UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: JUL 2 2 1980

SUBJECT: Thermal Incinerator Performance for NSPS, Addendum

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After reviewing the recent memo on incinerator performance, (Thermal Incinerator Performance for NSPS, June 11, 1980, DCM to Jack Farmer), you indicated several areas where further discussion was desired. These areas were as follows:

- continuous compliance of thermal incinerators
- the impact of compound on efficiency
- the impact of inlet concentration on cost effectivesness and efficiency

These three areas are discussed below preceeded by a summary of the conclusions.

Conclusions

In the absence of a demonstrated continuous VOC monitor for thermal incinerators, CPB is investigating alternate methods. After study of the cost and effectiveness of several such methods, the following should be considered: continuous temperature and flow monitoring and bi-annual compliance testing and inspection/maintenance. For example, in monitoring temperature and flow, a company could be required to run the incinerator between +50°F of the temperature, and between +20 percent and -50 percent of the flow, measured during the performance test.

Detailed analysis shows that type of compound does affect incinerator efficiency. However, due to the complexity of the relationship, no attempts were made in the June 11 memo to draw fine-tuned efficiency conclusions relating different efficiencies to different compounds at different temperatures. Rather, a more conversative approach was taken in which the efficiency conclusions were based on the most difficult compounds to combust. These conclusions, based on such a worst case analysis, would then apply regardless of compound.

Detailed analysis also shows that inlet concentration affects incinerator efficiency. However, unlike type of compound, statistical study of the relationship between inlet concentration and efficiency was possible. Based on this study, the conclusions in the June 11 incinerator memo are expressed in both ppmv and percent reduction. This dual format accounts for the effect of inlet concentration.

Inlet concentration also affects cost effectiveness. One effect is that as inlet concentration drops the energy content of the waste gas drops, increasing supplemental fuel use. However, this is not the major effect. By far the largest effect of inlet concentration on cost effectiveness is to change the amount of VOC controlled. Over a typical range of inlet concentrations (i.e. 10,000 to 500 ppm) and for an incinerator with 70 percent recuperative heat recovery, increasing fuel use can increase cost effectiveness 5 to 50 percent while decreasing VOC can increase cost effectiveness 5 to 2000 percent.

Discussion

Monitoring - One CPB goal is continuous monitoring of air pollution control equipment. At present, we are limited in achieving this goal for incinerators by the lack of a demonstrated continuous VOC monitor. Given this limitation, CPB is studying alternate monitoring methods, such as measuring firebox temperature, to indicate incinerator performance.

To develop alternate monitoring methods, two goals were considered. First, these alternate methods should detect all or most cases of poor incinerator performance. Second, the methods should have reasonable costs and impose reasonable recordkeeping requirements.

To meet these goals, the variables that affected incinerator performance were analyzed. These variables are temperature, mixing, type of compound, inlet concentration, residence time, and flow regime. Of these variables, the last three were judged of little concern when considering continuous monitoring. These three variables are essentially set after incinerator construction and adjustment and/or have only small impact on incinerator performance. The three remaining variables were then analyzed in more detail to define their impact on performance and the ability to monitor them.

Temperature was analyzed first. This analysis was based on data in the previous incinerator memo. Even with good mixing, the Union Carbide lab data and kinetic theory show that lower temperatures cause significant decreases in efficiency. In addition, the L.A. data indicate that increasing temperature can also adversely affect efficiency, apparently by changing mixing. In terms of cost, temperature monitors are inexpensive, costing less than $5000 installed with strip charts, and are easily and cheaply operated. Given the large effect of temperature on efficiency and the low cost of temperature monitors, this variable is clearly an effective parameter to monitor.

As an example, a specific requirement could be that an incinerator cannot be operated for more than three hours at an average firebox temperature above 50°F over, or under 50°F below, the average temperature recorded during performance testing. If an operating range greater than 100°F is desired, a company could perform performance tests at more than one temperature. The three hour time period would correspond to the period required for integrated bag sampling in a typical performance test. This would make the averaging period for temperature monitoring similar to that of the performance test. Finally, the company could be required to install, operate, and calibrate the monitor according to manufacturer's specifications. These specifications generally cover proper placement of the monitor.

The next variable studied was mixing. The most likely item to affect mixing, given a constant temperature and an already constructed incinerator, would be flow. No direct field data is available on the effect of flow on mixing efficiency. However, based on engineering judgement, increasing flow may lead to "shortcircuiting," where the increased kinetic energy of higher flow streams causes waste gas to jet through the incinerator unmixed. Decreased flow may lead to the opposite, where lower flow rates result in insufficient kinetic energy for complete mixing. As with temperature, flow monitors are inexpensive and easily operated. Given the potential impact of flow on efficiency, and the low cost of flow monitors, flow rate is also an effective parameter to monitor.

As an example, a specific requirement could be that an incinerator cannot be operated for more than three hours at an average flow less than 50 percent or greater than 120 percent of the average waste gas flow recorded during a performance test. The permissible range would be intentionally broad due to the lack of field data on the impact of flow on mixing and efficiency. The upper restriction would be tighter than the lower since increase flow not only may adversely affect mixing but decreases residence time. Any adverse effects of decreased flow may be offset by the increased residence time. The above discussion for temperature on widening the operating range, the three hour time limit, and installation, operation and calibration of the monitor would hold for this flow monitoring example.

The final variable analyzed was type of compound. For most incinerator applications, the compounds in the waste gas are set by the process to which the incinerator is attached. Thus, type of compound is of no concern. However, certain applications may have differing compounds in the waste gas. A coating operation may have at one time a solvent with an MEK base, and then switch to a solvent with a toluene base. MEK is oxidized easier than toluene, and thus an incinerator which achieves compliance on an MEK stream may be inadequate for the toluene stream.

The judgement on this item is that no general monitoring requirement on type of compound can be specified. Most cases will have the waste gas compounds set by the process. In those that do not, considerable difficulty is envisioned in defining, in a general way, when the waste gas compounds have changed enough to require additional compliance tests. For example, differentiating between solvent formulations would be difficult. The same generic name of solvent may show greater variations in composition than two different name specialized solvents. However, though a general requirement on type of compound cannot be set, specific requirements may be desired for certain standards.

Temperature and flow monitoring do not measure incinerator performance directly. Thus, concern exists over the long term stability of incinerator performance, even with temperature, flow and type of compound held constant. Data on this issue is shown in Table 1. The top part of the table shows data from L.A. County where the same incinerator was tested in different years. The bottom part lists possible incinerator malfunctions that could affect performance, without changing temperature and flow.

Based on Table 1, incinerators, if properly designed and adjusted, are judged to have fairly stable performance over time. The L.A. units showed only small changes in efficiency over time. The efficiencies of these units changed less than two percentage points over several years, except one case. In addition, the listed malfunctions are judged to occur infrequently. This is based on several factors. First, these malfunctions involve non-moving parts subject to little wear. Also, the typical waste gases are not highly corrosive and the typical incinerator fuels, natural gas and fuel oil, have low sulfur and ash content. Finally, even though incinerators undergo wide temperature swings, incinerator components are designed to withstand these changes, given proper cooling and heating of the unit.

The above conclusion should not be overstated. Though fairly stable, all four L.A. data sets show some drop in performance over time. And though improbable, incinerator malfunctions are not impossible. Thus, the conclusion from the data is not that no additional requirements are needed over temperature and flow monitoring. Rather, the conclusion is that the costs and recordkeeping of additional monitoring requirements must be carefully balanced against emissions potentially prevented by them.

After this balance was studied, two additional requirements were considered. These are bi-annual performance testing and bi-annual inspection and maintenance (I & M) for incinerators. The performance testing would follow the method specified in the standard. The I & M would involve visual inspection for items such as corrosion and firebox deterioration, calibration and testing of control instrumentation, and so on. Such I & M could most likely be performed at the same time as a process turnaround.

These two additional monitoring methods would effectively detect drops in incinerator performance not detected by temperature and flow monitoring. Performance testing is the most direct means of detecting poor efficiency. The I & M will catch drops in performance by spotting equipment failures or impending failures that could lead to poor performance. The I & M has the added advantage that impending failures which could lead to incinerator shutdown would also be spotted. The two year period for compliance testing and I & M is based on the rate at which incinerator performance is likely to deteriorate. The two year period for I & M also corresponds to the typical time between process turnarounds. Thus, with a bi-annual I & M the incinerator I & M could be performed at the same time as process equipment I & M, and it would not be necessary to shut down the process just to check the incinerator. Finally, the timing of the performance test and the I & M are not linked. They can be done together in any order or apart.

Type of Compound - One factor which affects incinerator efficiency is type of compound. The June 11 memo on incinerator efficiency excludes this factor from its conclusions, but discusses only briefly the reasons for this exclusion. This section discusses the impact of this factor on efficiency and explains in more detail the reasons for its exclusion.

In terms of the impact of compound on efficiency, the available incinerator data does show a moderate impact. The Union Carbide lab data demonstrates this most clearly. In cases where different compounds were incinerated at the same temperature, residence time, and flow regime, variations in efficiency of up to 5 percent points occurred for temperatures above 1400°F. At lower temperatures, the efficiency variations increased up to 20 and 30 percentage points.

However, as a practical matter, including compound as a factor in an efficiency conclusion would be difficult. First, a precise quantitative relation between compound and efficiency could not be determined. As with mixing, no single value could be assigned to an individual compound to represent ease of combustion. Thus, analysis of the relation between efficiency and compound was limited. Second, even if a relationship could be devised, it would be complex and difficult to apply. The relationship would likely involve kinetic rate constants, autoignition temperatures, factors for molecular configuration and structural groups and similar variables.

To avoid these difficulties, an alternative approach was taken. No initial attempts were made at drawing a fine-tuned efficiency conclusion showing differing efficiencies at differing temperatures for different compounds. Rather, a conservative approach of choosing a simple set of incinerator conditions and efficiencies based on the most difficult compounds to combust was pursued. This approach proved successful.

Several factors aided in the success of this approach. First, the available test data covered a wide range of compounds. The compounds on which test data were available included C_1 to C_5 alkanes and olefins, aromatics such as benzene, toluene, and xylene, oxygenated compounds such as MEK and isopropanol, nitrogen containing species such as acrylonitrile and ethylamines and chlorinated compounds such as vinyl chloride. With such a range of compounds and the consideration of kinetics, it was concluded that worst case compounds had been taken into account. The second factor was the discovery that increasing combustion temperature resulted in only negligible energy penalties and moderate cost increases. Thus, choosing a higher temperature to cover the worst cases did not make incinerators unaffordable or too energy intensive.

Inlet Concentration - A second factor which affects efficiency is inlet concentraton. Unlike type of compound, an allowance for this factor was included in the efficiency conclusions. Specifically, these conclusions included not only an efficiency of 98 percent but a minimum exit concentration of 20 ppmv by compound. Thus, as inlet concentration drops, the minimum ppmv lowers the efficiency required. For example, with a 500 ppmv inlet concentration for a waste gas containing oxygen, the 20 ppmv minimum translates to a 96 percent efficiency; with a 250 ppmv inlet, a 92 percent efficiency. This section explains in more detail the reasons for this allowance for inlet concentration.

The test results from L.A. County form the major basis for this allowance. These results show a strong trend where lower inlet concentration results in lower efficiency. For example, for inlet concentrations less than 1600 ppmv as carbon, the median L.A. efficiency was approximately 92 percent. For inlet concentrations between 1600 and 2400, the median L.A. efficiency was approximately 94 percent. For inlet concentrations above 2400, the median efficiency was approximately 97 percent.

Kinetic considerations also support the allowance for inlet concentration. The most likely kinetic model where inlet concentration does <u>not</u> affect efficiency is a first order model. However, available literature indicates that combustion follows complex reaction mechanisms.[1,2] In cases, these mechanisms can be fit to a first order model. However, as a general rule, these mechanisms, which involve chain reactions, free radicals and multiple pathways, cannot be reduced to first order models.

The June 11, 1980, incinerator memo concluded that the L.A. incinerators did not all achieve proper mixing. This improper mixing may have caused or influenced the relation between efficiency and inlet concentration in the L.A. data. If this is the case, then an allowance for inlet concentration may permit lower efficiencies than are actually achievable in incinerators with proper mixing. However, the possible effect of poor mixing on the relation of efficiency and inlet concentration remains just that, possible; no conclusive statement can be made. Given this, a more conservative approach was taken and lower efficiencies for lower inlet concentrations were allowed.

Inlet concentration also impacts cost effectiveness, i.e. costs per unit weight VOC controlled. The precise impact depends on molecular weight, the size of the incinerator and the ratio of waste gas energy content to VOC. Figure 1 show these impacts.

A surprising conclusion in the analysis of inlet concentration vs. cost effectiveness is the role of supplemental fuel. The increasing cost for supplemental fuel as inlet ppm drops is not a major factor in cost effectiveness. Incinerator size and the amount of VOC being destroyed are much more important factors. An illustrative example is a 5000 SCFM incinerator burning benzene in nitrogen. The extra fuel required when dropping the inlet contration from 5000 to 500 ppmv increases the cost effectiveness only 20 percent. The fact that only one-tenth the benzene is being destroyed for about the same cost increases the cost effectiveness 1000 percent. And decreasing the stream size to 1000 SCFM increases the cost effectiveness about 300 percent. Clearly, increasing fuel costs at lower ppmv is only a minor factor.

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[1] Rolke, R.W., et. al. Afterburner System Study, U.S. Environmental Protection Agency, Report S-14121, Shell Development Company, 1971.

[2] Barnes, R.H., et. al Chemical Aspects of Afterburner Systems, IERL Report U.S. Environmental Protection Agency, EPA-600/7-79-096. Batelle Columbus Laboratories, April 1979.

Long Term Incinerator Performance

Part A - L.A. Test Data*

ompany	Test No.	Date	Inlet (ppmv	Outlet carbon)	% VOC Destruction	Flow(SCFM)/ Temp. (^{o}F)
ay & Night	1754	10-30-73	443	33	92.5	3270/1300
anufacturing	2442	7- 7-76	1030	91	91.4	2020/1300
	2443	8-10-78	716	94	87.3	2050/ -
lasteel, Inc.	2286	5-12-75	6020	52	99.0	1210/1260
	2402	2-17-76	5860	71	98.9	4150/1375
ational Can	1430	6-10-70	4900	31	99.4	2520/1500
	1746	3-21-74	7370	104	98.6	1990/1500
ational Can	1451	6-10-70	3500	22	99.4	4620/1460
	1746	3-21-74	6247	82	98.0	4660/1420
			7370	79	98.0	4650/1525

Part B - Possible Incinerator Malfunctions**

alfunction	Cause	Possible Effect on VOC Control
Firebrick Deterioration	Improper heating & cooling of incinerator during start-up & shutdown; firebox temperature too high	Deteriorated wall allows local heat loss resulting in cool spots in firebox, and thus potentially lower destruction efficiency in those spots
Insulation Loss from Incinerator Exterior	General weathering & corrosion from rain, cold, incinerator start-up & shutdown & so on	Same as previous; insulation loss leads to local heat loss & cool spo in the incinerator
Corrosion of ducts, baffles & other exposed metal	Ash, acids, salts, etc. in fuel or waste gas	Severe corrosion of metal parts affects the gas flow patterns through and around them, potentiall affecting mixing & thus efficiency
Plugging of Burners	Ash & carbon build-up	A plugged or partially plugged burn affects the flow patterns & temperature profiles in the firebox potentially lowering destruction efficiency
Breaking of Recuperative Heat Exchanger Seals	General corrosion; temperature warping from hot spots in the exchanger, improper heating & cooling during start-up & shutdown	Inlet waste gas leaks into the outl flue gas without passing through the firebox.

The listed data are from incinerators which were tested in more than one year.
The listed malfunctions include only those which would likely not affect temperature at a single point firebox temperature monitor or inlet/outlet flow.

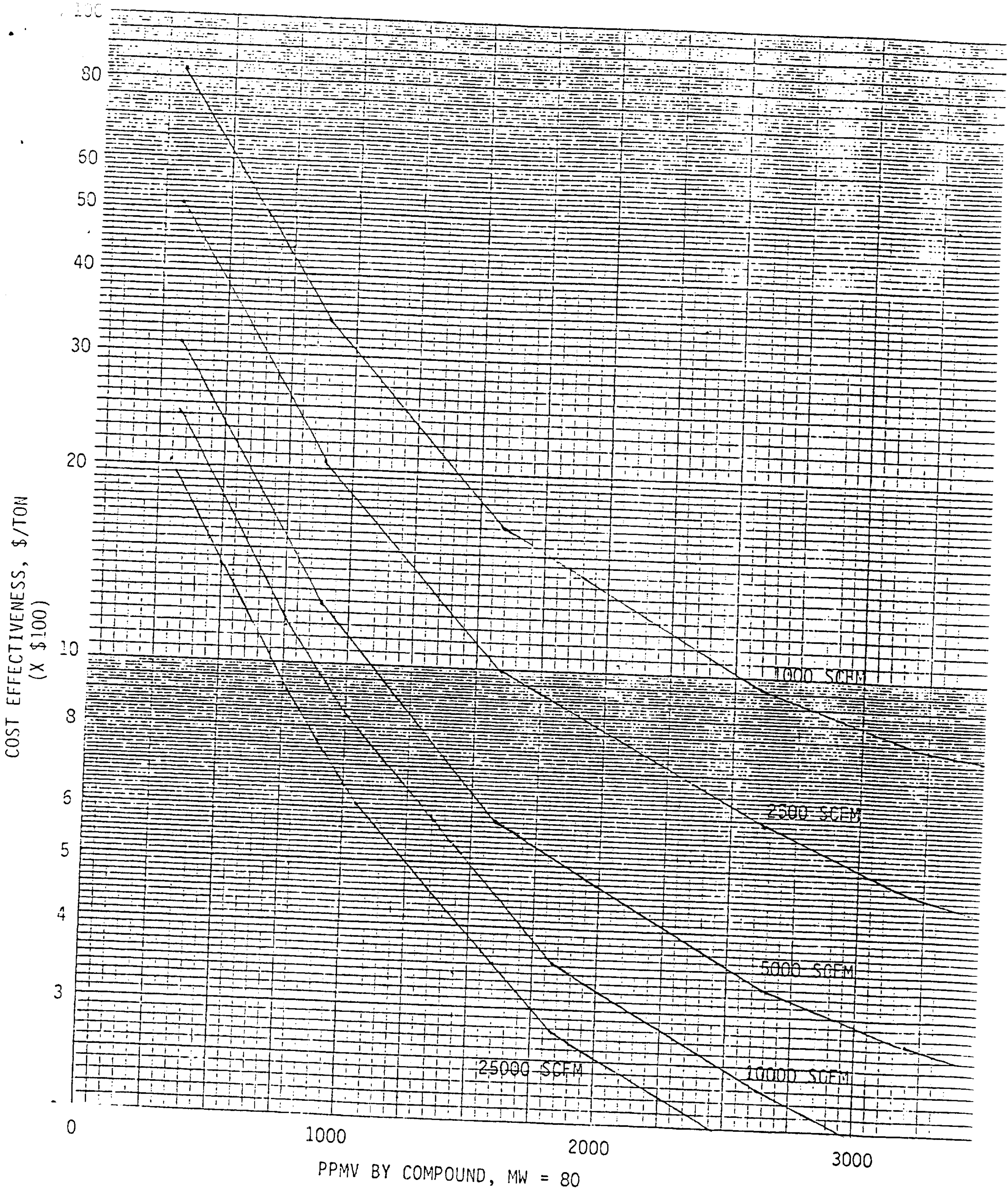

Figure 1 - Cost Effectiveness for Thermal Incinerators by Inlet Concentration and Waste Gas Flow

Figure 1 - Notes and Explanation

Figure 1 shows the cost effectiveness of thermal incinerators by inlet concentration and waste gas flow. The cost effectiveness is in hundred dollars per 2000 pound ton; inlet concentration is ppmv by compound; and the flow rate is in SCFM. The costs in the figure assume a waste gas deficient in air, and a compound with a molecular weight of 80 and a heat of combustion of 15,000 BTU/lb VOC. The thermal incinerator operates at 1600°F and .75 seconds and achieves 70 percent recuperative heat recovery.

The figure can be used to approximate cost effectiveness for situations other than that described in the above paragraph. For compounds with different molecular weights, the x-axis scale should be increased by 80 over the molecular weight of the compound. For example, for a compound with molecular weight of 40, the x-axis scale would read 2000, 4000, and 6000. For cases where the waste gas contains sufficient oxygen for combustion, the cost effectiveness should be decreased by the following percentages:

1000 SCFM	7%
2500 SCFM	14%
5000 SCFM	21%
10000 SCFM	26%
25000 SCFM	30%

This adjustment accounts for the smaller size and lower fuel requirements of these cases. Finally, for cases where the combustion value of the stream per pound of VOC is higher, the below listed decreases approximate the costs. These adjustments assume 30,000 BTU/lb VOC.

for ppmv <500	No adjustment	
for ppmv between 500 & 3000	1000 SCFM	5%
	2500 SCFM	10%
	5000 SCFM	15%
	10000 SCFM	20%
	25000 SCFM	25%
for ppmv >3000	No adjustment	

This adjustment accounts for the lower fuel use at higher BTU/lb levels.