°C at 4°C min^{-1}. Quantitative GC-MS analysis was accomplished by means of sequential specific ion monitoring, using a Finnigan 3200 mass spectrometer with methane (chemical ionization). Species not reported were below the detection limit, which was 1 ng.

Treatment of data on water(composite sample clean water)

The three (3) clean water samples for inlet, return, and make-up liquor (each 250 mls) were combined by Battelle labs to make a 750 ml composite sample. LC-FTIR Analysis resulted in amounts for different organic classes given in mg/750 ml water. But because this sample is a composite, the results cannot be converted to lbs/quench as were values for other samples.

In the quenching process, the concentration of organic compounds in the inlet water is ultimately a function of the mixing between return and make-up water. It would seem reasonable to assume that the average concentration of organic compounds in return and make-up water is approximately the

509683

the same as the concentration of these compounds in inlet water. The values for TOC (total organic carbon) in clean water tent to substantiate this reasoning:

Clean H_2O	inlet	return	Make-up
	9.6 mg/l	13.7 mg/l	3.8 mg/l

avg. for return and make-up = 8.8 mg/l
avg. for all = 9.0 mg/l

The average value for return and make-up is close to the inlet value. This may be typical of their mixing in the quenching process. The average of all three is also close to the inlet value. This mixing of all three fractions is what happened when a composite was made for analysis. Therefore, the values resulting from analysis are probably representative of the concentration of organic compounds in the inlet water.

For the conversion of mg/l values to lbs/quench for the clean water composite fractions, the total inlet water of 34,822 l. (9200 gal)/quench is used rather than an average of the total volume for inlet, make-up, and return.

509683

4.3.6 Calculations

These calculations were used to obtain concentration values and lbs/quench for Classes of Organic Compounds and PAH found in Tables 4-68 and 4-73.

Stack Gas

given in $\frac{mg}{Vnstd}$ where: Vnstd = Vscfd, volume of dry gas sampled.

1) $\frac{mg}{Vnstd} \times \frac{1}{0.02832 \frac{scmd}{scfd}} \quad \frac{Mg}{m^3}$

2) $\frac{mg}{Vnstd} \times \frac{gr}{mg} \times 0.00857 \times Qs \times \frac{hr}{min} \times \frac{min}{quench} = \frac{lbs}{quench}$

where: gr/mg = 0.0154

Q_s = mean volumetric flow of gas

hr/min = 0.01667

min/quench = 2.25

Water

$\frac{gm}{mg} = 0.001$

lb/gm = 0.0022

Contaminated water given in mg/250 ml

3) $\frac{mg}{l} \times \frac{1}{quench} \times \frac{gm}{mg} \times \frac{lb}{gm} = lb/quench$

where: l/quench for inlet = 34,822 l

return = 27,631 l

makeup = 7,192 l

Clean water composite given in mg/750 ml

509687

4) $\frac{mg}{l} \times \frac{34,822\ l}{quench} \times \frac{gm}{mg} \times \frac{lb}{gm} = \frac{lb}{quench}$

where: $\frac{34,822\ l}{quench}$ is average for inlet water*

Coke Quenched

given in mg/20 gm

5) $\frac{mg}{gm} \times \frac{gm}{quench} \times \frac{gm}{mg} \times \frac{lb}{gm} = \frac{lb}{quench}$

where: gm/quench = 8,697,600

gm/mg = 0.001

lb/gm = 0.0022

* See "Treatment of data on water composite sample".

509663

5.0 WATER FLOW AND CONTAMINATION PARAMETERS

The basic functions of the quench tower are to quickly provide a large quantity of water to cool the incandescent coke below its ignition temperature, and to recover the excess water for re-use.

Most of the volatile material present in the coal is driven off by the coking process. However, a certain amount of both organic and inorganic materials are introduced to the quench process by the coke. These materials then enter the atmosphere during subsequent quenching operations. In addition, when process flushing liquor is used as a make-up source for the quench water, additional contaminants are introduced. This flushing liquor is used to cool the gases produced during the coking operation.

In order to assess the contributions of these sources, and to make determinations regarding their ultimate contributions to pollutant emissions, the chemical composition of the quench water was determined during varying operating conditions. Similarly, it was necessary to derive mass balances throughout the process to define the stream flows, which in many cases could not be directly measured.

To establish relationships, various parts of the process were isolated, and inputs and outputs analyzed. This is shown in Figure 5-1. Using this method, the following relationships are stated:

Around Boundary - - - - - - -	$Q_2 = Q_4 + Q_5$
Around Boundary -0-0-0-0-0-0-	$Q_6 + Q_2 = Q_1 + Q_4 + Q_3$
Around Boundary -X-X-X-X-X-X	$Q_6 + Q_5 = Q_1 + Q_2$

These relationships involve the following assumptions:

509687

- Return of water in the ditch leading to the sump was not significantly retarded.
  - This ditch was sloped toward the sump and was above its level. The ditch could be partially obstructed by coke but the force of the water flow was sufficient to keep the ditch open. The ditch was usually empty by the time the next car arrived for quenching.
- Flow into the head tank exactly equalled flow out of it.
  - To assure this, the tank was filled to overflowing when measurements concerning this quantity were performed.
- All losses are included in Q_3.
  - Car drainage and the amount of water retained by the quenched coke were estimated and are subsequently discussed.
  - The baffles and walls of the tower were dripping wet, but the quantity involved from quench to quench would not measurably differ, and it was assumed that a state of equilibrium existed.
  - No other significant losses were apparent as from the bottom of the tower or from sump leakage.

Certain water flows such as Q_1 and Q_2 were measured, while others such as Q_4, Q_5 and Q_6 were calculated. Q_3 was an estimated value. The reliability of the quantities shown in Table 5-1 is reinforced by thermodynamic considerations. In Section 5.1.2, the amount of water required to cool the coke was calculated thermodynamically and the results are close to that reported as stack flow (Q_1).

Water flow quantities are identified in Table 5-1, and in Figure 5-1 are as follows:

509690

TABLE 5-1. WATER FLOW

Description	Identifier	(gals/quench) Min.	Max.	Avg.
Stack Flow	Q_1	900	2500	1800
Inlet to Nozzle (Sprayed on Coke)	Q_2	8100	10500	9200
Losses - retained by coke - car drainage - evaporation	Q_3	NA	NA	150
Return to Sump	Q_4	NA	NA	7300
Make-up to Sump	Q_5	NA	NA	1900
Moisture in Induced Air	Q_6	7	50	20

The contaminants in the quench water primarily originated from two sources - the coke itself, and the flushing liquor which had been previously used to cool the gases produced by the coking process.

A significant difference in the concentrations of certain chemicals present in the quench water was observed when the make-up to the quench water supply was provided by the flushing liquor (referred to as "contaminated" water), rather than the service (river) water supply.

As compared to instances in which the service water was used, those periods where flushing liquor supplied the make-up were accompanied by the following increases in contamination levels:

- Chlorine content in the quench water was approximately 10 times higher (when flushing liquor is used in the make-up).
- Ammonia content was approximately 50 times higher.
- Phenol content was approximately 500 times higher.
- Cyanide content was about 40 times higher.
- TOC was about 100 times higher.
- Total and dissolved solids were about 10 times higher.

509691

Oil and grease, suspended solids, and volatile solids were slightly higher when flushing liquor was used; sulfides and sulfate concentrations remained about the same, while calcium and sodium were either the same or slightly lower.

The concentrations of chlorides, ammonia, phenol, and cyanide were characterized as follows:

- They were present in the flushing liquor at a substantially higher level than in the service water.
- They were concentrated by the recycling of the quench water, and were found in even higher concentrations in the quench water than in the make-up water.
- In examining the ratios of clean vs. contaminated quench water constituents, it is evident that relative concentrations remained approximately constant.

5.1 Water Flow

5.1.1 Water Balance

Measured Flow

Stack Water Flow (Q_1)

The stack water flow (Q_1) ranged between 900 to 2500 gal/quench, and averaged 1800 gal/quench. This average was for 25 tests covering 101 quenches as detailed in Section 4.0, and summarized in Table 5-2. This quantity includes the water droplets collected in the in-stack cyclone and the water collected in the impinger section of the EPA Method 5 sampling train.

509692

Figure 5-1

WATER BALANCE

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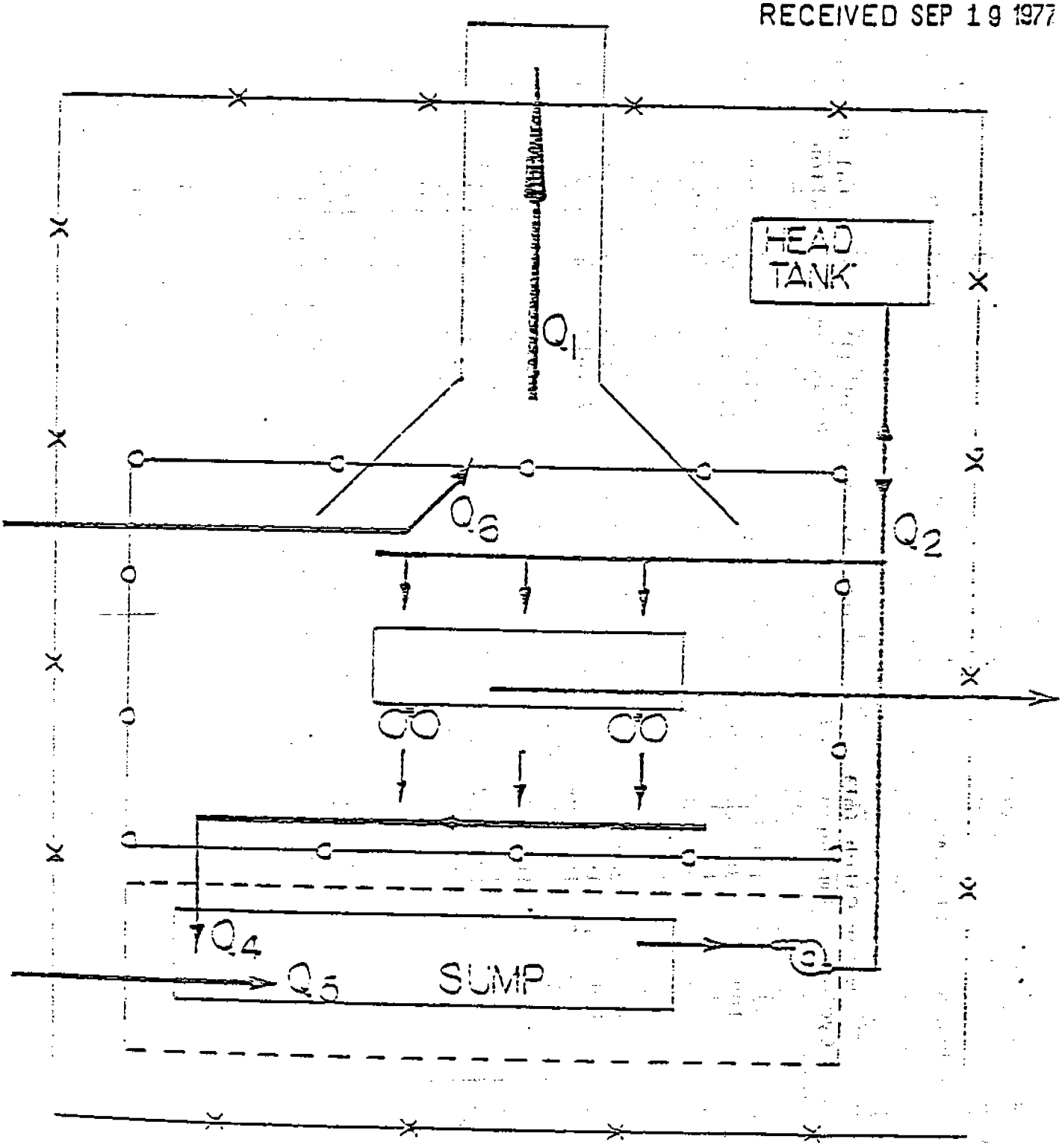

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TABLE 5-2. UP-STACK WATER FLOW AS EXTRAPOLATED FROM CYCLONE AND IMPINGER CATCH

Test Code Identifier	Water Catch (ml) Cyclone	Water Catch (ml) Impinger	Water Catch (ml) Total	Quantity Up-Stack (lbs) By Cyclone	Quantity Up-Stack (lbs) By Impinger	Total Up-Stack Gallons	Total Up-Stack Pounds
4B20	75	171	246	5871	13,386	2309	19,257
5B50	100	305	405	4934	15,049	2396	19,983
6B80	70	103	173	3557	5,234	1054	8,790
7C50	30	271	301	1524	13,771	1834	15,295
8C20	65	197	262	5088	15,420	2459	20,508
9C80	20	282	302	1016	14,329	1840	15,346
10D50	110	268	378	5592	13,623	2304	19,215
11D80	110	197	307	5591	10,013	1871	15,604
12D20	50	195	245	2541	9,911	1493	12,452
13A50	60	150	210	3050	7,625	1280	10,675
14A20	50	107	157	3913	8,372	1473	12,285
15A80	90	168	258	7046	13,153	2422	20,199
1C81	40	135	175	2648	8,936	1389	11,584
3C21	55	205	260	2787	10,390	1580	13,177
1B51	29	209	238	1842	13,278	1813	15,120
2B21	15	252	267	789	13,263	1685	14,053
3D81	49	173	222	3113	10,990	1691	14,103
4D51	37	192	229	1899	9,852	1409	11,751
5D21	42	210	252	2171	10,856	1562	13,027
6D81	56	230	286	3570	14,661	2186	18,231
7A51	18	147	165	1167	9,533	1283	10,700
8A81	44	93	137	2341	4,948	874	7,289
9A21	34	248	282	1785	13,018	1775	14,803
10	35	230	265	2184	14,354	1983	16,538
12	27	262	289	1723	16,724	2212	18,448
Average				3109	11,627	1767	14,757
Rounded	Average			3100	11,600	1800	14,700

509694

The following calculation shows how Table 5-2 was constructed:

Taking Test No. 4B20 (which consisted of four separate quenches) from Table 4-3 as an example:

75 ml of water caught in the cyclone
171 ml of water caught in the impinger
Total: 246 ml of water collected during the four quenches

Assuming:

- The gas flow was uniform, or could be averaged.
- Water concentration was uniform in the gas sample and in the tower cross-section for the entire test period, or could be averaged.
  - There was variability from test location to test location, and individual test results ranged from 900-2500 gal/quench. However, the overall water balance and thermodynamics (discussed in Section 5.1.2) allow the averaging of flow and water concentrations.

Based upon the above assumptions, the quantity of water evaporated up the stack is given as:

$$\frac{\text{Quantity of Water Collected}}{3785} \times \frac{(\text{Tower Diameter})^2}{(\text{Orifice Diameter})^2} \text{ gal/test}$$

For Test No. 4B20

$$\left[\frac{246}{3785}\right]\left[\frac{(188.5)^2}{(0.50)^2}\right] = 9237 \text{ gal/test}$$

$$\left[\frac{9237}{4}\right]\left[8.34\right] = 19.259 \text{ lbs water/quench}$$

Inlet to Nozzle Flow (Q_2)

The quantity Q_2 (inlet to nozzle) was also measured. This was done with an ultrasonic flow meter, called a Clampitron, which was mounted on the piping which supplied the nozzle header with water.

509695

This quantity ranged from 8100 - 1050 gallons of water per quench.

Using this device, the flows at several different locations were evaluated. These were:

- In the nozzle header
  - Position 3, close to the nozzles
  - Position 1, close to the pump
- In the vertical pipe coming from the head tank (Position 3)

These numbered locations are shown in Figures 5-2 and 5-3.

A preliminary check of the Clampitron was made on August 24 and August 30, 1976 during the velocity profile work. This check consisted of installing the sensor at Position 2 (Figure 5-2). In this position, ideal hydraulic flow conditions were indicated, and the instrument operated without any apparent fault. However, it was noted that the sump pump was controlled by the level in the head tank in such a way that the pump was activated during the quench itself. Since the flow quantities to be determined at Position 2 did not include provision for the amount being supplied by the sump pump during a quench, an attempt was made to install the sonic flowmeter at Position 3. However, here the exterior of the pipe was extensively corroded, and no coupling could be obtained. The pipe was deeply pitted, and the presence of a small leak suggested that it would not be feasible to grind the surface. As a result, the sonic couplers were installed at Position 1. This location, although not ideal, was the best that could be found. At this point, flow conditions did cause some turbulence; and additionally, the temperature was close to the boiling point of water, and there was reason to suspect the presence of vapor pockets and cavitation.

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FIGURE 5-2

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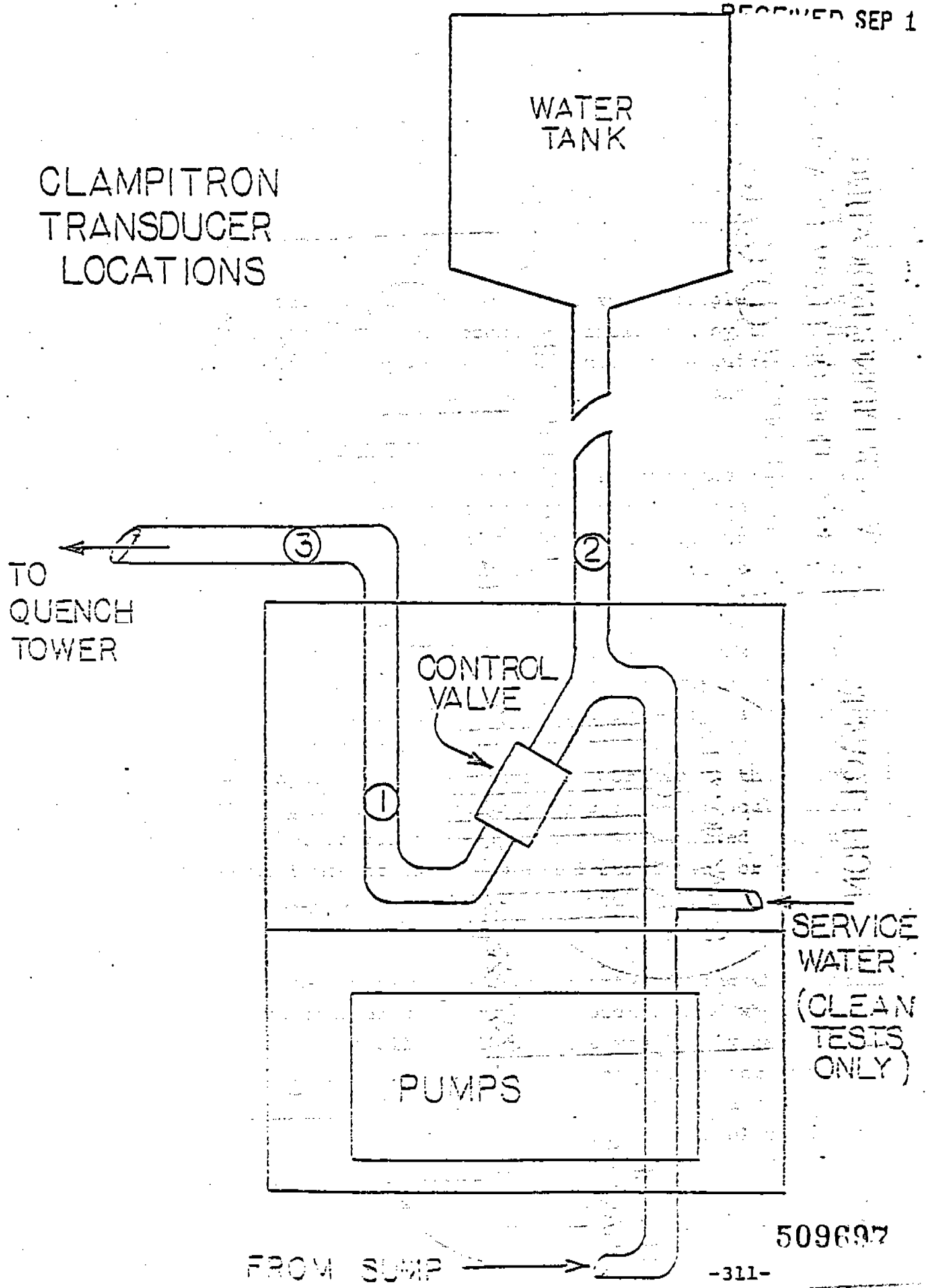

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Figure 5-3

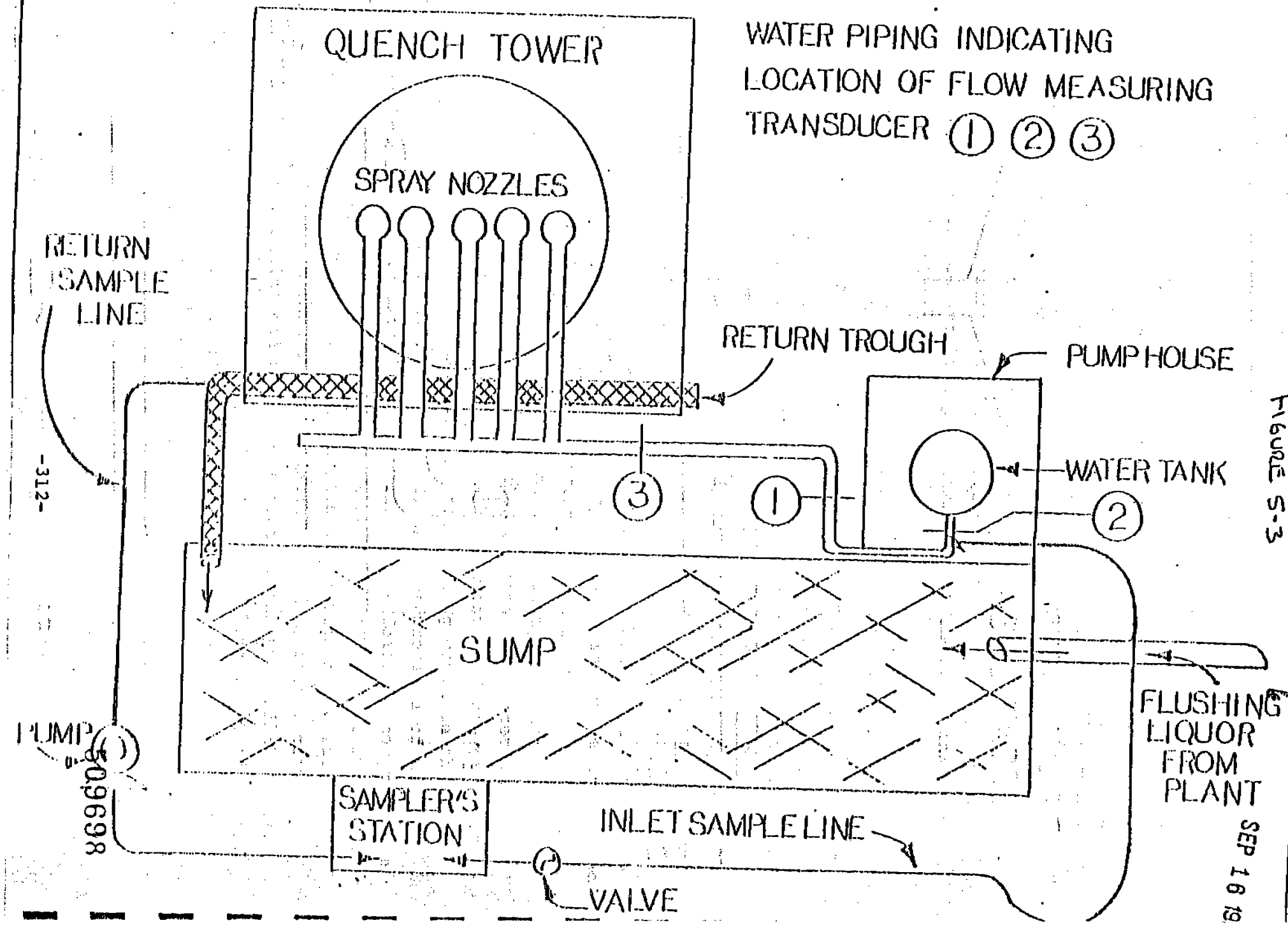

Figure 5-3

SEP 16 19

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Whenever the flow conditions and/or the sonic coupling were unsatisfactory, the instrument provided a warning through a "fault light". This indicated that the flow was not being accurately measured. When these conditions prevailed, the indicated flow was less than the actual flow.

During some of the tests with the sonic couplers located at Position 1, a fault condition indicated by the Clamp-itron caused some of the flow values to be quite low. These have been identified in Table 5-3 in order that they can be disregarded.

Review of all the flow quantities as reported in Table 5-3 indicates the amount of water going to the car was typically a little different for each car. Therefore, for each set of 4 quenches making up a test, some variation in the amount of water on to the car was expected.

This quantity was usually far in excess of the amount required for cooling the coke; generally by a factor of 4-8. The exact amount was not critical to the quenching operation, nor would variation in the quantity of water have much effect on the amount evaporated up the stack. Too much quench water for too long a period would allow the coke to retain more water than was desired for the subsequent use of the coke, and insufficient or poor distribution of the quench water would allow hot spots of unquenched coke to remain in the car.

Some of the low flow readings reported during the testing with contaminated water may have been caused when the head tank was not totally filled. This was likely because several times during the test period, quenching operations were discontinued on Tower No. 1 because of a clogged sump screen, pump failure, or failure of level controls both on the head tank and on the sump.

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In an attempt to minimize flow errors attributable to turbulence and cavitation, the pump was turned off during the quench. During tests when this was done, instrument fault conditions were reduced but not totally eliminated.

A final effort to improve the quality of the flow data was made by again installing the sonic couplers at Position 2 (the straight pipe coming down from the head tank), manually controlling the filling of this tank until it overflowed, and shutting off the pump for the actual quench. The clean make-up water source was closed manually with a shut-off valve to prevent service water from entering the car through the automatic controls. During these tests there was little or no disturbance of the flow. There was no fault condition during any part of these measurements, and therefore they appear to be the most accurate of the entire series of flow measurements. The results of the 8 quenches when this was done are reported in Table 5-3 and indicated as Tests 9A21 and 10M1.

During such manual operations there was always the possibility that a hot car might be brought into the tower before the head tank was full. This possibility had several dangerous consequences and was to be avoided. Therefore, the number of measurements that could be made under these ideal hydraulic conditions was limited.

509700

TABLE 5-3. WATER FLOW (INLET TO NOZZLE) MEASUREMENTS

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
8/24-30/76	--	2	6200	--	During Velocity Profile Work
9/8/76	4B20	2	NA	--	10 Quenches averaged
	4B20	2	NA	--	18 Quenches averaged
	4B20	2	NA	--	Transducer not installed
	4B20	2	NA	--	
9/10/76		2	4200	--	These data do not include all flow and is presented for comparison purposes
		2	3700	--	
		2	4400	--	
		2	4100	--	
		2	3000	--	
		2	2800	--	
		2	1800	--	
		2	2500	--	
		2	3800	--	
		2	3700	--	
		2	1400	--	
		2	4300	--	
	5B50	2	3500	--	Sonic Coupling Inadequate
	5B50	2	3300	--	
	5B50	2	4100	--	
	5B50	2	2200	--	
	5B50	2	1400	--	
9/11/76	6B80	2	1800	--	
	6B80	2	NA	--	
	6B80	2	NA	--	
	6B80	2	2400	--	
	6B80	2	2800	--	
	6B80	2	5900	--	
		2	6200	--	
		2	6400	--	
		2	5300	--	
	7C50	1	5500	--	

509701

TABLE 5-3. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
9/11/76	7C50	1	5800	--	
	7C50	1	1600	x	
	7C50	1	1600	x	
9/12/76	8C20	1	5400	--	
	8C20	1	5300	--	
	8C20	1	6100	--	
	8C20	1	6200	--	
		1	5600	--	
		1	6700	--	
		1	6600	--	
		1	3500	x	
9/12/76	9C80	1	NA	--	Readjusting Sensors
	9C80	1	NA	--	Readjusting Sensors
	9C80	1	NA	--	Readjusting Sensors
	9C80	1	8700	--	
	10D50	1	NA	--	Readjusting Sensors
	10D50	1	NA	--	Readjusting Sensors
	10D50	1	NA	--	Readjusting Sensors
	10D50	1	NA	--	Readjusting Sensors
9/13/76	11D80	1	6300	--	
	11D80	1	5100	--	
	11D80	1	6900	--	
	11D80	1	6300	--	
		1	6000	--	
		1	6300	--	
		1	6600	--	
		1	6000	--	
		1	5900	--	
		1	6200	--	
		1	6400	--	

5097702

TABLE 5-1. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
9/13/76	12D20	1	5300	--	
	12D20	1	5900	--	
	12D20	1	4800	--	
	12D20	1	NA	--	
		1	6200	--	
		1	1400	--	
		1	5000	--	
		1	3800	--	
		1	4900	--	
	13A50	1	NA	--	
	13A50	1	6500	--	
	13A50	1	6100	--	
	13A50	1	4700	--	
9/14/76	14A20	1	NA	--	Reinstalling sonic couplings
	14A20	1	NA	--	Ditto
	14A20	1	NA	--	"
	14A20	1	NA	--	"
		1	7200		"
		1	4000		"
		1	4400		
		1	6900		
		1	4800		
		1	7300		
	15A80	1	5300	--	
	15A80	1	1500	x	
	15A80	1	7500	--	
	15A80	1	7500	--	
		1	4500	--	
		1	7500	--	
		1	4400	--	
		1	4300	--	

509703

TABLE 5-3. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
9/14/76	15A80	1	5900	--	
		1	6500	--	
		1	6500	--	
		1	4300	x	
		1	3600	x	
		1	8000	--	
		1	6500	--	
10/5/76	1C81	1	7400	--	
	1C81	1	NA	--	
	1C81	1	NA	--	
	1C81	1	NA	--	
	1C81	1	NA	--	
	1C81	1	5600	--	
	1C81	1	7300	--	
	1C81	1	6600	--	
10/7/76	3C21	1	NA	x	
	3C21	1	NA	x	
	3C21	1	3300	x	
	3C21	1	5700	--	
		1	3900	--	
		1	6900	--	
		1	6900	--	
		1	6200	--	
		1	7000	--	
		1	6300	--	
		1	6800	--	
		1	6200	--	
		1	NA	--	
		1	8500	--	
		1	NA	--	
		1	9700	--	
		1	6900	--	

5097704

TABLE 5-3. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
10/29/76		1	11100	--	
		1	8400	--	
		1	11700	--	
	1B51	1	11100	--	
		1	9700	--	
		1	9500	--	
	1B51	1	11000	--	
	1B51	1	13500	--	
		1	7400	--	
		1	12200	--	
		1	11000	--	
		1	10200	--	
10/30/76		1	7600	--	
		1	5900	--	
		1	8000	--	
	2B21	1	8600	--	
	2B21	1	6400	--	
	2B21	1	7500	--	
	2B21	1	8000	--	
		1	4700	--	
	3B81	1	6200	--	
	3B81	1	8200	--	
	3B81	1	8200	--	
	3B81	1	7900	--	
11/1/76		1	7900	--	
		1	7900	--	
		1	7900	--	
	4D51	1	7900	--	
	4D51	1	8000	--	
	4D51	1	7900	--	

509705

TABLE 5-3. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
11/1/76	4D51	1	8200	--	
	4D51	1	7200	--	
		1	9600	--	
		1	3500	x	Pump off
		1	2500	x	Pump off
		1	8600	--	
		1	8200	--	
		1	7300	--	
		1	7500	--	
		1	10000	--	
	5D21	1	1000	x	Pump off
	5D21	1	4300	--	Pump off
	5D21	1	9700	--	Pump off
	5D21	1	9700	--	Pump off
		1	8600	--	Pump off
		1	6300	--	
		1	9200	--	
		1	7000	--	
		1	4100	--	
		1	7500	--	Pump off
		1	10000	--	Pump off
	6D81	1	5400	--	
	6D81	1	5700	x	Pump off
	6D81	1	9700	--	Pump off
	6D81	1	10000	--	Pump off
11/2/76		1	7200	--	
		1	7300	--	
		1	9700	--	
	7A51	1	8100	--	Pump off
	7A51	1	8200	--	Pump off
	7A51	1	8400	--	Pump off
	7A51	1	NA	x	Pump off

509702

TABLE 5-3. (CONTINUED)

Date	Test Code Identifier (where applicable)	Sensor Position (Ref. Fig. 5-2)	gal/quench	Fault Light Observed (x)	Comment
11/2/76	7A51	1	6700	--	
		1	7500	--	
	8A81	1	NA	x	Pump off
	8A81	1	3700	x	Pump off
	8A81	1	4000	x	Pump off
	8A81	1	7300	--	Pump off
11/2/76	9A21	2	9900	--	Pump off
	9A21	2	10300	--	Pump off
	9A21	2	10400	--	Pump off
	9A21	2	10500	--	Pump off
11/3/76	10M1	2	8100	--	Pump off
	10M1	2	8200	--	Pump off
	10M1	2	8100	--	Pump off
	10M1	2	8300	--	Pump off

509707

The measurements made in Position 2 on August 24 through September 11, 1976 should be disregarded due to the previously mentioned reasons. Also, those measurements that experienced several fault warnings from the Clampitron are marked with an X in Table 5-3 and should similarly be disregarded. The balance of the measurements were grouped by size classes and plotted on Figure 5-4. They averaged 7200 gal/quench. It is likely that this value is lower than the actual flow due to occasional instrument fault conditions caused by turbulence and cavitation.

The 20 water flow measurements made with the pump shut off (eliminating several where a fault was noted) averaged 8800 gal/quench. However, some of these still included an occasional fault condition and are probably slightly low due to turbulence caused by the valve and elbow. Therefore, the 9200 gallon average rate determined during quenches No. 9A21 and 10M1 provide the best average rate of water to the spray nozzles. This average appears adequate for the purposes of calculating a water balance and a heat balance of the quenching operation.

Estimated Flows

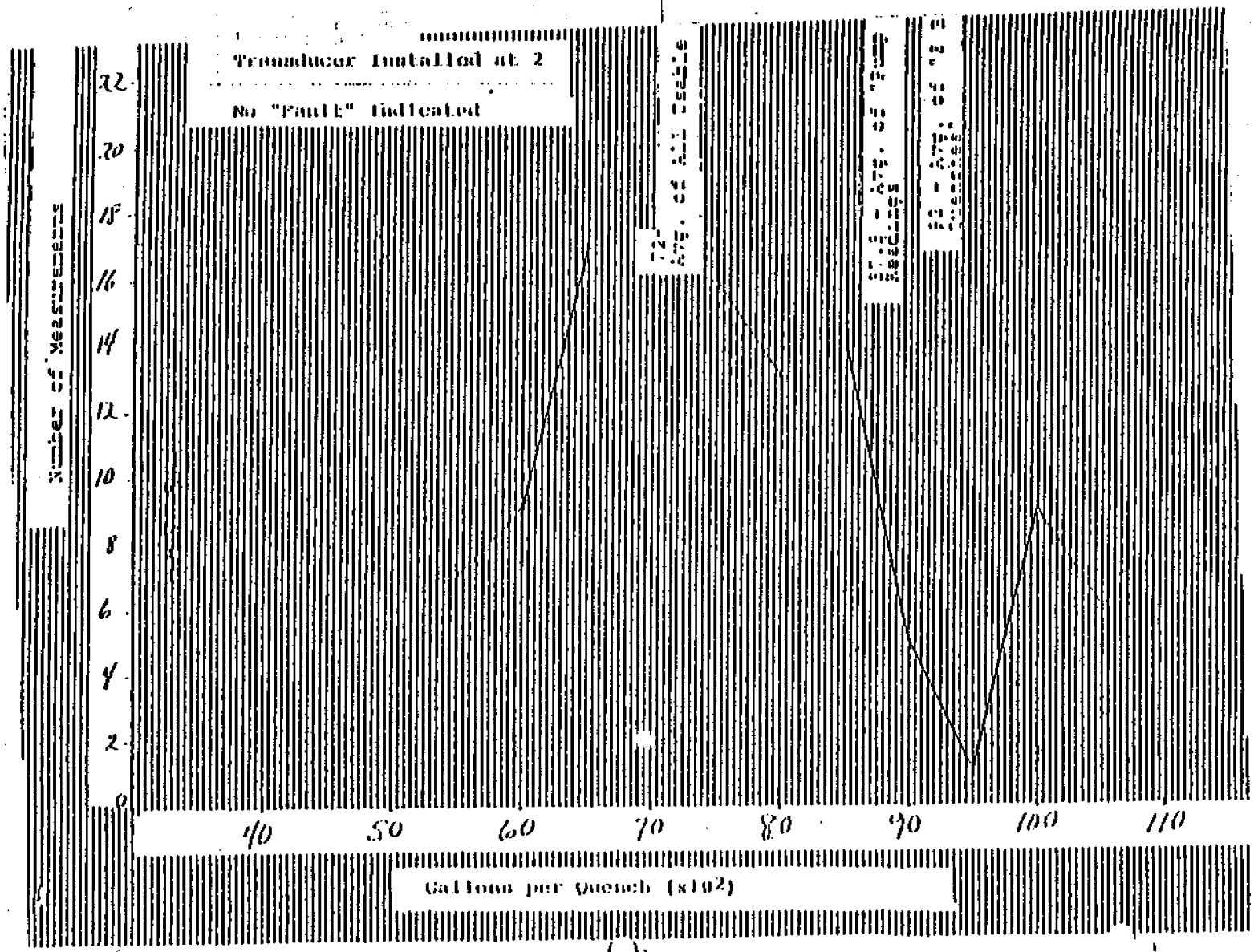
Losses (Q_3)

Water losses (Q_3) were estimated to be 154 gal/quench, as follows:

Retained by coke (est. @ 5% wt. of coke) . .	115 gal/quench
Drainage from car	9 gal/quench
Evaporation from the sump surface	25 gal/quench
TOTAL	149 gal/quench

- The amount of moisture retained by the coke as it left the quench tower was estimated to be about the same as the average moisture content of coke samples as reported in Section 6.0.

509708


Transducer Installed at 2
No "Fault" Indicated
Number of Measurements
0
2
4
6
8
10
12
14
16
18
20
22
40
50
60
70
80
90
100
110
Gallons per Quench (x102)

509700

TABLE 5-4. TABULATION OF SUMP DEFICIT DATA

Date	Test Code Identifier	No. of Quenches	Sump Level Deficit(in.)	Equivalent Water Volume in gal/quench*
10/6/76		1	1.500	1554
10/6/76		1	1.250	1295
10/6/76		1	1.500	1554
10/8/76		1	1.750	1813
10/8/76		2	2.500	2590
10/8/76		4	6.000	6215
11/1/76	4D51	1	0.875	906
11/1/76	4D51	1	1.000	1036
11/1/76	5D51	1	1.188	1230
11/1/76	5D51	1	1.250	1295
11/1/76	5D51	1	1.500	1554
11/2/76	6D81	1	1.375	1424
11/2/76	6D81	1	1.250	1295
11/2/76	7A51	1	1.188	1230
11/2/76	7A51	1	0.750	777
11/2/76	8A81	1	0.875	906
11/2/76	8A81	1	1.750	1813
11/2/76	9A21	1	1.188	1230
11/2/76	9A21	2	1.625	2719
11/2/76	9A21	1	1.250	1295
11/3/76	10M1	1	1.063	1101
11/3/76	10M1	1	1.313	1360
11/3/76	10M1	1	1.063	1101
11/3/76	13A5P1	1	1.188	1230
11/3/76	13A5P1	1	1.000	1036
11/3/76	13A5P1	1	1.250	1295
11/4/76	13A5P1	1	0.875	906
			Mean	1305
			Median	1360

* Based upon 1036 gallons/inch of sump level.

509710

- Drainage from the car was observed, and although no actual measurements were made, the estimate is considered reasonable.
- Evaporation from the sump surface was estimated based upon the following relationship:[28]

$$W_v = \frac{955 + 0.425\ V\ (e_w - e_a)}{\lambda}\ S$$

where: S = Cross-sectional area (1662 ft^2)

V = Air flow (440 ft/min assumed)

λ = Latent heat of vaporization (under temperature and humidity conditions from Table 5-3; 1052 Btu/lb)

e_w = Saturated vapor pressure of pure water (12.2 inches Hg at 170°F)

e_a = Vapor pressure of existing air-water (0.74 inches Hg at 170°F)

At these conditions, W_v = 5270 lbs/hr assuming 2.25 min/quench

W_v = 25 gal/quench.

Water was being continuously evaporated, and since the time period from quench to quench averaged 10 minutes or more, the quantity of water and chemicals evaporated over a substantial period of time would be greater than 30 gal/quench. (This is treated in more detail in Section 5.5). However, the time frame of measurement related to determining this water balance was the time of the quench (i.e., car-in to car-out). Therefore, only sump evaporation during this period is considered.

Since it was not possible to measure the quantity of return water, the portion of water evaporated (Q_1) from the 9200 gallons that cooled the coke could not be directly calculated. However, it was thought that the amount evaporated could be estimated in two other ways, and these values compared with the amount of water that

509711

was recovered from the stack gases (Q_1):

- One of these, a calculation based upon the dynamic considerations, conclude that the amount of water in the stack gases (1000 gallons) was within 20 gallons of the amount required for a latent heat balance.
- Another method of estimating the amount evaporated was to measure the change in water level in the sump (Table 5-4). However, this method proved unreliable since a loss of 65 gallons would be indicated by a change in water level of only 1/16 inch (see Table 5-4 and Figure 5-5).

Data from Table 5-5 illustrate the disappearance of water from the sump as determined by measuring the change in level due to usage of water in quenching.

Data from Table 5-5 is presented in Figure 5-6 indicating the disappearance of water from the sump as determined by measuring the change in level due to usage of the water in quenching.

All three of the methods are summarized in Table 5-5:

TABLE 5-5. QUANTITATIVE COMPARISON OF WATER DISAPPEARANCE FROM THE SUMP TO THE WATER RECOVERED FROM STACK GASES

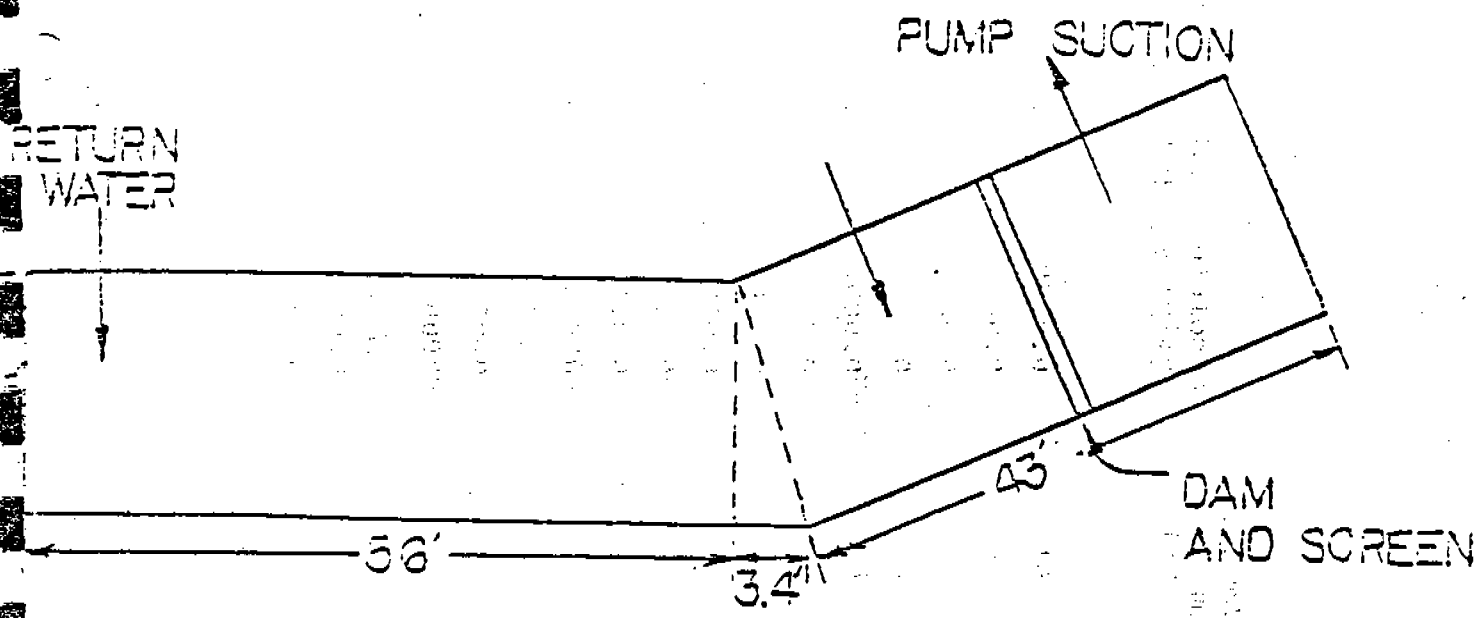
	GALLONS OF WATER PER QUENCH			
Number of Quenches Averaged	Water disappearance from sump by Measurement (Table 5-5) (Rounded)	Losses (Q_3)	Net water up the stack from sump measurements	Water recovered from stack gases (Q_1)
101				1800
32	1350	150	1200	

509712

RECEIVED SEP 19 1977

SEP 16 1977

Figure 5-5



16.5' x 56'	=	924 sq. ft.
16.5' x 43'	=	709.5 sq. ft.
½ x (3.4 x 16.5)	=	28.4 sq. ft.
		1661.9 sq. ft.

1661.9 sq. ft. x 1/12 x 7.48 gal/ft^3 = 1035.94 gal/1"

= 1035.94 gal/1" of depth

DIMENSIONS OF SUMP OF QUENCH TOWER #1

U. S. STEEL LORAIN WORKS

509713

TABLE 5-6. MOISTURE IN INDUCED AIR

Test Code Identifier	Volume scfmd	Sampling Time (Min)	lbs Air per Quench	Relative Humidity (%)	Ambient Temperature (°F)	Absolute Humidity	gals water per Quench
4B20	226275	9.7	41,117	NA			
5B50	201161	9.6	28,948	62	61	0.0070	24
6B80	175087	7.57	24,835	72	60	0.0082	24
7C50	174197	7.9	25,786	83	55	0.0074	22
8C20	167901	9.05	28,472	81	63	0.0096	33
9C80	155652	6.76	19,716	84	62	0.0096	22
10D50	153788	8.78	25,300	87	59	0.0096	29
11D80	161734	9.1	27,577	71	68	0.0105	34
12D20	202294	9.0	34,114	78	64	0.0100	40
13A50	182456	8.9	30,427	87	60	0.0098	35
14A20	233506	9.0	39,378	73	71	0.0115	53
15A80	166000	9.2	28,616	79	68	0.0118	40
16C5PO	265633	9.2	42,144	NA	NA	NA	
1C81	204452	9.3	35,627	56	54	0.0049	21
3C21	184985	9.1	31,542	57	48	0.0039	14
1B51	199894	9.8	36,706				
2B21	195338	9.5	34,771	55	42	0.0031	13
3B81	218638	9.4	38,509	65	44	0.0040	16
4D51	157604	9.6	28,350	54	38	0.0026	12
5D21	178030	9.4	31,357	50	40	0.0028	9
6D81	152613	9.5	27,166	75	29	0.0030	11

509714

TABLE 5-6. (Continued)

Test Code Identifier	Volume scfmd	Sampling Time (Min)	lbs Air per Quench	Relative Humidity (%)	Ambient Temperature (°F)	Absolute Humidity	gals water per Quench
7A51	207740	9.7	3,775	62	39	0.0032	10
8A81	173289	9.5	30,846	43	51	0.0029	11
9A21	194496	9.5	34,622	46	50	0.0035	13
10M1	175486	9.7	31,895	46	50	0.0035	14
11MP1	251822	7.0	44,039	31	44	0.0020	7
12M1	236107	9.2	40,701	46	35	0.0021	10
13A5P1	186110	8.1	37,662	NA	NA	NA	
AVERAGE			32,000				23

509715

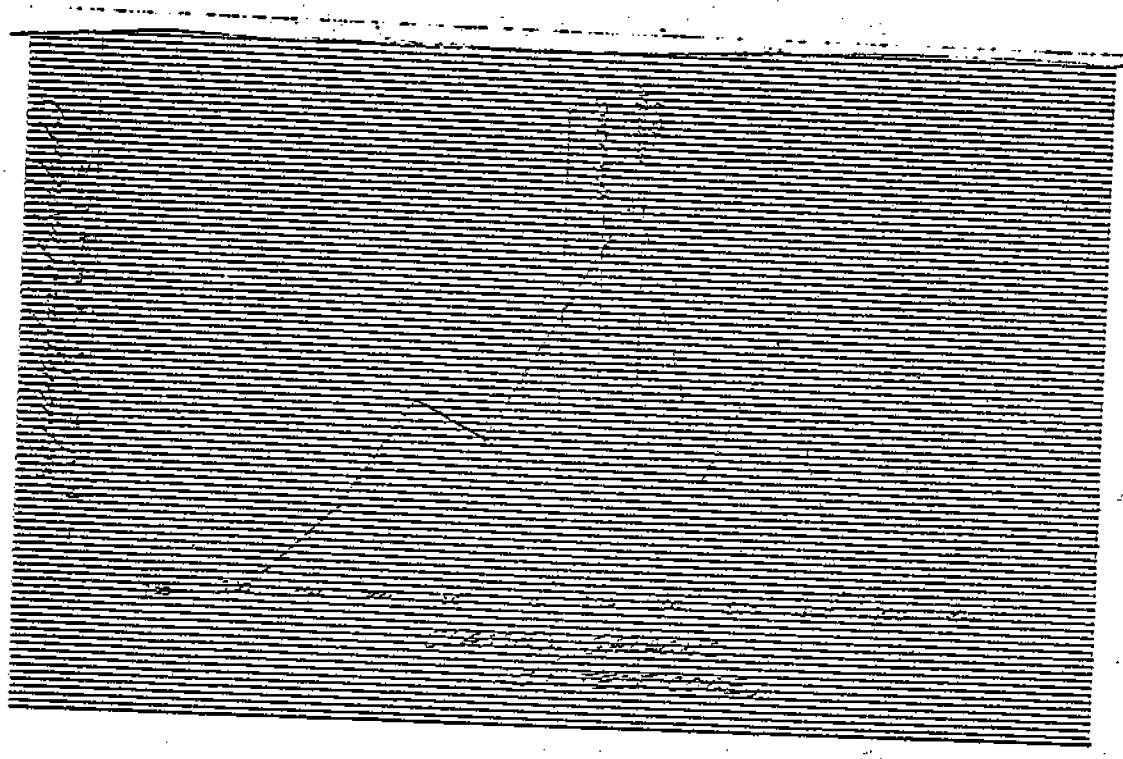


FIGURE 5-6

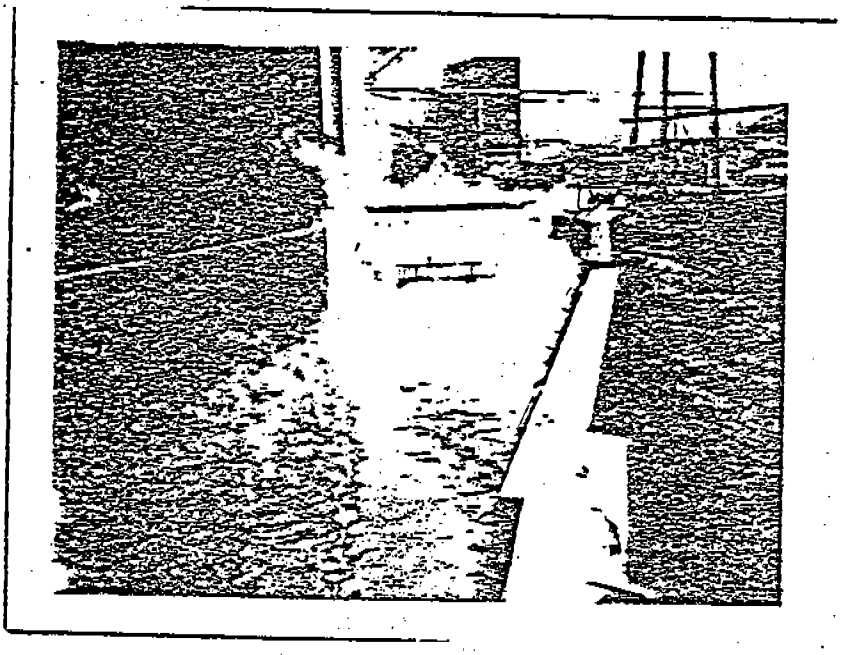
509716

The water recovered from the stack gases during each test has been used to calculate the total amount of water being carried up the stack with the plume (Q_1). These quantities have been listed in Table 5-2. The average quantity was calculated to be 1800 gallons per quench, and differs from the 1200 gallon per quench quantity calculated from the change in sump level. This difference is due to:

- Every carload of coke evaporated a certain amount of water during the quenching process depending on the temperature and weight of coke in each car. Since these varied from car to car, the amount of water evaporated varied from car to car.
- During some of the measurements, there may have been differences in water level in the sump not due to usage or as discussed below:
  - In order to make sump measurements, it was necessary to fill the sump so that the level of water was several inches above the top of the internal baffle (Figure 5-7). Then, the make-up water supply was shut off, and after the head tank was filled, the level was measured as an initial starting point. Subsequently, measurements of disappearance were made after each quench always making sure the head tank was filled. It was necessary to observe the screen separating the main body of the sump from the pump section to make sure it had not plugged (which would cause a difference of level in the two parts of the sump). After two or three quenches the sump would be refilled manually bypassing the automatic level controls and a new series of measurements were started as above.

509717

FIGURE 5-2



NO. 1 SUMP SHOWING DAM/SCREEN SEPARATING THE SETTLING CHAMBER (FOREGROUND) FROM THE PUMP SUPPLY PIT (BACKGROUND).

509718

Calculated Flows

Return to Sump (Q_4)

Several attempts to measure the return to sump flow (Q_4) were made but proved unsuccessful. This was because of the relatively short distance and steep slope between the car and the sump inlet. It was too dangerous to allow a man in this area during a quench, and steam and fog made remote observation impossible. Similarly, the shower of incandescent coke and the steam and water temperature (approximately 200°F) soon rendered instrumentation inoperative.

The construction of a settling basin was considered but would have been costly and was deemed unjustifiable since the return flow rates could be adequately estimated as follows:

Since $Q_6 + Q_2 = Q_1 + Q_4 + Q_3$

Then $Q_4 = Q_6 + Q_2 - Q_1 - Q_3$

$Q_4 = 20 + 9200 - 1800 - 125$

$Q_4 = 7300$ gal/quench

Make-up to Sump (Q_5)

Sump make-up (Q_5) was similarly calculated:

$Q_5 + Q_6 = Q_1 + Q_3$

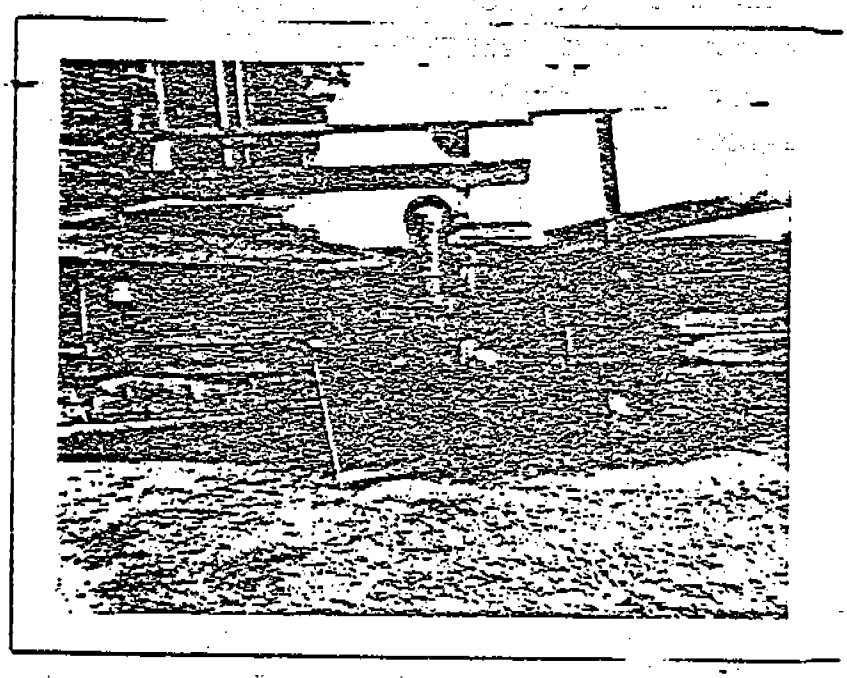
$Q_5 = 1800 + 150-20$

$Q_5 = 1900$ gal/quench

Water make-up to the sump was intermittent and was controlled through the use of automatic level devices. In the case of contaminated water, the flow rate was normally controlled by a float valve and a manual shut-off valve (Figure 5-8). During clean water tests, the contaminated water supply was closed and locked with a chain, while the flow of service water was controlled by an automatic valve which was opened or closed by level sensors in the

509719

FIGURE 5-8.



FLOAT CONTROLLED VALVE ON THE FLUSHING LIQUOR SUPPLY LINE TO THE MAKE-UP.

509720

sump. The flow rates through these inlets was variable, depending upon supply pressure, degree of valve port opening, and the length of time the supply valve was opened. Typical flow rates were estimated to be 200 gpm.

Moisture in Induced Air (Q_6)

The moisture present in the ambient air (Q_6) which was induced into the up-stack flow is presented in Table 5-6, and was calculated as follows:

Using Test No. 10D50 as an example:

$$\frac{(\text{dry scfm})\ (0.07495)(\text{test time})}{\text{No. of quenches per test}} = \text{lbs dry air/quench}$$

$$\frac{(153788)(0.07495)(8.78)}{4} = 25{,}300 \text{ lbs dry air/quench}$$

The relative humidity and temperature of the ambient air for each test were used to describe the absolute humidity. The moisture per pound of dry air was determined using an ASHRAE psychrometric chart. Then:

$$Q_6 = \frac{(\text{lbs of air per quench})(\text{lbs water per lb dry air})}{8.45}$$

$$Q_6 = 29 \text{ gallons}$$

5.1.2 Thermodynamics of the Process

In order to fully understand the physical process of quenching, it is appropriate to present a heat balance. This analysis ties together almost every measurement made.

If the amount of heat into the quench process reasonably balances against the amount of heat out, credibility is lent to the test procedures, and to some extent the assumptions involved in the water balance are substantiated.

509721

The same "Q" terminology is used for the thermodynamic discussion as was used in the preceding Sections.

The flows are illustrated in Figure 5-9. Table 5-7 presents the heat content of the various water quantities into and out of the process.

TABLE 5-7. HEAT BALANCE-BASED ON WATER

Water Flow Code	Amount	Enthalpy (14) (Btu/lb)	Btu/Quench
Q_1 (Stack Flow)	1800 gal (Note 1)		
	3100 lbs liquid @ 180°F	148	(458,800)
	11600 lbs vapor @ 180°F	1138	(13,200,800)
Q_2 (Inlet to Nozzle)	9200 gal @ 180°F	148	11,355,744
Q_3* (Losses)	100 gal @ 170°F(Note 2)	138	(115,092)
Q_4 (Return to Sump)	7300 gal @ 185°F	153	(9,314,946)
Q_5 (Moisture Content of Induced air)	20 gal @ 70°F	1042	173,806
		TOTAL:	(11,560,088)

Note 1: These figures are rounded averages (Table 5-2)

Note 2: Q_3* Includes losses associated with moisture in coke and car drainage - does not include sump evaporation

A typical calculation is as follows:

Q_x gallon/quench x 8.34 lbs/gal x Enthalpy Btu/lb = Btu/quench

In order to proportion the stack flow Q_1 into a liquid phase and a vapor phase, at least two mechanisms should be considered. All of the water found in the stack gases could have been vaporized by the incandescent coke. Some portion of this vapor could have been condensed by the cool air and the condensed droplets removed by the cyclone in the test train. Some small amount of the droplets were no doubt formed in just this way.

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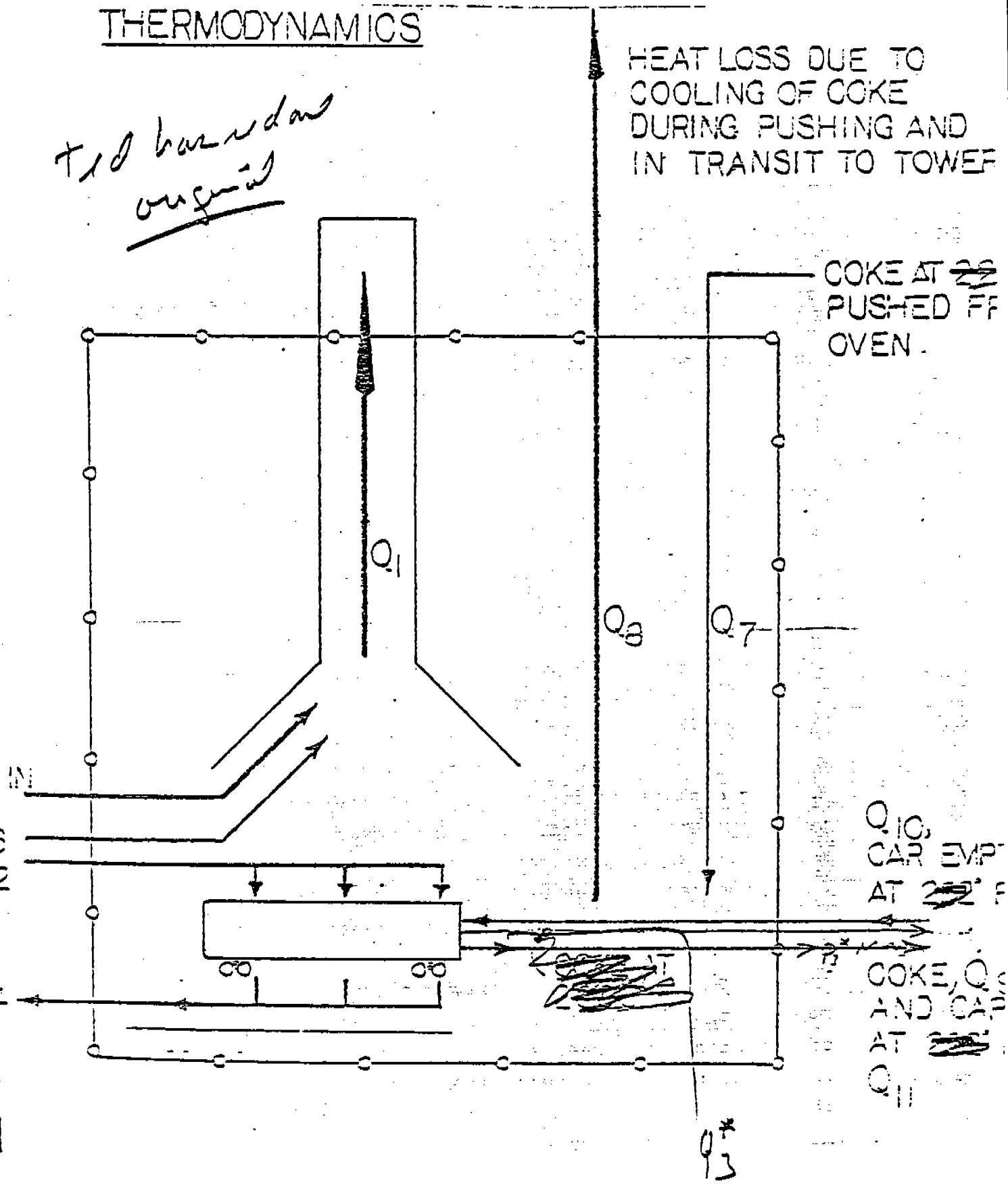
FIGURE 5-9



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However, it should be noted that the temperature for the two phases was assumed at 180°F. Actually, some of the water vapor was superheated by the incandescent coke and at some stage of the quench jets of this vapor may have exited the car at superheated temperatures approaching the temperature of the incandescent coke. Such superheated vapor tended to reduce the amount of water vapor to be condensed on the way up this tower. The thermodynamics of the process support the assumption that most of the water droplets were formed directly from the water sprayed onto the coke. Thus, they did not require any latent heat of vaporization. The major basis for this assumption is that there is more than enough water in the stack gases to account for all the cooling required to bring the coke from an incandescent temperature to the quenched temperature.

Six thermocouples on 3/4 inch pipe extending a few inches into the stack were installed at 15 foot intervals along the stack. These thermocouples were linked to two strip chart recorders which were activated when the quench car entered the tower. Continuous temperature readings were recorded until the temperature within the stack was returned to 20-30°F above the ambient temperatures. Three pens were used on each recorder; one for each thermocouple. All of the pens could not physically be in the same place at the same time, so a small distance separated each pen from the others. Since the recorder ran at a relatively high speed (1 cm per 10 seconds), this small distance between the pens added up to several seconds difference in time between the first and the sixth pen. Therefore, the temperature/time graph representing temperature near the bottom, middle, and top of the stack have been selected, and after correcting for the offset in time, have been reproduced in Figure 5-10 through 5-13. These temperature profiles indicate the movement of the hot mixture up the stack. The thermocouples

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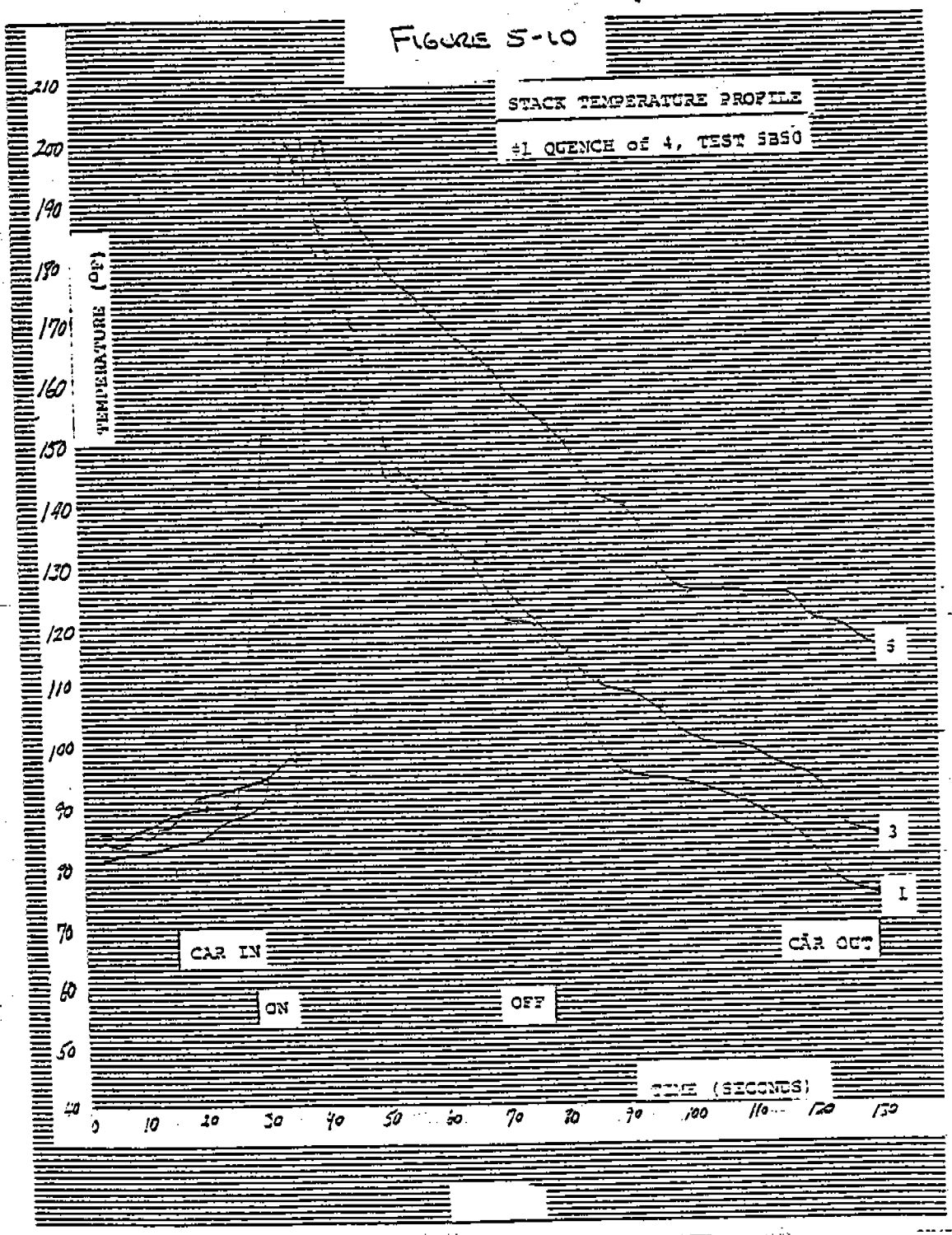
FIGURE 5-10



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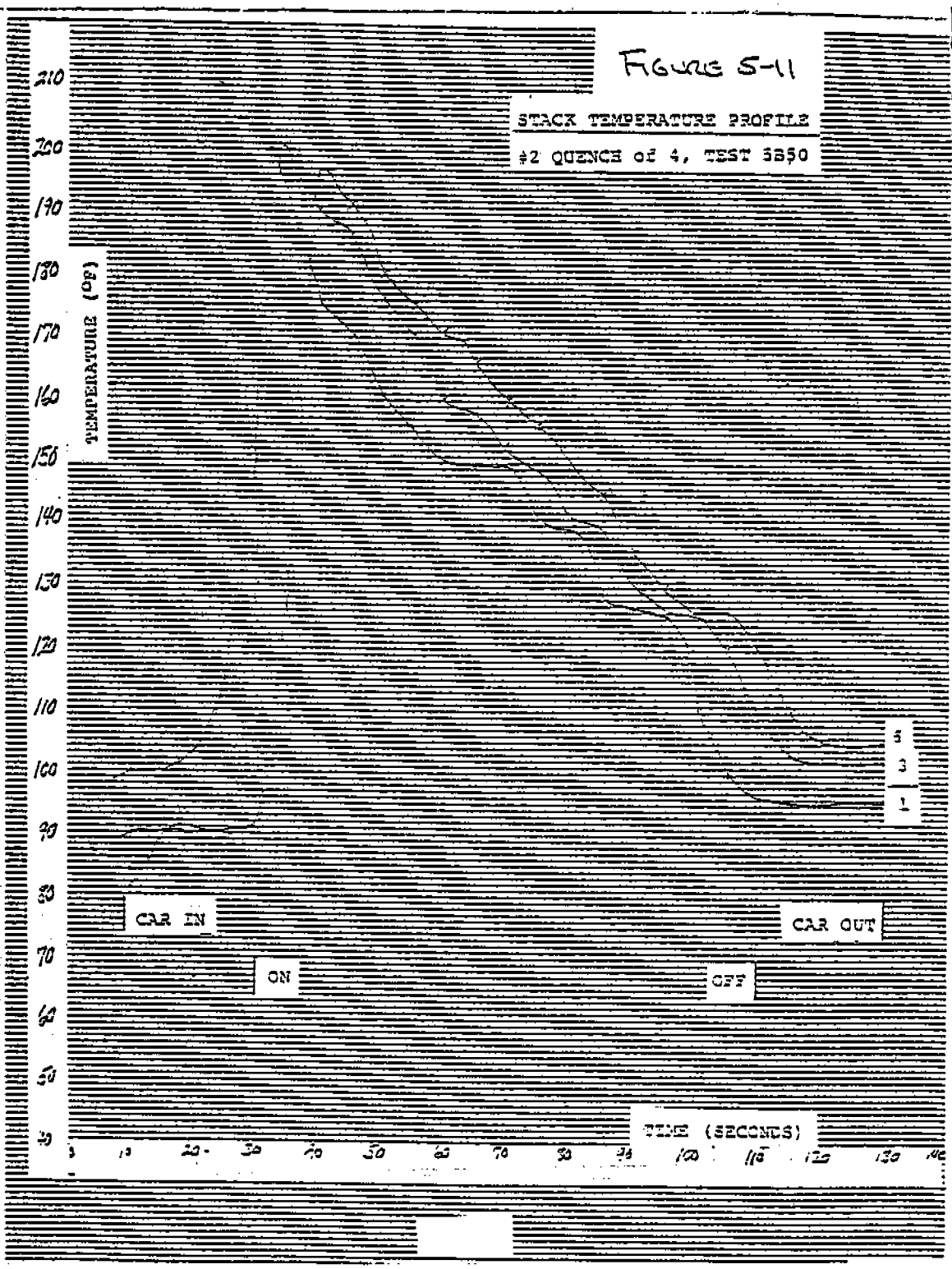
FIGURE 5-11
STACK TEMPERATURE PROFILE
#2 QUENCH of 4, TEST 5850
TEMPERATURE (°F)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
5
3
1
CAR IN
CAR OUT
ON
OFF
TIME (SECONDS)
10
20
30
40
50
60
70
80
90
100
110
120
130

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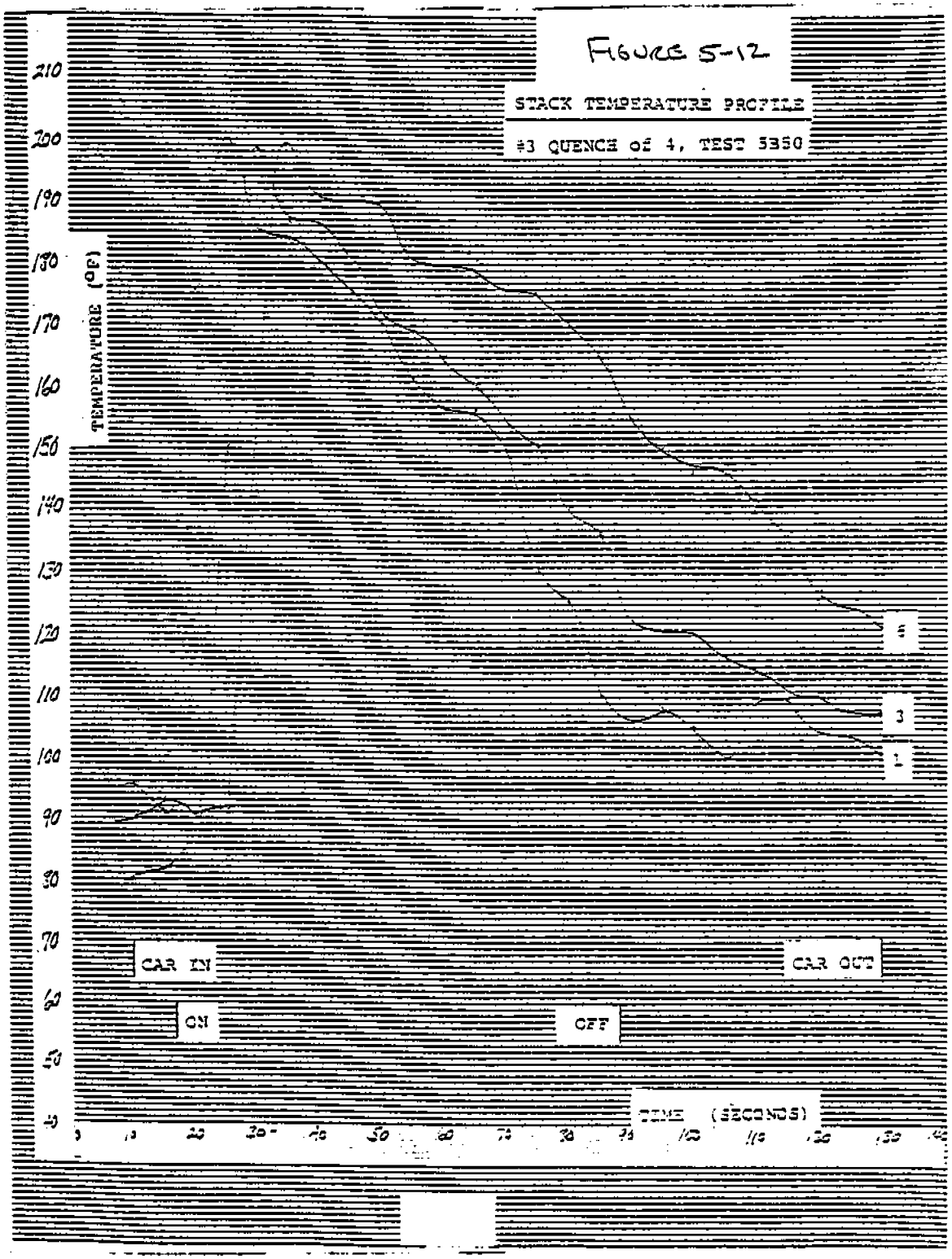
FIGURE 5-12
STACK TEMPERATURE PROFILE
#3 QUENCH of 4, TEST 5350
TEMPERATURE (°F)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
5
3
1
CAR IN
CAR OUT
ON
OFF
TIME (SECONDS)

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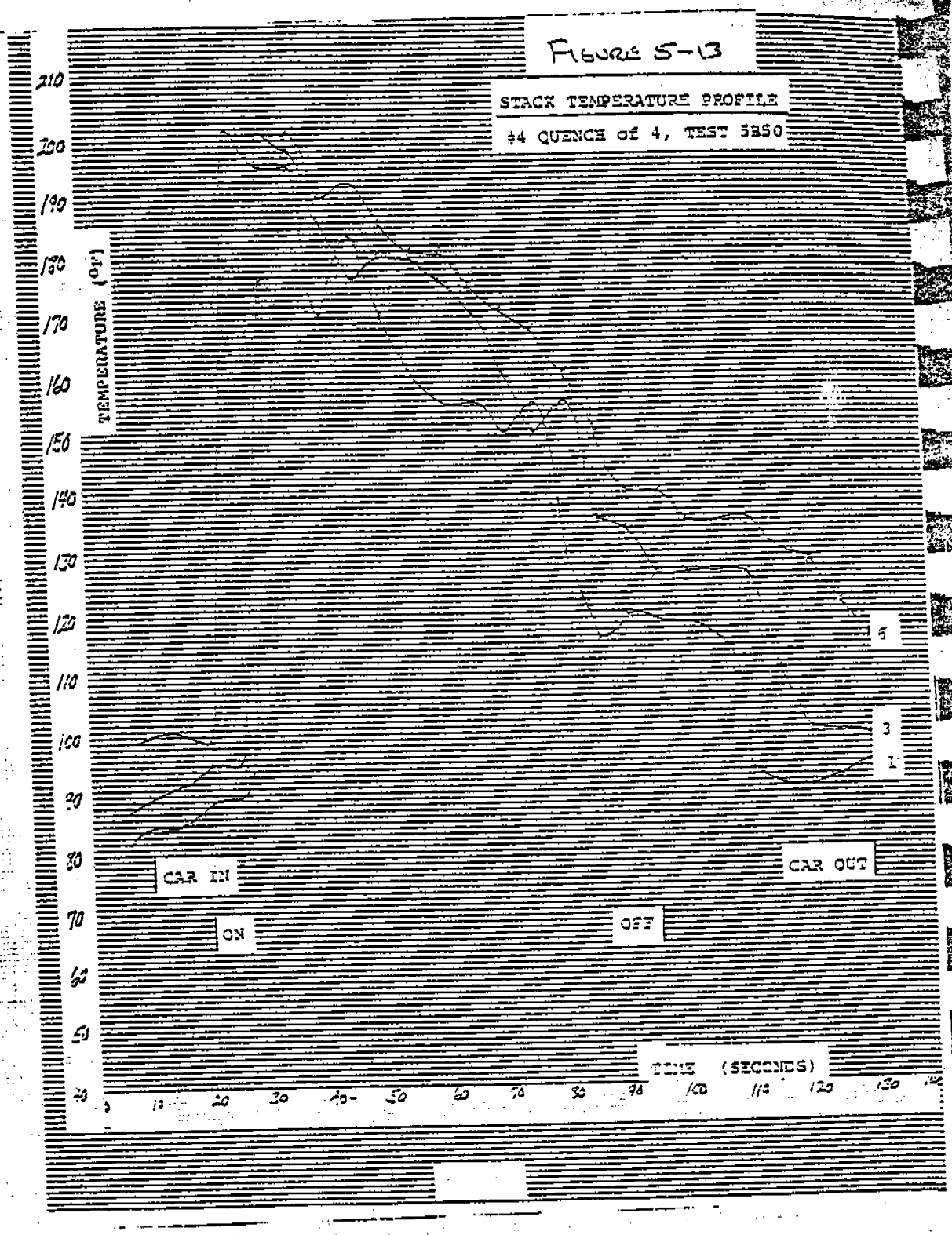

Figure 5-13

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were small rapid response types with a lag time of about one second. The data were taken on a line close to the stack wall and are not meant to represent a cross-sectional distribution or average temperature. The thermocouple positions are shown in Figures 5-14 and 5-15.

Shortly after the car came into the tower, temperatures started to rise. There was enough open area in the baffles to allow some radiant effect, so there was an immediate rise of warm air. As soon as the water came in contact with the hot coke, steam jetted up through the baffles. The temperature of these steam jets was not observed, but it was certainly superheated above 212°F. There was substantial turbulence and mixing associated with a strong draft of induced air so that temperatures near the wall did not exceed 200°F. The average velocity of the stack gases for this test was 37 ft/sec which caused a delay of only about two seconds between the response of the bottom thermocouple and that of the top thermocouple. This time interval may have been as long as 6 to 10 seconds at the beginning of the flow.

Since some of the thermocouple temperatures approached 212°F, it can be assumed that in addition to the jets of superheated steam, there were masses of vapor in the 225° to 250°F range which moved up the tower while being cooled by the induced air.

However, since the conditions during sampling at the test station are averaged for the entire quench, and since the stack gas temperature at the test probe averaged approximately 180°F, this temperature has been used in the thermodynamic calculations.

Coal is coked at high temperatures for periods of 17-24 hours, then the contents of each oven are pushed into an open railroad car. This car is transferred to a quench tower where

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LOCATION OF THERMOCOUPLES ON STACK

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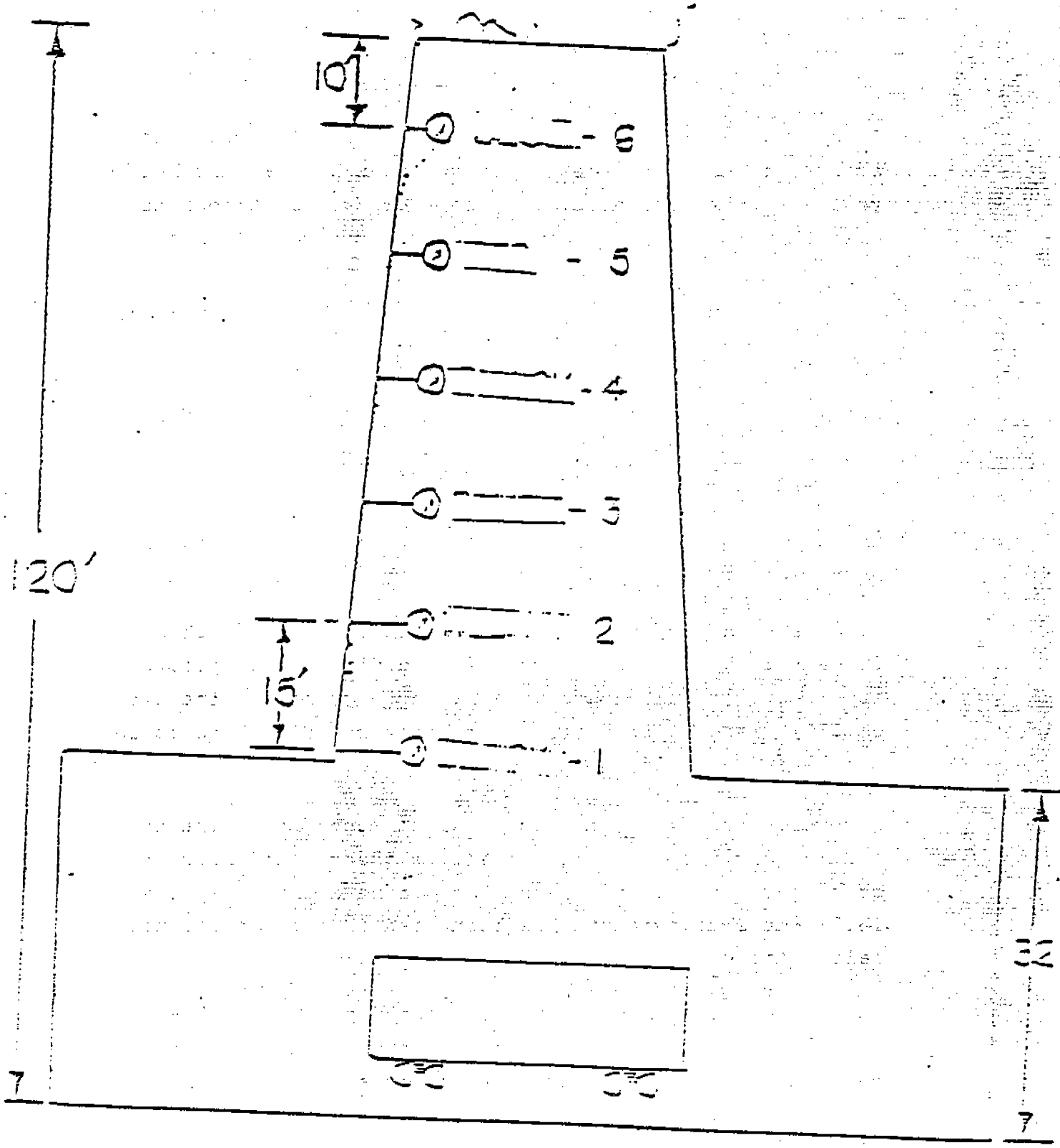

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FIG 5-14

5-15

FIG. ~~5-11~~

LOCATION OF THERMOCOUPLES (TC) ON STACK

~~SEE ALSO FIG. 5-10.~~

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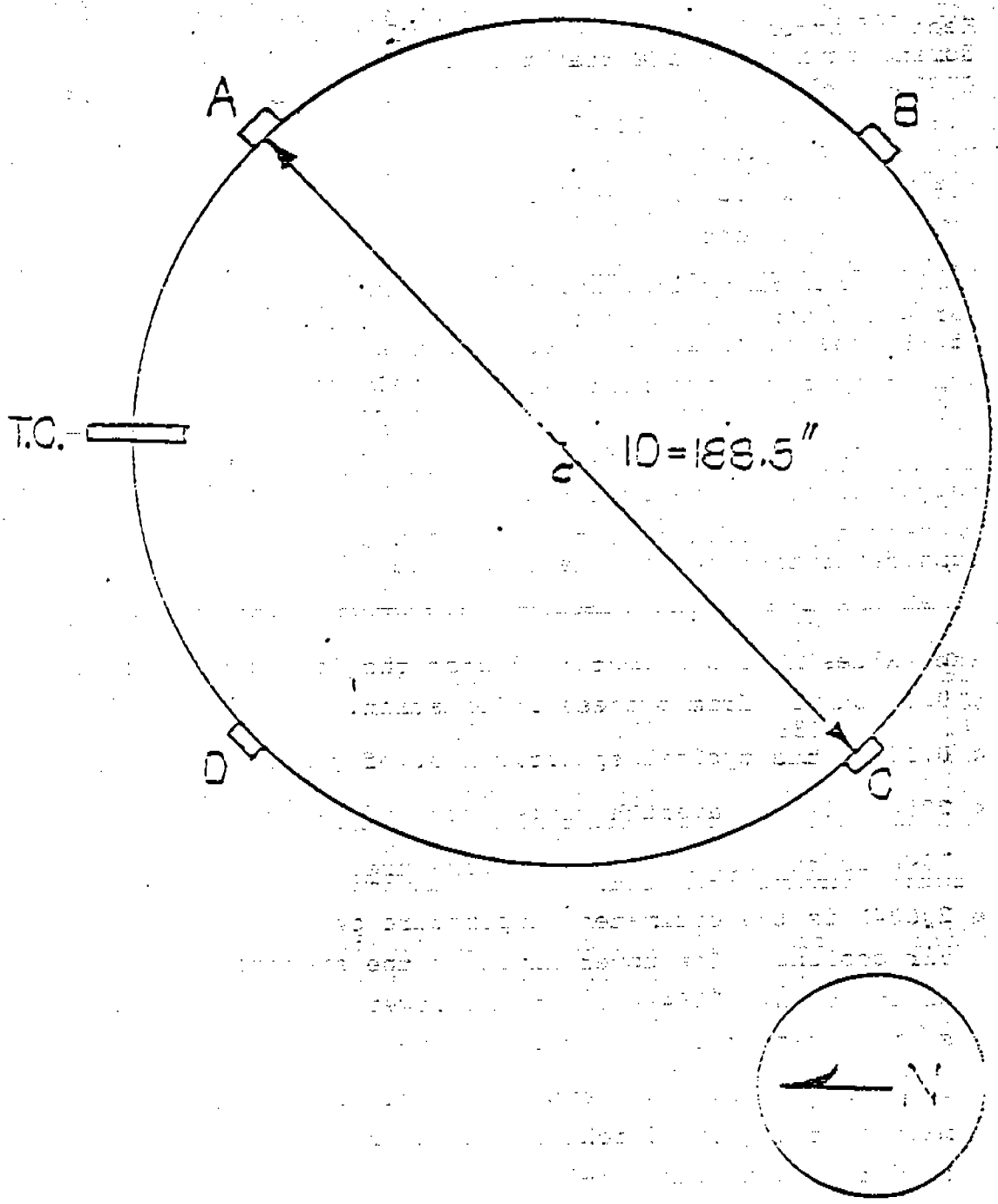

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FIG. 5-15

large quantities of water are used to cool the car and its contents. This operation is shown schematically in Figure 5-7 and is summarized in the following Table.

TABLE 5-8. HEAT BALANCE-BASED ON COKE

	Btu/Quench
Coke from the oven 9.6 tons x 2000 x .35 (2254°F-70°F)	= 14,676,480
Heat to atmosphere due to cooling of coke during push and while transporting to quench tower 9.6 x 2000 x .35 x (2254°F-2000°F)	=(1,706,880)
Heat out in quenched coke 9.6 x 2000 x .35 (252°F-70°F)	=(1,223,040)
Net heat input from coke	= 11,746,560
<u>Effect of car used to transfer the coke</u>	
Car would come to the oven at approximately 252°F (the temperature of the quenched coke) Weight of car x specific heat x (252°F-70°F)	= Btu/Car
The car would leave the system at approximately the same temperature Weight of car x specific heat x (252°F-70°F)	= (Btu/Car)
Therefore the effect of the car is not considered in the above heat balance	

The values used were obtained from the following sources:

- 9.6 tons is from process information.
- 0.35 is the typical specific heat of coke.
- 2254°F is the average temperature of 97 quenches.
- 70°F is the assumed base temperature.
- 2000°F is the estimated temperature of the coke mass after air cooling. The upper limit is the average temperature of the ovens (2254°F), and the lower limit is the observed surface temperature of the incandescent coke (1736°F).
- 252°F is the average temperature of several measurements made on the quenced coke as it was dumped on the wharf as detailed in Table 5-9.

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The temperature for Q_3 was assumed to be 170°. The maximum temperature of water draining from the car was 212°F. No other losses of water were observed, but there may have been some small amount of drainage from the tower walls which would lower the average to about 170°F.

Temperature for Q_4 was observed as high as 195-200°F during short peak periods in the early part of the flow. There was some cooling in the ditch and in the sump. Since the water inlet was measured at 180°F, the return at 185°F indicates the typical trend for the sump to warm up during quenching. These temperatures are merely indicative of a relative relationship, and after prolonged heavy usage both the temperatures of Q_2 and Q_4 would be higher. However, the temperature difference of 5°F is representative and can be used for a typical heat balance.

TABLE 5-9. TEMPERATURE OF QUENCHED COKE ON THE WHARF (°F)

	Car 1	Car 2	Car 3	Car 4	Car 5
	185	250	280	150	180
	210	328	225	170	150
	450	300	215	180	140
	90	235	205	180	420
	100	210	365	820	300
	70	275	290	510	200
	55	260	275	420	320
		342	125	400	230
		270	165	350	240
		280	150	310	220
Average:	165	275	230	349	240
TOTAL AVERAGE = 252					

Large amounts of air are induced up the stack by the heat of the coke and the density effect of the steam. This air leaves the system at the top of the stack as indicated in Figure 5-9. The heat flow involved is tabulated below:

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TABLE 5-10. HEAT BALANCE-BASED ON AIR

	Enthalpy (Btu/lb)	Btu/Quench
32,000 lb of entering air at 70°F	9.1	291,200
32,000 lb of exiting air at 180°F*	35.6	(1,139,200)
Net Change		(848,000)

* The existing dry air plus the water in the stack gases (Q_1) make up the total stack flow.

It is convenient to consider the incoming air on a dry basis and include the effect of the moisture it contains in Table 5-7 as Q_6.

Exiting air is considered on a dry basis since the heat involved in the water vapor and water droplets was included as in Q_1.

The overall heat balance involved in the quench process is summarized in Table 5-11 below:

TABLE 5-11. HEAT BALANCE-SUMMARY

	Btu/Quench
Net to water	(11,560,088)
Net to air	(848,000)
Net from coke	11,746,560
Difference	(661,528)

This heat balance is very sensitive to changes in the amount of water carried up the stack as vapor. If the average Q_1 were 70 gallons or less, there would be an almost perfect balance of heat into the tower versus heat out. The results of this heat balance substantiate the validity of the 1800 gallons of water reported as recovered in the stack gases during the tests.

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5.2 Water Contamination

One of the reasons for selecting Lorain as a test site was that a comparison could be made between quench tower emissions using relatively clean water and using flushing liquors as make up to produce a contaminated quenching water. Here, the concentrations of the various chemical components were 2 or 3 orders of magnitude greater in the flushing liquor than in the service water. The compositions of the clean and contaminated water sump during the tests were very similar to the composition both as determined during pre-test surveys, and as reported in 1973 by the plant. Therefore, these test conditions meet the criteria for establishing a comparison of the two types of quench water.

In order to investigate the fates of the various contaminants, mass balances were calculated for the sump, the quench car, and the overall quench process. These balances are summarized in Table 5-12 for the contaminated water tests, and Table 5-13 for the clean water tests. In addition, their average mass concentrations and variability are included in Table 5-14 for the contaminated tests and Table 5-15 for the clean series. The average quantity of contaminants per quench found in the make up to the tower, the inlet to the nozzles, and the return from the car in both series of tests is presented in Table 5-16. Each individual chemical is discussed in detail because in some areas the mass balances are of questionable validity.

Figure 5-16 is presented to illustrate the origin of the flushing liquor and to provide an indication of the various process loops through which it passes.

Table 5-17 is presented to show the relative differences between the quantities of contaminants supplied to the

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Figure 5-15

Process Flow

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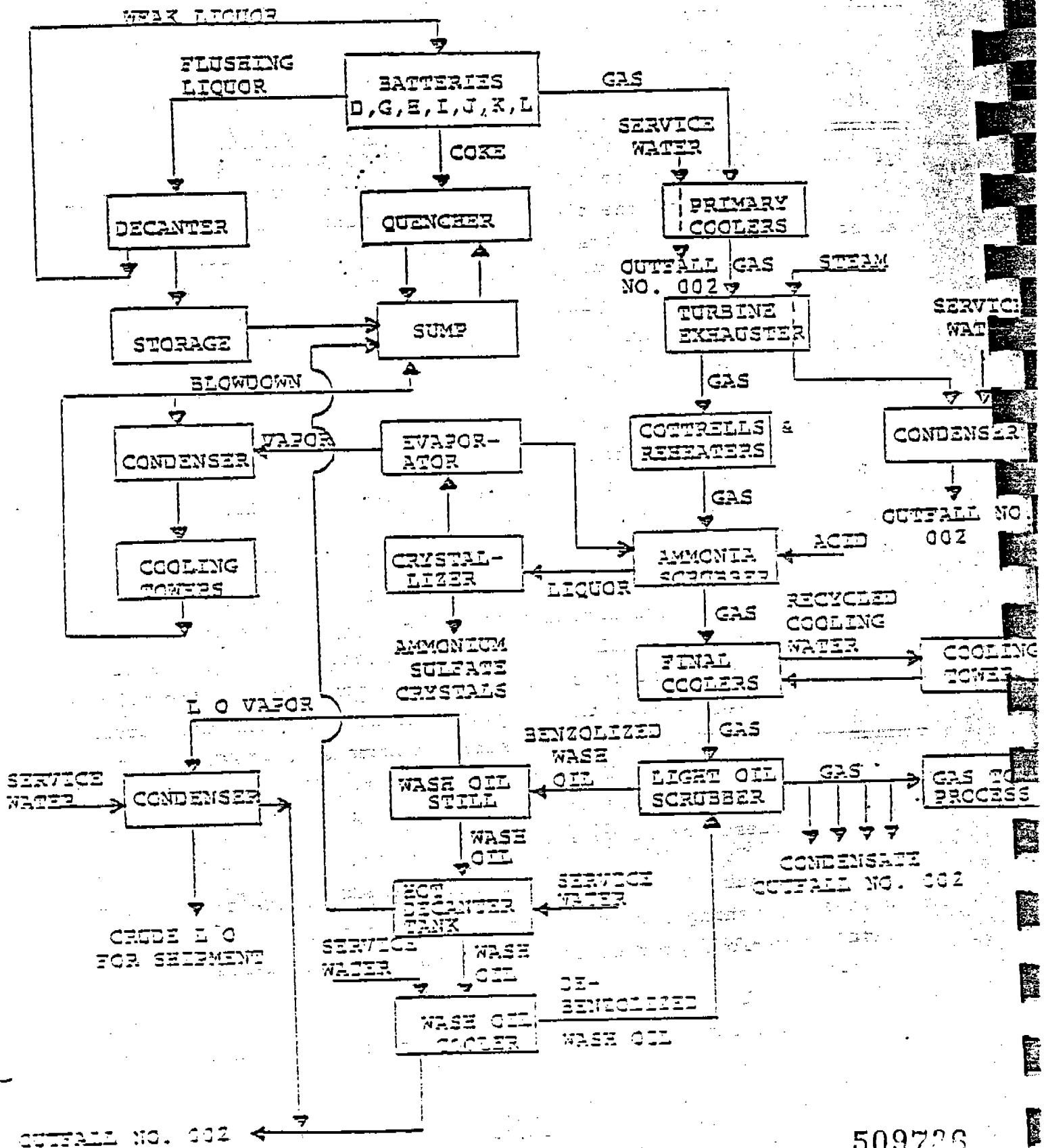

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TABLE 5-12, OVERALL QUENCH PROCESS EQUILIBRIUM x-x-x (Contaminated Test) (lbs/quench)

$$C_1 + C_{3A} + C_{3B} + C_{3C} = C_5 + C_6$$

Contaminants	Stack C_1 Particulates on Cyclone	Stack C_1 Particulates on Filter	Stack C_1 Gaseous Emissions	(C_{3A}) (+ or -)	Evaporation From Sump C_{3B}	Sediment C_{3C}	Makeup C_5	Induced Air C_6	Excess or (Loss)
Chloride	1.02	0.056	NA	-7	NA	Trace	125	NA	120
Ammonia	NA	NA	4.3	NA	6	9	17	NA	51.3
Phenol	NA	NA	2.9	-0.003	0.02	0.9	2	NA	(6)
Sulfide	NA	NA	NA	0	NA	NA	0.003	NA	-
Sulfate	1.31	0.012	NA	+86	NA	NA	1	NA	(86)
Cyanide	NA	NA	0.13	+0.003	NA	Trace	0.12	NA	(0.01)
Calcium	0.085	0.009	0	-50	0		0.20	NA	50
Sodium	NA	NA	0	-154	0	NA	0.60	NA	154
Fluoride	0.009	0.001	NA	NA	NA	NA	NA	NA	-
Total Solids	NA	NA	0	NA	0	NA	83	NA	-
Total Dissolved Solids		See Discussion	0	-6	0	NA	85	NA	-
Suspended Solids	2.7	NA	0	-10.8	0	10.3	2.2	NA	-
Volatile Solids	NA	NA	NA	NA	NA	NA	1.5	NA	-
SO_2	NA	NA	6.0	NA	NA	NA	NA	NA	-

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TABLE 5-13. ENTIRE SYSTEM EQUILIBRIUM x-x-x .(Clean Test) (lbs/quench)

$C_1 + C_{3A} + C_{3B} + C_{3C} = C_5 + C_6$

Contaminants	Stack C_1 Particulates on Cyclone	Stack C_1 Particulates on Filter	Stack C_1 Gaseous Emissions	(C_{3A}) (+ or -)	Evaporation From Sump C_{3B}	Sediment C_{3C}	Makeup C_5	Induced Air C_6	Excess or (Loss)
Chloride	0.019	0.056	NA	+4	Trace	Trace	7	NA	2.9
Ammonia	NA	NA	0.35	NA	0.2		0.2	NA	(2.1)
Phenol	NA	NA	0.05	-0.01	Trace	Trace	0.002	NA	(2.3)
Sulfide	NA	NA	NA	0	NA	NA	0.003	NA	-
Sulfate	0.31	0.012	NA		NA	NA	2.0	NA	0.8
Cyanide	NA	NA	0.029	0	NA	Trace	0.002	NA	(.03)
Calcium	0.10	0.089	0	+0.2	0	NA	0.61	NA	0.3
Sodium	NA	NA	0	+19.2	0	NA	1.2	NA	(13)
Fluoride	0.011	0.001	NA	NA	NA	NA	NA	NA	-
Total Solids	NA	NA	0	0	0	NA	0	NA	-
Total Dissolved Solids	See Discussion		0	3.7	0	NA	0	NA	-
Suspended Solids	1.72	NA	0	13.1	0	11.4	0.04	NA	-
Volatile Solids	NA	NA	NA	NA	NA	NA	0.4	NA	-
SO_2	NA	NA	0.07	NA	NA	NA	NA	NA	-
									(13.41)

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TABLE 5-14. AVERAGE CONCENTRATION OF VARIOUS PARAMETERS IN THE QUENCH PROCESS STREAM (in mg/l)

PARAMETER	INLET (C_2)	(RANGE)	CONTAMINATED QUENCH WATER RETURN (C_4)	(RANGE)	MAKE-UP (C_5)	(RANGE)
Chloride	11597	(6575-14150)	7723	(7700-11425)	7939	(5525-9950)
Ammonia	1350	(853-2891)	982	(456-1268)	1079	(873-1216)
Phenol	350	(264.7-389.5)	312	(231.1-409.5)	150	(133-174)
Sulfide	0.1	(0-0.1)	0.1	(0-0.1)	0.2	(0-0.2)
Sulfate	286	(268.8-319.2)	271	(206.4-297.6)	170	(136.8-247.2)
Cyanide	9.4	(7.2-12.4)	6.3	(4.4-7.3)	7.4	(6.2-8.6)
Calcium	31.5	(27.3-35.2)	34.8	(7.0-55.1)	12.5	(7.7-14.4)
Sodium	71	(65-80)	72	(63-85)	38	(35-45)
TOC	1098	(992-1179)	1074	(836-1231)	1195	(972-1312)
Oil & Grease	60	(40-70)	48	(0-140)	80	(40-60)
Total Solids	10525	(9505-13650.5)	10791	(8729.5-12155.5)	5230	(4261-6095.5)
Dissolved Solids	9850	(9143.4-13263)	9670	(8478-11168)	5368	(3405.4-6426.2)
Suspended Solids	165	(120-279.2)	340	(122-765.4)	140	(59.6-337.8)
Volatile Solids	93	(89.8-94.7)	93	(90.0-93.8)	96	(95.4-96.7)

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TABLE 5-15 AVERAGE CONCENTRATION OF VARIOUS PARAMETERS IN THE QUENCH PROCESS STREAM (in mg/l)

PARAMETER	INLET (C_2)	(RANGE)	CLEAN QUENCH WATER RETURN (C_4)	(RANGE)	MAKE-UP (C_5)	(RANGE)
Chloride	1237	(660-3200)	790	(720-1325)	440	(130-2400)
Ammonia	23	(17.5-30.2)	24	(12.7-31.8)	13	(0.1-2.1)
Phenol	0.72	(0.4-1.6)	0.76	(0.4-1.8)	0.10	(0.1-0.2)
Sulfide	0.1	(0-0.1)	0.1	(0-0.1)	0.1	(0-0.1)
Sulfate	303	(273.2-339.5)	248	(236.6-325.5)	130	(138.7-170.4)
Cyanide	0.26	(0.2-0.3)	0.36	(0.2-0.4)	0.10	(0-0.1)
Calcium	63.6	(38.5-77.3)	60.0	(37.7-85.3)	38.0	(27.5-65.0)
Sodium	120	(115-130)	127	(125-130)	77	(70-85)
TOC	9.6	(1.0-20)	13.7	(6.0-26)	3.8	(1.0-9.0)
Oil & Grease	9	(0-30)	0.1	(0-0.1)	23	(10-30)
Total Solids	1101	(1005.7-1258.8)	1489	(947.2-2165.5)	476	(331.9-557.3)
Dissolved Solids	1052	(325.3-110.1)	1040	(837.1-1261.2)	520	(318-1036.9)
Suspended Solids	60	(33.7-87.7)	270	(102.7-1245.2)	2.5	(5.2-41.6)
Volatile Solids	32	(18.4-74.8)	29	(22.4-47.0)	27	(4.4-83.3)

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TABLE 5-16. AVERAGE QUANTITIES OF CONTAMINANTS PER QUENCH (lb/quench)

Parameter	Contaminated Quench Water			Clean Quench Water		
	Inlet (C_2)	Return (C_4)	Make-up (C_5)	Inlet (C_2)	Return (C_4)	Make-up (C_5)
Chloride	889	470	126	95	48	7
Ammonia	103	60	17	1.7	1.5	0.2
Phenol	27	19	2	0.06	0.05	0.002
Sulfide	0.008	0.006	0.003	0.008	0.04	0.003
Sulfate	22	16	1	23	24.8	2.0
Cyanide	0.72	0.38	0.12	0.02	0.02	0.002
Calcium	2.4	2.1	0.20	4.9	3.6	0.61
Sodium	5.4	4.4	0.60	9.2	7.7	1.2
TOC	84	65	19	0.74	0.83	0.06
Oil & Grease	4.6	2.9	1.3	0.66	0.006	0.36
Total Solids	807	657	83	84	91	8
Dissolved Solids	755	588	85	80.5	63	8
Suspended Solids	12.6	20.7	2.2	4.6	16	0.04
Volatile Solids	7	5.7	1.5	2.5	1.8	0.4

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system when using "clean" service water, and "contaminated" flushing liquor as make-up. These values have been determined in order to establish the mechanisms by which these contaminants enter the environment.

TABLE 5-17. CONTAMINANT PATHWAYS AND QUANTITIES (lb/quench)

Route	Contaminated Water	Clean Water
Entering in make-up	85	8
On the quenched coke	6	(4)
In the cyclone catch	12	2
As stack gas	13	0.5
To the sump	10	10
Evaporated from sump	55	2
Leaving the system	96	10.5

The above is a simplification, but it is clear that an order of magnitude difference exists in the emissions from a quench tower using flushing liquor as make-up as compared to using relatively clean service water. There is also a contribution from the coke, but this is not clearly apparent because of the difficulty in obtaining and analyzing meaningful incandescent and quenched coke samples.

In reviewing the mass balances, it is apparent that there are some anomalies which are manifested in inexplicable gains or losses of contaminants. These anomalies are most apparent for contaminated water tests, and are as follows:

- A loss of 120 pounds of chloride per quench
- A loss of 58 pounds of calcium per quench
- A loss of 154 pounds of sodium per quench

The chloride level of the flushing liquors during the test period was higher than in June and July of 1976, and higher than the 1973 plant data (Table 5-44). This

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higher level may have been either due to sampling or analytical errors, or to the chemical combination of chlorides with organic compounds. If the latter were the case, the analyses for the chloride ions would not have detected the organic chlorides.

The calcium anomaly is apparently caused by the contribution of calcium by the incandescent coke. This supposition is based on the mass spectroscopy analysis, but is not supported by the data obtained from the coke samples taken during the clean water tests. If there were a large contribution of calcium from the incandescent coke, this should also have occurred during the clean water tests. Similar reasoning applies to the apparent contribution of sodium, although in this case there was a small contribution from the coke samples taken during the clean water tests. There is cause to suspect the validity of this contribution of calcium and sodium, because the calcium would be converted to an oxide form, and as slaked lime would precipitate. Then, if it did not go out on the coke, it would add to the amount of sludge to be removed. Similarly, sodium would leave the process either on the coke or in the sludge.

As can be noted in Table 5-16, those contaminants that were at a maximum during the tests with contaminated quench water were also present in the flushing liquor make-up in much higher concentrations than in the service water. Generally, these concentrations were higher in the flushing liquor than in the service by an order of magnitude.

To present the data, a format similar to that developed earlier in this section has been used (Figure 5-1 and Table 5-1). The water flow rates developed in Section 5-1 along with the contaminate concentrations for the various inputs and outputs are summarized in Table 5-14,

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and provide the basis for calculating the quantity of the various contaminants liberated per quench. These are summarized in Table 5-15. The letter identifier "C" has been used to indicate the various pathways of contaminants. This graphical analysis, which is shown in Figure 5-17, differs from Figure 5-1 in that C_{3c} (losses due to sump sediments) has been added.

The same relationships are stated as developed in Section 5-1:

around boundary ---	$C_{3B} + C_{3C} + C_2 = C_4 + C_5$
around boundary 0-0-0	$C_6 + C_2 = C_1 + C_4 + C_{3A}$
around boundary x-x-x	$C_6 + C_5 = C_1 + C_{3A} + C_{3B}$

These relationships involve the same assumptions defined in Section 5.1.

The mass flow rates of major contaminants are summarized in the following Tables:

<u>Using Contaminated Quench Water</u>

- Sump equilibrium — Table 5-18
- Car and Tower equilibrium — Table 5-19
- Entire System equilibrium — Table 5-12

<u>Using Clean Water</u>

- Sump equilibrium — Table 5-20
- Car and Tower equilibrium — Table 5-21
- Entire System equilibrium — Table 5-13

The range of values associated with the measurements of the 16 parameters found in the quench tower process streams are presented in Table 5-15.

Quench water sample analytical results are presented in Table 5-21 through 5-34.

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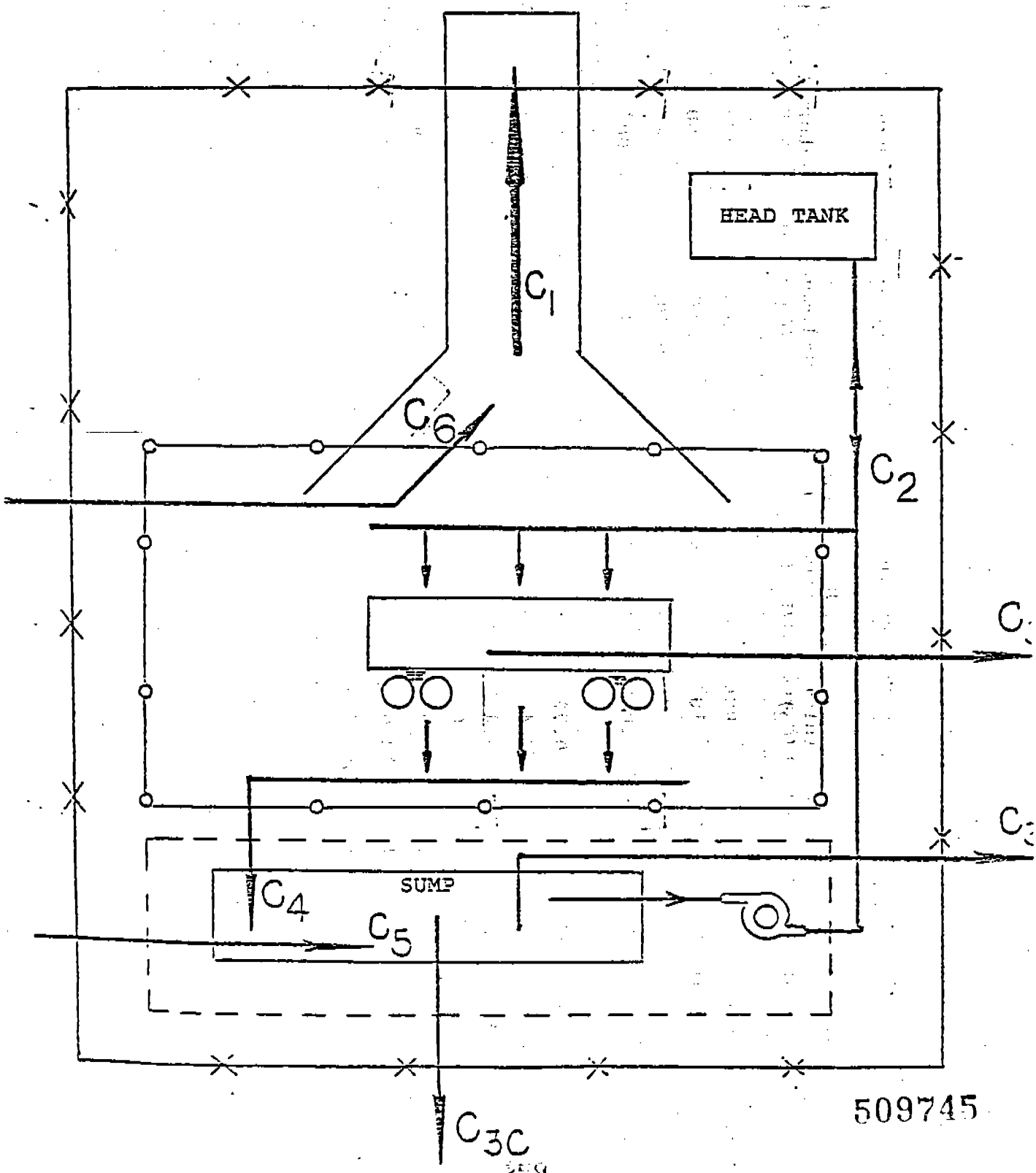
Figure 5 - 17

CONTAMINANTS



509745

TABLE 5-18. SUMP EQUILIBRIUM[1]-CONTAMINATED TESTS (lb/quench)

Contaminant	Inlet (C_2)	Evaporation From Sump (C_{3B})	Sediment (C_{3C})	Return (C_4)	Make-up Liquor (C_5)
Chloride	888	NA	Trace	470	125
Ammonia	103	6	0.02	60	17
Phenol	27	.02	0.002	19	2
Sulfide	0.008	NA	NA	0.006	0.003
Sulfate	22	0	NA	16	1
Cyanide	0.72	NA	Trace	0.38	0.12
Calcium	2.4	0	NA	2.1	0.20
Sodium	5.4	0	NA	4.4	0.60
Total Solids	807	0	NA	657	83
Dissolved Solids	755	0	NA	588	85
Suspended Solids	12.6	0	10.3	20.7	2.2
Volatile Solids	7	NA	NA	5.7	1.5

[1] $C_2 + C_{3B} + C_{3C} = C_4 + C_5$

509746

TABLE 5-19. CAR EQUILIBRIUM[1]-CONTAMINATED TESTS (lb/quench)

Contaminant	Stack (C_1) Particulate on Cyclone	Stack (C_1) Particulate on Filter	Gaseous Emissions	(C_{3A}) (+ or -)[2]	Return (C_4)	Inlet (C_2)	Induced Air (C_6)
Chloride	1.02	0.056	NA	-7.0	470	888	NA
Ammonia	NA	NA	4.3	NA	60	103	NA
Phenol	NA	NA	2.9	-0.003	19	27	NA
Sulfide	NA	NA	NA	0	0.006	0.008	NA
Sulfate	1.31	0.012	NA	+86.0	16	22	NA
Cyanide	NA	NA	+0.003	+0.003	0.38	0.72	NA
Calcium	0.085	0.089	NA	-58.0	2.1	2.4	NA
Sodium	NA	NA	NA	-1.54	4.4	5.4	NA
Fluoride	0.009	0.001	NA	NA	NA	NA	NA
Total Solids	NA	NA	NA	NA	657	807	NA
Dissolved Solids	NA	NA	NA	-6.0	588	755	NA
Suspended Solids	NA	NA	NA	-10.8	20.7	12.6	NA
Volatile Solids	NA	NA	NA	NA	5.7	7	NA
SO_2	NA	NA	6.0	NA	NA	NA	NA

1 $C_1 + C_{3A} + C_4 = C_2 + C_6$

2 (+) indicates a quantity supplied to the system: (-) a quantity subtracted from the system.

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TABLE 5-20. SUMP EQUILIBRIUM - - - (Clean Test)

$C_2 + C_{3B} + C_{3C} = C_4 + C_5$

lbs/quench

Contaminant	Inlet C_2	Evaporation from sump C_{3B}	Sump Sediments C_{3C}	Return C_4	Makeup C_5
Chloride	95	NA	Trace	48	7
Ammonia	1.7	0.2	0.005	1.5	0.2
Phenol	0.06	Negligible	0.0002	0.05	0.002
Sulfide	0.008	NA	NA	0.04	0.003
Sulfate	23	0	NA	24.8	2.0
Cyanide	0.02	NA	Trace	0.02	0.002
Calcium	4.9	0	NA	3.6	0.61
Sodium	9.2	0	NA	7.7	1.2
Total Solids	84	0	NA	91	8
Dissolved Solids	80.5	0	NA	63	8
Suspended Solids	4.6	0	11.4	16	0.04
Volatile Solids	2.5	NA	NA	1.8	0.4

509748

TABLE 5-21. CAR AND TOWER EQUILIBRIUM 0-0-0 (Clean test) (lbs/quench)

$C_1 + C_{3A} + C_4 = C_2 + C_6$

Contaminant	Stack (C_1) Particulate on Cyclone	Stack (C_1) Particulate on Filter	Gaseous Emissions	(C_{3A}) (+ or -)[2]	Return (C_4)	Inlet (C_2)	Induced Air (C_6)
Chloride	0.019	NA	NA	(+4)	48	95	NA
Ammonia	NA	NA	0.35	NA	1.5	1.7	NA
Phenol	NA	NA	0.05	-0.1	0.05	0.06	NA
Sulfide	NA	NA	NA	0	0.04	0.008	NA
Sulfate	0.31	NA	NA	(+86.4)	24.8	23	NA
Cyanide	NA	NA	0.029	0	0.02	0.02	NA
Calcium	0.10	NA	NA	(+ 0.2)	3.6	4.9	NA
Sodium	NA	NA	NA	(+19.2)	7.7	9.2	NA
Fluoride	0.011	NA	NA	NA	NA	NA	NA
Total Solids	NA	NA	NA	NA	91	84	NA
Total Dissolved Solids	NA	NA	NA	-3.7	63	80.5	NA
Suspended Solids	NA	NA	NA	13.1	16	4.6	NA
Volatile Solids	NA	NA	NA	NA	1.8	2.5	NA
SO_2	NA	NA	0.07	NA	NA	NA	NA

509740

TABLE 5-22

ANALYSIS OF EACH QUENCH WATER SAMPLE

CHLORIDES mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	10000.0	9480.0	-	4D51 5D21* 6D81	800	980	180
6B80	9590.0	8850.0	-	4D51 5D21 6D81	-	980	-
7C50	16150.0	10650.0	-	4D51 5D21 6D81	-	980	-
8C20*	6575.0	11425.0	9550.0	7A51*	720	720	230
9C80							
10D50*	9780.0	10450.0	9550.0	8A81*	660	580	2400
11D80*	14000.0	7700.0	7550.0	9A21*	800	720	450
12D20				10M1*			
13A50*	12500.0	8300.0	8950.0	11MP1	3200	620	130
14A20*	12575.0	8520.0	6750.0	12M1* 13A5P1	1500	720	130
15A80*	14150.0	7750.0	5225.0				
16C5PC	11250.0	9580.0	-				
1C81*	1670.0	1325.0	116.5				
3C21*	1100.0	725.0	140.0				
1B51	540.0	-	150.0				
2B21	-	580.0	180.0				
3B81*	680.0	720.0	180.0				

* Used for chloride concentration averages.

509750

TABLE 5-23

ANALYSIS OF EACH QUENCH WATER SAMPLE

AMMONIA mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	1231.2	-	NA	4D51* 5D21 6D81	18.9	19.2	0.1
6B80	1227.2	712.8	NA	4D51 5D21 6D81	NA	19.2	NA
7C50	1352.0	1016.8	NA	4D51 5D21 6D81	NA	19.2	NA
8C20*	1364.0	768.0	1216.8	7A51*	22.0	16.5	0.1
9C80 10D50*	1243.8	1140.8	1216.8	8A81*	20.0	27.5	0.9
11D80*	853.0	456.9	982.0	9A21*	20.0	29.5	1.0
12D20 13A50*	892.2	1268.8	873.6	10M1* 11MP1	26.0	29.2	2.1
14A20*	858.0	1045.2	1016.4	12M1* 13A5P1	17.5	26.3	2.0
15A80*	2890.8	1214.4	1169.2				
16C5PO	560.0	600.0	-				
1C81*	31.0	34.0	1.0				
3C21*	16.1	13.8	1.2				
1B51*	26.2	12.7	1.0				
2B21*	30.2	31.8	1.0				
3B81*	22.0	24.5	1.0				

* Used in ammonia concentration averages.

509751

TABLE 5- 24

ANALYSIS OF EACH QUENCH WATER SAMPLE

PHENOLS mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	193.0	207.8	NA	4D51 5D21 6D81	0.5	0.6	0.1
6B80	315.6	256.7	NA	4D51 5D21 6D81	NA	0.6	NA
7C50	285.6	263.7	NA	4D51 5D21 6D81	NA	0.6	NA
8C20*	389.5	231.1	137	7A51*	0.6	0.6	0.1
9C80 10D50*	389.5	324.6	137	8A81*	0.8	1.0	0.1
11D80*	433.7	276.4	149	9A21*	0.9	0.9	0.1
12D20 13A50*	264.7	409.5	174	10M1* 11MP1	0.9	0.9	0.2
14A20*	295.4	352.4	172	12M1* 13A5P1	0.4	0.5	0.1
15A80*	327.6	277.9	133				
16C5PO	NA	275.6	93				
1C81*	1.6	1.8	1				
3C21*	0.7	0.5	1				
1B51*	0.5	0.5	0.1				
2B21*	0.6	0.6	0.1				
3B81*	0.4	0.4	0.1				

* Used in phenol concentration average.

509752

TABLE 5- 25

ANALYSIS OF EACH QUENCH WATER SAMPLE

SULFIDE mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	0.2	0.1	-	4D51 5D21 6D81	0.1	0.1	0.1
6B80	0.1	NA	-	4D51 5D21 6D81	0.1	0.1	0.1
7C50	0.1	0.2	NA	4D51 5D21 6D81	NA	0.1	NA
8C20*	0.1	0.1	0.2	7A51	0.1	0.1	0.1
9C80 10D50*	0.1	0.1	0.2	8A81	0.1	0.1	0.1
11D80	0.1	NA	0.1	9A21	0.1	0.1	0.1
12D20 13A50	NA	0.2	0.6	10M1 11MP1	0.1	0.1	0.1
14A20	0.1	NA	0.6	12M1 13A5P1	0.1	0.1	0.1
15A80	NA	NA	1.0				
16C5PO	NA	NA	NA				
1C81							
3C21							
1B51	0.1	0.1	0.1				
2B21	0.1	0.1	0.1				
3B81	0.1	0.1	0.1				

* Used in sulfide concentration average.

509753

TABLE 5-26

ANALYSIS OF EACH QUENCH WATER SAMPLE

SULFATE mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	288.0	268.8	NA	4D51 5D21* 6D81	339.5	286.4	145.3
6B80	256.8	237.6	NA	4D51 5D21 6D81	NA	286.4	NA
7C50	278.4	319.2	-	4D51 5D21 6D81	NA	286.4	NA
8C20*	268.8	278.4	82	7A51*	311.5	325.5	140.7
9C80*	268.8	278.4	82	8A81*	315.2	257.2	NA
10D50*	268.8	278.4	82	9A21*	302.0	309.9	154.3
11D80*	290.4	206.4	55	10M1* 11MP1	281.9	236.6	170.4
12D20*	297.6	278.4	71	12M1* 13A5P1	299.2	299.2	160.0
13A50*	297.6	278.4	71				
14A20*	319.2	268.8	45				
15A80*	278.4	297.6	71				
16C5PO	68.8	331.2	-				
1B51	302.0	-	142.0				
2B21	NA	318.1	132.5				
3B81	273.2	279.8	138.7				

* Used in sulfate concentration averages.

509754

TABLE 5-27

ANALYSIS OF EACH QUENCH WATER SAMPLE

CYANIDE mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	6.7	5.3	NA	4D51 5D21 6D81	0.3	0.3	NA
6B80	6.0	5.3	NA	4D51 5D21 6D81	NA	0.3	NA
7C50	7.7	4.3	NA	4D51 5D21 6D81	NA	0.3	NA
8C20	10.2	1.2	NA	7A51*	0.3	0.3	0.1
9C80 10D50	10.2	4.8	NA	8A81*	0.2	0.2	0.1
11D80*	8.9	7.2	8.6	9A21*	0.2	0.3	0.1
12D20 13A50*	8.9	7.3	7.5	10M1* 11MP1	0.2	0.3	0.1
14A20*	12.4	4.4	6.2	12M1* 13A5P1	0.2	0.4	0.1
15A80	7.2	6.1	7.3				
16C5PO	8.3	15.5	NA				
1C81*	0.2	0.2	0.5				
3C21*	0.2	0.2	0.4				
1B51	0.3	0.3	0.1				
2B21*	0.2	0.2	0.1				
3B81*	0.3	0.3	0.1				

* Used in cyanide concentration averages.

509755

TABLE 5-28

ANALYSIS OF EACH QUENCH WATER SAMPLE

CALCIUM mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	33.6	33.6	-	4D51* 5D21 6D81	74.8	69.4	38.8
6B80	36.5	42.6	-	4D51 5D21 6D81	NA	69.4	NA
7C50	38.2	40.3	-	4D51 5D21 6D81	NA	69.4	NA
8C20*	32.6	42.0	12.7	7A51*	68.5	73.8	37.9
9C80 10D50*	29.4	33.6	12.8	8A81*	68.0	39.5	65.0
11D80*	27.3	46.0	14.4	9A21*	68.3	66.0	38.4
12D20 13A50*	31.5	25.3	14.3	10M1* 11MP1	65.3	60.7	38.5
14A20*	35.2	7.0	7.7	12M1* 13A5P1	60.0	60.1	39.0
15A80*	33.2	55.1	13.1				
16C5PO	4.0	37.7	-				
1C81*	38.5	39.5	28.0				
3C21*	38.5	37.5	27.5				
1B51*	73.5	56.2	34.9				
2B21*	77.3	85.3	36.5				
3B81*	65.5	72.4	36.5				

* Used in calcium concentration averages.

509756

TABLE 5-29

ANALYSIS OF EACH QUENCH WATER SAMPLE

C.O.D. mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	512.7	103.6	NA				
6B80	437.0	531.3	NA				
7C50	325.5	462.5	NA				
8C20*	457.6	572.6	682.1				
9C80 10D50*	373.6	246.5	682.1				
11D80*	776.1	372.4	144.3				
12D20 13A50*	710.5	407.3	888.1				
14A20*	316.7	368.9	634.6				
15A80*	504.8	458.7	830.0				
16C5PO	447.3	580.9	NA				
1C81	31.0	34.0	1.1				

* Used in COD concentration averages.

509757

TABLE 5-30

ANALYSIS OF EACH QUENCH WATER SAMPLE

T.O.C. mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	815.0	816.0	NA	4D51* 5D21 6D81	5.0	6.0	10.0
6B80	873.0	871.0	NA	4D51 5D21 6D81	NA	6.0	NA
7C50	866.0	1201.0	NA	4D51 5D21 6D81	NA	6.0	NA
8C20*	992.0	836.0	1226.0	7A51	7.0	-	NA
9C80 10D50*	1040.0	1059.0	1226.0	8A81*	15.0	17.0	1.0
11D80*	1179.0	1097.0	972.0	9A21*	10.0	11.0	3.0
12D20 13A50*	1161.0	1231.0	1130.0	10M1* 11MP1	10.0	12.0	4.0
14A20*	1112.0	1119.0	1312.0	12M1* 13A5P1	10.0	17.0	NA
15A80*	1105.0	1100.0	1306.0				
16C5PO							
1C81*	20.0	12.0	9.0				
3C21*	1.0	26.0	6.0				
1B51*	4.0	4.0	3.0				
2B21*	9.0	26.0	2.0				
3B81	12.0	6.0	1.0				

* Used in T.O.C. concentration averages.

509758

TABLE 5-31.

ANALYSIS OF EACH QUENCH WATER SAMPLE

TOTAL SOLIDS mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	9091.5	8523.5	-	4D51 5D21* 6D81	1098.7	1788.6	507.1
6B80	10248.5	9380.5	-	4D51 5D21 6D81			
7C50	9317.5	9250.0	-	4D51 5D21 6D81			
8C20*	12650.5	8729.5	6095.5	7A51*	1059.1	1417.1	501.5
9C80 10D50*	9560.5	10955.5	6095.5	8A81*	1100.9	1159.1	512.2
11D80*	9829.0	12155.0	4261.0	9A21*	1186.8	1244.7	522.6
12D20 13A50*	10675.0	11012.0	5422.0	10M1* 11MP1*	1005.7 1079.0	947.25 1206.5	531.0 557.3
14A20*	9930.5	11445.0	5105.0	12M1 13A5P1			
15A80*	9505.0	10450.0	4401.0				
16C5PO							
1C81	1258.8	2165.5	331.9				
3C21	1115.5	2153.6	336.9				
1B51	1121.8		501.65				
2B21		1371.4	494.25				
3B81*	1005.6	1317.1	481.6				

* Used in total solids concentration averages.

509759

TABLE 5-32

ANALYSIS OF EACH QUENCH WATER SAMPLE

DISSOLVED SOLIDS mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	8625.8	8910.6	-	4D51 5D21* 6D81	325.3	1149.4	495.4
6B80	8708.4	9143.2	-	4D51 5D21 6D81			
7C50	9252.4	8854.4	-	4D51 5D21 6D81			
8C20*	9244.0	8478.0	6426.2	7A51*	1044.0	1120.8	580.1
9C80*							
10D50	9269.8	11168.0	6426.2	8A81*	1042.7	939.7	1036.9
11D80*	9350.0	10462.2	5940.2	9A21*	1107.1	1107.1	512.7
12D20							
13A50*	9143.4	7817.6	3405.4	10M1* 11MP1*	994.5 1061.2	837.1 1054.7	514.2 533.4
14A20*	8822.2	9716.2	5426.8	12M1 13A5P1			
15A80*	13263.0	10374.2	4587.0				
16C5PO	9875.8	9796.0	-				
1C81	1197.2	1261.2	326.8				
3C21	1027.8	908.4	318.2				
1B51	1152.1		483.7				
2B21		1165.3	482.1				
3B81*	931.7	1085.0	492.9				

* Used in dissolved solids concentration averages.

509760

TABLE 5-33

ANALYSIS OF EACH QUENCH WATER SAMPLE

SUSPENDED SOLIDS mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	152.2	210.2	-	4D51 5D21* 6D81	81.3	545.3	17.2
6B80	150.6	225.0	-	4D51 5D21 6D81			
7C50	186.4	3I8.6	-	4D51 5D21 6D81			
8C20*	120.2	765.4	114.6	7A51*	33.7	273.0	13.0
9C80 10D50*	148.4	191.8	114.6	8A81*	72.7	211.6	41.6
11D80*	279.2	542.2	337.8	9A21*	67.0	218.3	19.4
12D20 13A50*	167.2	183.6	104.0	10M1* 11MP1*	34.3 39.6	102.7 177.7	29.1 40.3
14A20*	160.4	270.0	59.6	12M1 13A5P1			
15A80*	138.2	122.0	109.0				
16C5PO	133.0	489.0	-				
1C81	616.0	904.3	5.2				
3C21	87.7	1245.2	18.7				
1B51	45.0						
2B21		244.3	15.5				
3B81*	45.0	274.9	16.1				

* Used in suspended solids concentration averages.

509761

TABLE 5-34.

ANALYSIS OF EACH QUENCH WATER SAMPLE

VOLATILE SOLIDS mg/l

Test Code Identifier	Inlet	Return	Makeup	Test Code Identifier	Inlet	Return	Makeup
5B50	92.6	91.7	-	4D51 5D21* 6D81	18.4	22.4	14.2
6B80	91.7	92.6	-	4D51 5D21 6D81	NA	22.4	NA
7C50	91.9	91.9	-	4D51 5D21 6D81	NA	22.4	NA
8C20*	93.7	92.8	95.4	7A51*	22.6	28.5	9.7
9C80 10D50*	94.4	93.1	95.4	8A81*	25.7	24.9	13.5
11D80*	94.7	93.8	95.9	9A21*	26.2	24.1	12.4
12D20 13A50*	89.8	93.8	96.1	10M1* 11MP1	18.4	26.6	13.4
14A20*	92.9	93.0	96.7	12M1* 13A5P1	23.8	22.4	4.4
15A80*	92.5	90.0	96.7				
16C5PO	93.0	91.8	-				
1C81*	74.8	39.5	83.3				
3C21*	59.5	47.0	79.9				
1B51	21.7	-	12.8				
2B21	NA	23.6	13.1				
3B81*	20.4	25.4	12.2				

* Used in volatile solids concentration averages.

509762

TABLE 5-35. SODIUM (mg/l)

Contaminated		Clean	
Sample #	Inlet	Sample #	Inlet
69252	70	59732	130
69000	65	62637	115
69345	80	62519	115
69253	70		
Return		**Return**	
68936	65	62554	125
68975	85	62670	130
69155	65	59635	125
Makeup		**Makeup**	
69027	45	59641	75
69226	35	62651	85
69120	35	62512	70

509763

5.2.1 Sump Emissions

Since there was an odor of ammonia and phenol near the sump, and steam plumes were observed rising from its surface (Figure 5-19 and 5-20), an attempt was made to estimate the emission rates of these compounds. These rates are presented in Table 5-36.

TABLE 5-36. SUMP EMISSIONS

Compound	lb/hr	lb/quench
Ammonia (using flushing liquor)	154	6
Ammonia (using service water)	5.5	0.2
Phenol (using flushing liquor)	0.63	0.02
Phenol (using service water)	1×10^{-3}	4×10^{-5}
* Water evaporated (King's Method)[29]	1800	68
** Water evaporated (from Sec. 5.1.1)	5270	198

** This amount calculated in Sec. 5.1.1 - Presented for purposes of comparison. * Calculations in Appendix.

The flows of air and water during the quench process were measured from the period of time when the hot car entered the tower until the quenched car left the tower. This averaged 2.29 minutes. For the purpose of obtaining a mass balance during the quench period, this time factor was used in calculating the quantity per quench. The sump's contribution to atmospheric pollution continues for 24 hours a day, regardless of quenching activity. For this reason, an hourly emission rate is more meaningful than one based upon discrete quenches.

5.2.2 Sump Sediment

The sump is used for storing water and allows precipitation of some of the suspended solids. These are called breeze or grit and consist mostly of particles of coke. The sump is divided into sections as shown in Figure 5-20 and 5-21. The larger section is cleaned out whenever it becomes so filled with breeze and grit that the screen clogs.

Figure 5-18

Sump Emissions - Car entering

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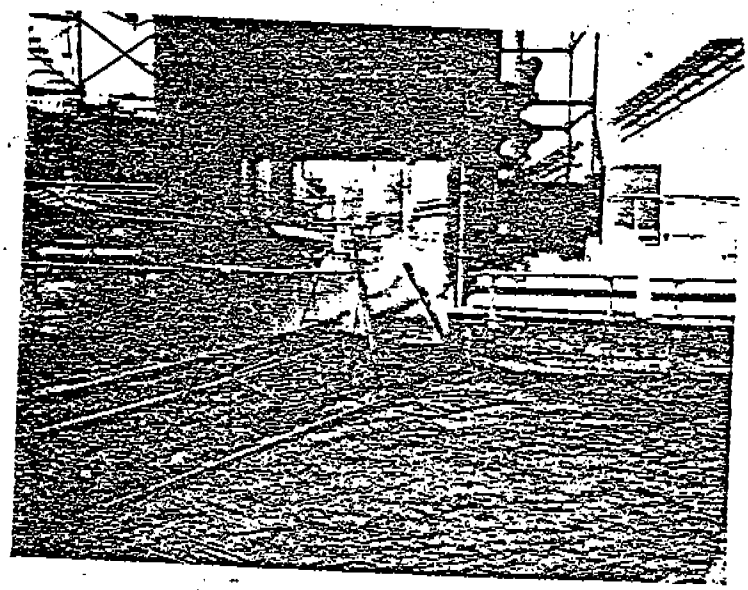

Figure 5-19

Sump Emissions

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Sediment samples were obtained from the sump during quench operations using both clean and contaminated quench water. The analytical results are reported in Table 5-37.

The amount of sediment generated can be estimated based upon the mass balance around the sump. These estimates show that 11.4 pounds of suspended solids are generated per quench using clean water, where 10.3 pounds per quench are generated using contaminated water. This indicates that the mechanism causing the fracturing of the coke and the production of breeze is independent of quench water quality.

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TABLE 5-37. SEDIMENT COMPOSITION (ppm)

Condition	Volatile Solids	Chloride	Phenol	Cyanide	Oil & Grease	Total Solids	Sulfate	Calcium
Clean	14,200,000	4	3	0.8	24,000	28.200,000	37.0	320
Dirty 1	22,100,000	3	200	0.05	2,500	44,500,000	32.0	92.5
Dirty 2	20,000,000	3	200	1.2	15,000	50,100,000	29	107.5

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Sump Showing DAM

Figure 5-20

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Sump

Figure 5-21

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5.2.3 Water Supply

Three river water intakes supply most of the water used by the U.S. Steel plant at Lorain. These intakes pump approximately 170 million gallons per day of water from the Black River for process and cooling purposes. Waste water and non-contact cooling water are discharged to the river through five outfalls. U.S. Steel also purchases over a million gallons per day of potable water from the City of Lorain. Most of this is returned to the City via sanitary sewage systems.

The river water is supplied to the coke plant by Number Two Pump House and the service water piping shown in Figure 5-22.

During the pre-test survey, the river water was sampled at the pump house. The service water was sampled at the point near quench tower No. 5 marked (C) on Figure 5-22. Samples of flushing liquor were also taken at that point. The analytical results are reported in Table 5-38.

The Black River contained pollutants such as phenol, chlorides and ammonia. However, these were in concentrations insufficient to cause a significant buildup in the sump during the clean water tests. The data available on the sediment found in the Black River and some of the plant outfalls (Table 5-39) show the levels of these pollutants.

In order to make a comparison between the contaminated water using flushing liquor and relatively clean water using river water/service water as a make-up, the quench tower was first operated with one type of water and then with the other.

During that series of contaminated tests, a profile of the sump composition was obtained by taking a sample of sump water every half hour for 5 hours and analyzing it for several components as reported in Table 5-40. These analyses compared very closely with similar data taken by U.S. Steel

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5-22

FIGURE 5-22

U.S. STEEL CORPORATION
SERVICE WATER - LORAIN, OHIO
SCHEMATIC PIPING DIAGRAM

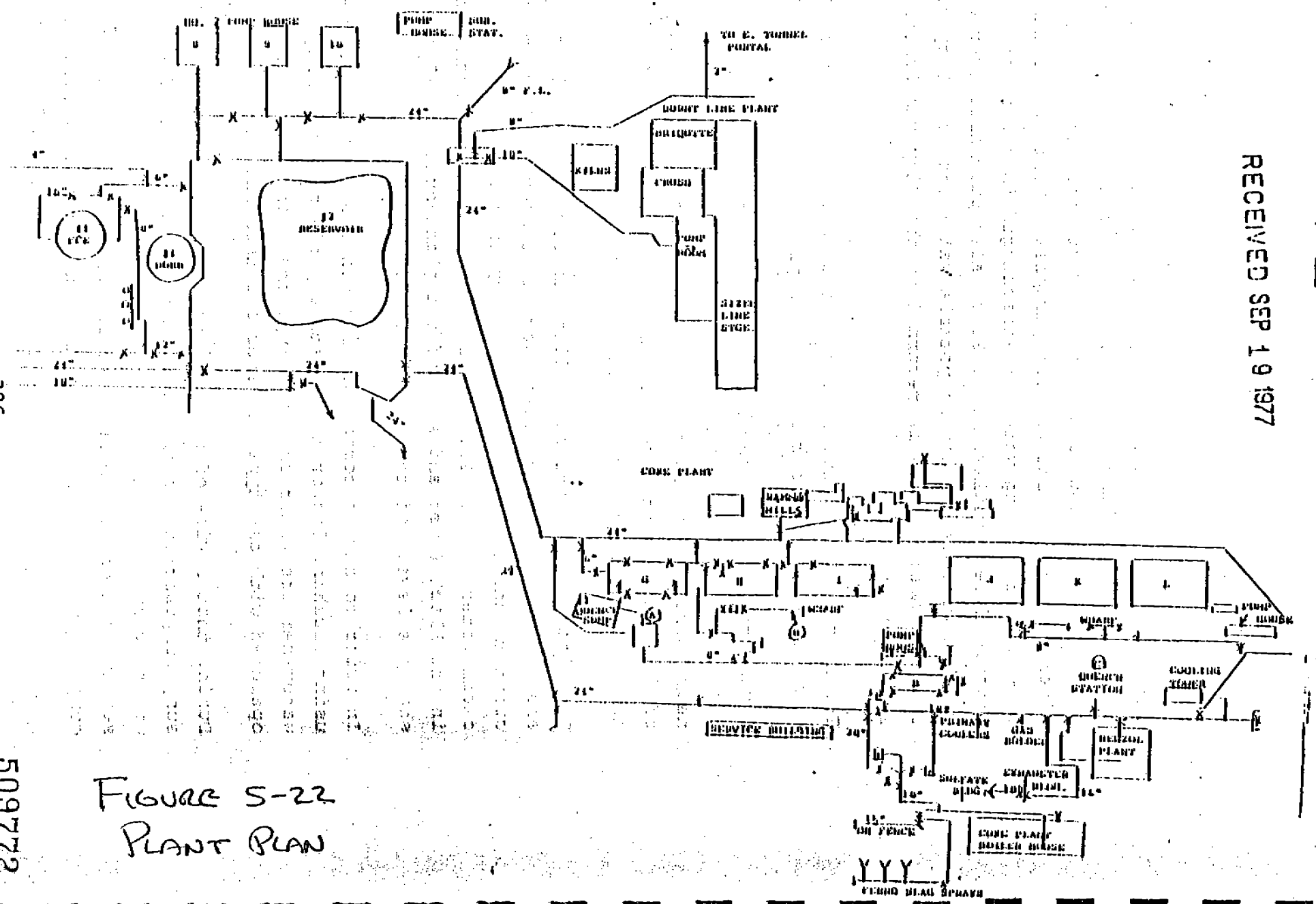

FIGURE 5-22
PLANT PLAN

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TABLE 5-38. COMPARISON OF RIVER WATER/SERVICE WATER AND FLUSHING LIQUOR TYPICAL OF MAKE-UP TO SUMP FOR CLEAN AND CONTAMINATED TESTS

	Conductivity (umhos/cm)	Chlorides (ppm)	COD (ppm)	Phenol (ppm)	Ammonia (ppm)	TOC (ppm)	Total Solids (ppm)	pH
River Water from Pump House No. 2								
7/23-24/74	260-420	35	11	.002	1.65	5	270	6.7-7.7
7-24-25/74	260-400	37	11	.016	1.68	5	280	6.1-7.3
7/25-26/74	390-410	34	10	.003	1.61	5	275	6.3-7.1
6/28/76			24-18	0.05		30		
8/20/76	500	7.3	21	0.05	2.4	29	359	
Service Water from a point near Quench Tower No. 5-marked C in Figure 5-52								
6/28/76	475	216	42	0.44	4.0	11	335	7.0
8/20/76	460	7.5	27	0.25	2.7	25	325	
		6.9	24	0.05	2.4	15	323	
Service Water from Point B								
10/5-10/7/76	485-510							
10/5-11/4/76		440	18	0.1	13	3.8	476	
Service Water								
9/9-9/15/76								
Flushing Liquor		7929	644	150	1079	1195	5230	
6/28-7/20/76	7800	2169	4880	240	1346	886	3750	8
1973 Plant Data-Contaminated Water		1922	2282		767(free) 1185(fixed)	700		

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TABLE 5-39. OUTFALL 002 COKE PLANT SEWER ENTERING BLACK RIVER

	Conductivity (umhos/cm)	Chlorides (ppm)	COD (ppm)	Phenol (ppm)	Ammonia (ppm)	TOC (ppm)	Total Solids (ppm)	pH
1974								
July 23-24	350-550	47	30	0.015	2.42	12	335	6.6-8.8
July 24-25	450-550	48	24	0.030	2.54	9	350	6.5-8.0
July 25-26	460-525	45	28	0.039	3.12	9	340	6.9-7.9

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TABLE 5-40. SUMP SEDIMENT COMPARISON TESTS (ppm)

9/15/76 No. 1 Sump

Conductivity (umhos/cm)	Chloride (ppm)	COD (ppm)	Phenol (ppm)	NH_3-N (ppm)	TOC (ppm)
18,500	8,800	480.76	379.54	780.0	1015
18,500	13,125	519.68	375.5	475.0	1129
19,000	11,150	890.88	317.62	1050.0	1112
20,000	12,000	519.68	322.61	1350.0	1202
19,000	11,950	432.51	347.58	N/A	N/A
19,000	16,000	416.44	345.58	1784.8	1135
18,500	13,750	580.94	251.53	840.0	1205
18,500	12,950	315.00	263.23	1350.0	1202
19,500	13,980	349.18	260.31	1335.0	1182
18,500	13,650	421.63	333.59	600.0	1058
Avg. 18,900	12,736	492.67	319.71	1062.8	1138
U.S. Steel Data					
17,500	6,662	6,160	212.1	1600	1100

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in 1976. After the contaminated water tests were completed, the sump was emptied and the sediment cleaned out. The quench operation was then resumed using service water as make-up. After several weeks of quenching with service water, a set of samples was taken (see Table 5-41). The conductivity results indicated that the sump was relatively clean.

During the clean water test period, another series of sump profile samples was taken (see Table 5-42), and as in the pre-survey tests (Table 5-34), the concentrations of the clean water sump were at least one order of magnitude less than the contaminated water sump. A similar relationship was reported by U.S. Steel in 1973 (Table 5-44). At that time, the ammonia concentration in the sump was 300 times higher in the contaminated than in the clean; however, the phenolics were only four times higher and the cyanide was about the same. As previously reported, the water and residue from the de-benzolized wash oil decanter was at one time added to sump No. 5. This has been discontinued and could possible account for the higher phenol levels in the clean water sump. The cyanide analysis as reported by U.S. Steel in Table 5-44 remains an anomaly.

As a precaution against any unforeseen change in the quality of the water during the clean tests, several additional conductivity measurements were made. The make-up water was tested for conductivity, and samples were taken of the quench water (C_2), and the return from the coke quenching (C_4). These conductivity values indicate that the make-up water averaged about the same as similar samples of service water and tower water taken in 1974, 1976, and during the pre-test survey. The water to the coke (C_2), and the return (C_4), averaged 1300 μ mhos/cm. This is the same order of magnitude as the average reported in Table 5-41 for the profile of the clean number five sump. These measurements

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validate the assumption that the clean water tests were indeed representative of a relatively clean water used as make-up.

Therefore it may be concluded that when the river water/ service water was used as make-up, there is a dramatic reduction in contaminants found in the quench water.

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TABLE 5-41. CONDUCTIVITY MEASUREMENTS AT BEGINNING OF CLEAN TEST 10/5/76 - 10/7/76 (umhos/cm)

Test Code Identifier	Conductivity	Location #1 Quench Tower
1C81	1580	Inlet
1C81	1660	Return
1C81	1475	Inlet
1C81	1510	Return
3C21	1330	Inlet
3C21	1180	Return
		Averages:
	1462	Inlet
	1450	Return

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TABLE 5-42. CONDUCTIVITY MEASUREMENTS DURING CLEAN TEST (umhos/cm)

Test Code Identifier	Conductivity Service Water Measured at B On Fig. 5-51 C_5	Water on Coke C_2	Water Returned to Sump C_4
1C81	675	1400	N/A
2B21	700	N/A	1450
3B81	180	1200	1400
6D81	750	1400	1400
7A51	690	1350	1400
8A81	680	1200	1325
9A21	650	1380	1350
10M1	650	1300	1175
11MP1	750	1275	1325
Average =	636	1325	1353

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TABLE 5-43. SUMP COMPARISON TESTS (ppm)

9/15/76 No. 5 Sump

Conductivity (umhos/cm)	Chloride (ppm)	COD (ppm)	Phenol (ppm)	NH_3-N (ppm)	TOC (ppm)
800	270	462.72	3.75	5.20	26
750	326	450.72	4.99	0.19	15
760	335	450.72	.99	1.75	21
860	310	525.84	7.24	0.14	22
900	290	153.47	5.94	N/A	26
	283	132.91	N/A	0.04	22
1000	315	148.96	3.57	1.14	15
875	295	123.26	0.91	0.11	29
900	277	79.36	1.37	1.52	32
850	339	124.92	1.25	1.92	42
Avg. 855	304	265.3	3.33	1.33	25
U.S. Steel Data					
730	730	162.7	1.85	9.9	26

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TABLE 5-44. DATA SUPPLIED BY USS LORAIN WORKS (ppm)
1973

Coke Quench Water Grabs	NH_3^-N	CN^-	Phenolics
"D" Battery Sump #5 (clean)	3.27	3.65	6.8
"G-H-I" Battery Sump #1 (contaminated)	920	3.80	26.0

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6.0 SOURCE PROCESS PARAMETERS

The relative concentrations of coal's 15 most abundant elements were paralleled by the concentrations found in the coke produced from such coal.

When flushing liquor was used as make-up for the quench water, some portions of these elements were redeposited on the quenched coke while other portions contributed to the constituents commonly found in the stack gas. Specifically, upon comparison with clean quench water, the following elements were noted to be at increased concentrations while using contaminated water:

- Strontium was increased by a factor of 10.
- Barium was increased by a factor of 4.
- Sodium was increased by a factor of 3.
- Potassium was increased by a factor of 2.
- Calcium was slightly increased.

Based upon these calculations, it is clear that the most abundant elements found in coal find their way into the quench process through the contribution from the flushing liquor and the coke. These elements also are introduced into the atmosphere.

Regarding the elements entering the atmosphere via the stack, the following was observed:

- Particles over 10 micrometers in size were enriched with magnesium, sodium, and chlorides.
- The smaller particles were enriched with calcium and chlorides.

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All of these elements were also found in the stack gas. It can thus be concluded that the composition and quality of the coal and coke affects the composition of the stack gas exiting the quench tower.

Oven temperatures were taken from production records and averaged 2288°F for those ovens tested. The surface of the coke in the car entering the quench tower averaged 1737°F. Coking time was approximately 17 - 18 hours. These factors all appear to be typical of the industry. Greenness of the coke for each push tested was rated on a scale of 0 to 5 for each car tested. 0 was the least smoke and 5 was the most. The tests (which consisted of 4 quenches each), averaged 1.75 and varied test to test from 1 to 3.25.

The quench tower baffles at Lorain had no significant effect on water droplets below about 40 micrometers, nor on particulate matter below approximately 30 micrometers.. Larger droplets having diameters more than 100 micrometers, and particulate matter above 70 micrometers are expected to impact with a removal efficiency of well over 70 percent. The average size of which passed through the baffles and exited the stack was about 3 micrometers.
G battery was being rebuilt during the test period, so that the amount of flushing liquor generated was about 1/7 less than normal. However, the amount of coke to be quenched was also reduced by 1/7, so the net change in the chemical make-up of the contaminated water is negligible.

6.1 Coal and Coke Quality

Many of the elements and compounds found in coal are expected to find their way into the quench process. U.S. Steel provided some analytical data on the coal used at the time of the test program. This information is presented in Table 6-1. Similar analytical information on the coke produced from this coal is included in Tables 6-2 through 6-5.

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During the test program, incandescent coke samples were obtained from the oven door area either just after it was opened or before it was closed. Samples were placed in labeled 1 gallon metal cans. The lid was closed and the can was allowed to cool so it could be returned to the YRC trailer where it was sealed.

Whenever possible, quenched and incandescent samples were taken from the car. A YRC technician would wait in the wharf area for the signal to pick up several pieces and place them in a labeled one gallon metal can and seal them. Analysis of these samples is summarized in Tables 6-3 through 6-6. In addition spark source mass spectroscopic techniques were used to analyze these same samples. These results are reported in Table 6-6.

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TABLE 6-1. COAL AND COKE ANALYSIS

	Date	% Volatile Matter	% Ash	% Free Moisture	% Sulfur
Coal	9/9	26.5	7	5	NA
	9/10	27.8	6.5	4.3	NA
	9/11	28.6	6.3	5.2	NA
	9/12	28.1	6.4	4.6	NA
	9/13	27.97	6.9	5.1	NA
	9/14	27.37	7.1	4.9	NA
	9/15	27.41	7.2	4.9	1.0
	9/16	27.53	6.7	5.8	0.98
	10/28	26.1	7.0	6.0	0.93
	10/29	26.67	6.72	5.88	1.12
	10/30	27.48	6.56	6.11	1.02
	10/31	27.48	6.56	5.62	1.02
	11/1	27.69	7.04	6.18	1.07
	11/2	26.83	6.86	4.50	0.92
	11/3	26.85	6.50	4.24	0.97
Coke	9/9	0.59	7.5	3.9	NA
	9/10	0.63	8.1	4.1	NA
	9/11	NA	NA	NA	NA
	9/12	NA	NA	NA	NA
	9/13	0.51	7.5	3.9	NA
	9/14	1.3	7.6	4.1	NA
	9/15	0.57	7.3	4.7	0.73
	9/16	0.60	7.5	4.8	0.71
	10/28	0.63	7.82	4.26	0.80
	10/29	1.70	8.05	2.73	0.90
	10/30	NA	NA	NA	NA
	10/31	NA	NA	NA	NA
	11/1	1.54	7.95	4.18	0.81
	11/2	0.52	8.18	4.57	0.78
	11/3	0.54	7.56	3.52	0.82

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TABLE 6-2. QUENCHED COKE ANALYSIS

Test Code Identifier	Dissolved Solids mg/g	Dissolved Solids lb/quench	COD mg/g	COD lb/quench	PHENOL mg/g	PHENOL lb/quench	CHLORIDE mg/g	CHLORIDE lb/quench
6B80 7C50	0.53	10.2	2.51	48.3	0.0036	0.069	0.26	5.0
8C20 9C80 10D50	1.08	20.8	0.12	2.4	0.0046	0.088	0.17	3.2
14A20 15A80	0.05	1.0	0.31	6.0	0.0038	0.073	0.00	1.6
16C5P0	0.29	5.6	0.44	8.4	0.0018	0.035	0.09	1.7
1C81	0.83	15.9	1.20	22.8	0.0028	0.054	0.14	2.6
3C21	0.46	8.9	0.92	17.6			0.20	3.8
6D81 7A51 8A81 9A21	0.28	5.5	1.31	25.2	0.0036	0.069	0.04	0.1
2B21 3B81	0.86	16.5	0.70	13.2	0.0030	0.058	0.12	2.2

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TABLE 6-3. QUENCHED COKE ANALYSIS

Test Code Identifier	CALCIUM mg/g	CALCIUM lb/quench	SULFIDES mg/g	SULFIDES lb/quench	CYANIDE mg/g	CYANIDE lb/quench	SULFATE mg/g	SULFATE lb/quench
6A80 7C50	0.21	4.3	0.0002	0.004	0.0006	0.011	0.03	0.6
8C20 9C80	0.30	5.8	0.0002	0.004	0.0003	0.006	0.04	0.8
14A20 15A80	0.07	1.4	0.0002	0.004	0.0002	0.004	0.04	0.8
16C5PO	0.18	3.5	0.0002	0.004	0.0005	0.010	0.02	0.4
1C81	0.29	5.6	0.0002	0.004	0.0003	0.006	0.03	0.6
3C21	0.16	3.1	0.0002	0.004	0.0002	0.004	0.09	1.7
6D81 7A51 8A81 9A21	0.13	2.5	0.0002	0.004	0.0003	0.005	0.08	1.5
2B21 3B81	0.22	4.2	0.0002	0.004	0.0003	0.006	0.04	0.8

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TABLE 6-4. INCANDESCENT COKE ANALYSIS

Test Code Identifier	DISSOLVED SOLIDS mg/g	DISSOLVED SOLIDS lb/quench	COD mg/g	COD lb/quench	PHENOL mg/g	PHENOL lb/quench	CHLORIDE mg/g	CHLORIDE lb/quench
6B80								
7C50	1.06	20.3	0.44	8.4	0.0034	0.065	1.4	27.3
14A20								
15A80	1.12	21.6	0.50	9.6	0.0034	0.065		
16C5P0	0.56	10.8	0.87	16.8	0.0036	0.069	0.10	2.0
1C81	1.02	19.7	0.74	14.1	0.0030	0.058	0.26	4.9
3C21	0.64	12.4	1.16	22.4	0.0046	0.088	0.26	5.0
2B21								
3B81	0.49	9.4	2.39	45.9	0.0030	0.058	0.13	2.0
6D81								
7A51								
8A81								
9A21	0.60	11.6	1.30	25.0	0.0046	0.084	0.86	16.5

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TABLE 6-5. INCANDESCENT COKE ANALYSIS

Test Code Identifier	CALCIUM mg/g	CALCIUM lb/quench	SULFIDES mg/g	SULFIDES lb/quench	CYANIDE mg/g	CYANIDE lb/quench	SULFATE mg/g	SULFATE lb/quench
6B80								
7C50	0.18	3.5	0.0002	0.004	0.0003	0.005	0.24	4.6
14A20								
15A80	0.17	3.3	0.0002	0.004	0.0003	0.006	0.18	3.5
16C5PO	0.18	3.5	0.0002	0.004	0.0002	0.004	0.11	2.1
1C81	0.25	4.8	0.0002	0.004	0.0004	0.007	0.12	2.3
3C21	0.19	3.6	0.0002	0.004	0.0004	0.008	0.04	0.8
2B21								
3B81	0.16	3.1	0.0002	0.004	0.0002	0.004	0.14	2.7
6D81								
7A51								
8A81								
9A21	0.22	4.2	0.0002	0.004	0.0002	0.004	0.15	2.9

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TABLE 6-6 MASS SPECTROGRAPHIC ANALYSIS OF COKE SAMPLES PPM (BY WEIGH

Element	Incandescent Coke	Quenched Clean Coke	Quenched Dirty Coke
Si	20,000	100,000	50,000
Al	20,000	50,000	50,000
Fe	10,000	50,000	50,000
Mg	10,000	10,000	10,000
Ti	3,000	5,000	5,000
Na	2,000	3,000	10,000
Ca	2,000	3,000	5,000
K	1,000	2,000	5,000
S	500	2,000	2,000
Si	300	300	3,000
As (a)	300	300	300
Mn	200	1,000	500
Ba	200	500	2,000
P	100	300	500
Cl	100	300	500
Cu	100	200	200
Cl^-	100	100	200
V	100	100	100
Cr	100	100	100
B	50	50	50
Co	50	50	50
Rb	30	100	100
Zr	30	100	100
Ga	30	30	30
Ni	20	100	300
Sc	20	30	20
Se(a)	>20	>30	>20
Y	10	30	100
La	10	50	50
Na	10	20	30
Be	10	5	20
Sn	5	100	10,000
Zn	5	50	100

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TABLE 6-6. (Continued)

Element	Incandescent Coke	Quenched Clean Coke	Quenched Dirty Coke
Cl	5	20	100
Br	5	30	50
Nb	5	20	10
Mo	5	5	20
Pb(a)	≥5	≥30	≥200
F	3	3	10
Tm	>3	>3	>3
Pr	2	10	10
Ge	>2	>10	>10
Ta	>2	>3	>3
Pd	>2	>1	>2
Ru	>>2	>2	>3
Cs	1	>3	20
Sb	1	>3	3
Cd	>1	>2	>3
In (a)	>1	>2	>10
Dy	>1	>1	>3
Hg	>1	>2	>2
Hf	>1	>2	>2
Er	>1	>1	>2
Sm	>1	>1	>1
Eu	>1	>1	>1
Gd	>1	>1	>1
Yb	>1	>1	>1
W	>1	>1	>1
Os	>1	>1	>1
Ir	>1	>1	>1
Pf	>1	>1	>1
Tl	>1	>1	>1
Te	>1	>1	>1
Ag	>1	>1	>0.5
Hu	>0.5	>0.5	>1
Lu	>0.5	>0.3	>1
Re	>0.5	>0.5	>0.5
Th	>0.5	>0.5	>0.5

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TABLE 6-6. (Continued)

Element	Incandescent Coke	Quenched Clean Coke	Quenched Dirty Coke
U	>0.5	>0.5	>0.5
Rh	>0.3	>0.3	>2
Tb	>0.3	>0.3	>0.3
Au	>0.3	>0.3	>0.3
Bi	>0.3	>0.3	>0.3
I	0.2	2	10

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The 15 elements most abundant in coal were found to be the most abundant in coke. When listed in decreasing order of abundance as in Table 6-7, they ranked in about the same order as they were found in coal. The major exceptions being calcium, sulfur, and sodium.

Calcium, phosphorus, and sulfur may have been volatilized by the high temperature of the coke in the oven and in the car.

Sodium seems to have been concentrated by the evaporation of the rinse water used for make up and they may have entered the system through chemicals used in the coal chemical plant.

In the quenched coke, the various elements were found in about the same ranking when clean water was used as compared to contaminated water with the following exceptions:

- There was more tin found in the quenched coke when contaminated water was used.
- When contaminated water was used, the sodium content was increased one third as compared to a 50 percent increase over incandescent coke when contaminated water was used.
- Potassium, barium, strontium and calcium were all present at a much lower level with clean water than when contaminated water was used. Thus it seems likely that these elements were recovered from the hot coke oven gases by the flushing liquor spray and other washes in the chemical plant. When these streams were used as make-up, they were found in the quenched coke at higher levels than when clean water was used.

In the cyclone catch (which was primarily aerosol particles and droplets above 10 micrometers) the ranking of the various elements changed dramatically:

TABLE 6-7

Elements found in coal listed in order of decreasing abundance compared to the quantities (as determined by mass spectrometry) associated with incandescent and quenched coke, and with those portions of the aerosol exiting the stack larger than 10 microns and those smaller than 3 microns.

Coal Rank	Major Elements in Coal (7)	ppm	Incandescent Coke ppm	Incandescent Coke lbs per quench	Incandescent Coke Rank	Quenched Coke: Contaminated water was used as make up ppm	Quenched Coke: Contaminated water was used as make up lbs per quench	Quenched Coke: Contaminated water was used as make up Rank	Quenched Coke: Clean water was used as make-up ppm	Quenched Coke: Clean water was used as make-up lbs per quench	Quenched Coke: Clean water was used as make-up Rank	Cyclone catch representing particles larger thn 10 microns in size ppm	Cyclone catch: lbs per quench	Cyclone catch Rank	Caught on filter representing particles smaller than 3 microns ppm	Caught on filter: lbs per quench	Caught on filter Rank
1	Silicon	most	20,000	384	(1)	50,000	960	(1)	100,000	1920	(1)	1	$9.\times10^{-6}$	(4)			
2	Aluminum		20,000	384	(2)	50,000	960	(2)	50,000	960	(2)	0.5	4.9×10^{-7}	(5)			
3	Calcium		2,000	384	(6)	5,000	96	(7)	3,000	57.6	(6)	0.5	4.7×10^{-6}	(6)	30,000	0.009	1
4	Iron		10,000	192	(3)	50,000	960	(3)	50,000	960	(3)	0.5	4.7×10^{-6}	(7)			
5	Magnesium	least	10,000	192	(4)	10,000	192	(4)	10,000	192	(4)	10	94×10^{-6}	(1)			
6	Sulfur	7800 to 11,000	500	9.6	(9)	2,000	38.4	(11)	2,000	38.4	(8)	2	1.9×10^{-6}	(3)	1,500	0.004	5
Trace Elements in an Eastern coal (12)																	
7	Titanium	1000	3,000	57.6	(5)	5,000	96	(8)	5,000	96	(5)	0.2	1.9×10^{-6}	(9)	80	2.4×10^{-4}	8
8	Potassium	1000	1,000	19.2	(8)	5,000	96	(9)	2,000	38.4	(9)	0.2	1.9×10^{-6}	(10)	5,000	0.015	4
9	Phosphorous	1000	100	1.92	(12)	500	9.6	(13)	300	5.8	(12)	0.03	0.3×10^{-6}	(13)	25	7.4×10^{-5}	9
10	Sodium	1000	2,000	38.4	(7)	10,000	192	(5)	3,000	57.6	(7)	5	47×10^{-6}	(12)			
11	Strontium	450	300	5.76	(10)	3,000	57.6	(10)	300	5.8	(11)	0.003	0.03×10^{-6}	(14)	900	0.003	6
12	Barium	300	200	3.84	(11)	2,000	38.4	(12)	500	9.6	(10)	0.03	0.3×10^{-6}	(12)	10,000	0.053	
13	Fluorine	160	.3	0.058	(15)	10	0.192	(15)	3	.058	(15)	.003	0.3×10^{-6}	(15)	200	5.9×10^{-4}	3
14	Tin		5	0.096	(14)	10,000	192	(6)	100	1.92	(14)	.05	$.47\times10^{-6}$	(11)			
15	Chloride Content of Selected American Coal (13)																
	Ohio	100															
	Illinois	100															
	Indiana	600	100	1.92	(13)	500	9.6	(14)	300	5.8	(13)	0.3	2.8×10^{-6}	(8)	19,000	0.056	2
	West Va.	700															
	Penna.	1400															
	Illinois	3500															

5097794

- Magnesium and sodium moved to the top of the rank, apparently because they were associated with larger fractions of the aerosol. This was a combined sample; that is, contaminated and clean cyclone catches were combined.

In the portion of the aerosol caught on the filter (representing particles smaller than 3 micrometers), the ranking of the several elements was quite different than in the coal, coke, quenched coke or larger fractions of the aerosol. Of the elements found in coal, only nine were found on the filter. They were; calcium, chlorine, barium, potassium, sulfur, strontium, fluorine, titanium, and phosphorus. Silicon, aluminum, iron, magnesium, sodium, and tin were not found on the filter (i.e., in particles smaller than 3 micrometers).

- Calcium became number one in rank, indicating that it had been volatilized in the incandescent coke, allowing it to form aerosols less than 3 micrometers. Some larger sized particles were caught in the cyclone, but the greatest effect was noted in the smaller size ranges.
- Chlorine became number two in rank, indicating the substances ammonia and chlorides were volatilized or formed by the hot coke causing them to form extremely small particles.
- Barium and strontium are in the same periodic group as calcium and enriched the particles under 3 micrometers.

Table 6-8 shows the level of sulfur found in the quenched coke samples.

TABLE 6-8. QUENCHED COKE ANALYSIS

Condition	% Sulfur
Clean Water	0.80
	0.55
	0.50
Contaminated Water	0.85
	0.60
	0.50

509795

Next to carbon, the following elements are discussed in the order of abundance in coal[32]:

Si - Found in coal ash and very frequently as part of minerals- alumino silicates and silica groups. A major element in Eastern U. S. coal. The most abundant element in coal.

Al - Found in coal ash; very frequently as part of minerals in coal - associated with the alumino silicates and silica groups. A major element in Eastern U.S. coal. The second most abundant element in coal.

Ca - Found in coal ash and very frequently as part of minerals in coal. Is a major trace element in Eastern coal. Listed as the 3rd most abundant major element in coal.

Fe - Found in coal ash and very frequently as part of minerals in coal. A major element in Eastern U.S. coal. 4th most abundant major element in coal.

Mg - Found in coal ash and very frequently as part of minerals in coke. A major element in Eastern U.S. coal. Listed as the 5th most abundant major element in coal.

S - Mineral coals do not contain free sulfur but inorganic and organic sulfur compounds. Low sulfur coals typically consist of organic sulfur over pyrite sulfur, whereas high sulfur coals consist mostly of pyrite sulfur. Up to 70% of the sulfur content of coal passes into the coke.

Sr - Found in coal ash.

K - Found in coal ash, and very frequently as part of minerals in coal. Associated with the mineral groups: alumino silicates, sulfides, and silica. Listed as a major trace element in Eastern U.S. coal.

Na - Found in coal ash, and very frequently as part of minerals in coke. Associated with the mineral group silica. A major element in Eastern U.S. coal.

The elements listed by Schroeder[33] as being emitted by the quench process are listed in Table 6-9. Many of these elements pose a threat to health due to their toxicity. During the test program, some were detected while others were not.

509796

TABLE 6-9.ELEMENTAL EMISSIONS FROM THE QUENCH PROCESS

Element	Detected	Not Detected
Chromium	X	
Nickel	X	
Silver		X
Titanium	X	
Antimony	X	
Beryllium	X	
Vanadium	X	
Fluorine	X	
Lead		X
Cadmium		X
Boron		X
Mercury		X
Germanium		X
Gallium		X
Tin	X	
Tungsten		X
Arsenic		X
Selenium		X
Zirconium	X	
Yttrium	X	
Bismuth		X

509797

6.2 Battery Operation

The coke manufacturing process at Lorain includes by-product recovery. Bituminous coal is heated in an oxygen-deficient atmosphere (coke oven) during which volatile components of the coal are driven off. At the completion of this process, the residue remaining in the oven is coke, the volatile components having been recovered and processed in the by-product plant to produce gas, tar, light oils, and other materials. The coking process is accomplished in narrow, rectangular, silica brick ovens which are arranged side-by-side in groups called batteries.

The coke ovens are 40 feet 1-3/4 inches long, 10 feet 1-7/8 inches high; 21 inches wide at the car end and 17 inches wide at the pusher end, averaging 19 inches in width. The working volume below the leveling bar in 560 cubic feet.

In order to charge the ovens, the coal is loaded into a hopper car. This car holds approximately 13.1 tons of coal in three hoppers. At Lorain, there were scales for weighing the coal, but they were not used. After loading the hopper car, it is moved to the top of a battery, where the coal is dumped through three ports in the oven top. This coal (oven density: 48-50 pounds per cubic foot), fills the oven to a point level with the top of the leveling bar door.

The coal is generally blended from lots originating from many different sources. During the time of testing, 16 different coals were available and 6-8 were used in any given blend.

The ovens are separated from each other by a space between the walls of the adjacent oven and gas is burned in this space to provide the heat necessary for the coking of the coal. This gas is about 40% of that produced from the coking process. The balance of the gas available from coking is used elsewhere in the steel plant. The combustion products from these inner wall furnaces are drafted out of the area by tall stacks. The ovens are operated under a very slight positive pressure so that any

009798

leakage occurs from the oven to the atmosphere or into the adjacent furnaces.

The gases and other volatile material from the coking processes are bled off the top of each oven through ascension pipes into the collection main which runs the length of the battery. Where the gas main leaves the battery, a back pressure valve maintains a positive pressure on the oven side against the negative pressure developed by the exhaust fans.

There are 413 coke ovens in use in seven batteries; each battery consisting of 59 ovens. These batteries were constructed and operated as indicated in the following Table:

TABLE 6-10. BATTERY OPERATION

Battery	No. of Ovens	Year Built	Manufacturer	Shut Down	Started Up	Condition
G	59	1956	Koppers	7/17/61	5/13/66	Rebuilding
H	59	1956	Koppers	8/10/61	5/13/66	" Sched.
I	59	1955	Wilputte	8/10/61	5/18/66	" "
J	59	1947	Wilputte	1/20/63	9/17/60	Good
K	59	1947	Wilputte	1/20/63	10/20/70	Good
L	59	1947	Wilputte	1/20/63	11/17/70	Good
O	59	1957	Koppers	12/23/60	7/11/66	Good

These ovens are normally operated three shifts per day, seven days per qeek, and convert upwards of 7,000 tons of coal per day to coke. Normal coking time is 17.3 hours. However, this may vary with the condition of the oven.

During the test period, batteries H and I always had several ovens on a 24-hour schedule and G battery was being rebuilt. The production of coke for typical periods during September and October are as follows:

509799

TABLE 6-11. COKE PRODUCTION DURING TEST PERIOD

Date	Tons	Date	Tons
1976			
Sept. 19	4611	Oct. 1	4472
20	4111	2	4557
21	4055	3	4618
22	3887	4	4635
23	4128	5	4577
24	4368	6	4664
25	4449	7	4673
26	4409	8	4470
27	4511	9	4663
28	4361	10	4398
29	4471	11	4470
Sept. 30	4466	12	4594
		13	4689
		14	4684
		15	4707
		16	4662

Average 4478 tons coke production per day. This was from six batteries (G was down for rebuilding).

The data in Table 6-11 are compared with that presented in Table 6-13 for the purpose of assessing the representativeness of production during the test period with normal production. Since G battery was being rebuilt during the test period, production was down by a factor of about one seventh. The production quantities presented in Table 6-12 were provided by U.S. Steel and are representative of the months of December 1975 through May 1976.

509800

TABLE 6-12. COKE PRODUCTION PRIOR TO TEST PERIOD

Week Ending	Tons
12/6/75	32,220
12/13/75	33,204
12/20/75	32,305
12/27/75	32,524
1/3/76	32,306
1/10/76	31,324
1/17/76	31,246
1/24/76	31,206
1/31/76	31,811
2/7/76	31,308
2/14/76	31,711
2/21/76	31,256
2/28/76	32,397
3/6/76	33,052
3/13/76	34,031
3/20/76	34,116
3/27/76	34,307
4/3/76	34,047
4/10/76	34,418
4/17/76	34,264
4/24/76	33,252
5/1/76	33,280
5/8/76	34,313
5/15/76	33,956
5/22/76	34,018
5/29/76	33,763

509801

TABLE 6-13. GREENNESS RATING FOR COKE ENTERING QUENCH TOWER

Test Code Identifier	Date	Time	Oven No.	Greenness Rating	Coke Oven Heater Temp. °F	Incandescent Coke Temp. °F
5B50	9/10/76	00:01	H-16	5	2350	
	9/10/76	00:12	H-36	1	2350	
	9/10/76	00:17	G-19	1	NA	NA
	9/10/76	00:22	G-29	1	NA	
6B80	9/11/76	20.:04	I-56	1	2445	
	9/11/76	20:14	G-5	4	NA	
	9/11/76	20:27	G-15	5	NA	NA
	9/11/76	21:00	H-8	2	2332	
7C50	9/11/76	23:45	G-29	5	NA	
	9/11/76	23:57	I-58	3	2445	
	9/11/76	24:08	H-1	2	2332	NA
	9/11/76	24:17	H-11	1	2332	
8C20	9/12/76	20:16	G-15	5	NA	
	9/12/76	20:30	G-25	1	NA	
	9/12/76	20:35	I-41	1	2455	NA
	9/12/76	20:40	H-51	1	2338	
9C80	9/12/76	21:40	I-13	1	2455	
	9/12/76	21:45	I-23	1	2455	
	9/12/76	21:50	I-33	2	2455	NA
	9/12/76	22:10	G-17	N/A	NA	
10D50	9/12/76	23:23	I-53	0	2455	
	9/12/76	23:27	I-63	0	2455	
	9/12/76	23:35	H-64	0	2338	NA
	9/12/76	23:42	H-5	1	2338	
11D80	9/13/76	19:59	I-55	0	2362	
	9/13/76	20:05	I-65	1	2362	
	9/13/76	20:08	G-5	3	NA	NA
	9/13/76	20:15	G-15	4	NA	
12D20	9/13/76	21:15	G-25	2	NA	
	9/13/76	21:50	G-17	1	NA	
	9/13/76	21:53	G-27	0	NA	NA
	9/13/76	21:58	G-9	4	NA	
13A50	9/13/76	23:24	H-23	1	2329	
	9/13/76	23:30	H-64	0	2329	
	9/13/76	23:37	H-59	3	2329	NA
	9/13/76	23:45	I-9	2	2362	
14A20	9/14/76	20:11	H-12	1	2315	
	9/14/76	20:16	H-32	0	2315	
	9/14/76	20:22	H-42	3	2315	NA
	9/14/76	20:52	G-7	0	NA	
15A80	9/14/76	23:15	I-62	1	2367	
	9/14/76	23:25	H-4	1	2315	
	9/14/76	23:30	H-14	1	2315	NA
	9/14/76	23:37	H-23	1	2315	

509802

TABLE 6-13. (Continued)

Test Code Identifier	Date	Time	Oven No.	Greenness Rating	Coke Oven Heater Temp. °F	Incandescent coke Temp. °F
1B51	10/29/76	18:55	G	1	2128	-
	10/29/76	19:02	G	1	2128	1709
	10/29/76	19:07	G	1	2128	1687
	10/29/76	19:15	-	1	-	1723
2B11	10/30/76	18:05	G-13	1	NA	1623
	10/30/76	18:15	I-1	2	NA	1787
	10/30/76	18:20	I-11	4	NA	1855
	10/30/76	18:25	I-21	3	NA	1802
3B81	10/31/76	01:15	G-29	4	NA	NA
	10/31/76	01:20	G-39	1	NA	1604
	10/31/76	01:25	H-5	1	2265	1670
	10/31/76	01:30	H-15	1	2265	1621
4D51	11/01/76	17:20	H-37	1	2340	1718
	11/01/76	17:25	H-47	1	2340	1940
	11/01/76	17:30	H-57	1	2340	1723
	11/01/76	17:40	G-21	2	2125	1710
5D21	11/01/76	23:35	I-6	1M	2366	1934
	11/01/76	23:40	I-16	1N	2366	1876
	11/01/76	23:45	I-26	1M	2366	1820
	11/01/76	23:55	I-46	1L	2366	1704
6D81	11/01/76	01:05	G-2	1N	2125	1668
	11/01/76	01:10	G-8	4L	2125	1616
	11/01/76	01:15	G-18	1N	2125	1829
	11/01/76	01:25	G-28	2N	2125	1940
7A51	11/02/76	17:10	H-57	1L	2381	1990
	11/02/76	17:15	G-21	3N	2114	1520
	11/02/76	17:20	G-31	2L	2114	1512
	11/02/76	17:25	G-41	1N	2114	1642
8A81	11/02/76	19:25	I-18	3L	2367	1875
	11/02/76	19:30	I-28	4N	2367	1843
	11/02/76	19:35	I-38	3N	2367	1751
	11/02/76	19:40	I-48	1N	2367	1727
9A21	11/02/76	20:55	G-17	1N	2114	1722
	11/02/76	21:00	G-27	4L	2114	1632
	11/02/76	21:05	H-1	1N	2381	1930
	11/02/76	21:10	H-11	2N	2381	1860
10M1	11/03/76	16:45	G-31	4L	2180	1439
	11/03/76	16:50	G-41	2N	2180	1703
	11/03/76	16:55	-	1N	NA	1693
	11/03/76	17:45	G-3	1N	2180	1553
11MP1	11/03/76	19:45	G-37	1L	2180	
	11/03/76	19:50	G-27	1N	2180	NA
	11/03/76	19:55	-	1N	-	
	11/03/76	-	-	-	-	

N - Normal Load of Coke in Car
M - More than Normal amount of Coke
L - Less than Normal amount of Coke

509803

TABLE 6-13. (Continued)

Test Code Identifier	Date	Time	Oven No.	Greenness Rating	Coke Oven Heater Temp. °F	Incandescent cok Temp. °F
12M1	11/03/76	21:40	G-17	1L	2180	
	11/03/76	21:45	G-27	1L	2180	
	11/03/76	21:50	G-37	1L	2180	NA
	11/03/76	22:10	H-5	1L	2180	
13A5P1	11/03/76	00:55	-	1N	-	
	11/03/76	01:00	G-2	1N	2180	
	11/03/76	01:10	G	5N	2180	NA
	11/03/76	-	-	-	-	
1C81	10/5/76	21:25	H-29	1		
	10/5/76	21:30	H-39	3		
	10/5/76	21:35	H-49	2	NA	NA
	10/5/76	21:50	G-9	4		
2						
2						
2						
2					NA	NA
3C21	10/7/76	19:00	I-64	1		
	10/7/76	19:07	G-23	5	NA	NA
	10/7/76	19:14	G-33	2		
	10/7/76	19:20	H-6	5		

509804

From 13.1 tons of coal per charge each oven yields:

9.6 tons of coke oven productions

-1.0 tons of breeze,

Total:8.6 tons furnace coke

Therefore, the equivalent coal usage with all seven batteries would have been about 7000 tons per day for a period in 1975.

Typical oven temperatures were obtained from production records and are summarized for those ovens tested in Table 6-13. Typical plant records of oven temperatures for the test period are included in the Appendix. The average coke oven temperatures for those ovens tested were:

Average temperature for G battery - 2147°F (23 quenches)
Average temperature for H and I batteries = 2358°F (46 quenches)

A weighted average of oven temperature for G, H, and I Batteries = 2288°F.

During the clean water phase a Barnes Infrared thermometer was mounted on the roof of the pump house. The upper surface temperature of the coke mass in the car just before it entered the quench tower was measured and reported.

Coke cars from G battery averaged = 1653°F (17 quenches)
Coke cars from H and I batteries averaged = 1812°F (19 quenches)

A weighted average coke surface temperature, in the car, was for G, H, and I batteries = 1737°F.

509805

At the end of the coking period the doors are removed from each end of an oven and the pushing machine pushes the incandescent coke into the quenching car. The quench car is then moved by a small electric engine to the closest quench tower.

Occasionally, some of the volatile matter may not be distilled from the coal. As a result varying amounts of grey or black smoke may arise from the coke as it is pushed from the oven. As the car is moved towards the quench tower varying amounts of these dark colored volatile materials arise from certain sections of the car. On such occasions, after the car is in the quench tower there is a discoloration of the heated air exiting from the stack before the steam plume starts. An effort was made to rate each car just before it entered the quench tower. In doing so, the density of the smoke and the area of the coke's surface emitting smoke were both visually evaluated in accordance with an arbitrary scale from 0 to 5 (zero indicating no smoke, and 5 indicating observable smoke from the entire surface of the car. The results of their observations are tabulated in Table 6-14.

TABLE 6-14. AVERAGE GREENNESS RATING FOR EACH TEST

Reference Code	Rating	Reference Code	Rating
1B51	1	5B50	2
2B21	2.5	6B80	3
3B81	1.75	7C50	2.75
4D51	1.25	8C20	2
5D21	1	9C80	1.33
6D81	1.75	10D50	.25
7A51	1.5	11D80	2
8A81	2.75	12D20	1.75
9A21	2	13A50	1.5
10M1	2	14A20	1
11MP1	1	15A80	1
12M1	1		
13A5P1	1.75		
1C81	2.5		
2			
3C21	3.25		

509806

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The correlation of the ratings of the several observers is presented in Figure 6-1. This indicates that there were very few ratings which deviated from others by more than one level of difference. These ratings were subsequently used in an effort to correlate emissions with greenness.

During the coking period the hot gases are continuously released. Three factors affecting the composition of these gases are:[34]

- Coking temperature (this mostly determines the hydrogen to hydrocarbons ratio. The higher the temperature, the higher the hydrogen content of the gas and the lower the hydrocarbon content).
- Coal compositions.
- The amounts of air and combustion products drawn into the coke oven. Oxygen reacts with the gas and coke to form more CO_2, CO, and N. (in the case of Lorain the oven was under positive pressure and effect was minimal)

This project did not include any investigation of the operations of the chemical by-products processes. However, since the make-up for the sump included flushing liquors and other excess wash waters from the by-products process, it is appropriate to include a brief description of the chemical recovery operations.

The hot gases from the batteries are cooled to below 212°F with sprays of flushing liquor which is then decanted to remove the crude tar. After the decanter the flushing liquor is recycled. Excess flushing liquor is stored and goes to the quench tower. The partially cooled gases are further reduced in temperature (to 110°F) by primary coolers which utilize service water (river water) for cooling the gas without direct contact between the cooling water and the chemicals in the gas stream. The gases pass through exhaust turbines and electrostatic precipitators to remove entrained tar. They then pass to an ammonia scrubber, a final cooler, a light oil scrubber, and are finally burned either in the coke plant or elsewhere in the steel mill. Four 25,000 cfm Cottrell precipitators were installed in 1947, and one Cottrell

509807

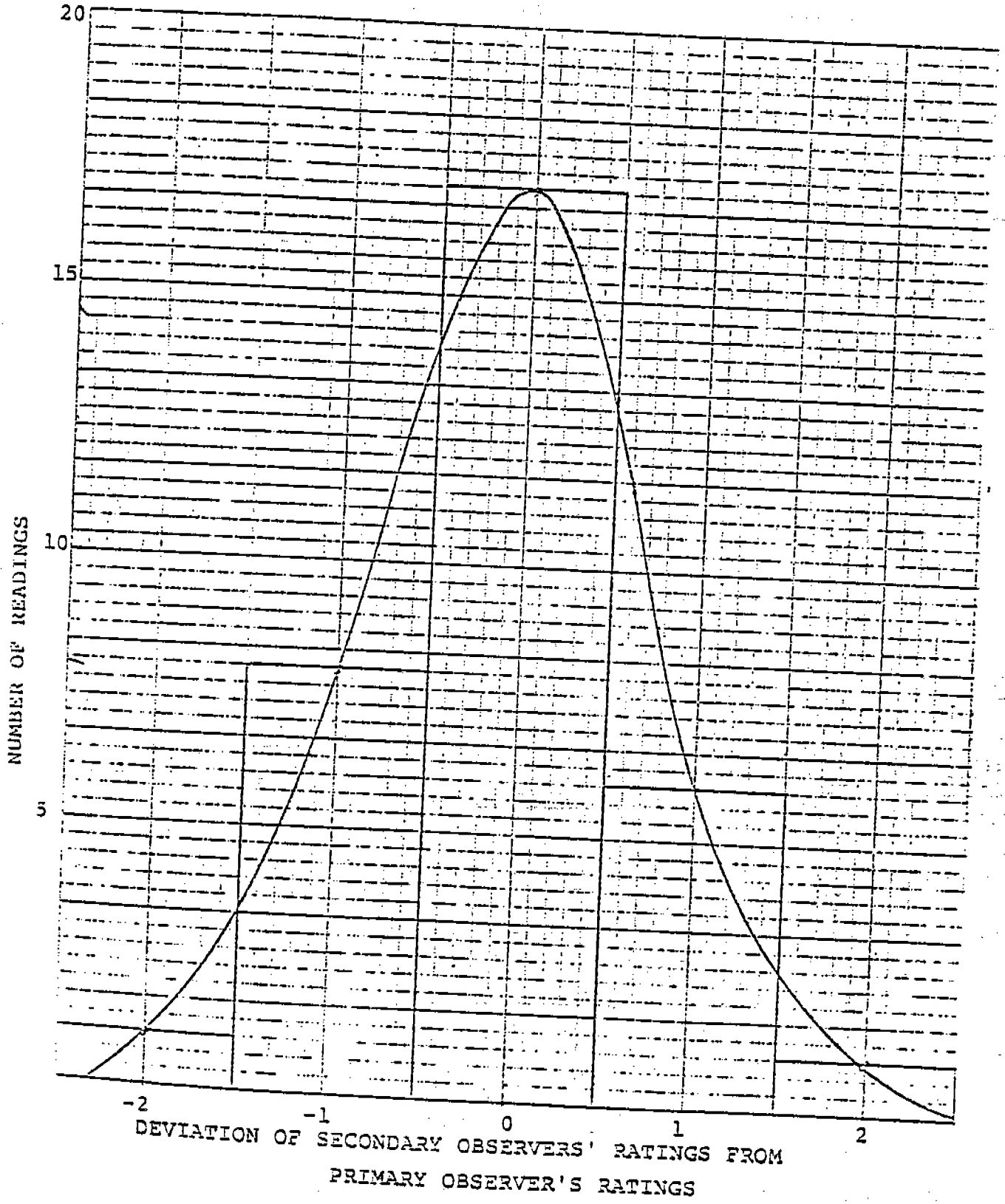

FIGURE 6-1

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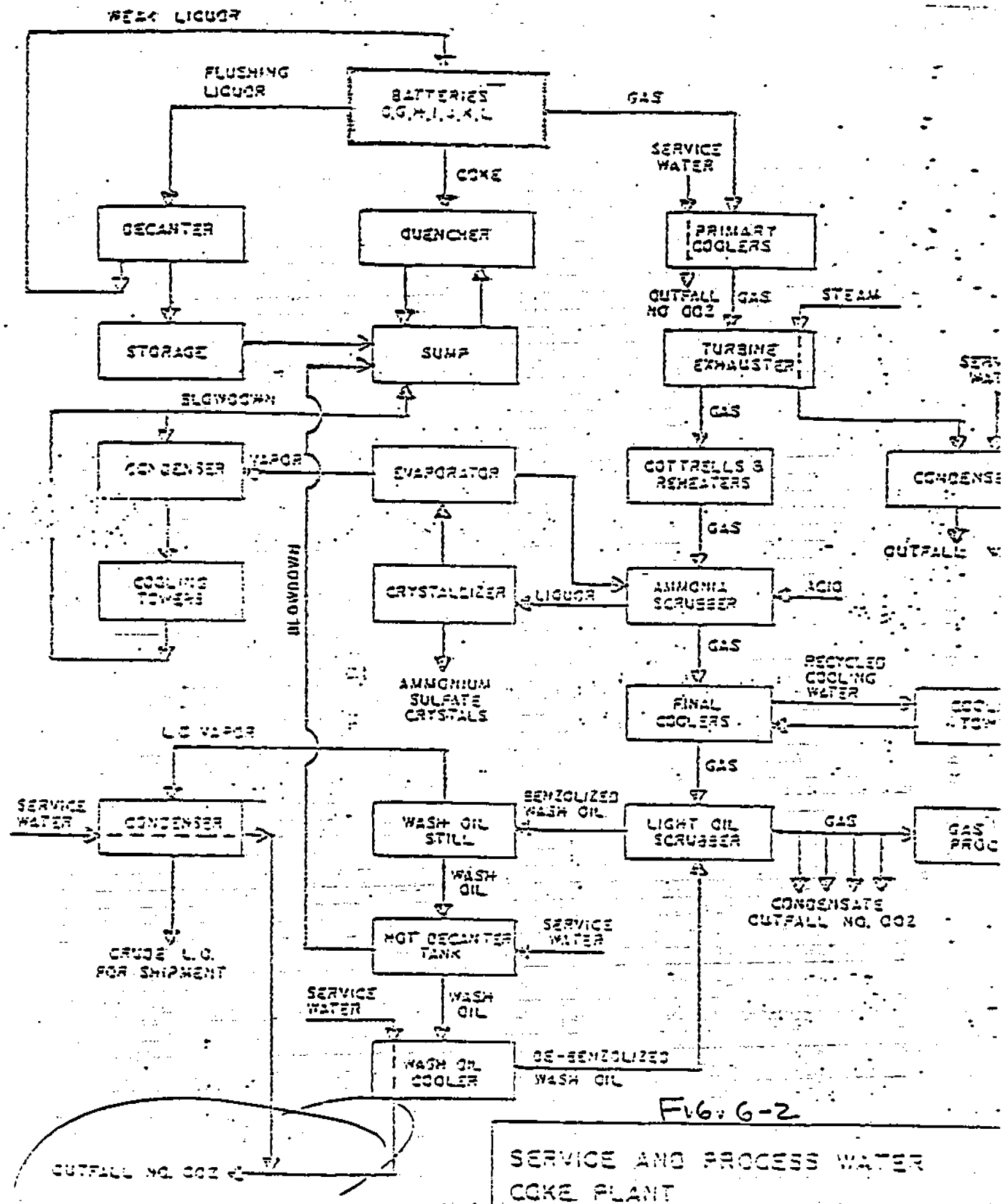

FIG. 6-2

SERVICE AND PROCESS WATER
COKE PLANT
LORAIN WORKS

509809

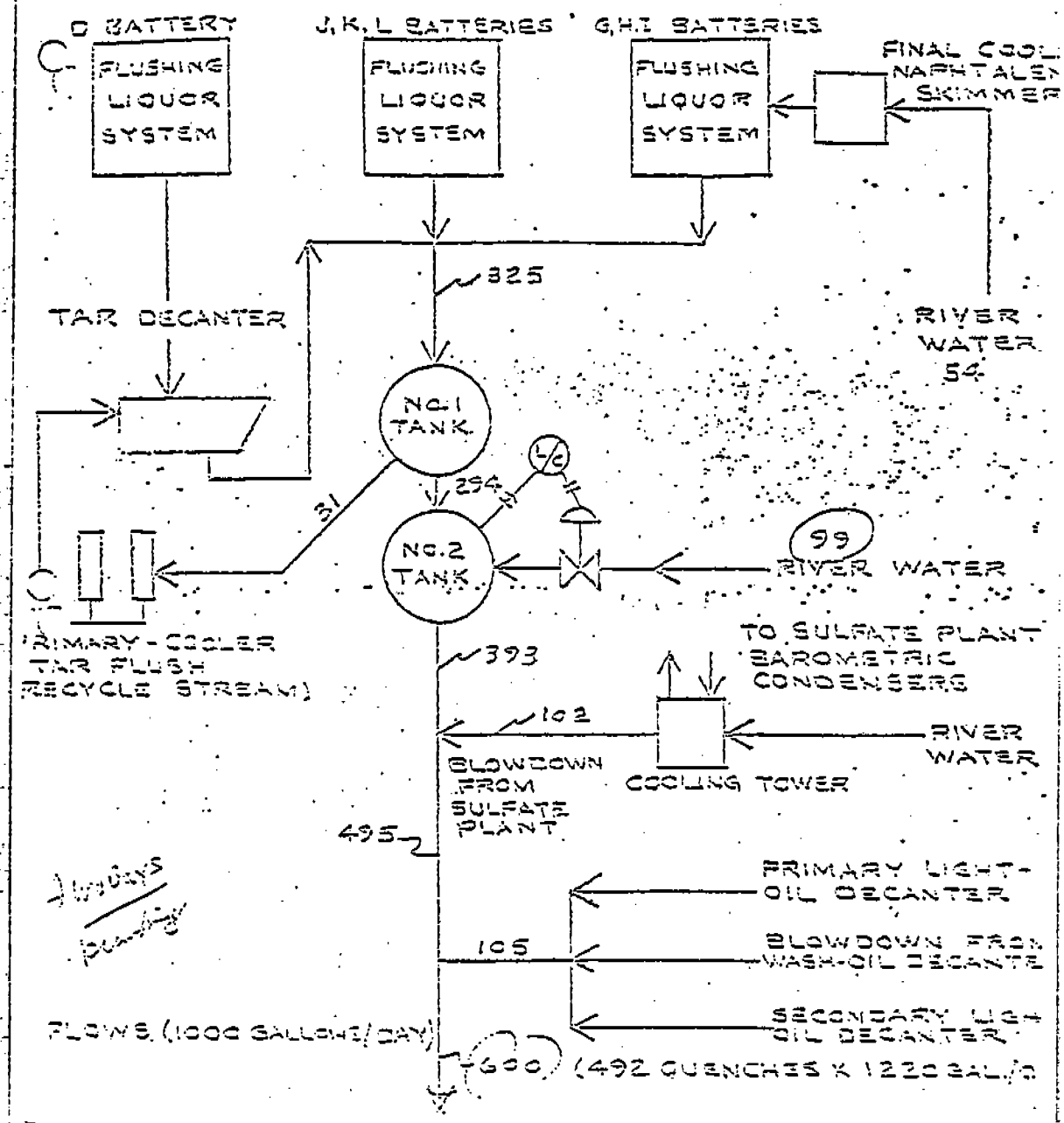

FIG. 6-3

PROCESS FLOW DIAGRAM

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rated at 13,900 cfm was installed in 1947 for the coke oven gas used in firing J, K, and L batteries.

Ammonia is removed as an ammonium sulfate. Crude light oil and crude coal tar are also recovered. No tar distillation, phenol recovery or light oil purification is employed. All of the excess flushing liquors and blowdown from the ammonium sulfate plant apparently are used to quench the coke produced in batteries G, H, I, J, K and L. D battery is normally quenched with river water. Figure 6-2 and Figure 6-3 illustrate the various operations in the chemical by-product plant.

Several drawings are listed in Table 6-15. These were received from U.S. Steel to further decant the coke process.

The operation of the coke ovens at Lorain appears to be typical of the industry insofar as operating temperature, coking time, and solids size is concerned. With one exception, no major differences in operating conditions were observed which would be cause for expecting abnormal quench tower emissions. The one exception has to do with greenness of coke. YRC has no broad data base to use as a basis for comparing the number of green pushes, and is not aware of any such study having been previously made.

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TABLE 6-15. DRAWINGS RECEIVED FROM U.S. STEEL CORP.

Wilputte Coke Oven Corporation - LA-42320
"Water Piping at Quenching Stations"

Wilputte Coke Oven Corporation - LA-42327
"Brick Hood for East Quenching Station"

Wilputte Coke Oven Division - LA-66346
"Water Piping at Quenching Station"

Wilputte Coke Oven Corporation - LA-42323
"Quenching Water Towers General Arrangement"

U.S. Steel - LA-100891, 3-27-74
"#1 Quenching Station Baffles General Arrg't."

U.S. Steel - LA-100892 - 3-26-74
#4 and #5 Quenching Station Baffles general Arrg't.

Koppers Company, Inc. - LA-69217
"Battery "G" Quenching Station, General Arrg't."

Koppers Company, Inc. - LA-69681
"Battery "D" Alterations to present East Quenching Station"

Koppers Company, Inc. - LA-69242
"Ovens Quenching Station Hood & Valve RM"

Koppers Company, Inc. - LA-69779
"Ovens Quenching Sta. Misc. & Stl Work"

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6.3 Baffles

Quench tower No. 1 at Lorain was equipped with baffles as described in Figures 6-4 and 6-5 which were based on U.S. Steel Drawing No. LA-100891 (included in the Appendix) although somewhat modified as described subsequently.

As can be seen in Figure 6-5 , the baffles were constructed in such a way as to allow a vertical area of one inch between the bottom of one baffle and the top of another. This vertical open area allowed a substantial portion of the stack flow to pass straight through the baffles with little opportunity for even larger size particles to impinge on the baffle surfaces. A typical flow pattern through this type of baffle has been schematically represented in Figure 6-6 and it is apparent that even with the change of direction caused by the 45° baffles there would be some particles which would tend to follow these vertical paths and not impinge.

Several baffles had been removed in order to provide additional open area. The U. S. Steel drawing calls for 11 slanted boards in each baffle section (See Figures 6-7 and 6-8) but only 10 boards were actually in place at the time of the test. The effect of removing these 2 rows would be to reduce the resistance to gas flow and increase the draft of the tower. It is the kind of modification one would make if fugitive emissions were excessive. In fact, the fugitive emissions even with the baffles removed were frequently so great as to make it necessary to scrub a series of tests.

The effect of removing one of the baffles from each section was to increase the vertical open area as can be seen in the following comparison:

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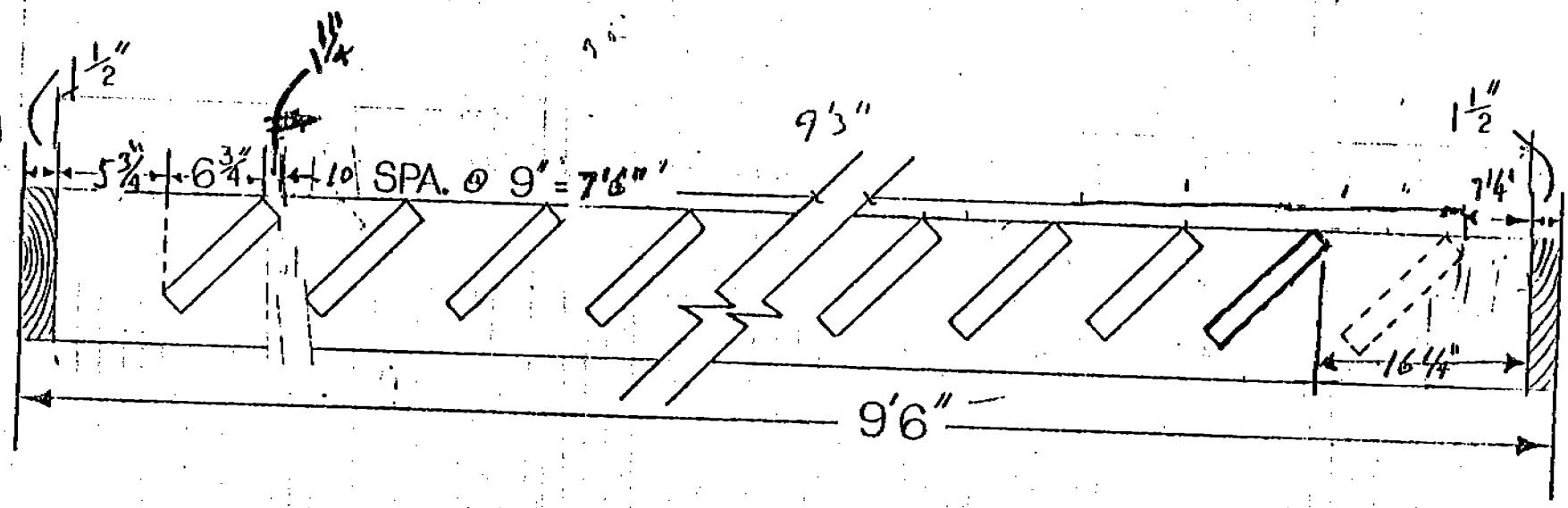

FIGURE 6-4

-429-

SIX SECTIONS INSTALLED

Lack Section 6'-3 1/2" x 9'6" OVERALL

6'-0 1/2" x 9-3" INSIDE

509814

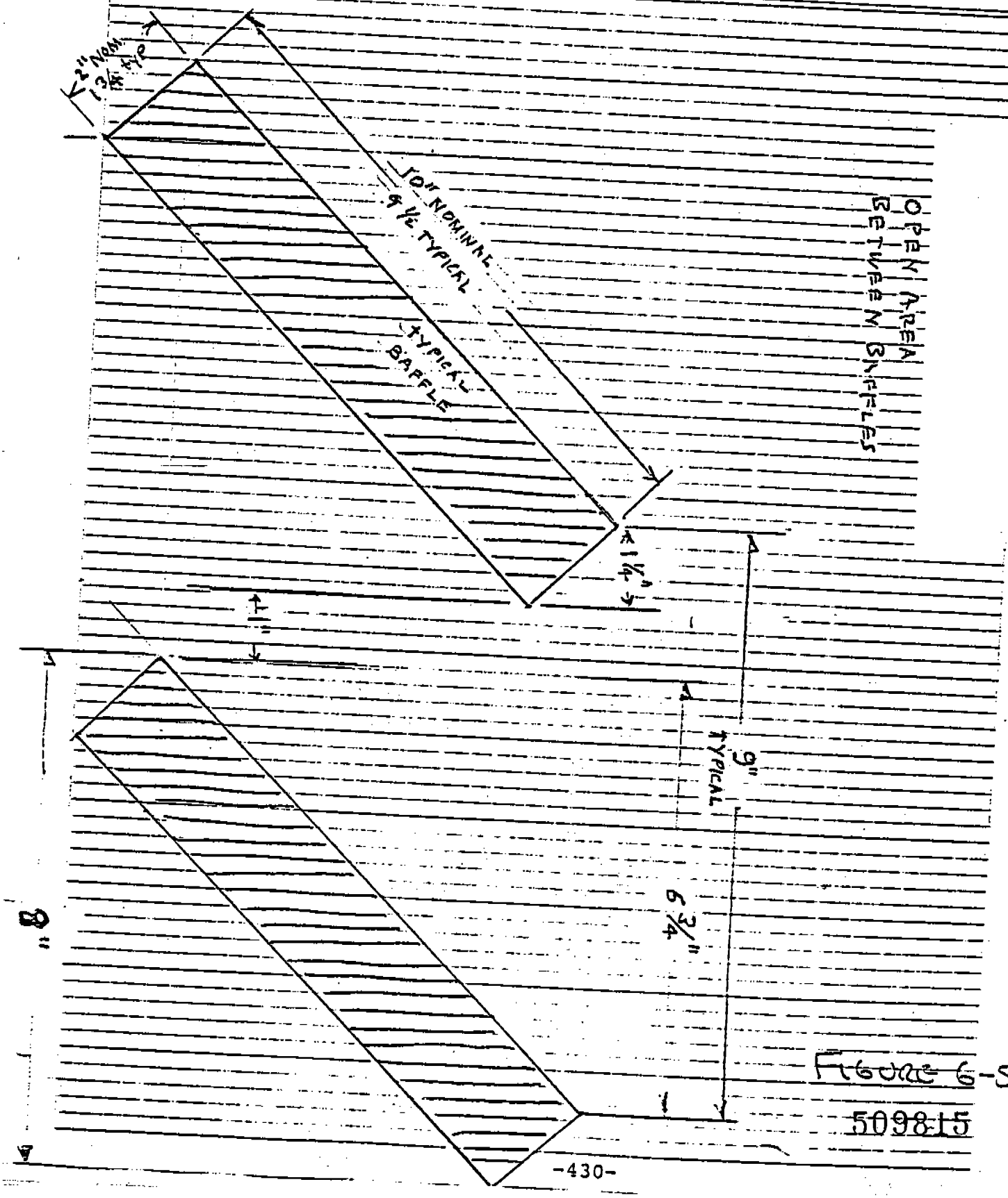

Figure 6-5.

509815

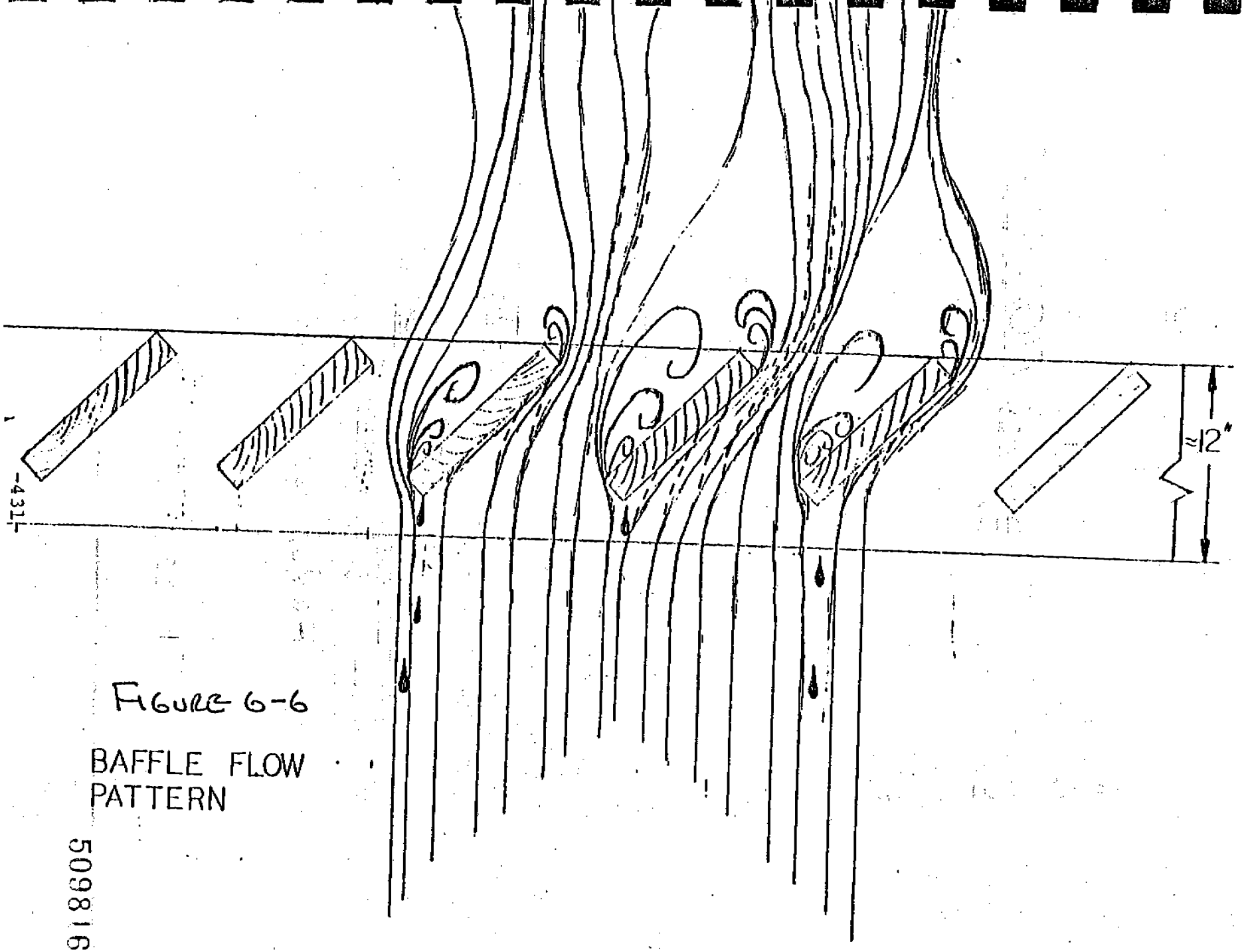

FIGURE 6-6

BAFFLE FLOW PATTERN

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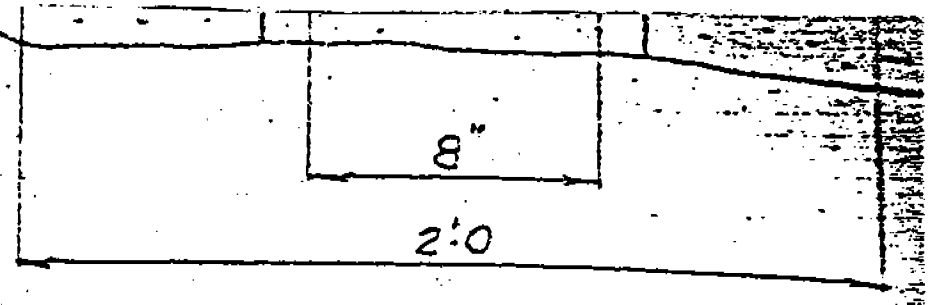
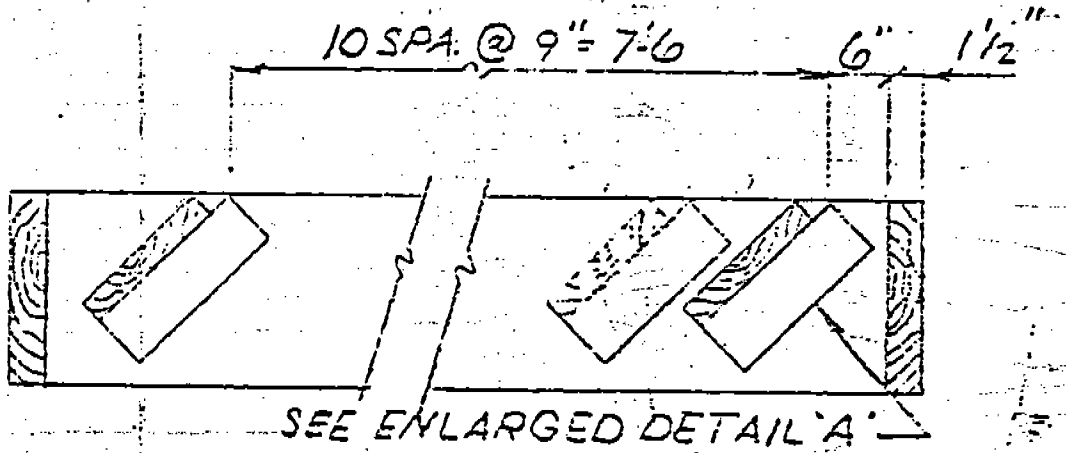


SECTION ~ C-C
NO SCALE

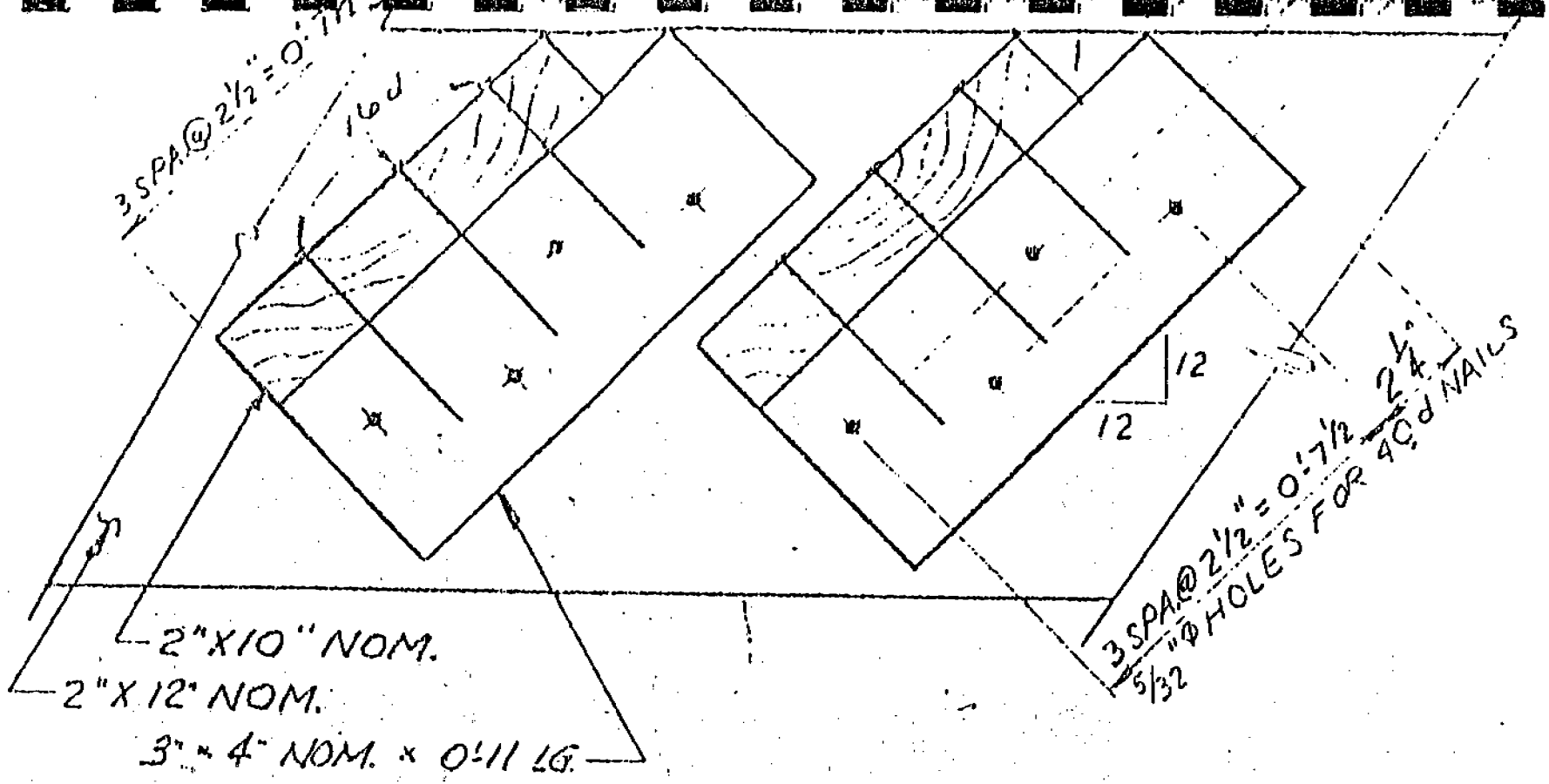


SECTION ~ D-D
NO SCALE

FROM U.S. STEEL DWG LA-100891

FIGURE 6-7

509817



ENLARGED DETAIL 'A'

NO SCALE

FROM U-S STEEL
DWG LA-100811

FIGURE 6-8

509818

-433-

6
5
4
3
2
1

TABLE 6-16. BAFFLE OPEN AREA

	Square feet	Open area as a % of total area
Total open area of the tower before any baffles were installed from Dwg. LA-100891 (U.S.S. Corp.) 19' - 2" x 19' - 2"	367	100
Total vertical open area of the tower after the baffles were installed. Based on U.S. Steel Corp. Dwg. LA-100891- 11 rows of baffles in each section	70	19
Total vertical open area with 10 rows of baffles in each section - As actually installed at time of test program.	94	26

Figure 6-10, a photograph taken almost vertically shows the top of the tower and a portion of the baffles, part of the open area created by removing the baffles and some of the supporting beams, piping and nozzles. This photo is out of proportion and is not meant to show any area relationship between unbaffled section and tower area.

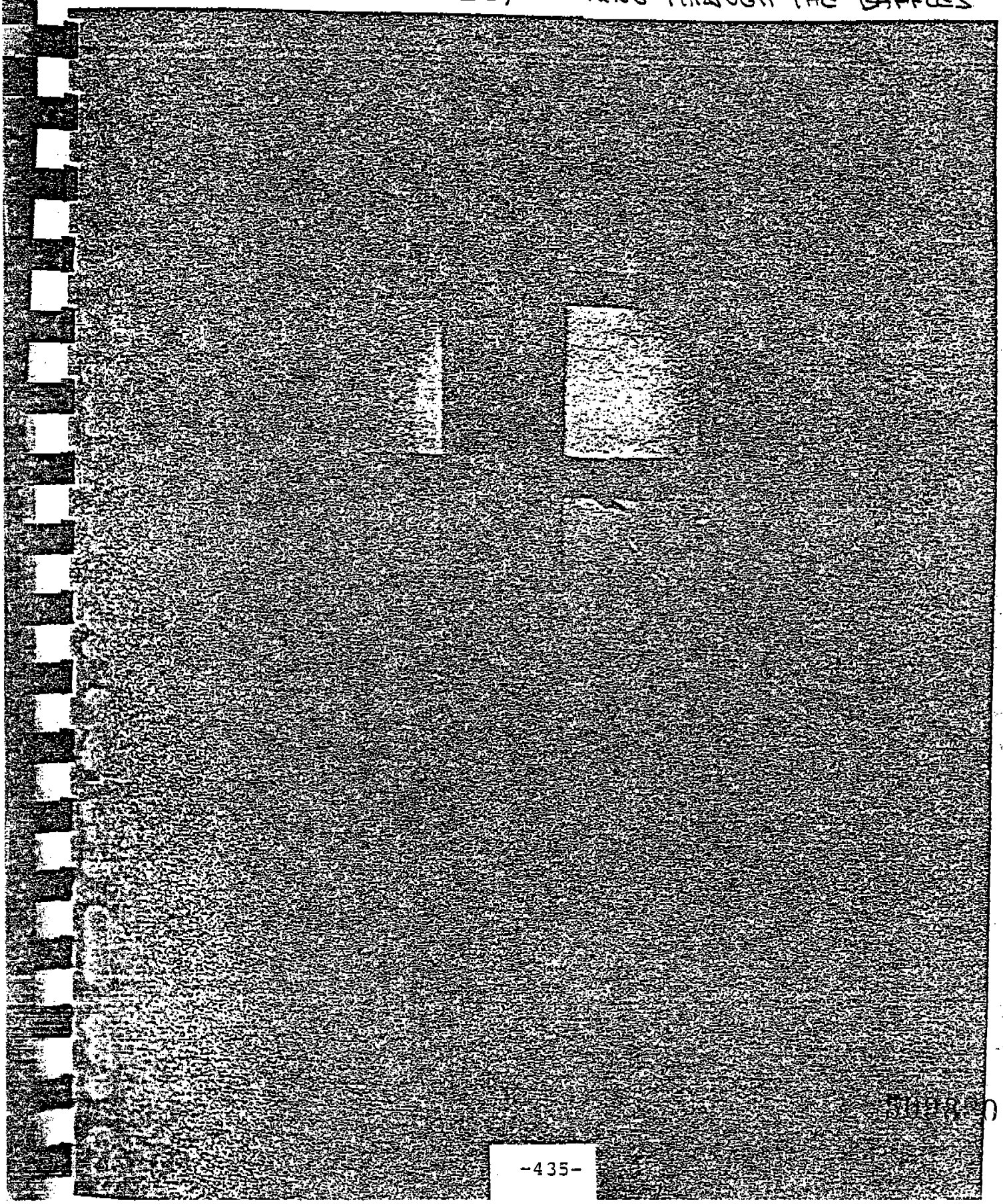
In addition to the effect of the 1 inch open space, and the open space created by removing center baffles, there is another factor inherent in the geometry of the tower which should be considered. From Figure 6-11 one can see how the total area of the baffles would not be utilized effectively since the steam jets and induced air would tend to flow up through the center area of the baffles.

A better design utilizing well-known engineering principles would call for the baffled area to be about the same as the entrance and exit area for at least several diameters up the stack. However, even if the most favorable opportunity for impaction could be assured; that is, assuming that all parts of the gas stream

509819

FIGURE 6-9

VIEW UP THE TOWER, LOOKING THROUGH THE BAFFLES



were directed at a plate or ribbon perpendicular to the gas stream, the efficiency of impaction would not be significant for particulate matter below 20 micrometers (see Figure 6-15).

Some fundamental work on air flow imparting against cylinders and plates was done by Sell and Brackwede[35] in 1931. Two examples of flow patterns they developed are reproduced on Figure 6-11 and 6-12.

In Figure 6-13 streamlines produced by dye in water are shown. From a study of the stream lines one can intuitively understand that larger particles will impact and smaller ones will be carried around the barrier. Subsequent work resulted in a mathematical form of this statement resulting in the well known separation number N_s. The baffle efficiency was calculated based on the probable impaction of certain sizes under quench tower conditions as predicted by the separation number N_s:

$$\text{where } N_s = \frac{Dp^2 \, v \, \rho_p}{18 \, \mu \, D_b} \quad \text{(dimensionless)}$$

was calculated as follows:

D_p = particle diam. ft.

v = relative velocity, gas to baffle ft-second^{-1}

ρ_p = particulate density, lb-ft^{-3}

μ = gas viscosity, lb-ft^{-1} second^{-1}

Db = Baffle thickness perpendicular to gas flow, ft

As an example:

For a 100 micron particle:

$$D_p = \frac{100 \times 10^{-4} \text{ ft}}{30.48} = 3.28 \times 10^{-4} \text{ ft.}$$

$$Va_v = \frac{\text{ACFM at the entrance to the baffles}}{\text{Area of tower just before the baffles}}$$

F00001

FIGURE 6-10

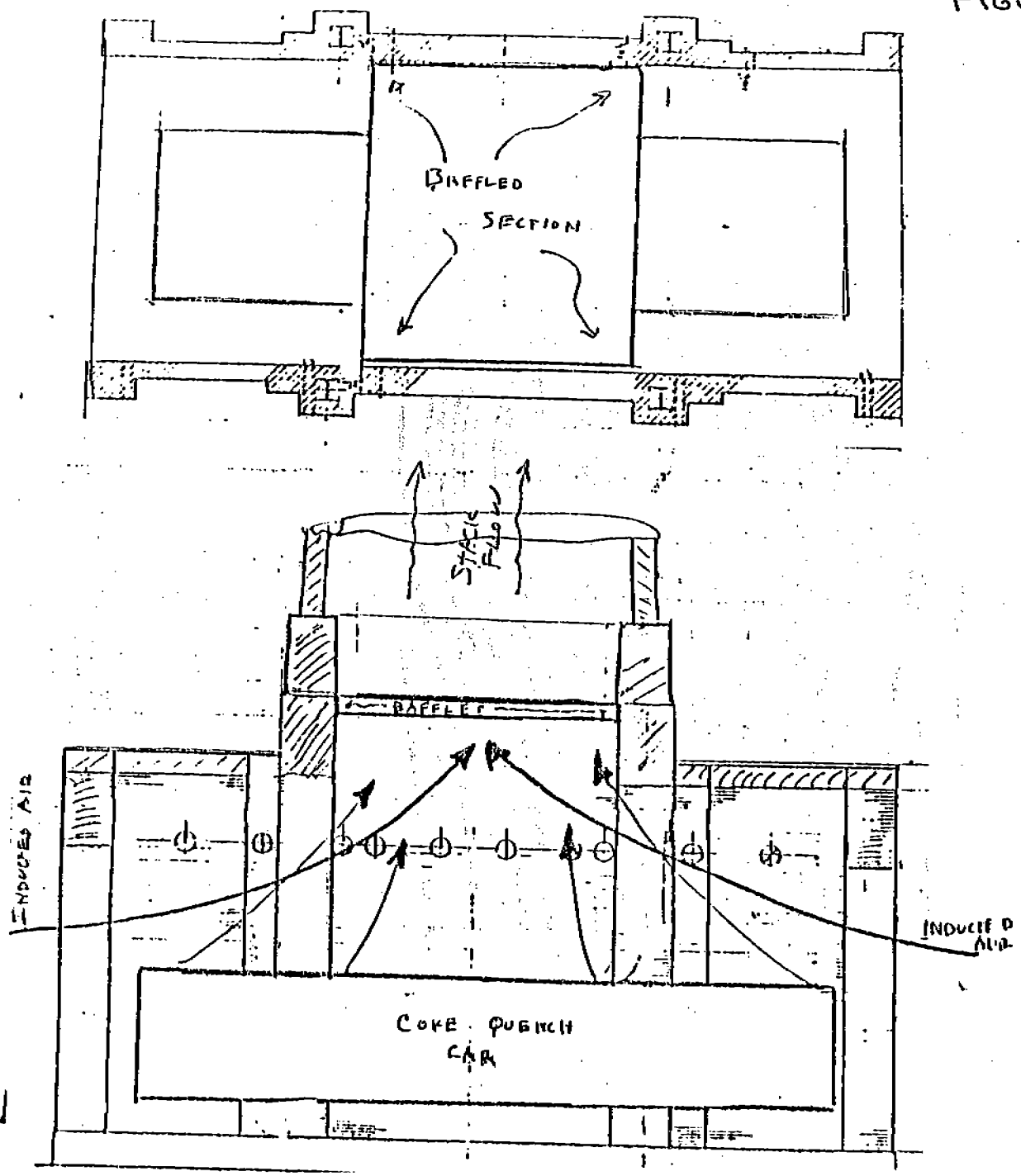


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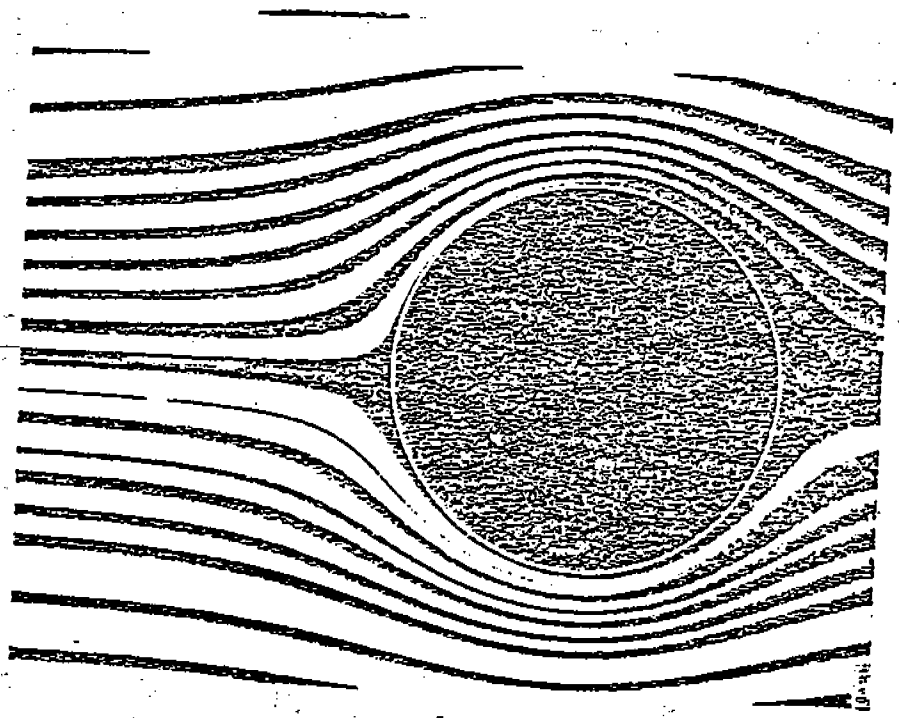
FIGURE 6-11

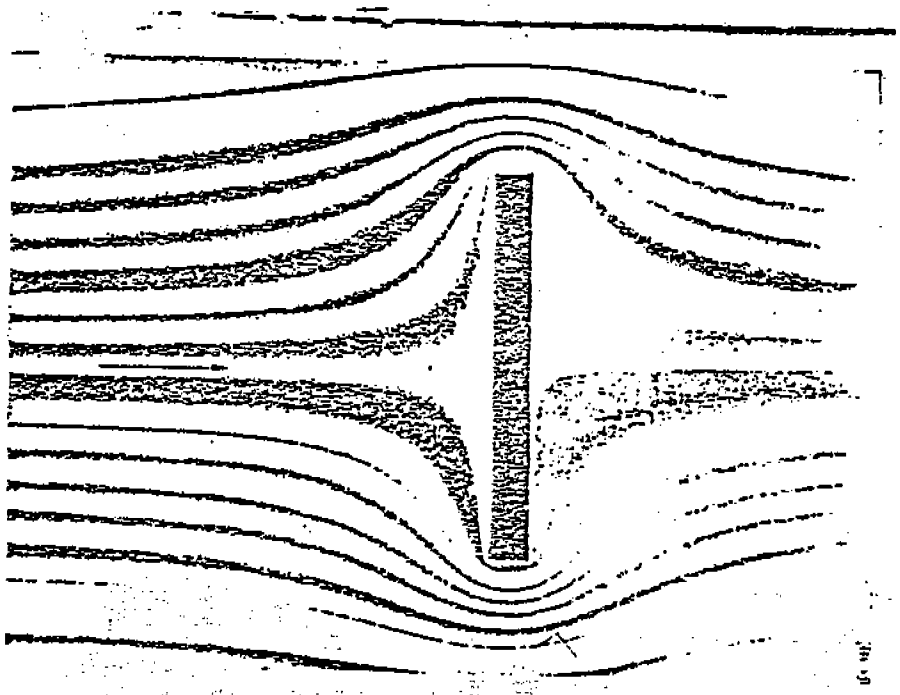
Streamlines around Cylinder



509823

FIGURE 6-12

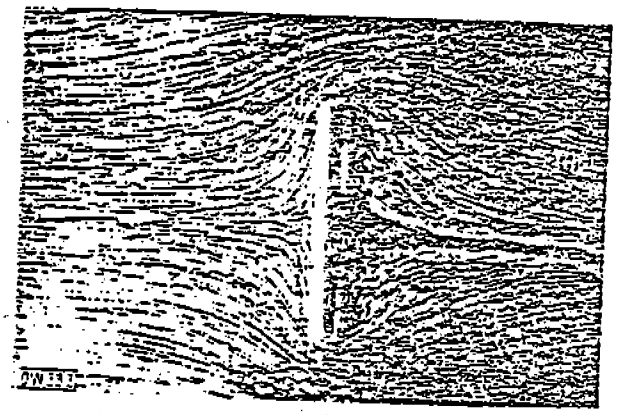
Streamlines around a Plate

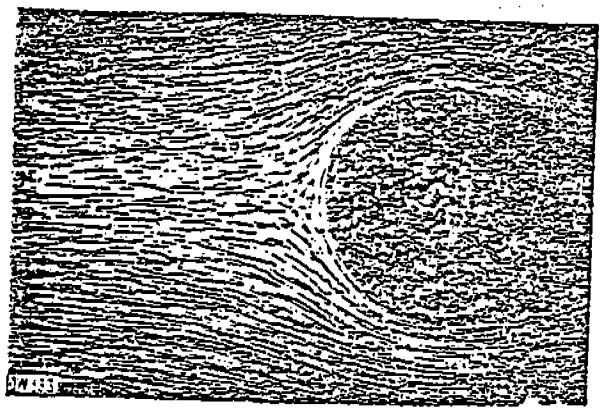


509824

FIGURE G-13

Streamlines using a dye in water





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To calculate Va_v :

The average lbs of water/lb of dry gas in the samples taken at the test platform averaged 0.36 for the 25 contaminated and clean tests. Average air flow was 32,000 lbs of dry air/quench, and the duration was 2.29 minutes per quench.

It is possible to calculate the average velocity (Va_v ,) of the gas mixture at the entrance to the baffle area, assuming that the actual cubic feet per minute at the baffles is approximately the same as that up the stack at the test station, and that the temperature of the mixture at the baffles averages 180°F. Then:

$$\frac{32,000}{2.29} = 13974 \text{ pounds of dry gas/minute}$$

From Tables [14] each pound of dry air along with the moisture associated with it, (i.e. 0.36 lbs of water, at 180°F would occupy a volume of 25.2 cubic feet).

13,974 x 25.2 = 352145 dubic feet/min

the area of the tower at the entrance to the baffles is 367 square feet, therefore:

$$Va = \frac{352,145}{367 \times 60} = 16 \text{ ft per second}$$

continuing with the other factors in order to calculate N_s:

ρ_p = 62.4 lbs per cubic foot for droplets and assumed to be 124.8 for particles

$\mu = 1.21 \times 10^{-5}$ lb-ft^{-1} - sec^{-1}

Db = target width taken as target dimension perpendicular to the direction of the gas stream as it approaches the baffles. In this case the gas stream was visibly turbulent during portions of the quench, but the average direction was vertical, and therefore the horizontal dimension of each baffle could be considered as the dimension perpendicular to the gas flow.

Db = 0.66 ft.

N_s for the 100 micron droplet would be 0.75 and reading from Figure 6-15 the Impact efficiency would be 71%.

The several examples listed in the following table will indicate how the impact efficiency N_s varies with size of particle on the size of droplet.

TABLE 6-17. WATER DROPLET IMPACT EFFICIENCY

Size in Micrometers	N_s	Impact Efficiency (percent)	N_s	Particle Impact Efficiency (percent)
20	0.03	0.01	0.06	.01
40	0.12	6	0.24	35
50	0.19	24	0.38	56
80	0.64	70	1.28	82
100	0.75	71	1.50	85
150	1.69	96	3.38	92
200	3.00	91	6.00	94

These values of impact efficiency have been plotted in Figure 6-15, and clearly indicate that the baffles have no significant effect on water droplets below approximately 40 micrometers, nor on particulate matter below approximately 30 micrometers. However, larger droplets with a diameter more than 100 micrometers, and particles over 70 micrometers would be expected to impact with efficiency well over 70 percent.

A United Nations Report [4] by the Economics Commission for Europe (dated 1968) included some efforts to determine the amount of grit with and without baffles, but very little information was available as to size distribution or methods used. These data are summarized in Table 6-18 and apparently represent the large particles of grit or breeze which is only a small part of the quench emissions. Little or no effort was made to collect or measure the dissolved solids contained in the mechanically entrained water nor were the fine particles captured. This information was reviewed and summarized by George Crane.[36] He concluded that dissolved solids could result in an emission factor of 2.6 pounds per ton of coal from an uncontrolled quench tower and 0.26 pounds per ton from a tower equipped with baffles.

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FIGURE 6-14.

Target Efficiency of Impingement

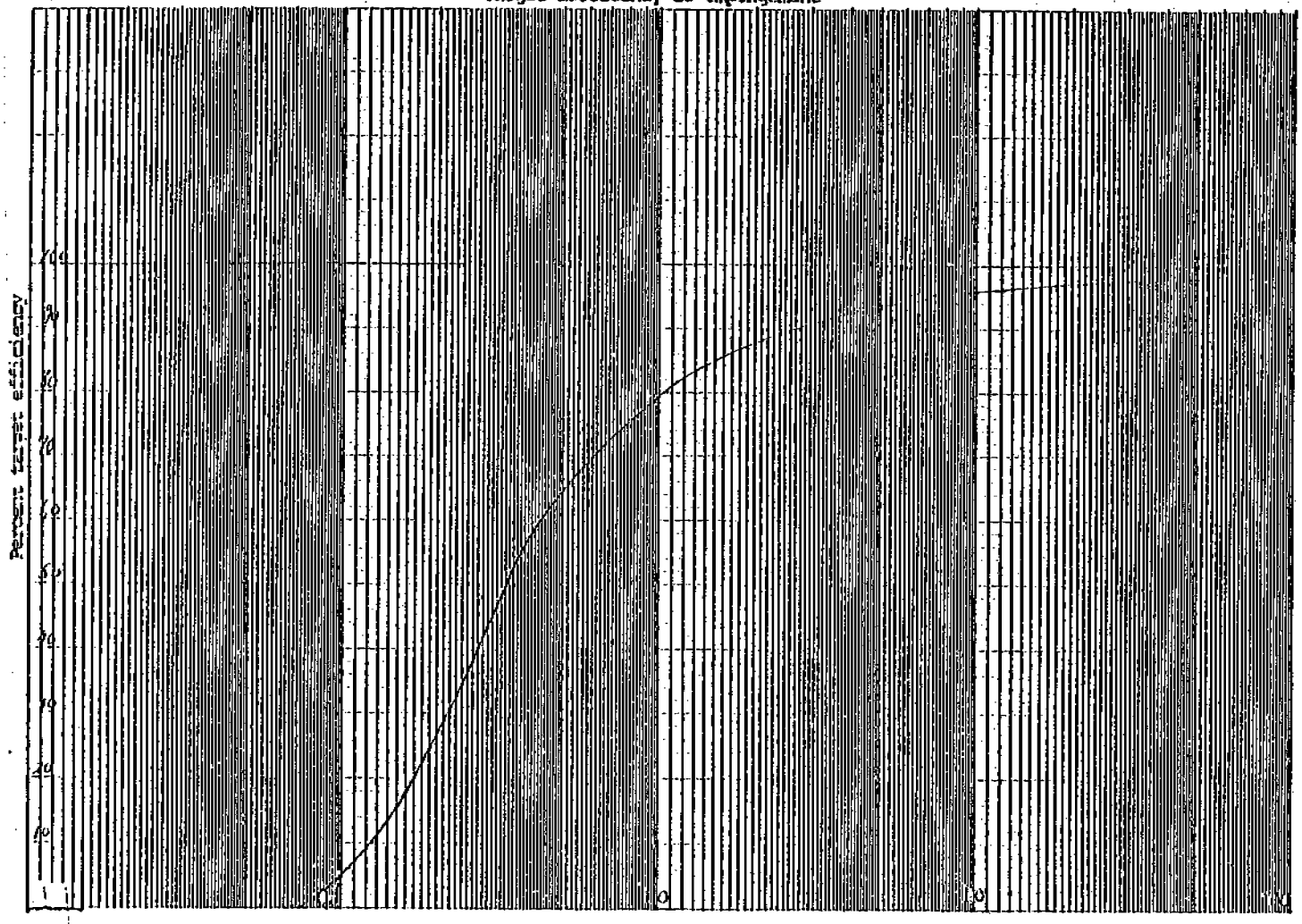

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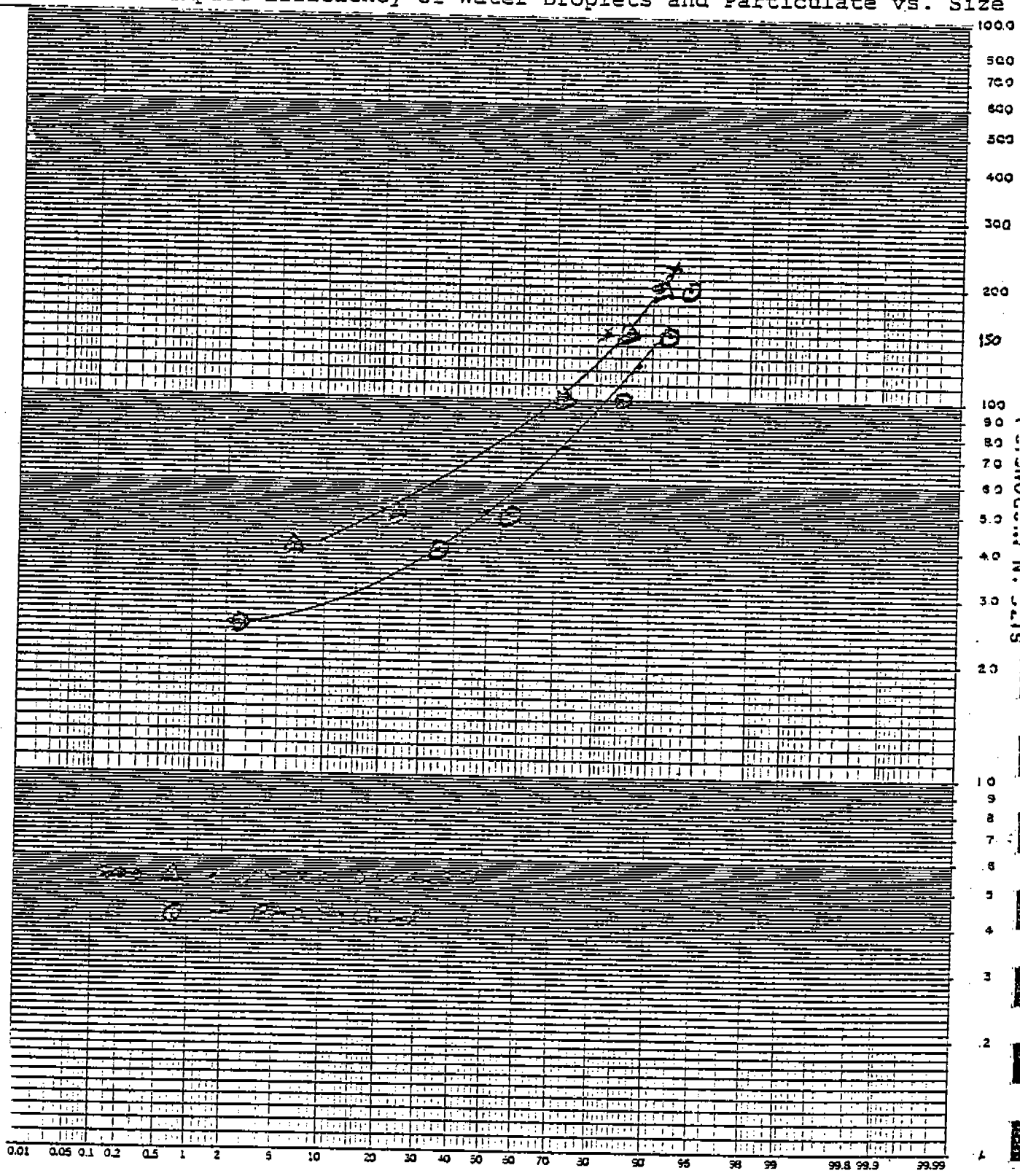
FIGURE 6-15

Baffle Impact Efficiency of Water Droplets and Particulate vs. Size



Collection Efficiency

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A mass balance based on the Clairton Coke Works test [37] concluded that particulate emissions could be on the order of 4.0 pounds per ton of coal at a quench tower equipped with baffles. In addition one pound per ton of coal was reported at San Bernardino County.[7]

Jackson and Waple [38] sampled grit emissions from a coking plant of Baird and Scottish Steel, Ltd. They used a 1½ inch diameter cyclone for collection. Test results are given in Table 6-18 for emissions with timber baffles in use, and without baffles. In addition as shown in the following table all of the material they collected was above 50 micrometers, whereas 99 percent of the particulate collected and measured at Lorain was less than 50 microns.

Fullerton [3] at U. S. Steel Clairton plant also used greased plates but only collected the larger particles of grit; that is, the fraction above 74 micrometers. As expected, baffles are effective in this size range.

Jackson [38] used a cyclone, and the results from a baffled configuration indicate several times as much grit as the large grit collected in the cyclone at Lorain on the clean and contaminated runs. Jackson also highlighted the effect of coking temperature claiming a 1/3 to 1/10 reduction in grit emissions caused by a 100°C lower coking temperature. The limited size distribution data of the grit collected by Jackson agrees with that of Fullerton and again confirms that the effect of baffles is on the large particles, reducing the 599 micrometer size from 10% to 5.6%; but again, almost all the grit material collected was larger than 50 or 70 micrometers, whereas almost all the grit collected at Lorain was less than 50 micrometers.

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TABLE 6-18. PARTICULATE STACK EMISSIONS - POUNDS PER TON OF COAL

Reference Source		With Baffles	Without Baffles	Unknown
(4)	France			0.1
(4)	In Poland			0.4
	" " (clean water)			
(4)	United Kingdom	0.03-.05	0.16	
(4)	Czechoslovakia			.7
(39)	Germany	0.8 to 0.12	0.2	
(37)	U.S. Steel Clairton plant			
	Grit	0.33		
	Dissolved Solids	2.31		
	Total	2.64		
(40)	Germany	.16	0.57	
(41)		1		
(42)		1		
(43)		1.1	3.1	
(3)	Fullerton, R.W.	0.75	6.0	
(38)	Jackson (Bairds) First minute of quenching grit only assuming 13 tons of coal:			
	Normal coke temperature	0.6	1.2	
	Coke temperature reduced 100°C from normal	0.23	0.18	
(44)	Harris Margam Coke Ovens grit only	0.03	0.19	
	U.S. Steel Lorain Ohio for Comparison			
		Clean	Contaminated	
	Large grit	0.13	0.20	
	Dissolved Solids	1.52	3.34	
	Total	1.65	3.54	

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TABLE 6-19. BAFFLE EFFICIENCY

grit size (microns)	Jackson[38] (Bairds) % weight of grit emissions less than size shown: without baffles	with baffles	U.S.Steel Clairton R.W. Fullerton(3): without baffles
599	10%	5.6	11%
297	-	-	45
149	-	-	84
74	-	-	97
53	80%	80.8	-
0	10%	13.6	3

The effectiveness of baffles such as used at Lorain in capturing particles above 30 to 50 micrometers and the ineffectiveness of such baffles in capturing particles below that size range is a well established engineering principle. For instance, Friedlander[45] in his handbook on air cleaning in 1952 for the Atomic Energy Commission never considered impaction or direct deposition to be of any significance on small particles except in a filtration bed or a filter. Lapple[46] states that: "Impingement separators are designed for a pressure drop in the range of 0.1 to 1.5 in. water depending on type and application and are limited to removing dusts that are predominantly larger than 10 to 20 microns diameter". However, there is apparently some disagreement with this statement; for instance in a recent article Young[47] states "Examples of well-proven technology widely in use today for pollution control (in the Steel Industry) includes.....baffles on coke quench tower."

The data reported here supports the contention that although certain improvements in impact efficiency can be obtained by careful design, there is an implied limitation with a natural draft tower, and any improvement in efficiency will be limited to what-

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ever pressure drop can be developed around the baffles. If fans are used to provide additional pressure drop through the baffles the principles outlined by Smith, J.L.[48] and Houghton[49] could be considered, tending towards closely spaced thin edged baffles which provide higher efficiency on particles and droplets but which would have corrosion and cleaning problems.

The constraints imposed by inherent corrosion and plugging problems seem to preclude any major improvement in design of baffles that would lead to the removal of a significant portion of the total aerosol, and it would require such an improvement in order to use contaminated water and remove enough of the resultant aerosol to meet the requirements of 0.9 lb/ton.

However, when clean water is used as make up, it might be possible to improve the quench tower design so as to remove enough of the aerosol to meet the 0.9 lbs standard. More closely spaced thin baffles designed so as to force a direction change of all the aerosol is certainly indicated. The increased pressure drop this would require would result in undesirable fugitive emissions at the door portals but this effect could be reduced by increasing the total cross sectional area of the baffles and by improved design.

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APPENDIX A

Films

509838

The following items were submitted to the EPA Project Officer in March, 1977 and, subsequently, duplicate copies were sent to U.S. Steel by EPA.

Copies are also on file at York Research Corporation.

Item 1 - "Super 8" approximately 200 feet of the following:

1. General View of Coke Batteries G, H, & I
2. 10/9/76 East Entrance — Not a test day
3. 10/9/76 West Entrance — Wind 15-20 knots (N)
4. 10/30/76 West Entrance — Wind Variable
5. 10/30/76 East Entrance — 5 knots/hr (S & SW)
6. Greenness 10/9/76

Item 2 - 16 mm approximately 400 feet as follows:

1. A complete quench from time car entered to time car left quench tower #1 taken from the south.
2. A second quench otherwise same as #1.
3. A complete quench view from the west.
4. A complete quench view from the east.
5. A complete quench view from the east.

Item 3 - 29 black and white 3½ x 5 mounted on 8 display boards depicting a quench as viewed generally from the east.

Item 4 - Twenty Polaroids, various views of Lorain Coke Plant facilities.

509839

APPENDIX B

Plant Drawings

509840

Wilputte Coke Oven Corporation - LA-42320
"Water Piping at Quenching Stations

Wilputte Coke Oven Corporation - LA-42327
"Brick Hood for East Quenching Station

Wilputte Coke Oven Division - LA-66346
"Water Piping at Quenching Station

Wilputte Coke Oven Corporation - LA-42323
"Quenching Water Towers General Arrangement

U.S. Steel - LA-100891, 3-27-74
"#1 Quenching Station Baffles General Arrg't.

U.S. Steel - LA-100892 - 3-26-74
#4 & #5 Quenching Station Baffles General Arrg't.

Koppers Company, Inc. - LA-69217
"Battery "G" Quenching Station, General Arrg't.

Koppers Company, Inc. - LA-69681
"Battery "D" Alterations to present East Quenching Station

Koppers Company, Inc. - LA-69242
"Ovens Quenching Station Hood & Valve RM

Koppers Company, Inc. - LA-69779
"Ovens Quenching Sta. Misc. & Sta. Work

509841

APPENDIX C

Calculations of Sump Emissions

509842

DIFFUSIVITY CALCULATIONS

The emission rate of a substance such as ammonia from the surface of a liquid depends upon several factors, namely:

- The concentration or mole fraction of the ammonia.
- The partial pressures of the ammonia in equilibriaum with the liquid phase and the gas phase.
- The diffusion coefficient of the ammonia into air.
- The diffusion coefficient of water to air.
- The wind speed above the surface.

King[29] suggests using the diffusivity coefficients as follows:

N_B = molar mass transfer rate (moles/m^2)
U = wind speed at 16 meters above surface (meters/sec)
D_{ab} = diffusion coefficient of component B in air
D_{aw} = diffusion coefficient of water in air
P_b^* = partial pressure of component B in equilibrium with water
P_b = partial pressure of component B in atmosphere above water

Then;

$$K_w = 0.429\ U^{0.8} \qquad \text{(Eq.1)}$$

$$K_b = K_w\ (D_{ab}/D_{aw})^{2/3} \qquad \text{(Eq.2)}$$

$$N_b = K_b\ (P_b^* - P_b) \qquad \text{(Eq.3)}$$

In order to calculate these various factors and ultimately establish N_b, it is necessary to calculate the following:

Vapor Pressure of Ammonia[31]

$$\log_{10}P^* = A - B/(C + T) \text{ where } T = {}^oC$$
$$= 7.55466 - 1002.711/(247.885 + 82)$$
$$= 4.5150826$$
$$P^* = 10^{4.5150826}$$
$$= 32740.2 \text{ mm Hg}$$

509843

Partial Pressure of Ammonia

As reported in Table 5-40, the sump was sampled ten times on 9/15/76 to establish a concentration profile of various components while using contaminated water as make-up. The ammonia concentration ranged from 456-1268 mg/l, and averaged 1079 mg/l.

Therefore, to calculate the mole fraction in water;

$$\frac{1.079 \text{ g } NH_3}{1000 \text{ g } H_2O} = \frac{18.10 \text{ moles } NH_3}{18000 \text{ moles } H_2O}$$

mole fraction = 0.001

Then, the partial pressure of ammonia in equilibrium with water was:

$$P_b^* \; NH_3 = (\text{Mole fraction } NH_2)(\text{Vapor pressure @ } 82^oC)$$

$$= (0.001)(32740.2)$$

$$= 32.93 \text{ mm Hg}$$

The partial pressure of ammonia in air may be assumed to be negligible, therefore:

$$P_b = 0$$

509844

Diffusion Coefficient of Ammonia

V_b = Molal volume of liquid (cm^2/g-mole)
T = Absolute temperature (^oK)
M_1 = Molecular weight of ammonia
M_2 = Molecular weight of air
P = Absolute pressure (Atm)
r_{12} = Collision Diameter (Å)
I_d = Collision interval for diffusion
r_o = $(1.18\ V_b)^{1/3}$
B = $\left[1.0-2.46(1/M_1 + 1/M_2)^{\frac{1}{2}}\right]\ 10^{-4}$
D_{ab} = $\left[BT^{3/2}\ (1/M_1 + 1/M_2)^{\frac{1}{2}}\right]\ /P^2_{r_{12}}\ I_d$

Then, from Perry [30] (Table 3-308):

r_{01} = 2.624 (ammonia)
r_{02} = 3.617 (air)
r_{12} = (2.624 + 3.617)/2 = 3.1205
B = $\left[1.0-2.46\ (1/17.03 + 1/29)^{\frac{1}{2}}\right]\ 10^{-4}$
$\frac{E_{12}}{k}$ = $\left[(E_1/k)(E_2/k)\right]^{\frac{1}{2}}$ = 174.79
$\frac{kT}{E_{12}}$ = (82 + 273)/ 174.79 = 2.03

From Perry [30] (Table 3-309):

I_d = 0.5373
D_{ab} = $\left[(0.24898 \times 10^{-4})(355)^{3/2}\ (1/17.03 + 1/29)^{\frac{1}{2}}\right]\ /(1)(3.1205)^2$
(0.5373) = 0.009716 cm^2/sec

The diffusivity of NH_3 to air = 0.009716 cm^2/sec

Calculating the diffusivity coefficient of water in a similar manner yields the following:

The diffusivity of H_2O to air = 0.009767 cm^2/sec

Then, the molar mass transfer rate may be calculated following King [29], as follows:

K_w = $(0.429)(2.33)^{0.8}$ = 0.815 (Eq.1)
K_b = $0.815\ (0.009716/0.009767)^{2/3}$ (Eq.2)
= 0.812

509845

$N_b = 0.812\ (32.93-0)$
$= 26.7$ g-mole NH_3/m^2

Since there was 1662 ft^2 (154.4 m^2) or sump surface (Figure 5-5), the emissions of ammonia from the sump would be:

$(26.7)(154.4)(17)/454$
$= 154$ lb/hr NH_3 (with contaminated water)

In a similar manner the fugitive ammonia emissions may be calculated for the period when "clean" water was used as make up:

From Table 5-43 concentration of ammonia was 2 mg/liter with "clean" water make-up.

The mole fraction would then be 3.6×10^{-5} and partial pressure of ammonia in equilibrium with H_2O would be:

$P_b^* = (3.6 \times 10^{-5})(32740) = 1.18$ mm Hg

and $N_b = (0.810)(1.18-0) = 9.5 \times 10^{-1}$ g-mole NH_3/m^2
$= 5.5$ lb/hr NH_3 (with clean water)

In a similar manner the water evaporation rate from the sump may be calculated. The water evaporation rate following Kings[illegible] equations is:

$K_w = (0.429\ u_{16})^{0.8}$
$K_w = 0.815$
$(15.24 - .74) \times 25.4 =$ mm Hg
Vapor pressure = 368 mm Hg
$N_b = (0.8)(368) = 295$ g-moles water/m^2

$$\frac{295 \times 154 \times 18}{454} = \underline{1800\ \text{lb/hour}}\ \text{water evaporation rate}$$

Evaporation rate = 1800 lb/hr

In a similar manner, the fugitive emissions of phenol from the sump was calculated and reported in Table 5-36.

509846

APPENDIX D

Field Data Sheets

509847

FIELD DATA

PLANT U.S.S. LORAIN
DATE 9-8-76
SAMPLING LOCATION STACK B-2
SAMPLE TYPE E.P.A. 5
RUN NUMBER 4
OPERATOR ZISKIN
AMBIENT TEMPERATURE 65
BAROMETRIC PRESSURE 30.00
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FL-127-16

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .150

METER BOX NUMBER 5011
METER ($\Delta H@_2$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24 hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	2131	593.85	(AVG)			(AVG)					
B-2A	2.5	2134	598.25	.20	.46	.46	180	75	75	5	250	68
START	2.5	2146	598.25									
B-2B	5.2	2149	602.18	.20	.45	.45	180	74	74	5	250	69
START	5.2	2156	602.18									
B-2C	7.4	2158	606.73	.20	.45	.45	181	71	74	6	250	69
START	7.4	2203	606.73									
B-2D	9.7	2205	609.09	.20	.43	.43	181	68	73	6	250	70
TOT/AVG	9.7		15.24				180.5	72	74	5.5	250	69

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT @ 2136	
O_2	CO_2
20.0	0.0
19.8	0.0
19.8	0.1

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-2-

5098848

FIELD DATA

PLANT U.S.S. Lorain
DATE 9-10-76
SAMPLING LOCATION Stack B-5
SAMPLE TYPE E.P.A. 5
RUN NUMBER 5
OPERATOR Ziskin
AMBIENT TEMPERATURE 64
BAROMETRIC PRESSURE 29.95
STATIC PRESSURE, (P_s) -0.1
FILTER NUMBER (s) FL-127-18

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63

METER BOX NUMBER 5011
METER (JDO2) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	1117	616.24	(AVG.)			(AVG.)					
B-5A	2.2	1119	620.28	.20	.49	.49	180	71	71	5	250	68
START	2.2	1130	620.28									
B-5B	7.75	1133	626.12	.20	.46	.46	181	72	71	5	250	68
START	7.75	1146	626.12									
B-5C	7.25	1148	630.96	.20	.45	.45	181	72	72	6	250	69
START	7.25	1200	630.96									
B-5D	9.75	1202	635.77	.20	.40	.40	181	73	72	6	250	70
START	9.75	1210	635.77									
B-5E	12.05	1213	639.89	.20	.44	.44	181	74	73	6	250	70
AVG.	12.05		23.65				181	72	72	5.6	350	69

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
19	H	16	00:01	00:55	5	43	
21	H	36	00:12	00:40	1	33	
22	G	19	00:17	00:30	1	41	24 hr.
23	G	29	00:22	00:30	1	22	24 hr.

ORSAT @ 2100	
O_2	CO_2
20.0	0.0
20.0	0.0
20.0	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

5098849

FIELD DATA

PLANT U.S.S. Lorain
DATE 9-11-76
SAMPLING LOCATION Stack A-8
SAMPLE TYPE EPA 5
RUN NUMBER 6
OPERATOR Zisk
AMBIENT TEMPERATURE 63
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) EX-31

PROBE LENGTH AND TYPE 10' SS
NOZZLE I.D. .63 .621

METER BOX NUMBER 5011
METER ($\Delta H@$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min / CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
				DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
STAR	0 2009	641.00	(AVG.)			(AVG.)					
B-2A	2.35 2010	645.27	.095	.62	.62	180	74	73	5	250	65
STAR	2.35 2014	645.27									
B-2B	4.65 2016	649.56	.095	.54	.54	181	74	74	6	250	67
STAR	4.65 2027	649.56									
B-2C	6.45 2029	653.14	.095	.50	.50	181	75	75	6	250	68
STAR	6.45 2100	653.14									
B-2D	7.57 2101	655.15	.095	.40	.40	181	74	75	7	250	68
Tot/Avg	7.57	14.15				181	74	74.5	6	250	67.0

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
12	G	29	2345	0:05	5	5500	
13	I	58	2357	0:05	3	5800	
14	H	1	2408	0:10	2	6600	w SW-7
15	H	11	2417	0:05	1	1600	

ORSAT @ 2015	
O_2	CO_2
20.0	0.0
20.1	0.1
19.8	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-4-

5098501

FIELD DATA

PLANT U.S.S. LORAIN
DATE 4-11-76
SAMPLING LOCATION STACK C-5
SAMPLE TYPE E.P.A. 5
RUN NUMBER 2
OPERATOR GRIFFIN/OLSEN
AMBIENT TEMPERATURE 68
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) 10.1
FILTER NUMBER (s) Fx-34

PROBE LENGTH AND TYPE 10' SS.
NOZZLE I.D. .63 .621
METER BOX NUMBER 5011
METER ($\Delta H@_{O_2}$) .111
PROBE HEATER SETTING 250°
HEATER BOX SETTING 250°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	2345	655.60									
C-5A	2.3	2347	659.89	.16	.41	.41	182	74	74	5	250	65
STOP	2.3	2357	659.89									
C-5B	4.1	2357	663.03	.17	.39	.39	180	73	73	7	250	65
STOP	4.1	2408	663.03									
C-5C	5.9	2410	667.23	.17	.51	.51	181	73	73	9	250	67
STOP	5.9	2417	667.23									
C-5D	7.9	2419	670.12	.17	.43	.43	181	73	73	10	250	70
AVG.	7.9	34	14.52				181	73	73		250	67

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
12	G	29	2345	0:05	5	5500	
13	I	58	2357	0:05	3	5800	
14	H	1	2408	0:10	2	6600	
15	H	11	2417	0:05	1	1600	

ORSAT @ 0010	
O_2	CO_2
20.0	0.0
19.9	0.0
20.0	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-5-

5098851

FIELD DATA

PLANT U.S.S. Geneva
DATE 9-12-76
SAMPLING LOCATION Stack C-2
SAMPLE TYPE E.P.A.5
RUN NUMBER 8
OPERATOR GRIFFIN/OLSEN
AMBIENT TEMPERATURE 65
BAROMETRIC PRESSURE 29.91
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) EX-36

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .50

METER BOX NUMBER 5011
METER ($\Delta H@_2$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
SMR	0	2016	674.74	(AVG.)			(AVG.)					
C-2A	2.2	2018	677.54	.15	.35	.35	180	73	73	5	250	65
SMR	2.2	2030	677.54									
C-2B	4.5	2033	681.53	.15	.30	.30	180	73	73	5	250	67
SMR	4.5	20	681.53									
C-2C	6.7	20	685.24	.15	.32	.32	180	74	75	6	250	68
SMR	6.7	20	685.24									
C-2D	9.05	2043	686.75	.15	.34	.34	180	75	75	7	250	69
Tot/Avg	9.05		12.01				180	74	74	6	250	67

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	CALS. TO NOZZLE	COMMENTS
11	G	15	20:16	0:30	5	5400	
12	G	25	20:30	0:35	1	5300	
13	I	41	20:35	0:30	1	6100	
14	H	51	20:40	0:25	1	6200	

ORSAT @ 2030	
O_2	CO_2
20.0	0.0
19.7	0.0
20.0	0.1

COKE TEMPERATURE	
INCAN.	QUENCHED

509852

FIELD DATA

PLANT V.S.S. LORAIN
DATE 9-12-76
SAMPLING LOCATION SCRUBBER C-8
SAMPLE TYPE E.P.A. 5
RUN NUMBER 9
OPERATOR GRIFFIN/OLSEN
AMBIENT TEMPERATURE 68
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FX-27

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .291

METER BOX NUMBER 5011
METER ($\Delta H@$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	2140	89.97	(AVG.)			(AVG.)					
C-8A	1.72	2142	92.51	.19	.52	.52	181	75	75	5	250	65
START	1.72	2145	92.51									
C-8B	3.53	2147	95.28	.19	.52	.52	181	75	75	6	250	66
START	3.53	2150	95.28									
C-8C	5.20	2152	97.80	.19	.50	.50	182	75	75	6	250	67
START	5.20	2210	97.80									
C-8D	6.76	2212	100.94	.19	.50	.50	181	75	75	8	250	67
TOT/AVG	6.76		10.97				181	75	75	6	250	66.0

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	CALS. TO NOZZLE	COMMENTS
23	I	13	21:40	0:35	1	N/A	
24	I	23	21:45	0:30	1	N/A	
25	I	33	21:50	0:05	2	N/A	
26	G	17	22:10	N/A	N/A	N/A	

ORSAT @ 2145	
O_2	CO_2
20.0	0.1
20.1	0.0
20.0	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

5098853

FIELD DATA

PLANT U.S.S. Gary
DATE 9-12-76
SAMPLING LOCATION Stack D-5
SAMPLE TYPE E.P.A. 5
RUN NUMBER 10
OPERATOR Griffin/Olsen
AMBIENT TEMPERATURE 69
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) F1127-26

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63 .621=

METER BOX NUMBER 5011
METER (JDO_2) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
Start	0	2323	701.00	(AVG.)			(AVG.)					
D-5A	2.18	2325	704.76	.12	.45	.45	181	73	73	5	250	65
Stop	2.18	2327	704.76									
D-5B	4.38	2330	708.84	.12	.45	.45	181	73	73	6	250	66
Stop	4.38	2335	708.84									
D-5C	6.20	23..	712.99	.12	.45	.45	182	73	73	6	250	67
Stop	6.20	2342	712.99									
D-D	8.28	2345	716.51	.12	.52	.52	182	73	73	7	250	68
Tot/Avg	8.28		15.51				181.5	73	73	6	250	66.5

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
29	I	53	2323	0:35	0	9400	
30	I	63	2327	0:30	0	9800	
31	H	64	2335	0:20	0	9000	
32	H	5	2342	0:35	1	7100	

ORSAT @ 2330	
O_2	CO_2
20.0	0.0
20.0	0.0
19.8	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-8-

5098854

FIELD DATA

PLANT U.S.S. LORAIN
DATE 7-13-76
SAMPLING LOCATION STACK D-8
SAMPLE TYPE E.P.A. 5
RUN NUMBER 11
OPERATOR GRIFFIN/OLSEN
AMBIENT TEMPERATURE 65
BAROMETRIC PRESSURE 29.92
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) EX-18

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63 .621

METER BOX NUMBER 5011
METER (JDO2) .111

PROBE HEATER SETTING 250°
HEATER BOX SETTING 250°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	1959	720.15									
D-8A	2.28	2001	724.11	.10	.38	.38	181	75	76	5	250	65
STAR	2.28	2005	724.11									
D-8B	4.53	2007	727.96	.10	.38	.38	182	75	76	7	250	60
STAR	4.53	2009	727.96									
D-8C	6.92	2012	732.08	.10	.38	.38	181	75	76	9	250	68
STAR	6.92	2015	732.08									
D-8D	9.12	2017	736.32	.11	.41	.41	180	75	76	12	250	69
TOT/AVG	9.12	16	16.17				181	75	76			67

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
5	I	55	1959	0:10	0	N/A	
6	I	65	2005	0:05	1	N/A	
7	6	5	2008	0:10	3	6300	
8	6	15	2015	0:10	4	5100	

ORSAT @ 2000	
O_2	CO_2
20.0	0.0
19.6	0.0
19.9	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

5098855

FIELD DATA

PLANT U.S.S. Gary
DATE 9-13-26
SAMPLING LOCATION Stack D-2
SAMPLE TYPE Grab S
RUN NUMBER 12
OPERATOR GRIFFIN
AMBIENT TEMPERATURE 63
BAROMETRIC PRESSURE 29.91
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FL-127-1

PROBE LENGTH AND TYPE 10' S.S
NOZZLE I.D. .63 .621

METER BOX NUMBER 5011
METER (JDO2) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min / CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O		STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE		PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
				DESIRED	ACTUAL		INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F			
START	0 2115	37.13	(AVG.)			(AVG.)					
D-2A	2.22 2117	40.89	.17	.40	.40	180	74	74	5	250	66
START	2.22 2150	40.89									
D-2B	4.52 2153	45.80	.17	.57	.57	182	74	74	6	250	66
START	4.52 2154	45.80									
D-2C	6.70 2156	50.86	.17	.67	.67	181	74	74	8	250	67
START	6.70 2158	50.86									
D-2D	8.95 2200	56.04	.17	.64	.64	181	74	74	10	250	67
Tot/Avg	8.95	18.91				181	74	74	7	250	66.5

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
18	G	25	2115	0:00	2	5300	
19	G	17	2150	0:00	1	5900	
20	G	27	2153	0:00	0	4800	
21	G	9	2158	0:00	4	N/A	

ORSAT @ 2145	
O_2	CO_2
20.0	0.0
20.0	0.0
20.1	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-10-

5098856

FIELD DATA

PLANT U.S.S. GORMAN
DATE 9-13-76
SAMPLING LOCATION STACK A-5
SAMPLE TYPE EA
RUN NUMBER 3
OPERATOR OLSEN
AMBIENT TEMPERATURE 64
BAROMETRIC PRESSURE 29.92
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FX-50

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63 .621

METER BOX NUMBER 5043
METER ($\Delta H@$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24 hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	2324	56.25	(AVG.)			(AVG.)					
A-5A	2.18	2326	60.48	.11	.46	.46	182	72	72	5	250	66
STOP	2.18	2330	60.48									
A-5B	4.38	2332	64.65	.11	.43	.43	182	73	73	6	250	67
STOP	4.38	2337	64.65									
A-5C	6.63	2339	68.80	.11	.43	.43	182	73	73	10	250	68
STOP	6.63	2345	68.80									
A-5D	8.88	2347	72.97	.11	.41	.41	182	73	72	12	250	68
TOT/AVG	8.88		16.72				182	73	72.5	8	250	67

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
27	H	23	2324	0:02	1	4900	
28	H	64	2330	0:10	0	6500	
29	H	59	2337	0:10	3	6100	
30	I	9	2345	0:05	2	4700	FAILED FOR 5 SEC.

ORSAT @ 2330	
O_2	CO_2
20.0	0.0
19.8	0.0
20.1	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

5098857

FIELD DATA

PLANT U.S.S. LORAIN
DATE 9-14-76
SAMPLING LOCATION STACK A-2
SAMPLE TYPE E.P.A. 5
RUN NUMBER 14
OPERATOR GRIFFIN/OLSEN
AMBIENT TEMPERATURE 68
BAROMETRIC PRESSURE 29.2 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) ~~F1-127-22~~ F1-127-22

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .50

METER BOX NUMBER .5011
METER (JDO_2) .111

PROBE HEATER SETTING 250°
HEATER BOX SETTING 250°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	2017	73.24									
A-2A	2.25	2020	76.73	.17	.32	.32	180	73	74	5	250	65
STAR	2.25	2023	76.73									
A-2B	4.55	2025	80.54	.17	.32	.32	182	74	74	7	250	66
STAR	4.55	2026	80.54									
A-2C	6.82	2029	84.27	.17	.32	.32	182	74	74	9	250	68
STAR	6.82	2057	84.27									
A-2D	9.0	2059	87.57	.17	.32	.32	181	74	74	12	250	70
Tot/Avg	9.0	42	14.33				181	74	74		250	67

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
8	H	12	2011	0:05	1	N/A	
9	H	32	2016	0:00	0	N/A	
10	H	42	2022	0:00	3	N/A	
11	G	7	2052	0:00	0	N/A	

ORSAT @ 2030	
O_2	CO_2
20.-	0.0
20.-	0.0
20.-	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-12-

509858

FIELD DATA

PLANT U.S.S.
DATE 9-14-76
SAMPLING LOCATION STACK A-8
SAMPLE TYPE E.P.A. 5
RUN NUMBER 15
OPERATOR OLSEN
AMBIENT TEMPERATURE 68
BAROMETRIC PRESSURE 24.93
STATIC PRESSURE, (P_s) -01
FILTER NUMBER (s) F1127-12

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .50

METER BOX NUMBER
METER ($\Delta H@_2$) .111

PROBE HEATER SETTING 250°F
HEATER BOX SETTING 250°F

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	2316	88.11									
A-8A	2.30	2319	90.40	.12	.30	.30	182	74	74	5	250	66
STAR	2.30	2320	90.40									
A-8B	4.70	2322	93.21	.12	.32	.32	182	74	74	6	250	67
STAR	4.70	2330	93.21									
A-8C	6.95	2332	96.03	.12	.29	.29	183	74	74	7	250	69
STAR	6.95	2337	96.03									
A-8D	9.19	2340	99.51	.12	.30	.30	183	74	74	9	250	70
Tot/Avg	9.19		11.40				182.5	74	74	7	250	68

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS
19	I	42	2310	0:00	1	6300	
20	E	62	2315	0:20	1	1500	
21	H	4	2325	0:10	1	7500	
22	H	14	2330	0:30	1	7500	

ORSAT @ 2315	
O_2	CO_2
20.0	0.0
20.0	0.0
20.0	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED

5098859

FIELD DATA

PLANT USS
DATE ~~10-4-76 [illegible]~~ 10-5-76
SAMPLING LOCATION 16-81
SAMPLE TYPE
RUN NUMBER
OPERATOR OLSEN
AMBIENT TEMPERATURE
BAROMETRIC PRESSURE 29.92
STATIC PRESSURE, (P_s)
FILTER NUMBER (s)

PROBE LENGTH AND TYPE S.S. AEROTHERM
NOZZLE I.D. 36

METER BOX NUMBER NEW
METER (JDO_2)

PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24 hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	21:30	110.276									
	2.33		114.340	.14	.41	.3	205	74	75	10	250	78
STAR	0	2135	114.340				~~[illegible]~~				250	
	2.30		118.270	.15	.41	.25	211	74	75	10	250	75
STAR	0	21:40	118.270		~~[illegible]~~	~~[illegible]~~					250	
	2.40		122.330	.14	.38	.25	210	75	75	10	250	66
STAR	0	2150	122.330								250	
	2.25		126.663	.17	.52	.25	202	74	75	10	250	68
Tot/Avg	9.28											

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2
20.0	0.0
19.8	0.0
19.9	0.0

COKE TEMPERATURE	
INCAN.	QUENCHED
1425	
1315	
1405	
1391	

509860

FIELD DATA — Position 2

PLANT U.S. Steel Coke Plant
DATE Oct. 7, 1970
SAMPLING LOCATION ~~[illegible]~~ 43C-21
SAMPLE TYPE Part.
RUN NUMBER 4
OPERATOR Griffin/Wahlig
AMBIENT TEMPERATURE 70
BAROMETRIC PRESSURE 29.79
STATIC PRESSURE, (P_s) +0.2
FILTER NUMBER (s) FI-53665

PROBE LENGTH AND TYPE
NOZZLE I.D. ~~[illegible]~~ 9/16"

METER BOX NUMBER NAW
METER (JDO_2) .110

PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min / CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O UP DESIRED	DOWN ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0 1700	934.888									
	2.4	939.388	.15	~~.49~~	~~.25~~	—	70	70	9	250	60
STAR	0	939.388	—	.58	.29	—					
	2.23	943.763	.14	.58	.29	—	71	70	10	250	65
STAR	0	943.763	—								
	2.25	948.913	.15	.47	.28	—	71	70	8	250	66
STAR	0	947.913	—								
	2.22	952.100	.14	.47	.28	—	71	70	6	250	~~66~~ 75
TOE/AVG											

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	CALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2
20	0
20	10
20	0

COKE TEMPERATURE	
INCAN.	QUENCHED

FIELD DATA

PLANT USS
DATE 10/29/76
SAMPLING LOCATION B-6
SAMPLE TYPE
RUN NUMBER 4NE
OPERATOR [illegible]
AMBIENT TEMPERATURE 50
BAROMETRIC PRESSURE 30.23
STATIC PRESSURE, (P_s) +8.1
FILTER NUMBER (s) EL 53687

PROBE LENGTH AND TYPE 12' SS
NOZZLE I.D. .5 L
METER BOX NUMBER #25
METER (JDO2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24 hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	1853	148.935									
1B-5A	2.5		153.600	.15	.46	.30	180	55	56	10	250	53
START	0	1900	153.600									
1B-5B	2.44		157.970	.15	.46	.30	180	55	55	10	250	51
START	0	1905	157.970									
B-5C	2.45		162.580	.15	.461	.30	180	55	55	10	250	53
START	0		162.580									
1B-5D	2.40		167.130	.15	.51	.32	180	55	55	10	250	55
TOT/AVG												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

209 ml

9861

-D-16-

5098862

FIELD DATA

PLANT [illegible]
DATE 12/30/76
SAMPLING LOCATION [illegible]
SAMPLE TYPE Part
RUN NUMBER T-10
OPERATOR Griffin
AMBIENT TEMPERATURE 45
BAROMETRIC PRESSURE 30.10
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FC5-3657

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. 9/16"
METER BOX NUMBER #17
METER ($\Delta H@_2$) .14
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min, θ	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
A-2	0	1803	987.159									
A-2A	2.37		991.647	.17	.51	.28	180	69	69	22	250	64
Stop	0	1812	991.647								250	
A-3B	2.31		996.168	.17	.51	.28	180	69	68	15	250	64
Stop	0	1818	996.168								250	
A-3C	1.40		000.827	.17	.51	.28	180	69	69	20	250	67
Stop	0	1824	000.827								250	
A-3C	2.42		005.428	.17	.51	.28	180	70	69	22	250	73
Tot/Avg											250	

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	CALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509863

FIELD DATA

PLANT USS
DATE 10/31/76
SAMPLING LOCATION Port B Quench 8
SAMPLE TYPE Part
RUN NUMBER Ramp #3
OPERATOR GRIFFIN
AMBIENT TEMPERATURE 40
BAROMETRIC PRESSURE 30.19
STATIC PRESSURE, (P_s) +.01
FILTER NUMBER (s) FL5-3672

PROBE LENGTH AND TYPE 10' SS
NOZZLE I.D. 7
METER BOX NUMBER #17 .56
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

RAMPS

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O UP DESIRED	DOWN ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	0107	010.805									
B-8A	2.35		15,707	.18	.56	.32	180	67	67	7	250	64
STAR	0	0115	15,707								250	
B-8B	2.32		20,201	.15	.45	.32	180	67	67	7	250	61
STAR	0	0122	20,201								250	
B-8C	2.40		24,996	.16	.51	.32	180	67	67	13	250	63
STAR	0	0127	24,996								250	
B-8D	2.35		29,052	.16	.51	.32	180	67	67	15	250	63
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509864

FIELD DATA

PLANT U.S.S. Lorain Ohio
DATE 11/1/76
SAMPLING LOCATION D-5
SAMPLE TYPE Part.
RUN NUMBER 4
OPERATOR Griffin/Wahlig
AMBIENT TEMPERATURE 41
BAROMETRIC PRESSURE 30.30
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) EL 5-3679

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. 9/16"
Hastings #17
METER BOX NUMBER
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O UP DESIRED	DOWN ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	1720	175.225									
D-5	2.40		179.488	.088	.40	.25	180	51	51	20	250	45
STAR	0	1825	179.492							1[illegible]	250	
D-5B	2.50		183.859	.088	.40	.25	180	52	51	18	250	44
STAR	0	1731	183.870								250	
D-5C	2.35		188.030	.088	.40	.25	180	53	51	14	250	47
STAR	0	1739	188.048								250	
D-5C	2.32		192.167	.088	.40	.25	180	53	51	12	250	49
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509865

FIELD DATA

QUALITY CONSTRUCTED YORK RESEARCH CORPORATION

PLANT U.S.S. Lorain O.
DATE 11/1/76
SAMPLING LOCATION D-2
SAMPLE TYPE Part
RUN NUMBER # 59
OPERATOR Griffin / Wellig
AMBIENT TEMPERATURE 40
BAROMETRIC PRESSURE 30.30
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FL5-3664

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63
Hastings. 25
METER BOX NUMBER
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ΔH UP DOWN DRIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ΔH UP DOWN DRIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR.	0	2328	203.410									
D-2A	2.3		207.286	.12	.52	.30	180	42	42	23	250	41
STAR.	0	2333	207.286									
D-2B	2.35		211.569	.12	.52	.30	180	42	42	16	250	41
STAR.	0	2338	211.569									
D-2C	2.35		216.025	.12	.52	.30	180	43	42	19	250	49
STAR.	0	2349	216.025								250	
D-2D	2.42		220.630	.12	.52	.30	180	43	42	16	250	49

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509866

FIELD DATA

PLANT U.S.S. Lorain O.
DATE 11/1/83
SAMPLING LOCATION D-8
SAMPLE TYPE Batch
RUN NUMBER 6
OPERATOR Green
AMBIENT TEMPERATURE 34
BAROMETRIC PRESSURE 30.30
STATIC PRESSURE, (P_s) -8.1
FILTER NUMBER (s) ELS-3681

PROBE LENGTH AND TYPE 10' SS
NOZZLE I.D. 3/16
Hastings 25
METER BOX NUMBER
METER (ΔDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

ΔH

UP DOWN

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
0-8	0	0057	221.088									
D8A	2.35		225.188	.09	.40	.28	180	41	41	11	250	43
SDR	0	0103	225.188									
D8B	2.50		229.790	.09	.47	.28	180	41	41	9	250	42
SDR	0	0114	229.790									
D8C	2.3		234.241	.09	.47	.28	180	42	41	8	250	42
SDR	0	0124	234.241									
D8D	2.35		238.639	.09	.47	.28	180	42	41	10	250	42
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

5098867

FIELD DATA

QUALITY CONTROLLED YORK RESEARCH CORPORATION

PLANT USS
DATE 11-2-76
SAMPLING LOCATION A-5
SAMPLE TYPE
RUN NUMBER 7
OPERATOR OLSEN/UMHILLIO
AMBIENT TEMPERATURE 50
BAROMETRIC PRESSURE 30.04
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FL5-3622

PROBE LENGTH AND TYPE 10' SS
NOZZLE I.D. .56
#25
METER BOX NUMBER
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

PROBE AT 95° ANGLE

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O UP DESIRED	DOWN ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR.	0	1703	240.913									
A-5A	2.4		245.200	.14	0.44	0.27	180	58	56	15	250	57
STAR.	0	1708	245.200									
A-5B	2.43		249.572	.14	0.44	0.27	180	58	56	15	250	57
STAR.	0	1713	249.572									
A-5C	2.58		254.504	.14	0.44	0.27	180	57	56	15	250	58
STAR.	0	1737	254.504									
A-5D	2.32		258.492	.14	0.44	0.27	180	57	56	15	250	57
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509868

FIELD DATA

PLANT U.S. STEEL
DATE 11/2/76
SAMPLING LOCATION A8
SAMPLE TYPE P
RUN NUMBER
OPERATOR WAHLIG/OLSEN
AMBIENT TEMPERATURE 50
BAROMETRIC PRESSURE 30.04
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) 223-3676

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .63
#25
METER BOX NUMBER
METER (JDO_2) 1.111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

PROBE ANGLE 110°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24 hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
	0	1920	259.193									
A-8A	2.3		262.523	.08	0.40	0.28	180	58	57	15	250	55
STAR	0	1925	262.523									
A-8B	2.38		266.947	.08	.40	.28	180	59	57	15	250	56
STAR	0	1929	266.947									
A-8C	2.42		271.260	.08	.40	.28	180	58	57	15	250	58
STAR	0	1933	271.260									
A-8D	2.4		275.445	.08	.40	.28	180	58	57	15	250	58
Tot/Ave												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509869

FIELD DATA

QUALITY CONTROLLED YORK RESEARCH CORPORATION

PLANT U.S. STEEL
DATE 11/2/76
SAMPLING LOCATION A2
SAMPLE TYPE
RUN NUMBER 9
OPERATOR WAHLIG/OLSEN
AMBIENT TEMPERATURE 50
BAROMETRIC PRESSURE 30.04
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FL5-3650

PROBE LENGTH AND TYPE 10' SS.
NOZZLE I.D. .621
#25
METER BOX NUMBER
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

PROBE ANGLE 110°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O UP DOWN OBSIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	2050	277.562									
A2A	2.32		282.030	.18	.54	.31	180	60	58	10	250	51
STAR	0	2057	282.030									
A2B	2.4		286.848	.18	.54	.31	180	60	59	10	250	54
STAR	0	2103	286.848									
A2C	2.39		291.253	.15	.45	.25	180	60	59	10	250	58
STAR	0	2108	291.253									
A2D	2.34		295.464	.16	.48	.24	180	61	59	10	250	67
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509870

FIELD DATA

PLANT U.S. Steel, Lorain O.
DATE 11/3/76
SAMPLING LOCATION A-Center
SAMPLE TYPE Part
RUN NUMBER 10
OPERATOR Gaffin, Vally
AMBIENT TEMPERATURE 46
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) EL5-3685

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. 3/8" .56
Hastings 25
METER BOX NUMBER
METER (JDO_2)
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

PROBE ANGLE 110°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	DRY GAS METER TEMPERATURE OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
	0	1648	297.839									
A-Ca	2.39		302.342	.15	.51	.28	180	56	55	16	250	53
	0	1658	302.342									
A-Cb	2.42		307.018	.15	.51	.28	180	56	55	14	250	51
	0	1704	307.018									
A-Cc	2.48		311.619	.15	.51	.28	180	56	55	16	250	51
	0	1745	311.619									
A-Co	2.4		311.624	.15	.51	.28	180	53	53	15	250	49
Tot/Avg			316.223									

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509871

FIELD DATA

QUALITY CONTROLLED YORK RESEARCH CORPORATION

PLANT U.S.S. Lorain O.
DATE 11/3/78
SAMPLING LOCATION A-5
SAMPLE TYPE Part.
RUN NUMBER 11
OPERATOR Graf Sin/Wohlig
AMBIENT TEMPERATURE 46
BAROMETRIC PRESSURE 29.93
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FCS-3653

Medium size cyclone - POM Test

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .375
Hastings 25
METER BOX NUMBER
METER (JDO_2)
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft^3	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
ST. A-5A	0	1740	337.920									
A-5A	2.33		340.258	.17	.18	.18	180	50	49	20	250	46
[illegible]	0	1745	340.258									
A-5B	2.35		342.745	.17	.18	.18	180	50	49	21	250	45
	0	1750	342.745									
	2.30		345.089	.13	.14	.10	180	50	49	22	250	45
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

QUENCH 1 : PULLED .1
2 " .08
3 " .05

-D-26-

509872

FIELD DATA

PLANT U.S. STEEL Lorain Ohio
DATE 11/3/76
SAMPLING LOCATION A-Center
SAMPLE TYPE
RUN NUMBER 12
OPERATOR Wahlig, Griffin
AMBIENT TEMPERATURE 39
BAROMETRIC PRESSURE 29.83
STATIC PRESSURE, (P_s) +0.1
FILTER NUMBER (s) FX-9

PROBE LENGTH AND TYPE 10' S. S.
NOZZLE I.D. (.56)
≈ 25
METER BOX NUMBER
METER (JDO_2) .111
PROBE HEATER SETTING 250
HEATER BOX SETTING 250

PROBE ANGLE: 110°

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F	OUTLET ($T_{m\,out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
STAR	0	2135	346.324									
A-CTR A	2.35		351.220	.26	.63	.30	180	47	48	22	250	42
STAR	0	2140	351.220									
AC B	2.32		356.169	.24	.57	.31	180	48	47	20	250	43
STAR	0	2145	356.169									
A-CC	2.28		360.863	.24	.57	.31	180	49	47	14	250	45
STAR	0	2205	360.863									
A-CD	2.30		365.318	.24	.57	.31	180	48	47	20	250	43
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

509873

FIELD DATA

PLANT U.S. Steel
DATE 11/3/76
SAMPLING LOCATION Center
SAMPLE TYPE
RUN NUMBER 13
OPERATOR Walling / Griffith
AMBIENT TEMPERATURE 39
BAROMETRIC PRESSURE 29.23
STATIC PRESSURE, (P_s) (-2.)
FILTER NUMBER (s)

Small Cyclone
POM

PROBE LENGTH AND TYPE 10' S.S.
NOZZLE I.D. .441

METER BOX NUMBER 5011
METER (JDO2) .111

PROBE HEATER SETTING 250
HEATER BOX SETTING 250

TRAVERSE POINT NUMBER	SAMPLING TIME, min	CLOCK TIME (24-hr CLOCK)	GAS METER READING (V_m), ft³	VELOCITY HEAD (Δp_s), in. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), in. H_2O DESIRED	ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{m\ in}$), °F	OUTLET ($T_{m\ out}$), °F	PUMP VACUUM, in. Hg	SAMPLE BOX TEMPERATURE, °F	IMPINGER TEMPERATURE, °F
START	0	0250	365.544									
A-C1	2.48		367.771	.08	.10	.07	208	43	42	23	250	40
START	0	0056	367.771									
A-C3	2.57		370.165	.08	.10	.07	209	43	42	23	250	37
START	0	0104	370.165									
A-C5	3.02		372.959	.08	.10	.07	199	43	42	22	250	37
Tot/Avg												

PUSH #	BATTERY #	OVEN #	TIME OF PUSH	FUGITIVE DURATION	GREENNESS	GALS. TO NOZZLE	COMMENTS

ORSAT	
O_2	CO_2

COKE TEMPERATURE	
INCAN.	QUENCHED

-D-28-

5098874

GAS SAMPLING FIELD DATA

JOB NO. 4-8479-29

DATE 9/13/76

CLIENT EPA

PLANT USS Lorain

UNIT TESTED STACK

DUCT NO. —

TEST NO. 1

SAMPLE FOR SOx

IMPINGER SOL'N —

FILTER —

PROBE HEATER SETTING 200

BAROMETRIC PRESSURE 29.92

AMBIENT TEMP. 68

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
2200	90.85	1	73
	93.88		

TOTAL 3.03 AVG.

COMMENTS:

509875

ES 055 (3/75)

YARG

GAS SAMPLING FIELD DATA

SOx

JOB NO. 4-8479-29

DATE 9/14/76

CLIENT EPA

PLANT USS Lorain

UNIT TESTED Stack

DUCT NO. —

TEST NO. 2

SAMPLE FOR SOx

IMPINGER SOL'N —

FILTER —

PROBE HEATER SETTING 200

BAROMETRIC PRESSURE 29.93

AMBIENT TEMP. 68

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
1928	83.29	1	74
	86.26		75

TOTAL 2.97 AVG. 74.5

COMMENTS:

509876

ES 055 (3/75)

GAS SAMPLING FIELD DATA

JOB NO. 4-8479-29

DATE 9/14/76

CLIENT EDA

PLANT USS Lorain

UNIT TESTED Stack

DUCT NO. —

TEST NO. 3

SAMPLE FOR SOx

IMPINGER SOL'N

FILTER —

PROBE HEATER SETTING 200

BAROMETRIC PRESSURE 29.93

AMBIENT TEMP. 68

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
1928	93.92	1	73
	97.00	1	74

TOTAL 3.08

AVG. 73.5

COMMENTS:

509877

ES 055 (3/75)

GAS SAMPLING FIELD DATA

JOB NO. 4-8479-29

DATE 9/13/76

CLIENT EPA

PLANT USS Lorain

UNIT TESTED —

DUCT NO.

TEST NO. 1-2

SAMPLE FOR Phenol/CN⁻

IMPINGER SOL'N 0.1N NaOH

FILTER —

PROBE HEATER SETTING 200

BAROMETRIC PRESSURE 29.92

AMBIENT TEMP. 70°

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
1740	86.03	1	75
	89.10		
1910	78.72	1	75
	81.80		
1920	81.8	1	75
	84.9		

TOTAL 1-3.07

2-3.08

3-3.00

AVG.

COMMENTS:

509878

GAS SAMPLING FIELD DATA

JOB NO. 4-8479-29

DATE 6/12/76

CLIENT EPA

PLANT USS Lorain

UNIT TESTED Stack

DUCT NO. —

TEST NO. 2-3-4

SAMPLE FOR NH_4

IMPINGER SOL'N .1N H_2SO_4

FILTER —

PROBE HEATER SETTING 200

BAROMETRIC PRESSURE 29.93

AMBIENT TEMP. 70

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
1913	77.31	1	74
	80.39		74
2057	80.43	1	74
	83.01		93
2314	83.09	1	74
	86.03		74

1 3 TOTAL 3.08

COMMENTS: 2 3 2.59

3 4 2.94

AVG. 74

509879

GAS SAMPLING FIELD DATA

JOB NO. 4-9231 E-A

DATE 11-3-76

CLIENT EPA

PLANT US Steel Lorain

UNIT TESTED Quench Tower B

DUCT NO.

TEST NO. 1

SAMPLE FOR Sulfides

IMPINGER SOL'N —

FILTER —

PROBE HEATER SETTING —

BAROMETRIC PRESSURE —

AMBIENT TEMP. 42°F

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
1800	175.78	.25	54°
2000	178.80	.25	50°

TOTAL _____ AVG. _____

COMMENTS:

509880

ES 055 (3/75)

YRC

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-3-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. B

TEST NO. 2

SAMPLE FOR Sulfides

IMPINGER SOL'N —

FILTER —

PROBE HEATER SETTING —

BAROMETRIC PRESSURE —

AMBIENT TEMP. 41°

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
2000	178.93	.25	53°
2210	181.75	.25	52°

TOTAL _____ AVG. _____

COMMENTS:

509881

ES 055 (3/75)

YRG

GAS SAMPLING FIELD DATA

JOB NO. 4-9231 F-A

DATE 11-3-76

CLIENT EPA

PLANT US Steel Lorain

UNIT TESTED Quench Tower

DUCT NO. B

TEST NO. 3

SAMPLE FOR Sulfides

IMPINGER SOL'N —

FILTER —

PROBE HEATER SETTING —

BAROMETRIC PRESSURE —

AMBIENT TEMP. 36°F

TEST CONDITIONS —

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
0005	182.17	.25	51°
0110	185.26	.25	54°

TOTAL _____ AVG. _____

COMMENTS:

509882

ES 055 (3/75)

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 10-30-76

CLIENT U.S. Steel

PLANT Lorain

UNIT TESTED Quench Tower

DUCT NO. A

TEST NO. 1

SAMPLE FOR Cyanide + Phenols

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 48° F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
5:30	155.89	.25	54°
6:30	158.92		52°

TOTAL _____ AVG. _____

COMMENTS:

509883

ES 055 (3/75)

YRC

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 10-2[illegible]

CLIENT [illegible]

PLANT [illegible]

UNIT TESTED [illegible]

DUCT NO. C

TEST NO. 2

SAMPLE FOR Phenol + Cyanide

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. [illegible]°F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
6:00	402.22	.25	[illegible]°F
6:55	405.98	[illegible]	[illegible]°F

TOTAL _____ AVG. _____

COMMENTS:

509884

ES 055 (3/75)

YRC

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 10-30

CLIENT US Steel

PLANT Lorain, Ohio

UNIT TESTED Quench

DUCT NO. C

TEST NO. 3

SAMPLE FOR Phenols & Cyan

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 46°

TEST CONDITIONS Rain

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
7:45	405.94	.25	54°
	409.11		<40°

TOTAL _____ AVG. _____

COMMENTS:

509885

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 10-30-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. A

TEST NO. R 1

SAMPLE FOR SO_x

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 47

TEST CONDITIONS Rain

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
7:30	159.99	.25	55°
	162.00		57°

TOTAL _____

AVG. _____

COMMENTS:

509886

ES 055 (3/75)

YRC

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-1-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench Tower

DUCT NO. A

TEST NO. 2

SAMPLE FOR SO_x

IMPINGER SOL'N H_2O_2

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 42°

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
4:30	163.45	.25	53°
5:45	166.60	.25	52°

TOTAL _____ AVG. _____

COMMENTS:

509887

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-1-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. A

TEST NO. 3

SAMPLE FOR SO_x

IMPINGER SOL'N H_2O_2

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 41°F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
7:25 a.m	166.70	.25	50°F
8:10	169.71	.25	54°F

TOTAL _____ AVG. _____

COMMENTS:

509888

YRC

ES 055 (3/75)

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-1-76

CLIENT U.S. Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. C

TEST NO. 1

SAMPLE FOR NH_3

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 42° F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
4:30	409.44	.25	52°
5:50	412.49	.25	54°

TOTAL _____ AVG. _____

COMMENTS:

509889

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-1-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. C

TEST NO. 2

SAMPLE FOR NH_3

IMPINGER SOL'N _____

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 41°F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
7:25	412.70	.25	50°F
8:10	415.91	.25	55°F

TOTAL _____ AVG. _____

COMMENTS:

509890

ES 055 (3/75)

YRC

GAS SAMPLING FIELD DATA

JOB NO. _____

DATE 11-1-76

CLIENT US Steel

PLANT Lorain

UNIT TESTED Quench

DUCT NO. A

TEST NO. 3

SAMPLE FOR NH_3

IMPINGER SOL'N H_2SO_4

FILTER _____

PROBE HEATER SETTING _____

BAROMETRIC PRESSURE _____

AMBIENT TEMP. 37°F

TEST CONDITIONS _____

CLOCK TIME	METER READING (FT.^{3})	SAMPLE RATE (CFM)	METER TEMP. (°F)
9:30 a.m.	170.18	.25	53°F
10:45	172.79	.25	55°F

TOTAL _____ AVG. _____

COMMENTS:

509891

REPORT NO. TABLE 6-16 PAGE

DATE: 9-8-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	-	-	-	Specific data not available
I	-	-	-	Specific data not available

BATTERY		PUSHER SIDE (°F)	COKE SIDE (°F)
H	AVERAGE	2320	2340
	TOTAL AVERAGE	2330	
I	AVERAGE	2258	2351
	TOTAL AVERAGE	2318	

509892

REPORT NO.

TABLE 6-17

PAGE

DATE: 9-9-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	-	-	-	Specific data not available
I	-	-	-	Specific data not available
H	AVERAGE	2307	2338	
	TOTAL AVERAGE	2332		
I	AVERAGE	2360	2408	
	TOTAL AVERAGE	2384		

509893

REPORT NO. TABLE 6-18 PAGE

DATE: 9-10-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	-	-	-	Specific data not available
I	-	-	-	Specific data not available
H	AVERAGE	2356	2345	
	TOTAL AVERAGE	2350		
I	AVERAGE	2398	2414	
	TOTAL AVERAGE	2406		

509894

DATE: 9-11-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2319	2319	
H	7	2341	2342	
H	17	2322	2326	
H	27	2329	2333	
H	37	2325	2335	
H	47	2342	2334	
H	57	2322	2327	
H	65	2345	2348	
I	1	2423	2434	
I	7	2440	2450	
I	17	2448	2442	
I	27	2443	2448	
I	37	2458	2474	
I	47	2435	2437	
I	57	2446	2456	
I	65	FIRE	2443	
H	AVERAGE	2331	2333	
	TOTAL AVERAGE	2332		
I	AVERAGE	2442	2448	
	TOTAL AVERAGE	2445		

509895

REPORT NO. TABLE 6-20 PAGE

DATE: 9-12-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2329	2326	
H	2	2324	2321	
H	12	2331	2329	Plug N.
H	22	2347	Brick	MTY-(Pusher side)
H	32	2331	2335	
H	42	2335	2335	
H	52	2340	2343	MTY-(Pusher side)
H	62	2318	2325	
H	65	2338	2889	
I	1	2417	2440	
I	2	2430	2442	
I	12	2438	2438	
I	22	2440	2442	
I	32	2444	2444	
I	42	2440	2600	
I	52	2448	2580	
I	62	2445	2449	
I	65	2435	2437	
H	AVERAGE	2325	2350	
	TOTAL AVERAGE	2338		
I	AVERAGE	2433	2476	
	TOTAL AVERAGE	2455		

509896

DATE: 9-13-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2320	2322	
H	6	FIRE	2330	
H	16	2328	BRICK	
H	26	2337	2338	
H	36	2329	2342	
H	46	2328	2341	
H	56	2333	BRICK	MTY (Pusher side)
H	65	2335	2338	
I	1	2215	2437	
I	6	2229	2437	
I	16	2235	2450	
I	26	2220	2435	
I	36	2243	2427	
I	46	2226	2442	
I	56	2235	2450	
I	65	2226	2434	
H	AVERAGE	2305	2353	
	TOTAL AVERAGE	2329		
I	AVERAGE	2290	2434	
	TOTAL AVERAGE	2362		

509897

DATE: 9-14-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2219	2324	
H	3	2218	2333	
H	13	2232	2328	
H	23	2235	2332	
H	33	2224	2338	
H	43	2228	2333	
H	53	2250	BRICK	COT(PUSHER SIDE)
H	63	2258	2338	
H	65	2231	2342	
I	1	2315	2328	
I	3	2319	2336	
I	13	2333	2331	
I	23	2333	2330	
I	33	2340	2331	
I	43	2334	2344	
I	53	2355	2355	
I	63	2341	2351	
I	65	2328	2333	
H	AVERAGE	2294	2337	
	TOTAL AVERAGE	2315		
I	AVERAGE	2350	2385	
	TOTAL AVERAGE	2367		

509898

REPORT NO. TABLE 6-23 PAGE

DATE: 9-15-76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2317	2332	
H	7	2336	2336	
H	17	2327	2350	
H	27	2331	2335	
H	37	2338	2323	
H	47	2342	2343	
H	57	2320	2332	
H	65	2340	2342	
I	1	2340	2439	
I	7	2330	2448	
I	17	2348	2437	
I	27	2337	2439	
I	37	2321	2424	MTY (PUSHER SIDE)
I	47	2328	2432	
I	57	2341	2449	
I	65	2331	2434	
H	AVERAGE	2357	2347	
	TOTAL AVERAGE	2352		
I	AVERAGE	2335	2438	
	TOTAL AVERAGE	2387		

509899

REPORT NO.

TABLE 6-24

PAGE

DATE: 10/29/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	1	2250	2350	
G	4	2140	2150	
G	5	2180	2200	
G	8	2070	2130	
G	9	2030	2020	
G	13	1920	1820	
G	14	2000	1950	
G	17	2120	2260	
G	18	2140	2160	
G	22	2150	2100	
G	23	2240	2170	
G	26	2030	2240	
G	27	2110	2110	
G	31	1750	2040	
G	32	2180	2280	
G	35	2100	2360	
G	36	2040	2250	
G	39	2120	2190	
G	41	2180	2170	
G	44	2080	2190	
G	45	2210	2190	
G	AVERAGE	2097	2159	
	TOTAL AVERAGE	2128		
	AVERAGE			
	TOTAL AVERAGE			

509900

REPORT NO. TABLE 6-25 PAGE

DATE: 10/31/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	1	2222	2328	
G	11	2207	2311	
G	21	2213	2282	
G	31	2271	2201	
G	41	2215	2213	
	AVERAGE	2265	2268	
	TOTAL AVERAGE	2267		
	AVERAGE			
	TOTAL AVERAGE			

509901

DATE: 10/31/76 -73

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2119	2338	
H	11	2113	Leak	
H	21	2148	2357	
H	31	2120	Brick	
H	41	2115	2324	
H	51	2125	2331	
H	61	2118	2339	
	AVERAGE	2165	2365	
	TOTAL AVERAGE	2265		
	AVERAGE			
	TOTAL AVERAGE			

509902

REPORT NO. TABLE 6-27 PAGE

DATE: 10/31/76 - 73

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
I	1	2323	2328	
I	11	2329	2323	
I	21	2335	2325	
I	31	2328	2325	
I	41	2336	2347	
I	51	2342	2342	
I	61	2334	2338	
I	66	2330	2330	
	AVERAGE	2324	2311	
	TOTAL AVERAGE	2320		
	AVERAGE			
	TOTAL AVERAGE			

509903

DATE: 11/1/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	1	2123	2114	
G	5	2123	2131	
G	15	2102	2121	
G	25	2110	2101	
G	35	2115	2111	
G	45	2125	2128	
	AVERAGE	2150	2184	
	TOTAL AVERAGE	2161		
	AVERAGE			
	TOTAL AVERAGE			

509904

REPORT NO. TABLE 6-29 PAGE

DATE: 11/1/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H	1	2324	2339	
H	5	2311	2336	
H	15	2371	BRICK	
H	25	2330	2340	
H	35	2327	2337	
H	45	2325	2334	
H	55	2332	2353	
H	65	2327	2332	
H	66	2330	2380	
	AVERAGE	2306	2386	
	TOTAL AVERAGE	2340		
	AVERAGE			
	TOTAL AVERAGE			

509905

DATE: 11/1/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
I	1	2329	2439	
I	5	2338	2443	
I	15	2329	2450	
I	25	2331	2448	
I	35	2326	2430	
I	45	2334	2424	
I	55	2329	2435	
I	65	2338	2446	
I	66	2333	2437	
I	48	2329	2450	
	AVERAGE	2314	2420	
	TOTAL AVERAGE	2366		
	AVERAGE			
	TOTAL AVERAGE			

509906

REPORT NO. TABLE 6-31 PAGE

DATE: 11/1/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	2	2100	2116	
G	3	2109	2114	
G	6	2109	2110	
G	7	2124	2117	
G	11	2105	2116	
G	12	2107	2117	
G	15	1940	2102	
G	16	2110	2115	
G	19	2113	2111	
G	21	2114	2192	
G	24	2110	2119	
G	25	2106	2122	
G	28	2117	2111	
G	29	1990	2114	
G	33	2121	2117	
G	34	2121	2131	
G	37	2112	2121	
G	38	2116	2102	
G	42	2110	2108	
G	43	2110	2116	
G	46	2110	2116	
G	AVERAGE	2098	2118	
	TOTAL AVERAGE	2108		
	AVERAGE			
	TOTAL AVERAGE			

509907

DATE: 11/1/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	1	2124	2116	
G	4	2118	2119	
G	5	2120	2128	
G	8	2106	2112	
G	9	2106	2102	
G	13	2102	2101	
G	14	1770	2120	
G	17	2110	2124	
G	18	2116	2117	
G	22	2118	2112	
G	23	2121	2117	
G	26	2105	2132	
G	27	2114	2118	
G	31	1790	2107	
G	32	2121	2136	
G	35	2107	2137	
G	36	2104	2125	
G	39	2110	2117	
G	41	2120	2117	
G G	44 45	2113 2127	2122 2132	
G	AVERAGE	2082	2120	
	TOTAL AVERAGE	2101		
	AVERAGE			
	TOTAL AVERAGE			

509908

REPORT NO. TABLE 6-33 PAGE

DATE: 11/2/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	2	2000	2100	
G	3	2006	2110	
G	6	2008	2105	
G	7	2018	2111	
G	11	2005	2113	
G	12	2005	2116	
G	15	2000	2101	
G	16	2008	2120	
G	19	2011	2104	
G	21	2016	2106	
G	24	2006	2115	
G	25	2006	2121	
G	28	2012	2103	
G	29	2000	2111	
G	33	2014	2110	
G	34	2021	2124	
G	37	2007	2116	
G	38	2011	2100	
G	42	2007	2105	
G	43	2009	2113	
G	46	2015	2110	
G	AVERAGE	2009	2110	
	TOTAL AVERAGE	2060		
	AVERAGE			
	TOTAL AVERAGE			

509909

YORK RESEARCH C

REPORT NO.

TABLE 6-34

PAGE

DATE: 11/2/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE(°F)	COKE SIDE(°F)	COMMENTS
G	1	2125	2125	
G	4	2116	2119	
G	5	2121	2126	
G	8	2106	2111	
G	9	2114	2106	
G	13	2101	2100	
G	14	1930	2121	
G	17	2110	2122	
G	18	2113	1880	
G	22	2120	2107	
G	23	2123	2116	
G	26	2176	2129	
G	27	2112	2117	
G	31	1760	2105	
G	32	2120	2132	
G	35	2105	2135	
G	36	2105	2127	
G	39	2110	2114	
G	41	2119	2116	
G G	44 45	2111 2126	2121 2135	
G	AVERAGE	2092	2108	
	TOTAL AVERAGE	2100		
	AVERAGE			
	TOTAL AVERAGE			

509910

REPORT NO. TABLE 6-35 PAGE

DATE 11/2/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G	9	2123	2223	
G	19	2119	2211	
G	29	2106	2225	
G	39	2123	2233	
	AVERAGE	2182	2212	
	TOTAL AVERAGE	2197		
	AVERAGE			
	TOTAL AVERAGE			

509911

REPORT NO.

TABLE 6-36

PAGE

DATE: 11/2/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H		2321	2340	
H	9	2397	2305	
H	19	Fire	Brick	
H	29	2312	2345	
H	39	2321	2341	
H	49	2339	2332	
H	59	2321	2331	
	AVERAGE	2390	2372	
	TOTAL AVERAGE	2381		
	AVERAGE			
	TOTAL AVERAGE			

509912

DATE: 11/2/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
I		2323	2338	
I	9	2332	2343	
I	19	2343	2337	
I	29	2330	2331	
I	39	2335	2328	
I	49	2328	2338	
I	59	2338	2350	
	AVERAGE	2356	2378	
	TOTAL AVERAGE	2367		
	AVERAGE			
	TOTAL AVERAGE			

509913

REPORT NO.

TABLE 6-38

PAGE

DATE: 11/3/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
G		2120	2221	
G	6	2110	2210	
G	16	2108	2228	
G	26	2111	2233	
G	36	2110	2227	
G	46	2119	2224	
	AVERAGE	2116	2244	
	TOTAL AVERAGE	2180		
	AVERAGE			
	TOTAL AVERAGE			

509914

REPORT NO. TABLE 6-39 PAGE

DATE: 11/3/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE(°F)	COMMENTS
H		2122	2209	
H	6	2132	2236	
H	16	2133	Brick	
H	26	2134	2243	
H	36	2131	2248	
H	46	2129	2235	
H	56	2139	2234	
	AVERAGE	2116	2244	
	TOTAL AVERAGE	2180		
	AVERAGE			
	TOTAL AVERAGE			

509915

REPORT NO.

TABLE 6-40

PAGE

DATE: 11/3/76

COKE OVEN FIELD DATA
HEATER TEMPERATURE

BATTERY #	OVEN #	PUSHER SIDE (°F)	COKE SIDE (°F)	COMMENTS
G	1	2125	2125	
G	4	2116	2119	
G	5	2124	2124	
G	8	2106	2110	
G	9	2115	2107	
G	13	2102	2101	
G	14	1950	2122	
G	17	2106	2120	
G	18	2103	2106	
G	22	1990	2107	
G	23	2118	2107	
G	26	2108	2131	
G	27	2114	2117	
G	31	1750	2101	
G	32	2120	2129	
G	35	2106	2131	
G	36	2106	2126	
G	39	2112	2121	
G	41	2121	2116	
G G	44 45	2110 2126	2119 2138	
G	AVERAGE	2082	2118	
	TOTAL AVERAGE	2100		
	AVERAGE			
	TOTAL AVERAGE			

509916

Date: 9/10/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
5B50	H	16	18 Hrs.	
5B50	H	36	18 Hrs.	
5B50	G	19	24 Hrs.	
5B50	G	29	24 Hrs.	

509917

Date: 9/11/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
6B80	I	56	18 Hrs.	
6B80	G	5	24 Hrs.	
6B80	G	15	24 Hrs.	
6B80	H	8	18 Hrs.	
7C50	G	29	24 Hrs.	
7C50	I	58	18 Hrs.	
7C50	H	1	18 Hrs.	
7C50	H	11	18 Hrs.	
		-D-72-		509918

TABLE 6-43

Date: 9/12/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
8C20	G	15	24 Hrs.	
8C20	G	25	24 Hrs.	
8C20	I	41	18 Hrs.	
8C20	H	51	18 Hrs.	
9C80	I	13	18 Hrs.	
9C80	I	23	18 Hrs.	
9C80	I	33	18 Hrs.	
9C80	G	17	24 Hrs.	
10D50	I	53	18 Hrs.	
10D50	I	63	18 Hrs.	
				509919
		-D-73-		

Date: 9/13/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
11D80	I	55	18 Hrs.	
11D80	I	65	18 Hrs.	
11D80	G	5	24 Hrs.	
11D80	G	15	24 Hrs.	
12D20	G	25	24 Hrs.	
12D20	G	17	24 Hrs.	
12D20	G	27	24 Hrs.	
12D20	G	9	24 Hrs.	
13A50	H	23	24 Hrs.	
13A50	H	64	24 Hrs.	
13A50	H	59	18 Hrs.	
13A50	I	9	18 Hrs.	
		-D-74-		509920

Date: 9/14/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
14A20	H	12	18 Hrs.	
14A20	H	32	18 Hrs.	
14A20	H	42	18 Hrs.	
14A20	G	7	24 Hrs.	
15A80	I	62	18 Hrs.	
15A80	H	4	18 Hrs.	
15A80	H	14	18 Hrs.	
15A80	G	12	24 Hrs.	
				509921
		-D-75-		

TABLE 6-46

Date: 9/15/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
6C5PO	H	16	18 Hrs.	
6C5PO	H	26	18 Hrs.	
6C5PO	H	36	18 Hrs.	
6C5PO	I	6	18 Hrs.	
		-D-76-		509922

REPORT NO. TABLE 6-47 PAGE

Date: 10/5/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
1C81			18 Hrs.	
1C81			18 Hrs.	
1C81	G		24 Hrs.	
1C81	G		24 Hrs.	

509923

YORK RESEARCH

Date: 10/07/76

PROCESS DATA
COKE OVEN

REF. CODE	Battery #	Oven #	Coking Time	Comments
3C21	I	64	18 Hrs.	
3C21	G	23	24 Hrs.	
3C21	G	33	24 Hrs.	
3C21	H	6	18 Hrs.	

509924

Date: 10/29/76

PROCESS DATA
COKE OVEN

REF CODE	Battery #	Oven #	Coking Time	Comments
1B51	G		24 Hrs.	
1B51	G		24 Hrs.	
1B51	G		24 Hrs.	
1B51			18 Hrs.	

509925

Date: 10/30/76

PROCESS DATA
COKE OVEN

REF CODE	Battery #	Oven #	Coking Time	Comments
2B21	G	13	24 Hrs.	
2B21	I	1	18 Hrs.	
2B21	I	11	18 Hrs.	
2B21	I	21	18 Hrs.	
3B81	G	9	24 Hrs.	
3B81	G	39	24 Hrs.	
3B81	H	5	18 Hrs.	
3B81	H	15	18 Hrs.	
				509926
		-D-80-		

Date: 11/01/76

PROCESS DATA
COKE OVEN

REP CODE	Battery #	Oven #	Coking Time	Comments
4D51	H	37	18 Hrs.	
4D51	H	47	18 Hrs.	
4D51	H	57	18 Hrs.	
4D51	G	21	24 Hrs.	
5D21	I	6	18 Hrs.	
5D21	I	16	18 Hrs.	
5D21	I	26	18 Hrs.	
5D21	I	46	18 Hrs.	
6D81	G		24 Hrs.	
6D81	G		24 Hrs.	
6D81	G		24 Hrs.	
6D81			18 Hrs.	
				509927
		-D-81-		

Date: 11/02/76

PROCESS DATA
COKE OVEN

REF CODE	Battery #	Oven #	Coking Time	Comments
7A51	H	57	18 Hrs.	
7A51	G	21	24 Hrs.	
7A51	G	31	24 Hrs.	
7A51	G	41	24 Hrs.	
8A81	I	18	18 Hrs.	
8A81	I	28	18 Hrs.	
8A81	I	38	18 Hrs.	
8A81	I	48	18 Hrs.	
9A21	G	17	24 Hrs.	
9A21	G	27	24 Hrs.	
9A21	H	1	18 Hrs.	
9A21	H	11	18 Hrs.	
		-D-82-		509928

Date: 11/03/76

PROCESS DATA
COKE OVEN

REF CODE	Battery #	Oven #	Coking Time	Comments
10M1	G	31	24 Hrs.	
10M1	G	41	24 Hrs.	
10M1				
10M1		3	24 Hrs.	
11MP1	G	37	24 Hrs.	
11MP1	G	27	24 Hrs.	
11MP1	G		24 Hrs.	
12Mp1	G	17	24 Hrs.	
12MP1	G		24 Hrs.	
12MP1	G		24 Hrs.	
12MP1	H	5	24 Hrs.	
13A5P1			24 Hrs.	
13A5P1	G	2	24 Hrs.	
13A5P1	G		24 Hrs.	
		-D-83-		

509929

APPENDIX E

Project Participants

509930

YRC PROJECT PARTICIPANTS

Field Personnel

H. Laube, Project Manager
J. Jeffery, Project Director
M. Ziskin, Assistant Project Director
J. Griffin, Test Engineer
M. Horowitz, Test Engineer
J. Olsen, Test Engineer
R. Lamothe, Field Chemist
R. Keith, Field Lab Technician
N. Pollock, Test Technician
S. Wahlig, Test Technician
R. Woolrich, Test Technician

Management and Office Personnel

K. Melmed, President
R. Rinehart, Vice-President, Operations
D. Sommerer, Director, Environmental Sciences
R. Egdall, Chief Engineer
B. Ranck, Manager, Systems Analysis and Data Processing
B. Knapp, Computer Analyst
F. McMichaels, Consultant

Lab Personnel

R. Bradley, Manager, Chemical Analytical Services
G. Pantchenko, Principle Chemical Consultant
M. Kozik, Senior Chemist
J. Gale, Senior Chemical Technician
D. Francis, Senior Chemical Technician
R. Knapp, Senior Chemical Technician
D. Raskin, Senior Chemical Technician

509931

APPENDIX F

Instrument Specifications

509932

MODEL DC-1 DROPLET COUNTER

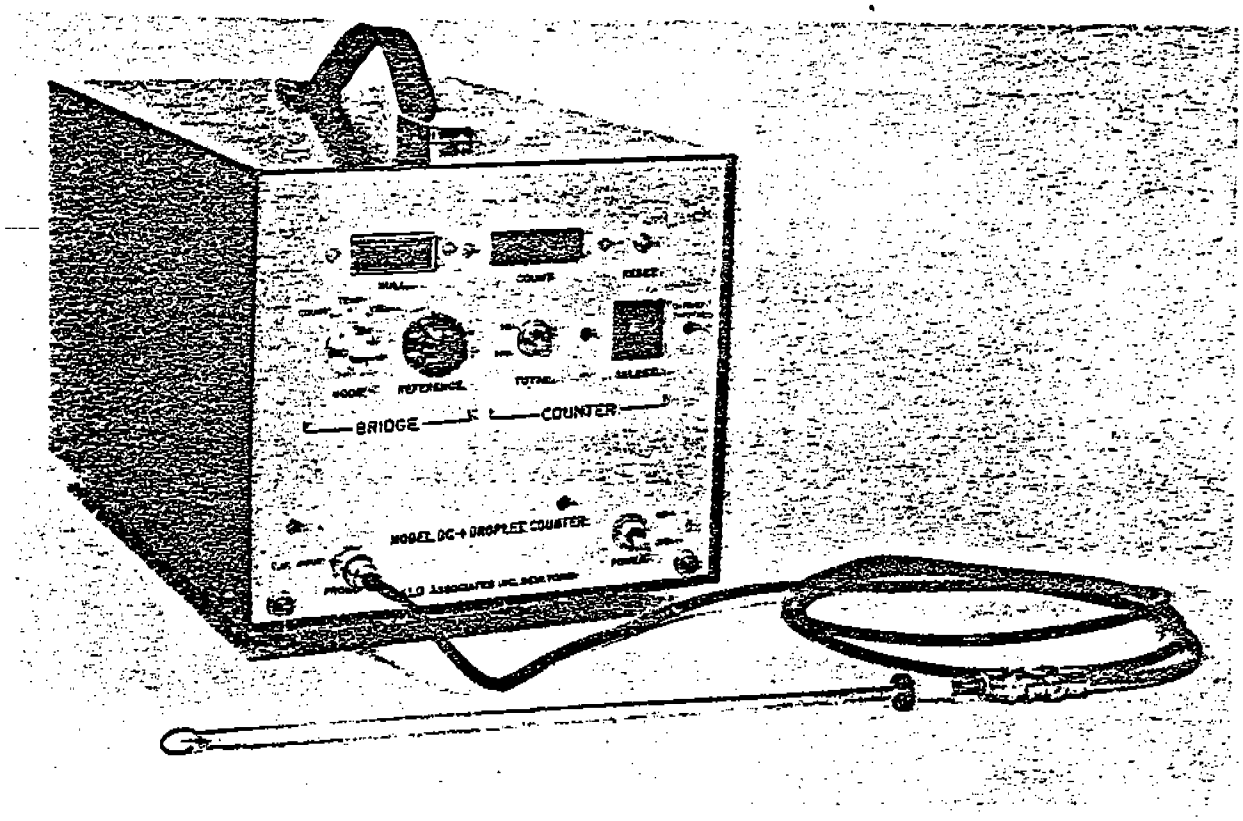
Purpose of the Model DC-1 Droplet Counter

This instrument measures the size and concentration of water droplets present in the stream of scrubbers. Other parameters pertinent to this measurement, such as flow velocity, air temperature and time count interval are also provided.

The result of the droplet counting is displayed in decimal form.

Principle of Operation

The DC-1 uses a hot wire probe to generate pulses for counting the water droplets. Each droplet contacting the probe cools a wire length proportional to the droplet diameter, reducing the wire electrical resistance proportionately. The probe forms one leg of an electric bridge which is unbalanced by this resistance change, thus generating a pulse. An electronic circuit analyses, counts and sorts the pulses. In this manner a drop size distribution is accumulated and displayed.



KLD ASSOCIATES, INC.
7 HIGH STREET, HUNTINGTON, N. Y. 11743
516-549-9803

OVER

509933

MODEL DC-1 DROPLET COUNTER

Specifications

- Drop Material: Aqueous solutions - DC-1 discriminates between liquids and solids.
- Droplet Size: 1 micron to 600 microns.
- Count Rate: Up to 500 counts/sec.
- Number of Droplet Bins: 6 plus 1 TOTAL bin.
- Sample Total: 99 or 999 (operator select).
- Sample Time Interval Measured: To 99.9 sec.
- Time Interval Resolution: 0.1 sec.
- Flow Velocity: Up to 3 meters/sec.
- Flow (Probe Ambient) Temperature: 0°C to 100°C.
- Count Mode: To predetermined sample total or 99.9 seconds, whichever comes first.
- Operating Modes: Droplet Counting, Flow or Ambient Temperature, Flow Velocity.
- Display: Three decimal digits, LED Multiplexed display of:
  6 size bins (independently stored data)
  1 total bin (independently stored data)
  1 time interval (independently stored data)
- Power: 60 Hz., single phase, 3 wire, 115 V AC, 12 watts.
- Processor Dimensions: 190 mm high
  200 mm wide
  310 mm deep
- Probe Dimensions: 350 mm long
  6 mm diameter
  Sensor wire: 1 mm long
  5 microns diameter
- Processor Weight: 6 Kgm
- Environment:

Processor
Temp: 10° to 50°C
Humidity: to 95% @ 40°C
Altitude: to 15,000 meters

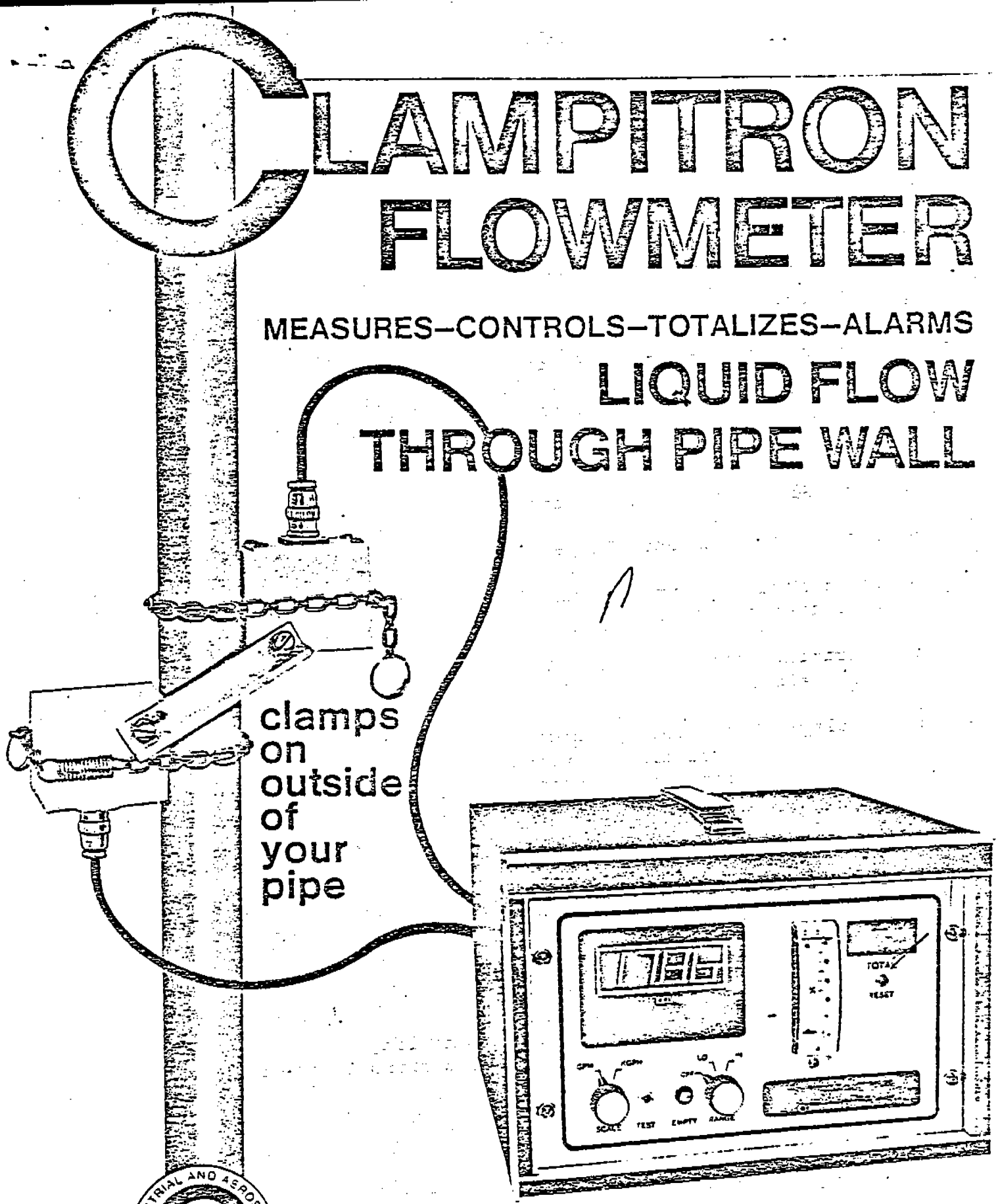
Probe
Temp: 0° to 100°C
Humidity: to saturated conditions
Altitude: to 25,000 meters

509934

CLAMPITRON FLOWMETER

MEASURES–CONTROLS–TOTALIZES–ALARMS

LIQUID FLOW THROUGH PIPE WALL



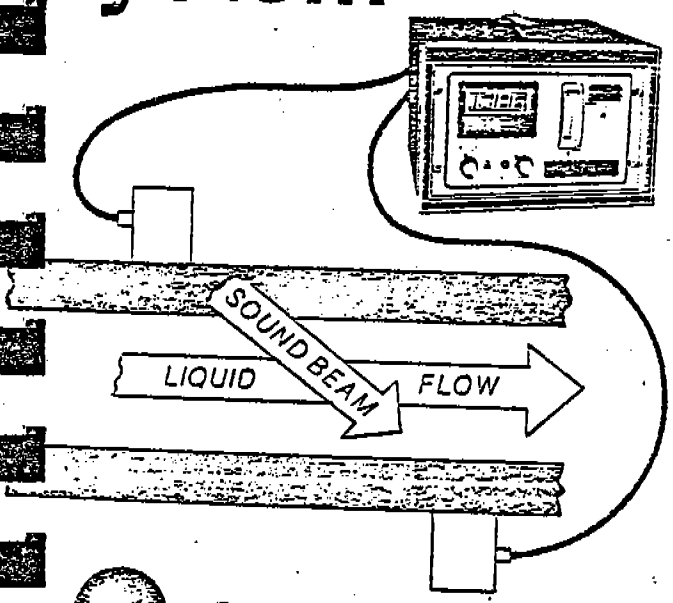
INDUSTRIAL AND AEROSPACE CONTROL SYSTEMS

CONTROLOTRON CORPORATION

111 BELL STREET, WEST BABYLON, L.I., NEW YORK 11704 • (516) 249-4400

509935

series 240 flow measurement system



features

1. TRANSDUCER CLAMPS OUTSIDE PIPE
   - No Contact with Liquid
   - No Cutting of Pipe
   - 1" to 60" Pipes Standard
   - No Pipe Obstruction
   - No Pipe Pressure Drop
   - No Installation Shutdown
   - No Moving Parts
   - No Corrosion—Sanitary
2. ALL FLOW FUNCTIONS
   - Display, Control, Alarm, Totalization
   - Computer/Recorder Interface
3. EXCELLENT PERFORMANCE FEATURES
   - Accuracy to 1%
   - Rangeability from .001 to 30'/sec.
   - Factory Calibrated
   - Built-in Fault Alarm/Test
   - Insensitive to Pipe Noise
4. WIDE RANGE OF MODELS
   - Portable, Weatherproof, Explosionproof, Rack Mount
   - Full line of Remote Displays/Controls
5. ECONOMICAL
   - Fast simple installation
   - Quickly moved to different locations

principle of operation

On command from the Series 241 Flow Display Computer, the Series 240 Transducer transmits a beam of ultrasonic sound through the pipe wall, through the liquid, and into the receive transducer after passing through the second pipe wall. While passing through the liquid, the beam velocity is increased (or decreased) proportional to the velocity of liquid flow.

The received signal is analyzed by the 241 Flow Display Computer which computes the absolute value of flow in GPM or GPH (etc.) to a flow resolution as high as .001'/sec. The Flow Display Computer automatically calibrates itself for variations in the velocity of sound of the liquid, and is effectively independent of the attenuation of sound in the liquid provided a minimum signal amplitude is received, a condition met by essentially all homogeneous liquids.

description

The Series 240 Flowmeter System (Patents Pending) offers the unique advantage of sensing liquid flow from outside the pipe. It also provides all the flow functions (digital/analog display, control, alarm, totalization and computer/recorder interface) that could be required in any flow sensing application. The Series 240 is not merely a device, but rather a full line system offering standard hardware for a wide range of applications and environments including portable, weatherproof, explosionproof and rack mount equipment. It also includes a full complement of remote display and control accessories plus outputs for standard controllers and recorders.

The Series 240 can be installed in minutes by non-technical personnel, on existing pipes without shutdown or flow calibration. Its operation is independent of liquid temperature, density or corrosivity and depends merely on the ability of the liquid to pass ultrasonic sound without excessive attenuation—a property of essentially all homogeneous liquids. Where doubt exists, Controlotron will test a 16 ounce sample of liquid at no charge and, if approved, offers a full Guarantee against Misapplication (see page 2).

All computer circuits utilize highly reliable integrated circuits located on easily replaced printed circuit plug-in modules. A built-in fault alarm automatically signals any improper operation and an accessible test connector permits fast identification of a defective module. A complete line of test equipment simplifies operational test and maintenance.

509936

series 240 transducers

Series 240 transducers are specified for a particular pipe size (O.D.), schedule (wall thickness) and pipe material and in general will operate properly only with the specified pipe. They are supplied with integral mounting clamps and spacer bars which assure simple mounting in the precise location required for each application without need for special tools or spacing measurements. No special pipe preparation is required other than removal of rust and scale.

240 Transducers are completely sealed and contain no moving parts. They may be specified for Nema 4 environments, with condulet and barrier terminals, or for portable use with BNC quick mating connectors. All models are intrinsically safe for Class I Group D areas, including hydrogen atmosphere. They mount up to 500 ft. from Series 241 Flow Display Computers.

series 241 flow display computers

Series 241 Flow Display Computers control transmission of ultrasonic signals into the pipe and extract the flow information from the transducer output signal using state of the art digital computer techniques developed by Controlotron. Flow is displayed digitally in GPM or GPH with both analog display and totalizer display optionally available.

241 models are specified for a particular pipe size, schedule and pipe material in the same way as 240 transducers, and will operate properly only when connected to the transducer specified for the same pipe. They are available in portable (241P), Nema 4 (241N), explosion proof (241E) (Class I, Group D) and rack mount (241R) configurations. Also available is a multi-pipe size model (241MP), which operates over a specified group of pipe sizes by use of a series 243 plug-in adapter, and the appropriate transducer, for each pipe in its group.

functions: STANDARD DIGITAL DISPLAY*

All 241 Flow Display Computers offer 3½ digit flow display in selectable units (GPM or GPH). Auto ranging places the display decimal point automatically to cover flow rates from 0 to over 30'/sec. with a resolution of up to 1 part in 20,000 (.005%). Parallel BCD output available on 241N, 241R and 241E (Add "D" to P/N).

OPTIONS*

ANALOG DISPLAY PACKAGE: The integral Analog Display option includes settable Hi and Lo flow alarm with remote output, plus 0-10 volt and 4 to 20 ma proportional control outputs. The vertical scale display can be set to 100% for flow rates as low as 1'/sec., automatically scaling the proportional outputs to 10 volts and 20 ma.

TOTALIZER: The totalizer option includes integral 6 digit electro-mechanical display, locally or remotely resettable, plus serial pulse output for remote 242-5 units. It normally resolves the second least significant digit on the digital display Hi range (1 gallon in a 1" pipe) but can resolve 1/10 this quantity when the totalizer is set in the "Fastot" condition. A separate "Tentot" output with ten times greater resolution (1/10 and 1/100 gallon in 1" pipes respectively) is also provided for driving electronic registers.

features: Included in all 241 Flow Display Computers are:

1. Accessible Zero & Scale Adjustment.
2. Plug-in Flow profile (Reynolds Number) Compensator ($N_R = 10^4$ Standard)
3. Manual "HiRange" Selector.
4. GPM/GPH Scale Selector.
5. Settable "Empty Pipe Indicator" to shut down 241 operation and provide alarm if pipe empties.
6. Automatic "Fault Alarm" Indicator to alarm and shut down 241 operation if basic flow sensing is not operating properly.
7. Self Test Button permits quick test of all flow display functions.
8. Integral Test Connector permits operational check of all 241 computer modules plus connection to field test and calibration equipment.
9. Plug-in Modular Construction permits fast replacement of any defective module to restore field operation in minutes.

*Consult factory for option availability on portable and explosion proof models.

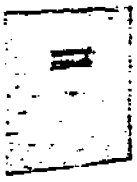
series 242 remote accessories

Series242 Remote Accessories provide flow display and control at locations remote from the 241 Flow Display Computer in Nema 4 or panel mount for factory, field or instrument room locations.

242-2 Hi/Lo Flow Alarm Relay: Provides 5 amp on-off control of pumps, valves or alarms.

242-3 Remote Digital Display: Repeats 241 Flow Display reading remotely.

242-4 Remote Analog Display: Repeats 241 Analog Display & Hi/Lo flow alarm settings remotely.



242-5 Remote Totalizer: Provides remote 6 digit totalization with common or independent reset.

242-5P Remote Presettable Totalizer: Provides 2 amp relay contact to shut down flow at presettable total flow quantity.

242-6 Four Transducer Selector Switch: Enables monitoring flow in four identical pipes.

BCD Converters:

242-7S converts 241 BCD output to serial pulse for transmission. **242-7R** reconverts at receive end

509925

application information

1. LIQUIDS The Series 240 Clampitron Flowmeter is intended primarily for homogeneous, non-aerated liquids without undissolved solids. Liquids containing solids may be approved on submission of a 16 oz. test sample accompanied by Liquid Submission Form 240-LT.

TYPICAL LIQUIDS

water	acids	coolants	chemicals
oil	sewage	milk	seawater
gasoline	paper pulp	glue	cryogens

2. PIPES 240 equipment can be used only on the exact pipe size, schedule and material for which it was specified. If pipe is not American Standard, or is of unknown origin, a section of pipe wall (8" x 2" for pipes over 2" O.D.) must be submitted for test prior to delivery of equipment. Lined pipe must be tested prior to system quotation. In general, pipes subject to internal coating or corrosion should be avoided except if tested and approved by Controlotron.

3. APPLICATION REVIEW Controlotron maintains a complete application review service. For assistance, request and submit Application Information Form 240-A. Equipment purchased on the basis of Controlotron liquid and pipe test and/or specific approval is Guaranteed Against Misapplication in accordance with conditions specified on quotation.

Installation at locations of fully developed flow is recommended to minimize flow profile effects. It is essential that pipe fittings be sufficiently tight to exclude incursion of air into line and that recirculation tanks have their returns made under liquid surface to avoid aeration. Similarly, cavitation conditions at the 240 transducer location should be avoided. Field service personnel are available to evaluate applications at firsthand.

*application guarantee

In the event that within 30 days after receipt a 240 system is reported not operating as specified on applicable quotation, when used under approved installation conditions, Controlotron will accept return at full credit, provided Controlotron personnel cannot correct operation on customer approved visit.

Warranty

Series 240 equipment is warranteed against intrinsic defects for a period of one year from date of shipment.

CONTROLOTRON CORPORATION

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240 CLAMPITRON FLOWMETER VAALER AWARD CONTROLOTRON

other Controlotro equipment

- Series 200
  Liquid Level Control
- Series 205
  Liquid Level Control
- Series 210
  Liquid Level Controls
- Series 215
  Liquid Level Controls
- Series 230
  Liquid Level Controls
- Series 260
  Liquid Level Indicator
- Series 290
  Liquid Level Indicator

240 CLAMPITRON FLOWMETER PUTNAM AWARD CONTROLOTRON

509938

systems options

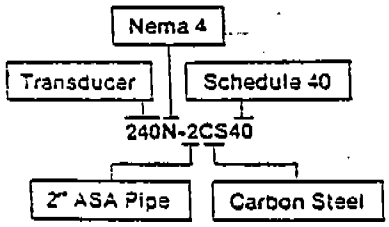
how to order:

1. Select system compatible with application environment from Chart A:
2. Select system components from Charts B & C. Choose part number to identify desired construction & optional features.

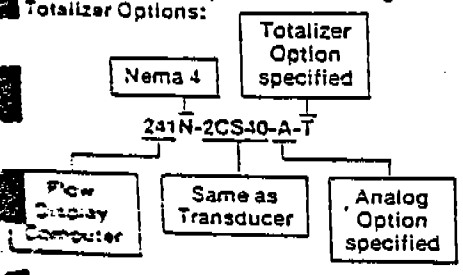
Example:

A. Pick System 2 from Chart A: Nema 4 System.

B. Pick Transducer & Flow Display Computer from Charts B & C respectively.

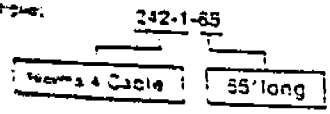


Flow Display Computer with Analog & Totalizer Options:

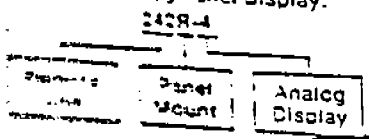


Select desired accessories from Chart D.

Example:



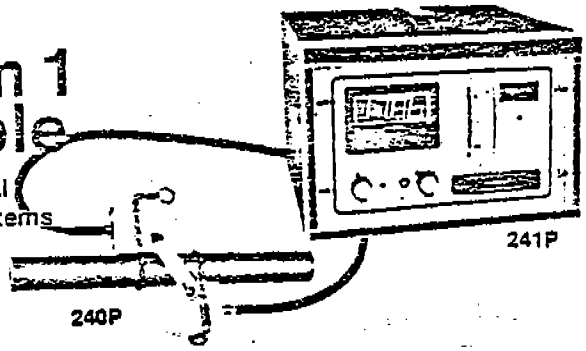
Remote Analog Panel Display:



Select desired test accessories from Chart E.

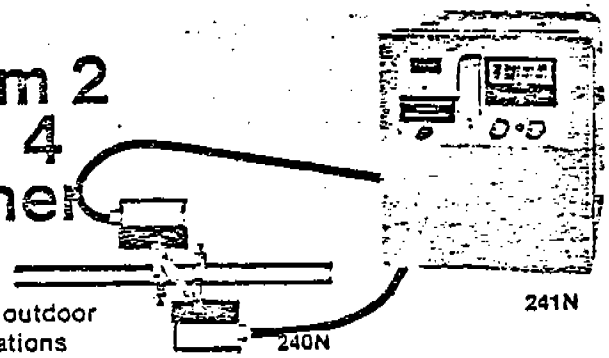
system 1 portable

Most economical for survey of systems of one pipe size



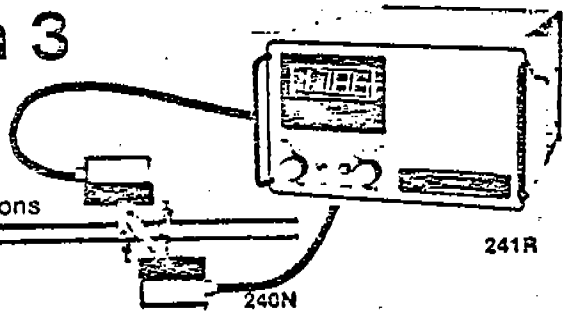
system 2 nema 4 weather proof

Use in plant or outdoor fixed installations



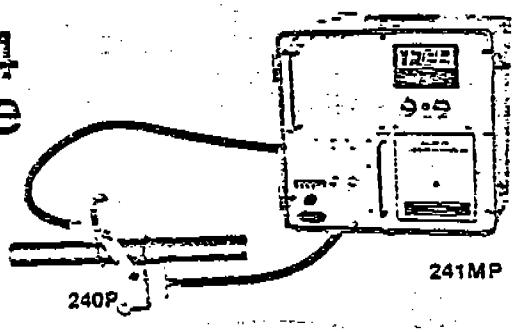
system 3 panel mount

For fixed installations with control panel



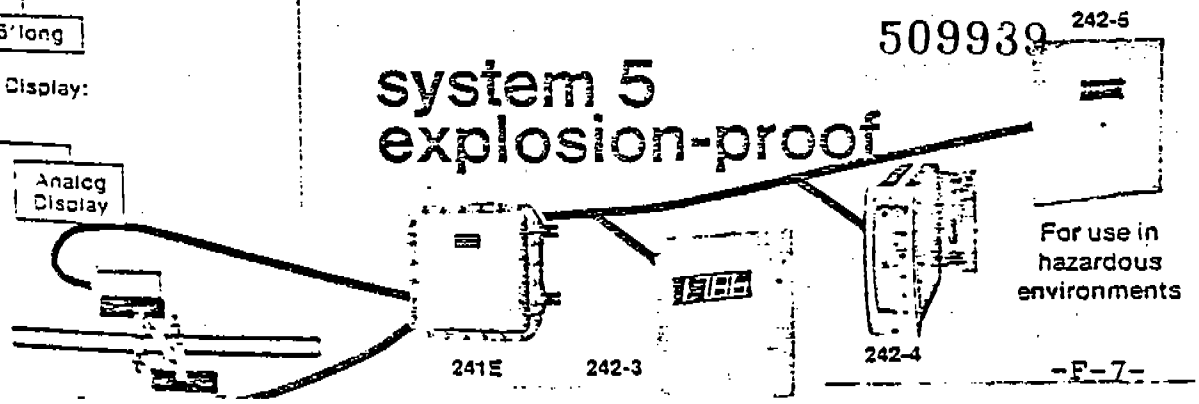
system 4 multipipe portable

For survey of systems of various pipe sizes. Specify pipe sizes required.



509939

system 5 explosion-proof



For use in hazardous environments

transducer options: chart B

ITEM	PART NUMBER	DESCRIPTION
Portable Transducer	240P- 20"	A: Your pipe size in inches, if ASA B36.10 pipe. All others specify OD in decimal inches.
Nema 4 Transducer	240N-	B: Your pipe material: (A) aluminum; (CS) carbon steel: (SS) stainless steel; (P) PVC; (G) glass; (B) brass; (C) copper. Request other material designations.
		C: Wall thickness or schedule. Use schedule # for ASA B36.10 pipe. All others, specify wall in decimal inches. Submission of sample of pipe will help insure highest possible accuracy.

flow display computer options: chart C

ITEM	PART NUMBER	DESCRIPTION
Portable	241P-	Provides operation of 240 Transducers & flow computation, plus 3½ digit flow display visible at 40' distance. Display shows flow direction and is selectable for GPM or GPH units. Also included are Self-test Switch, Fault Monitor Lamp, Test Connector, Flow Profile Compensator, Zero and Scale Adjustments.
Nema 4	241N-	
Explosion Proof	241E-	
Panel Mount	241R-	
Multipipe Portable	241MP-	
Plug-in Adapters	243- 20"	

A B C — A T

Specify to match Transducer in Chart B

Analog Option (Integral): If desired (add "A" to P/N) Includes 0-100% vertical scale display, settable Hi & Lo flow alarms, 0-10V & 4-20 ma proportional control outputs. Required if remote analog display is specified.

Totalizer Option (Integral): If desired (add "T" to P/N) Includes 6 digit display resolving second LSD on Digital Display Hi scale with local or remote reset and electronic output for main and high resolution (10x) outputs. Has "Fastot" switch for increase of resolution by additional factor of 10. Required if remote totalizer is specified.

N — A T AS ABOVE

Substitute group # desired for "N" from chart below. Then specify 243 plug-in for each transducer ordered in this group. #1 = 1" to 4"; #2 = 5" to 12"; #3 = 14" to 22"; #4 = 24" to 36"; #5 = 38" to 60". 5" to 22"

A B C

Specify to match Transducer in Chart B

Scales 241MP for each pipe to be monitored within applicable group pipe size range.

-509940

242 remote accessories: chart D

ITEM	PART NUMBER	DESCRIPTION
Transducer Cable	242-1-L Nema 4 242-1P-L Portable	Cable for 240N or 240P Transducers. One set of two required per system. Replace L by length in feet up to 500'. (Request approval over 100')
Hi/Lo Flow Relay	242-2 Nema 4	Dual 5 amp DPDT Relay with 1 second time delay in Nema 4 case. Operates from Hi-Lo Alarm signal from 241 Flow Display Computer.
Digital Display	242R-3 Panel Mount 242N-3 Nema 4	Repeats Flow Display up to 3000 feet from 241 Flow Display Computer. Use 242-7 for minimum wiring. Specify 241 BCD output (add "D" to 241 P/N).
Analog Display	242R-4 Panel Mount 242N-4 Nema 4	Repeats Analog Display up to 3000 feet from 241 Flow Display Computer. 242R-4 includes settable Hi/Lo Flow Alarm. Specify Analog option on 241.
Totalizer	242R-5 Panel Mount 242N-5 Nema 4	Repeats Totalizer Display up to 3000 feet from 241 Flow Display Computer. Has common or separate reset capability. Specify Totalizer option of 241.
Presettable Totalizer	242R-5P Panel Mount 242N-5P Nema 4	Enables preset of desired flow quantity with automatic shutdown of flow. 2 amp relay contact provided. Specify Totalizer option on 241.
Four Transducer Switch	242-6	Enables manual selection of any of four identical 240 Transducers to a 241 Flow Display Computer.
BCD Converter	242-7S 242-7R	Converts 241 Flow Display Computer BCD output to TTL compatible serial pulse (and vice versa) for computer and remote display use. Specify 241 BCD option.

244 test accessories: chart E

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ITEM	PART NUMBER	DESCRIPTION
Pipe Simulator	244-1	Enables operation and test of 241 system without need for pipe or liquid.
Transducer Tester	244-2	Enables bench test of 240 Transducers.
Flowmeter Calibrator	244-3	Enables field calibration and test of 241 Flow Display

240 transducer specification

Temperature:
-40°F to +250°F: (Standard)
(No Frost or Gas Vapors in Pipe)
Cryogenic Temperatures up to +1000°F:
(Special Order)

Pipe Noise/Shock:
Insensitive to 120 db noise/20g shock

Construction:
Epoxy potted plastic and aluminum:
(Standard)
Epoxy paint and stainless steel:
(Special Order)

240N:
Condulet Fitting: Waterproof, weather-proof, oiltight. Clamp mount.

240P:
Quick Disconnect: Weatherproof if connector caps are used. Spring mount.

Rating:
Intrinsically safe.

Pipe Sizes:
1" to 60": Standard. Advise material, diameter and wall thickness.
Below 1" and above 60": (Special Order)
Lined pipe, cement pipe or open stream:
(Special Order)

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241 flow display computer specificatio

PERFORMANCE

Zero Stability	.05% of FS (Hi range)
Linearity	1% of reading above 1 fps.
Accuracy*	Quoted per application on request
Intrinsic Calibration:	1-4% of range (typical)
Actual flow Calibration:	0.5-1.5% of range (typical)
Repeatability	±3 digits s.d.
Flow Range	0 to 30 ft/sec (minimum)
Digital Display Resolution	20,000 digits (two ranges)
Digital Display Update Interval	4 seconds
Analog Update Interval	0.1 sec (nom) Faster update on special orc
Totalizer Update Rate	Continuous (Real Time)
Liquid Characteristics Standard:	Homogeneous. No undissolved solids or gases, V_L from 900 to 2100 m/sec.
Approval Required:	Non-homogeneous liquids or undissolved solids in liquid

*For nominal pipe size, wall thickness, in specified pipe material and for homogeneous non-aerated liquids.

ENVIRONMENT

Temperature	-20°F to +100°F (Hi-temp unit available)
Vibration/Shock	Suitable for portable and factory use

CONSTRUCTION

241P, 241R	Nema 1 (Portable/ Rackmount-indoor use)
241N	Nema 4 (Outdoor or Factory—wall mount)
241E	Class I, Group D (Explosion proof—indoor/outdoor)
241MP	Gasket Sealed (Multisize portable—indoor/outdoor)

POWER

241P, 241MP, 241R	70 watts
241N, 241E	115V, 50/60 Hz 115/230V, 50/60 Hz

We invite your inquiry on special requirements or updated specifications.

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