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Plume Parameters and Particulate Emissions from the By-Product Coke Oven Pushing Operation

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Introduction

A total of 66 coke oven pushing plumes have been sampled using a specially designed mobile laboratory for characterizing the plume parameters of temperature, velocity, shape, and particulate emission. An earlier publication by this author[1] reported on the first 15 samples while this work concentrates on the complete sample set of 66. This paper will be helpful to those involved in the quantification and control of coke oven pushing emissions and the design of fugitive emission sampling techniques.

Measurement Methodology

The pushing emission can be classified as a "fugitive emission" of sorts in that it does not emanate from a confined conduit or stack. As such, quantification of the particulate emissions has a "high degree of difficulty" and requires a special experimental design. The basic approach in this study was to place sampling nozzles and sensors for temperature and velocity in a stationary plane in the plume over the duration of the push. Meandering of the plume around the sampling nozzle caused by atmospheric motion reduced the biasing effect of large variations in plume parameters. Figure 1 contains a cross-section view of the sampling apparatus aligned adjacent to the coke oven. Note the mobility of the apparatus and freedom of any supports from the coke oven structure itself. This provided for unrestricted movement of the sampling laboratory and no interference with the coke oven production schedule. The sampling nozzle and instrumentation were at the elevation of the top of the coke guide and positioned approximately over the center of the quench car.

Temperatures were measured with two iron/constantan thermocouples at the end of the boom. A cup anemometer provided plume velocities and particulate samples were taken at a rate of approximately 43 scfm through

8 x 10 inch glass fiber filters.

Cross-sectional plume shape was determined by taking 16 mm black and white motion pictures in two planes over the duration of each push. Subsequent stop-action projector analysis yielded plume cross-sectional dimensions. The camera set-up is shown in Figure 2. Since the motion picture camera frame rate was calibrated, plume velocities could be checked by use of a stop watch. In addition, the gas sample volume was easily corrected for those instances where the sampling nozzle was not in the plume by examination of the film.

The particulate concentration was determined by drawing a gas sample at an approximate rate of 43 scfm through a 8 x 10 inch glass fiber filter. The gas sample volume was determined with an orifice plate and the sampling rate was controlled from within the vehicle to achieve an isokinetic rate as a function of the anemometer readout. The reader is referred to the primary author for specific hardware details. Knowing the weight of coal charged to each furance, an emission factor was subsequently computed for each push.

Results and Discussion

Plume Temperature

Fifteen of the 66 pushes sampled were taken in December and the remaining in April. Since the steel mill was located in Northwest Indiana, ambient temperatures were significantly different in each of these seasons. The December ambient temperatures were close to 0^{o} F and the April temperatures were close to 40^{o} F. This difference in temperature is partially reflected in average plume temperatures seen in Table 1.

Table 1

Coke Oven Push Plume Temperatures °F

	No. of Samples	Average	Range	One Standard Deviation
DECEMBER				
GREEN	7	157	81-309	77
CLEAN	8	89	77-108	11
OVERALL	15	121	77-309	62
APRIL				
GREEN	33	232	109-534	101
CLEAN	18	117	71-167	25
OVERALL	51	191	71-534	99

Note from Table 1 that the green push plume temperaturesare about twice that of the clean pushes regardless of the season. This is a result of the incomplete combustion of the remaining volatiles in the green push coke and the attendant flames. Also, the range of plume temperatures is quite wide from 71 F to 534 F as is probably expected but it is interesting to note that the clean pushes have a significantly lower standard deviation value as compared to green pushes. The December and April standard deviations were 11 and 25 F for the clean pushes respectively and 77 and 101 for the green pushes. Apparently, the clean push plume temperature is more closely related to the coke temperature which is relatively constant from push to push as compared to a green push whose temperature is probably more closely related to the amount of flame in the plume which can vary greatly from one green push to another.

The temperature-time history characteristic curve would be of interest to those designing capture hoods or other control devices. Figure 3 contains a plot of the three highest temperatures recorded over the 66 pushes sampled. Note that the maximum temperature was 534 F and corresponds to a green push. The average rate of increase in temperature for the three temperature curves in Figure 3 was 4 ^{o}F/sec with the maximum occurring about 40% of the total time into the push.

Plume Velocity

The buoyancy of the push plumes result in a vertical velocity which was measured with a cup anomometer whose cups were located in a vertical plane. Table 2 below contains the average statistics:

Table 2
Push Plume Velocity, ft/sec

	No. of Samples	Plume Average	Velocity Range	One Standard Deviation
Green	40	15.7	6.8-21.3	3.9
Clean	26	14.1	6.2-20.9	3.3
Overall	66	15.0	6.2-21.3	3.7

From Table 2 it is seen that the average and range of plume velocities are not greatly different for the clean or green pushes. Note also that one standard deviation about the average value is not exceptionally large and reflects the relatively consistent plume velocity from push to push. The overall range, however, is quite wide from 6.2 to 21.3 ft/sec; a 3.5 to 1 change.

Figure 4 shows a typical green push velocity-time history plot. Note the erratic nature of the trace reflecting the billowing nature of the plume. Also, the peak velocities occur about 15 seconds in the push, are sustained for 15 seconds and decay in about one-half the time it took to reach peak velocity.

Plume Cross-Sectional Shape

Analysis of the two motion picture film records which were shct at approximately 90^{0} to one another (Refer once again to Figure 2) allowed the plume crossectional shape to be defined. The procedure involved the use of a stop action projector and measuring the plume width frame-by-frame for each 90^{0} view. Table 3 shows the resulting plume dimensions.

Table 3

Plume Cross-Sectional Shape

	Plume Shape, ft. Average	Range	One Standard Deviation
Length "A"			
	18.2	10-29	3.8
Length "B"			
	17.8	10-31	5.6
Overall	18.0	10-31	4.7
Ratio of "A"/"B"	1.02	1.0-0.94	0.3

Note that the two diameters are very nearly equal with a ratio of 1.02. This indicates that a circular plume cross-sectional area is a reasonable model to use for estimation of the emission parameters.

From Tables 2 and 3 the plume volumetric flow rate can be estimated on an average basis. Table 4 shows the plume actual volumetric flow rate as calculated from the statistics in Tables 2 and 3.

Table 4

Plume Actual Volumetric Flow Rate

	ft^3/min
Average	229,000
One Standard Deviation about the average	94,000-454,000
Observed overall range	61,000-920,000

Table 4 indicates the average volumetric flow rate to be 229,000 actual

ft^3/min. Using one standard deviation value to both reduce and increase the plume diameter and velocity a one standard deviation range on volumetric flow rate was calculated. This range as seen in Table 5 is 94,000 to 454,000 actual ft^3/min. The observed minimum and maximum values are also shown in Table 4.

These volumetric flow rates are of interest to those involved in the design of control hardware and yield an estimate of gas flow rate that must be handled. However, keep in mind that these measurements were made in the open atmosphere where gaseous and particulate diffusion is relatively unlimited. If the control hardware confines the push plume, significantly lower plume volumes will probably result. One reason for this is the restruction on plume diffusion and dilution. For green pushes, a confined duct limits the amount of oxygen available to the remaining coal volatiles thus inhibiting combustion and therefore temperatures which results in lower volumetric flow rates.

Particulate Emissions

The concentration of particulates measured in the push plume is seen in Table 5.

Table 5

Push Plume Total Particulate Concentration*

	No. of Samples	Range grams/m^3	Average grams/m^3	One Standard Deviation grams/m^3
Green	39	0.22-16.0	3.3	2.9
Clean	25	0.07-5.0	1.8	1.2
Overall	64	0.07-16.0	2.7	2.5

*per standard conditions of 70 F, 1 atm.

As expected, the green pushes have a significantly higher particulate concentration relative to a clean push. The green pushes were 3.3 grams/m^3 as compared to 1.8 for clean. Note the large standard deviation for both the green and clean pushes. The coefficient of variation (average ÷ std. dev. x 100) for green and clean pushes is 88% and 67% respectively.

Emission rates and factors of total particulates are shown in Table 6. The emission factors are based on steel mill records of coal charged for each push sampled and indicated an average oven charge of 30,000 lb-coal.

Table 6

Summary of Mass Emission Rates and Emission Factors for Total Particulates

	No. of Samples	Range	Average	One Standard Deviation
Mass Emission Rate (grams/sec)				
Green	39	21-1495	382	335
Clean	25	11-377	138	79
Overall	64	11-1495	287	291
Emission Factor (lb/ton-coal)				
Green	39	0.09-9.0	2.0	1.9
Clean	25	0.05-2.0	0.7	0.4
Overall	64	0.05-9.0	1.5	1.6

In an earlier paper[1], the average mass emission rate of the first 15 December samples was reported. The values were 407 grams/sec for green pushes and 147 grams/sec for clean pushes. It is interesting to note that these values compare favorably with those reported for the total sample set of 64. In other words, the initial 15 samples when reported were reasonably representative of the larger sample mean composed of many more samples.

The emission factors expressed as lb-part./ton-coal charged range from 0.05 to 9.0, a change of 180 to 1. This is a relatively wide variation and is reflected in the large standard deviation values. The resulting "coefficient of variation" for green and clean pushes is 95% and 57% respectively. This indicates the clean push emission factors are not quite as variable as the green pushes and reflects the degree of flame and remaining volatiles in green push.

The average emission factors are of interest and were 0.7 lb/ton for the clean pushes and 2.0 lb/ton for the green pushes. The overall value was 1.5 lb/ton. The emission factor reported in "AP-42" for total particulates[2] for coke "discharging" is 0.6 lb-part./ton-coal charged.

The distinguishing feature of the emission factors is the wide variability. However, whether or not one will experience a green or clean push appears to be directly related to the individual coke oven. In this sampling program, the same ovens were repeatedly sampled. Upon analysis of the data it appeared that a specific oven would either yield a clean push or a green push. Table 7 contains a listing of the ovens that were sampled three or more times and how many of the samples were classified clean or green.

Table 7

Characterization of Coke Push Plumes by Individual Ovens

Oven Number	No. of Times Sampled	No. of Green Plumes	No. of Clean Plumes
49	5	0	5
52	3	0	3
54	4	1	3
57	5	4	1
59	5	5	0
62	4	4	0
64	4	0	4
67	3	3	0
69	5	5	0
72	4	4	0

It is interesting to note that ovens #49, 52, 54 and 64 were sampled 16 times and all were clean pushes except one. This contrasts to the record of ovens #57, 59, 62, 67, 69 and 72 which were sampled a total of 26 times. Of these, all were green pushes except one. These results suggest that a clean or green push is a function of the oven from which it came. It may be related to the condition of the internal heat transfer surfaces and to the time between rebuilds. It should be stated that no correlation whatsoever was found between the coking times and the particulate emission factors.

Summary and Conclusions

For the 66 coke pushing plumes sampled the overall average parameters observed were:

1)	temperature	121 F
2)	velocity;	15 ft/sec
3)	shape	circular w/ratio front to side = 1.02
4)	volumetric flow rate;	229,000 ACFM
5)	particulate concentration;	2.7 grams/m^3
6)	particulate emission rate;	287 grams/sec
7)	particulate emission factor;	1.5 lb/ton coal charged

Specific significant differences were measured for green and clean pushes. Generally, green pushes were greater in all of the above parameters by at least 2 to 1 except the velocity which was approximately the same. The one dominant facit regarding all of the pushes sampled was the wide variability in plume parameters not only between green and clean but within each of these categories. One standard deviation values expressed as a percentage of the mean value approached 100% in some cases.

The data suggested that a green or clean push is a strong function of the oven from which it came. Repeated sampling of the same ovens showed a trend that some ovens produce consistently clean pushes while others yield green pushes. Oven maintenance and condition may be the important factor here.

References

1. R. B. Jacko, D. W. Neuendorf and J. R. Blandford, "The By-Product Coke Oven Pushing Operation: Total and Trace Metal Particulate Emissions", APCA paper no. 76-12-2 Portland, Oregon, 1976.

2. "Compilation of Air Pollutant Emission Factors", U.S. EPA, 2nd edition, 1973.

Acknowledgments

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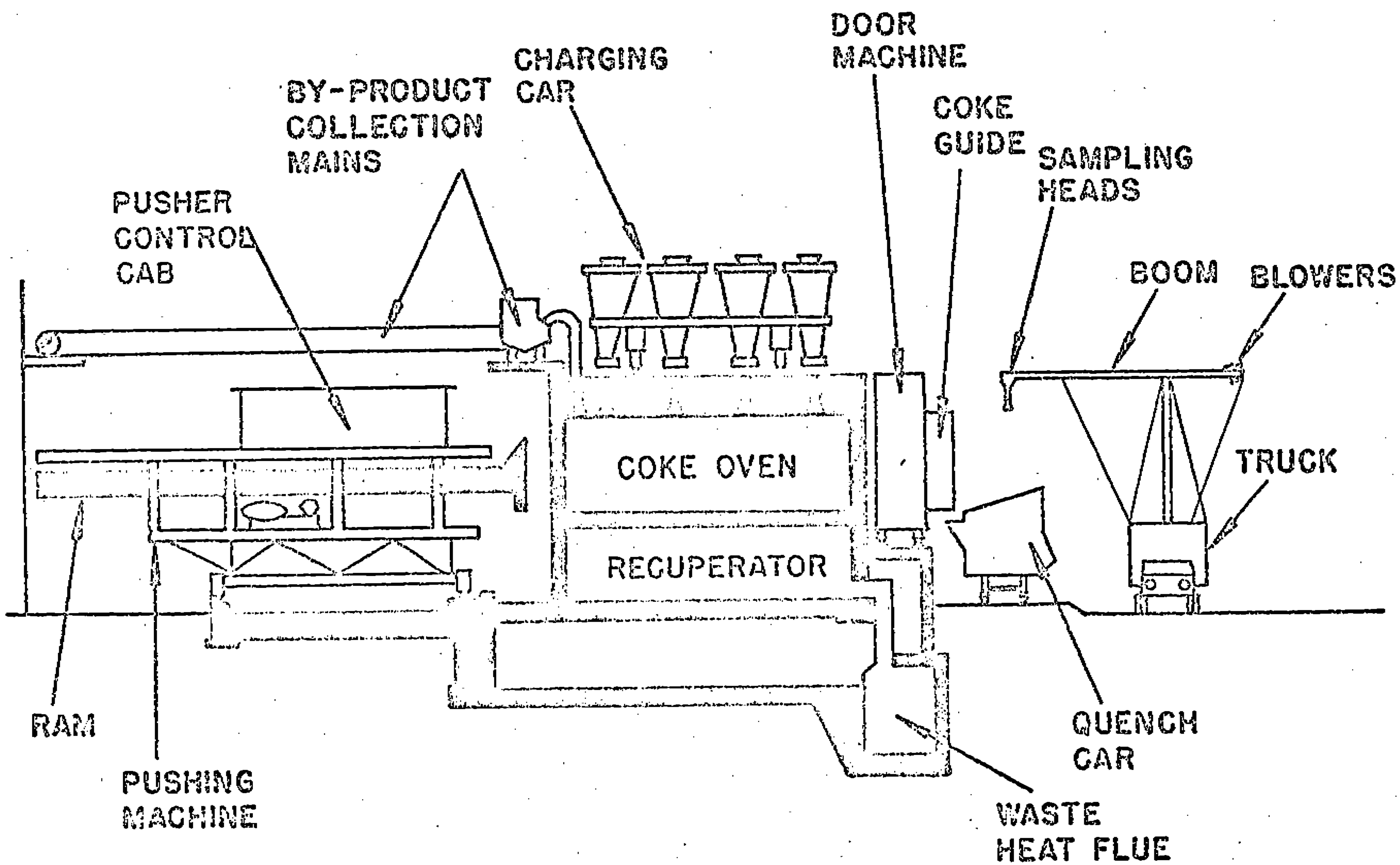

Figure 1 VIEW OF COKE OVEN AND SAMPLING VEHICLE PLACEMENT

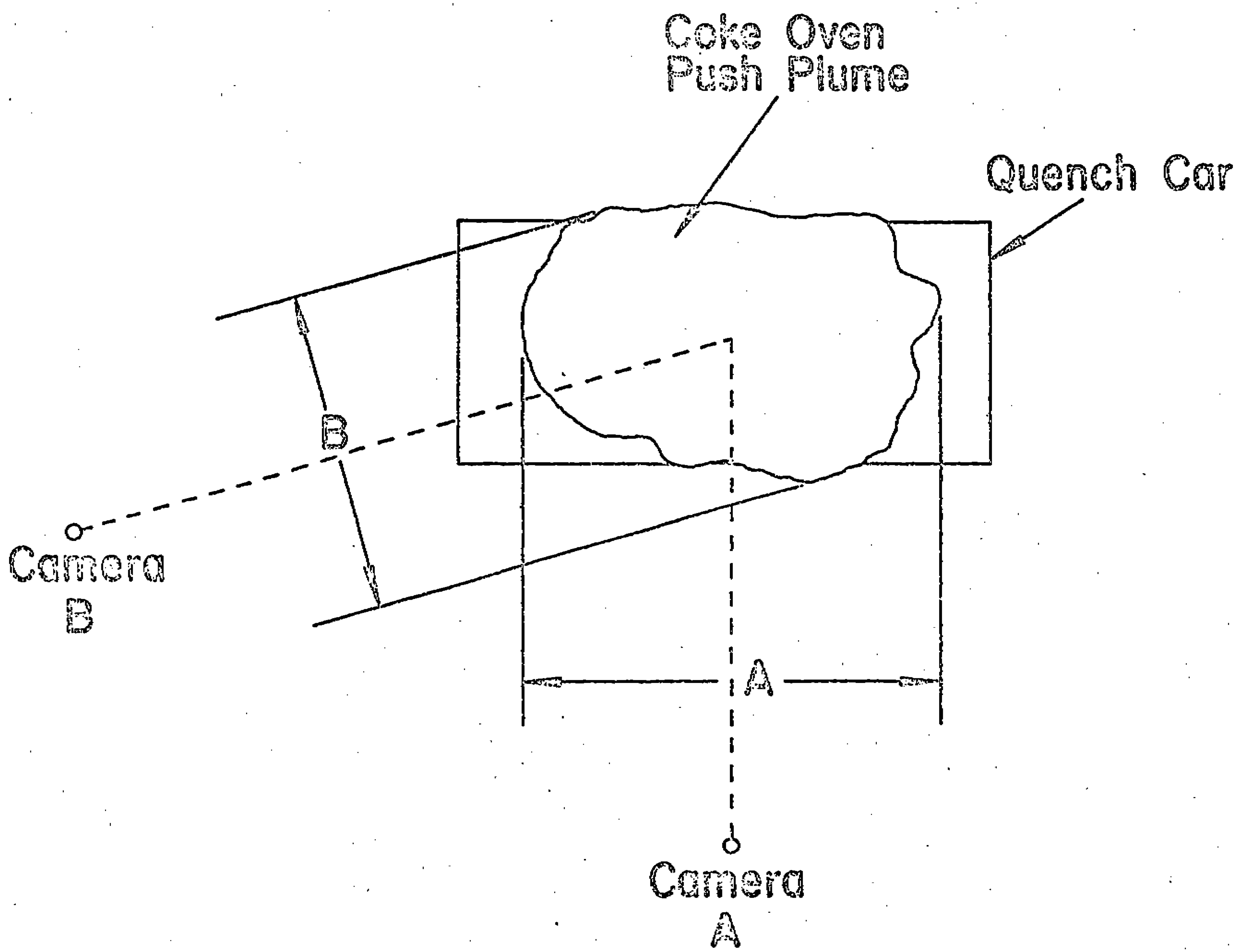

Figure 2 TOP VIEW OF PUSH PLUME MOTION PICTURE CAMERA SETUP

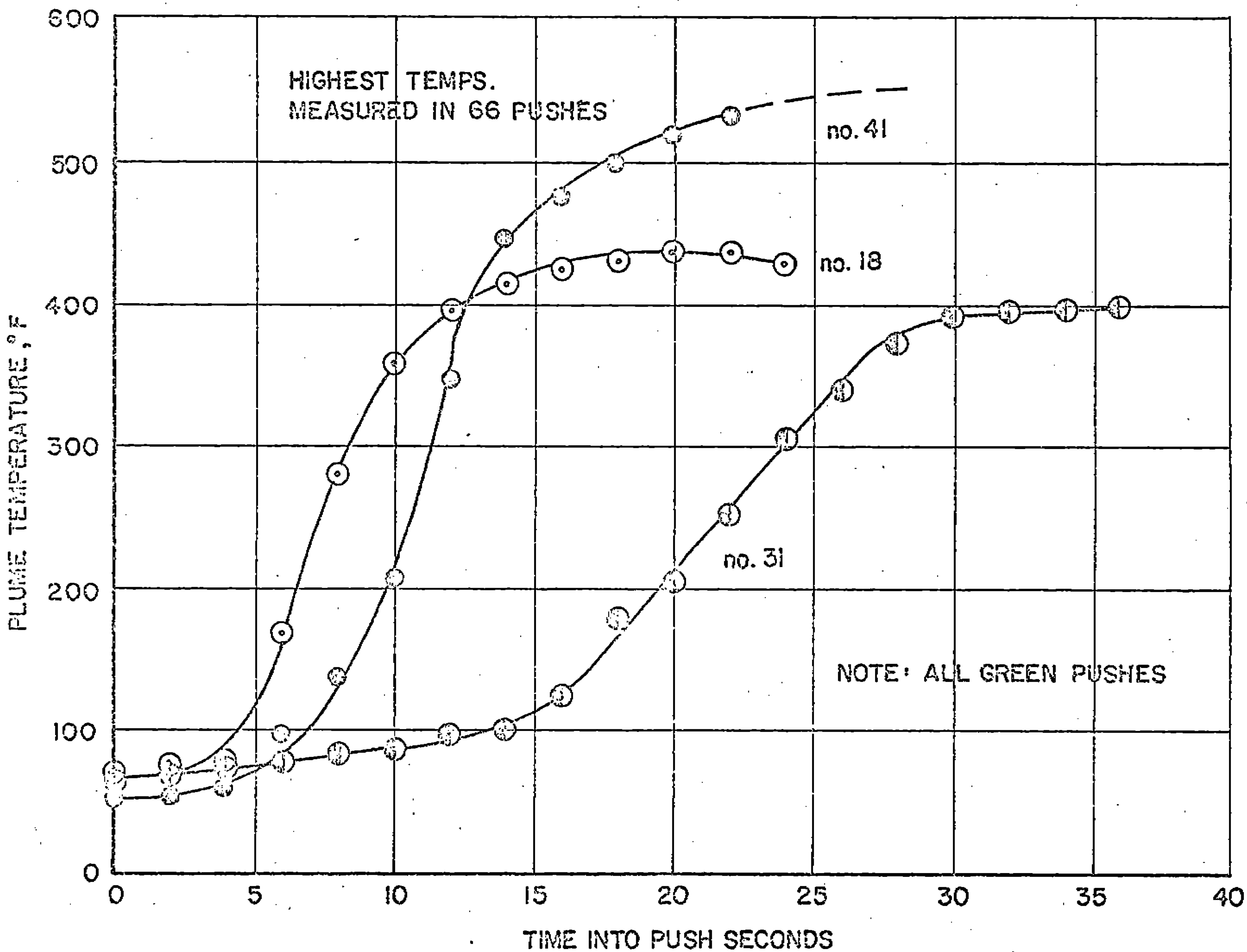

Figure 3 COKE OVEN PUSH PLUME TEMPERATURE - TIME HISTORIES FOR THE 3 HIGHEST TEMPERATURES MEASURED

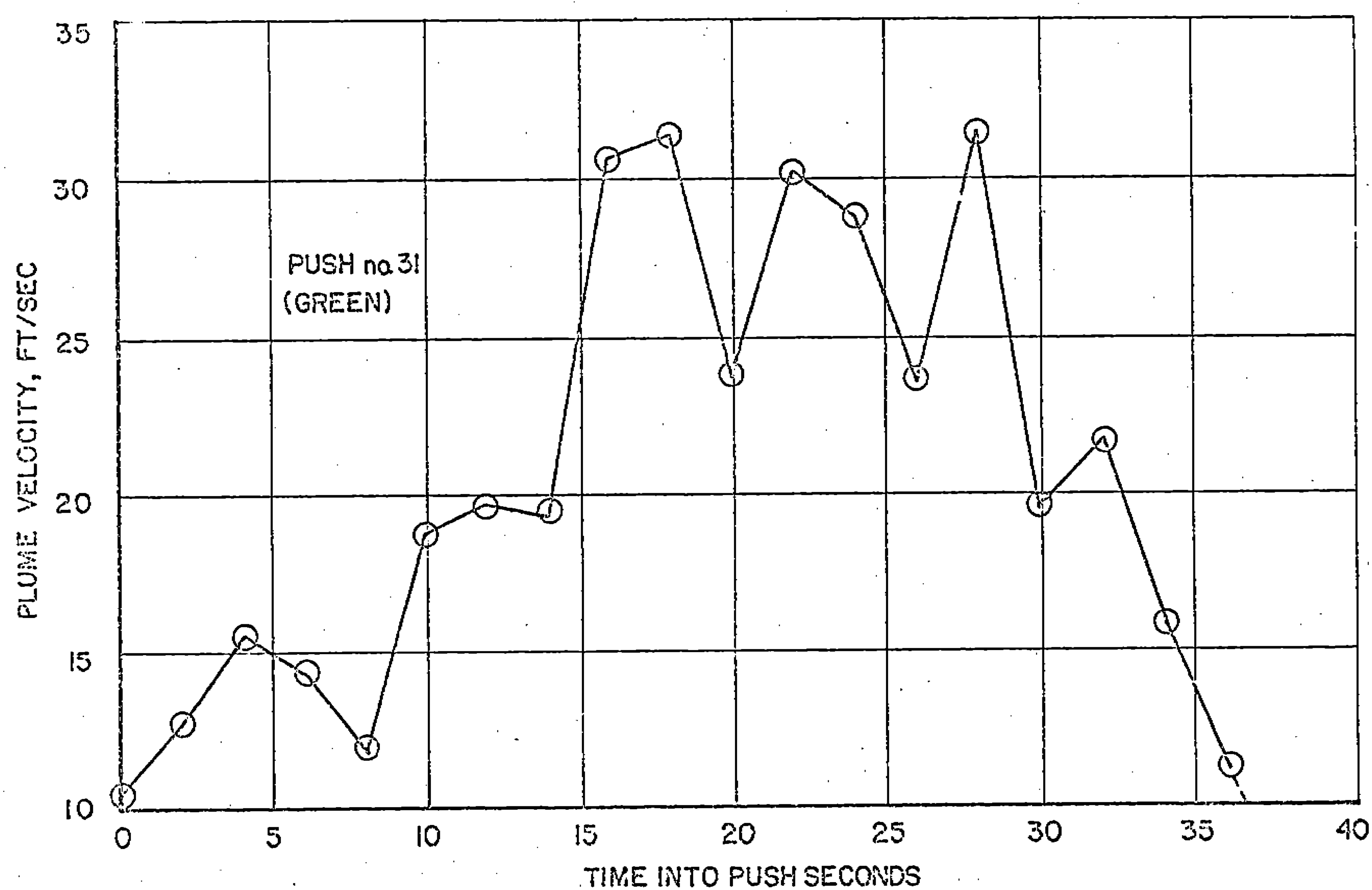

Figure 4 COKE OVEN PUSH PLUME VELOCITY-
TIME HISTORY FOR A TYPICAL GREEN PUSH

Title: see title page

Plant and Location: –

SCC: 30300303

Test Date:

By Whom: ~~Purdue~~ Purdue

SK – ~~special~~ no plant name – just put in separate box at end of library

Encoded By:

Date Encoded:

Completed By:

Form No.: