THE EFFECTS OF THE OPERATING VARIABLES AND REFUSE TYPES ON THE EMISSIONS FROM A PILOT-SCALE TRENCH INCINERATOR

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ABSTRACT

This work defines the air pollutant emissions from a trench incinerator burning three types of refuse material: low ash, moderately high heat content materials characterized by cord wood; high ash, high heat content material characterized by rubber tires; high ash, low heat content material characterized by municipal refuse. Use of a trench incinerator for the disposal of the high ash content materials studied generated particulate emissions which, in all cases, exceeded 1 grain per standard cubic foot at 12 percent carbon dioxide and is therefore not recommended. For disposal of low ash, high heat content materials, the data indicate that, except for nitrogen oxides, emission levels from the trench incinerator may be acceptable if rigid operating controls are predetermined for the specific refuse materials.

INTRODUCTION

In 1964, E. S. Monroe, Jr., of E. I. Dupont de Nemours Company, designed a novel incinerator, commonly called a trench incinerator, for the thermal destruction of wastes having a high calorific value and a low ash content [1]. Since the trench incinerator is attractive from the standpoints of construction and operating costs, attempts have been made to apply it to the problem of disposal of municipal refuse, landscape refuse, and certain industrial wastes, all of which possess fuel characteristics different from those for which this incinerator was originally designed. Since no actual emission testing has been done, the National Center for Air Pollution Control (NCAPC) and the National Center for Urban and Industrial Health (NCUIH) found it necessary to characterize emissions from this incinerator before further proliferation of the units occurred, possibly increasing our widespread air pollution problem.

PILOT UNIT

Because of the open construction of a trench incinerator, representative sampling of pollutants from a full-scale unit is difficult. To facilitate sampling, a pilot-scale unit was constructed at the NCAPC facility in Cincinnati, Ohio, based on Monroe's design criteria.

The NCAPC unit consists of an above-ground pit supplied with overfire air from a manifold arrangement along the upper edge of one side (Fig. 1). The combustion space, designed for a total heat release rate of 1.44 million Btu per hour, has interior side dimensions of 3 ft and is 4 ft deep. The walls are constructed of two rows of first quality No. 1, 3000 F refractory brick, and the floor is composed of one layer of 2.5-in. first quality refractory brick over a layer of 2.5-in. 2300 F insulating brick.

Ash is removed through cleanout doors located in one side of the unit. Air is supplied to the incinerator manifold and nozzle system by a 5-horsepower blower capable

of delivering 600 scfm at 23 inches water static pressure. The air supply rate is controlled by throttling the blower outlet with a gate valve. Six nozzles, located 5 inches on center along the manifold, are inclined 30 degrees below the horizontal to provide a curtain of air across the top of the pit and to direct air into the pit for combustion. The nozzles reduce from a 2-in. diameter at the manifold to 1 in. at the discharge orifice.

Effluent gases from the incinerator are collected by a 10-ft conical hood 8 ft in diameter at the base and connected to a 30-in.-diameter stack 10 ft high. The hood and stack are supported 2 ft above the top of the trench incinerator. This arrangement makes it possible to utilize standard stack sampling techniques (Appendix) for the measurement of emissions. Scaffolding is utilized for access to sampling ports located 2 ft from the top of the stack (20 ft above the pit top).

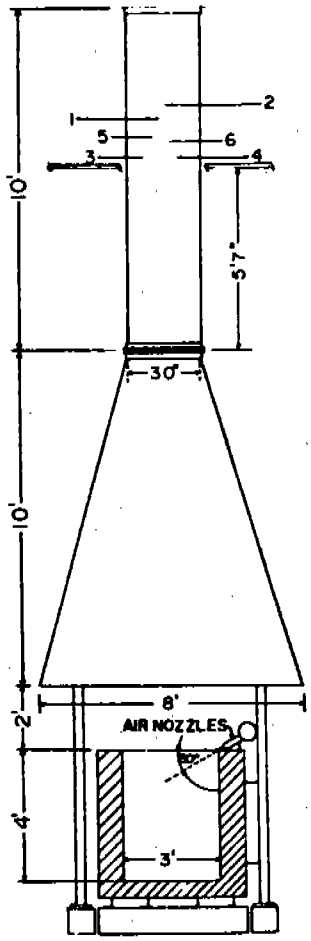

FIG. 1 PILOT-SCALE TRENCH INCINERATOR

TEST PROCEDURE

The independent variables of air rate, refuse type, and amount of refuse charge were studied to ascertain their effects on emissions of particulates, carbon dioxide, carbon monoxide, total hydrocarbons, oxygen, total carboxyls (organic acids), total carbonyls (aldehydes and ketones), oxides of sulfur, oxides of nitrogen, and temperature. The response variables carbon dioxide, carbon monoxide, total hydrocarbons, oxygen, and flame temperature were monitored and recorded continuously. Particulate emissions were sampled isokinetically by standard techniques. Gaseous samples for sulfur oxides, carboxyls, and carbonyls were taken at proportionate rates through appropriate chemical absorption trains; grab samples were taken for the determination of nitrogen oxides (Appendix).

All experiments were conducted on a batch basis, i.e., a single charge per test run. The pre-weighed test batch was placed in the pit, and the blower air rate set to a minimum. The top surface of the charge was ignited with a hand torch, and the blower rate gradually increased to permit the flames to spread over the entire charge. When burning was adequate, the air rate was increased quickly to the test level. At this point draft sufficient to produce stable stack gas flow was established within 1 minute, and emission monitoring was begun.

The maximum burning rate was established early in the run as shown by the curves in Figs. 2 and 3 for carbon dioxide, temperature, and total stack gas flow. The curves presented are for a 318-pound charge of cord wood burned at an air rate of 420 scfm. During normal operation, curves of this form were typically obtained; the general shape of the curves was the same for each refuse type studied although the location and maximum value of the peaks did change. Test sampling was continued until the charge was exhausted; the blower was then turned off, and the residue removed after it had cooled.

The overall average burning rate for a given run was calculated as the weight of charge burned per total run time. The charge weights for cord wood, municipal refuse, and rubber tires were 318, 70 to 150, and 30 to 80 pounds per batch respectively. The average burning rate was found to be a function of the refuse material. On a basis of incinerator volume, the average burning rates, expressed as pounds per minute per cubic-foot, for the three refuse types were 0.10 for cord wood, 0.061 for rubber tires, 0.042 for municipal refuse. The value for cord wood is in excellent agreement with the value reported for the large-scale unit [2].

Difficulty in conducting tests was encountered when wind velocities were greater than 10 to 15 mph; burning

was unstable and there was considerable "spillage" of gases from the collection hood. The pilot unit was shielded on two sides with screens to prevent undue influence of ambient wind on test conditions. This shielding permitted operation under most normal wind conditions, and no effect of wind was detectable upon the measured emissions, however, it was impossible to conduct reliable tests when wind gusts above 15 mph occurred.

Experimentation on a batch basis requires the calculation of time average values to obtain average concentrations. For example, in order to determine the average carbon dioxide concentration used to correct grain loading to 12 percent CO_2, it is necessary to determine the total carbon dioxide and total gas emitted. That is

$$\text{Avg } \% CO_2 = \frac{\text{Total Volume of Carbon Dioxide in Stack Gas (scf)}}{\text{Total Volume of Stack Gas Emitted (scf)}} \times 100$$

$$= \frac{\sum_{t=o}^{t=T} Q_i \times C_{CO_{2i}} \times \Delta t}{\sum_{t=o}^{t=T} Q_i \times \Delta t}$$

where Q_i is the instantaneous stack gas flow rate, $C_{CO_{2i}}$ is the volume percent instantaneous carbon dioxide concentration, Δt is a small time interval, and T is the total duration of the run. The time average carbon dioxide concentrations used to adjust particulate concentrations to 12 percent CO_2 were calculated in this manner through appropriate computer programs. Since correction of measured concentrations to the 12 percent CO_2 level requires precise and accurate measurement of CO_2, the test unit was provided with a non-dispersive infrared analyzer for continuous measurement of the CO_2 concentration. This instrument was calibrated before and after each test to insure accurate determinations of CO_2. Such continuous measurement has the distinct advantage of providing information over the entire run at any point of interest whereas grab sampling provides limited information that must be coordinated with pitot readings (for total flow) to allow use of the above calculation method.

PARTICULATE EMISSIONS

Data for particulate emissions are presented in Table 1 and in Figs. 4 and 5. These data show that at all conditions tested grain loadings were heavy during the incinera-

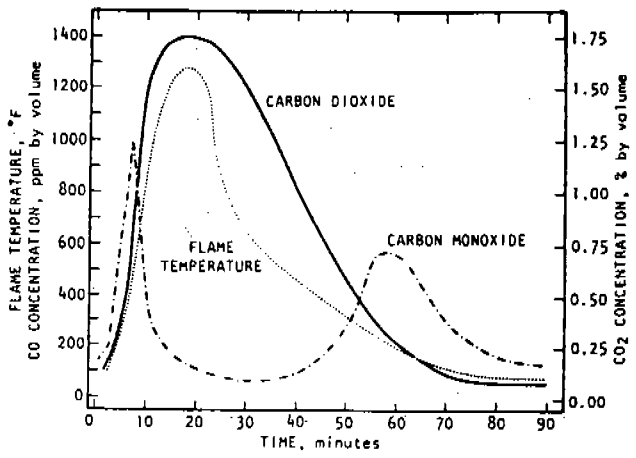

FIG. 2 EMISSION CURVES FOR A TYPICAL BURN (AS-MEASURED BASIS)

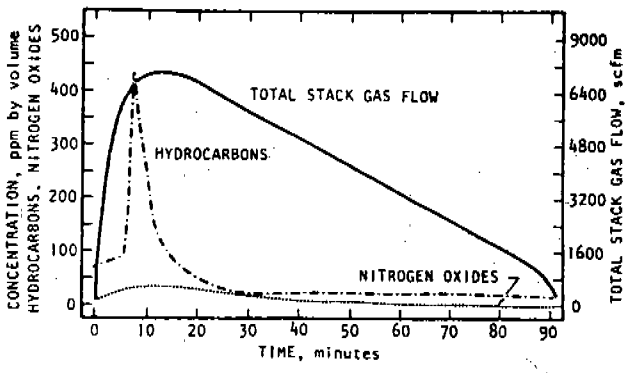

FIG. 3 EMISSION CURVES FOR A TYPICAL BURN (AS-MEASURED BASIS)

TABLE I
PARTICULATE EMISSIONS FROM PILOT-SCALE TRENCH INCINERATOR

Fuel	Air Rate scfm	Particulate Emissions gr/scf @12% CO_2 dry basis	Particulate Emissions lbs Particulate per ton Refuse Burned
Cord	200	0.14	4.6
Wood	420	0.53	12.7
	600	0.50	12.8
Rubber	200	1.62	49.1
Tires	420	1.57	135.2
	500	4.57	172.4
	577	4.10	193.1
Municipal	420	1.15	20.6
Refuse	470	1.45	32.9
	500	5.18	35.8
	575	7.38	59.0

tion of rubber tires and municipal refuse and generally high during incineration of cord wood, however, it was possible under certain conditions to achieve reasonably low emissions during incineration of cord wood. Within the range investigated, the particulate emission per ton of refuse charged is essentially a linear function of air rate for rubber tires and municipal refuse, and up to a limit of 12.7 pounds of particulates per ton for cord wood (Fig. 4).

Examination of the literature reveals that raw woods have an ash content of about 0.30 to 0.80 percent by weight [3] (the cord wood tested had an ash content of 0.40 percent); rubber tires, 6.6 percent [4] including bead wire (3.2 percent excluding bead wire); and municipal refuse, about 5 [4] to 10 percent [5]. Assuming complete combustion so that only ash could escape as particulate, these figures would correspond to 6 to 16 pounds per ton for cord wood, 64 pounds per ton for rubber tires, and 100 to 200 pounds per ton for municipal refuse. During incineration of rubber tires and municipal refuse, glowing particles were observed to rise from the pit, quench in the cooler stack gas, and then escape up the stack. This behavior demonstrates that much of the particulate emitted was unburned combustibles and explains why a greater quantity of particulate was emitted than was available as theoretical ash from rubber tires and cord wood. However in the case of municipal refuse, emissions were lower than predicted by theoretical ash content; examination of the residue obtained from burning municipal refuse revealed that much ash was retained in the pit either because its particle size was too large to permit entrainment in combustion gases or because the ash was trapped in the pit by inert materials.

Based on these data, incineration of high ash content refuse of either high or low heat content could not be performed with acceptably low emissions under any conditions. Incineration of low ash, high heat content materials was performed reasonably well under certain rigidly controlled operating conditions. It should be emphasized at this point, however, that indiscriminate

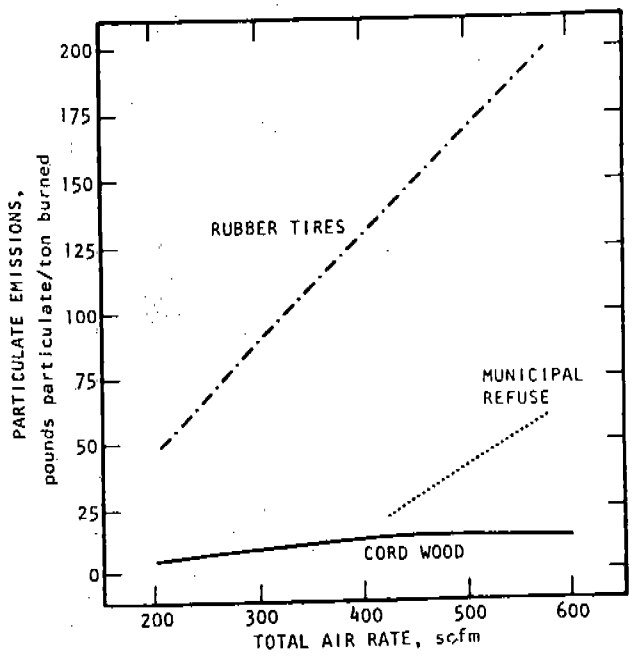

FIG. 4 PARTICULATE EMISSIONS

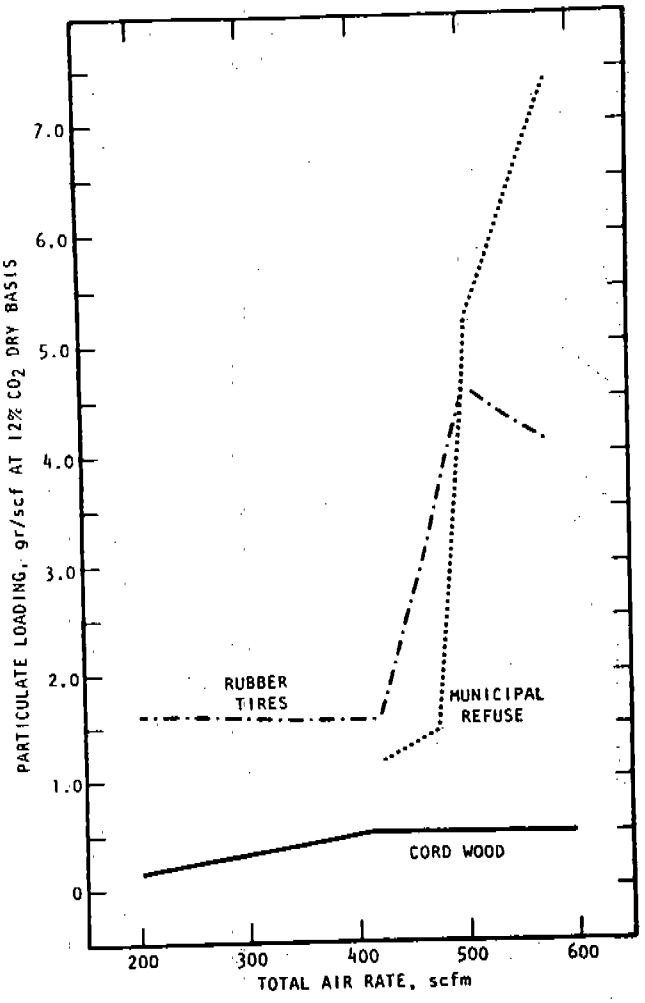

FIG. 5 PARTICULATE EMISSIONS CONCENTRATIONS

application of the trench incinerator to the disposal of low ash, high heat content materials is not warranted by the data presented for two reasons. First, the operating conditions under which low emissions could be expected are not well defined and a full-scale unit would require testing to establish the maximum allowable air rate. Second, the effect of the size of individual pieces of refuse material comprising the charge is not known. For example, mixtures of woodchips and saw dust may not conform simply because of carry-out of small particles, either raw or partially burned, which could easily be entrained by the flue gases and blown out of the incinerator before complete combustion could be obtained.

Preliminary investigations of the influence of batch charge weight on particulate emissions during incineration of rubber tires indicated that the concentration of particulate emissions was independent of the charge size. Furthermore, a test was performed where an additional tire was charged periodically to the incinerator when the flame temperature dropped to about 700 F. Particulate emissions from this test were not significantly different from those obtained on a one-batch-charge basis at the same operating conditions. This indicated little difference between batch and semi-continuous operation for high Btu materials where the heat release is high and operating temperatures are reached very rapidly. The effect of continuous burning of low Btu refuse probably would be more significant since gradual heating of the refractory would eventually lead to higher operating temperatures and better combustion. However, the very high emissions for municipal refuse and the relation between ash content and emissions leads one to conclude that acceptable levels could not be achieved.

A comparison of particulate emissions from the trench incinerator to those from other types (Table II) burning municipal refuse shows that the trench incinerator performs about as well as open burning and some flue-fed units, but multiple-chamber municipal units are significantly superior. Particulate emissions from a full-scale trench installation burning driftwood [2] are comparable to those from the pilot-scale unit burning cord wood.

GASEOUS EMISSIONS

The gaseous emissions typically obtained from a burn are illustrated in Figs. 2, 3, 6, and 7. Figs. 2 and 3 represent emissions on the "as-measured" basis, Fig. 6 on the 12 percent CO_2 basis, i.e. the effect of dilution air is removed, and Fig. 7 represents instantaneous emissions on a quantitative basis. These emission curves reveal essentially three major phases of burning: ignition, rapid combustion, and burn-down.

The ignition phase is characterized by high emissions of hydrocarbons and carbon monoxide accompanied by low combustion temperatures. During this phase the fuel bed temperature is low and combustion is just beginning; organic compounds, expressed as hydrocarbons and measured as parts propane per million parts gas sample

TABLE II
COMPARATIVE PARTICULATE EMISSION CONCENTRATIONS*

Incinerator Type	Reference	Number of Tests	Emission Concentrations Average	Range
Municipal	[6]	17	0.64	0.467-1.099
	[7]	2	0.74	-----
Flue Fed	[8]	6	0.72	0.25-1.41
	[9]	4	1.42	1.3-1.55 w/o raking
		2	2.32	2.17-2.48 w/raking
Open Burning	[10]	2	1.63	----- municipal refuse
		2	2.89	----- landscape refuse
Trench, Full Scale	[2]	---	0.5	----- driftwood

*NOTE: All values expressed as grains/scf @12% CO_2 dry basis, 70 F, 29.92 inches Hg.

volume, are distilled off and carbon monoxide and carbon dioxide are formed. As the temperature rises, the hydrocarbons are released at a very rapid rate beginning at 300 F and peaking at 500 F. Since most lower molecular weight organic compounds ignite at temperatures between 450 F and 800 F, this hydrocarbon peak is attributed to the rapid release of hydrocarbons by distillation at temperatures insufficient for ignition. Carbon monoxide emissions also peak at about 500 F. Since there is sufficient oxygen present for complete combustion, this peak is probably caused by a temperature effect.

The rapid combustion phase is characterized by high temperatures, high concentrations of carbon dioxide, and

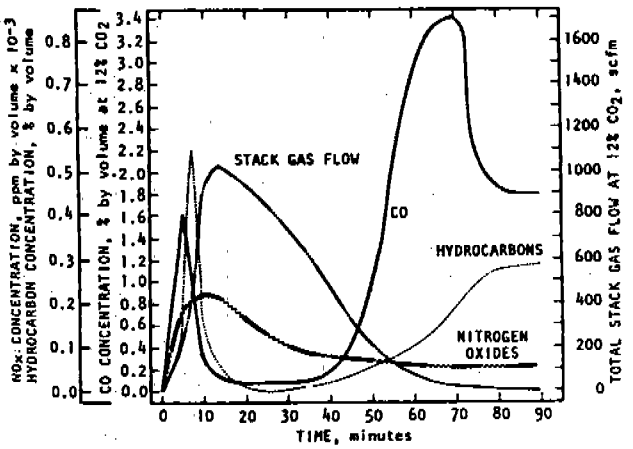

FIG. 6 GAS EMISSION CONCENTRATIONS AT 12 PERCENT CO_2 DRY GAS BASIS

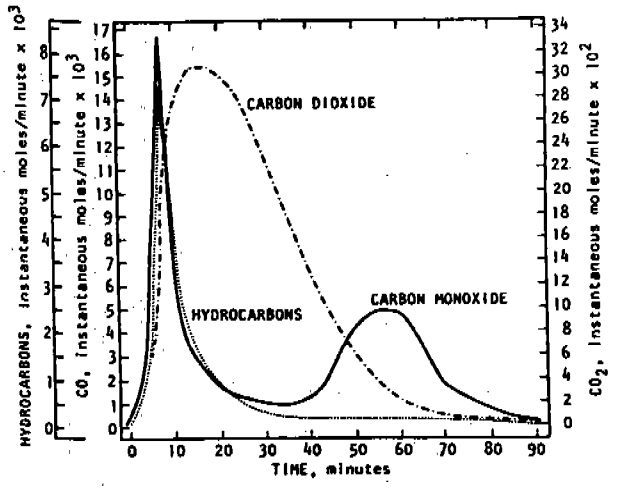

FIG. 7 INSTANTANEOUS GAS EMISSIONS

the generation of large quantities of combustion gases, all of which indicate rapid burning rates. The relatively low amounts of carbon monoxide and hydrocarbons emitted during this phase indicate good combustion conditions.

The burn-down phase is accompanied by a rapid decline in temperature, carbon dioxide, and combustion gas generation and a rapid increase in the carbon monoxide and hydrocarbon concentrations (where compensation for dilution air has been made). A characteristic second peak of carbon monoxide occurs during this phase; it is of interest that carbon monoxide concentration starts to increase rapidly when the temperature drops to about 500 F. This second carbon monoxide peak is attributed to flame cooling by the large amount of excess air supplied to the reduced fuel bed and resultant poor combustion conditions.

Gaseous pollutant emissions for the trench incinerator are presented in Table III for carboxyls and carbonyls. Carboxyls are expressed as weights of acetic acid and carbonyls as weights of formaldehyde; total emissions are taken as weight of acetic acid and are equal to the carboxyls plus the carbonyls expressed as carboxyls. Over the ranges studied, total emissions increased with increases in air rate and tended to reach a maximum. Nitrogen oxides emission concentrations ranged from 50 ppm to 500 ppm, adjusted to 12 percent CO_2; maximum NO_x concentrations were emitted at conditions of maximum flame temperature and maximum stack gas flow rate. The quantity of NO_x emitted during a typical test with cord wood was calcu-

TABLE III
GASEOUS EMISSIONS FROM PILOT-SCALE TRENCH INCINERATOR

Fuel	Air Rate	Gaseous Emissions lbs emission/ton refuse burned		
		carboxyls as acetic acid	carbonyls as formaldehyde	total as acetic acid
Cord	200	0.40	0.41	1.21
Wood	420	1.27	0.92	3.11
	600	0.41	----	----
Rubber	200	2.34	1.08	4.51
Tires	420	3.5	1.49	6.51
	500	5.76	0.47	6.7
	575	5.4	0.45	6.3
Municipal	420	3.13	1.24	4.34
Refuse	470	7.46	1.36	10.17
	500	8.00	6.06	20.11
	575	13.00	2.24	17.48

lated to be 4 pounds of nitrogen dioxide per ton of refuse burned. This value is high in comparison to NO_x emissions from other types of incinerators (Table IV) and is attributed to the reaction of oxygen and atmospheric nitrogen at high temperatures and short residence times.

For the disposal of municipal refuse, the trench incinerator appears to perform slightly better than an apartment flue fed unit in regard to gaseous emissions but not as well as a municipal multiple chamber incinerator (Table IV).

CONCLUSIONS

Based on the data obtained to date for the operation of a trench incinerator on a batch basis, these conclusions are drawn:

1) The use of the trench incinerator for the disposal of high ash content refuse of either high or low heat content resulted in particulate emissions which in all cases exceeded 1.0 grain per standard cubic foot at 12 percent carbon dioxide.

2) The trench incinerator may be applicable to the disposal of low ash, high heat content refuse under rigidly controlled operating conditions where the nature and the quality of the refuse is carefully considered. Since it is apparent that acceptable levels of particulate emissions can easily be exceeded without a noticeable change in plume appearance, standard methods and criteria to obtain good operating control of particulate emissions must be developed.

3) For the disposal of municipal refuse, the trench incinerator is significantly inferior to the multiple-chamber municipal incinerator, in regard to both particulate emissions and gaseous pollutant emissions.

4) Federal Executive order 11282 establishes a rigid emission code for all Federal facilities. The point of interest reads as follows: "--- for installations burning 200 pounds of refuse or more per hour, emissions shall not exceed 0.2 grains of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide (without the contribution of auxiliary fuel)---". This directive precludes the use of the trench incinerator at Federal facilities for all except perhaps special applications to low ash, high heat content material where it can be demonstrated that emission levels will not exceed this Federal standard.

NOTE

Trade names are used to avoid confusion. Their use is not intended as an endorsement by the U.S. Public Health Service.

APPENDIX

The sampling train illustrated in Fig. 8 was used for particulate sampling. Isokinetic conditions were maintained by adjusting pump flow to obtain a predetermined pressure differential across the calibrated orifice meter equivalent to the measured velocity head of the stack gases at the sampling nozzle. Because stack gas velocities changed considerably with time, it was necessary to adjust the sample flow rate at short intervals. Particulate was collected by the cyclone and glass fiber mat. Condensable organics that passed the filter were collected in the bubblers. The liquid was removed from the bubblers and extracted with ether. Both the ether and water

TABLE IV

REPRESENTATIVE GASEOUS EMISSIONS FACTORS FOR INCINERATORS

	lbs emission/ton refuse		
	carboxyls	carbonyls	NO_x
Municipal multiple-chamber [11]	0.6	1.1	2.1
Apartment flue-fed [11]	22.	5.	0.1
Burning Dump [11]	1.5	4.	0.6
Backyard Burning [11]	1.5	3.6	0.5
Trench Incinerator, Pilot-Scale			
cord wood	0.4-1.3	0.4-.9	4.0
rubber tires	2.3-5.8	0.45-1.5	---
municipal refuse	3.1-13.	1.2-6	---

portion were subsequently evaporated to dryness and the residue weights included in the value for total particulate.

Gaseous emissions were measured by the methods outlined in Table V. The gas samples for carboxyls, carbonyls, and sulfur oxides were time average samples obtained by proportional sampling techniques. Samples for nitrogen oxides were obtained by grab sampling. The remaining gaseous emissions, carbon dioxide, carbon monoxide, hydrocarbons and oxygen, were monitored and recorded continuously by onstream analyzers. Sampling points are indicated in Fig. 1, where the following points are: 1) particulate sampling probe, thermocouple, and pitot tube; 2) gas sampling probe for continuous analyzers; 3) organic acids; 4) sulfur oxides; 5) nitrogen oxides; 6) carbonyls.

TABLE V
ANALYSIS METHODS

Emission	Method	Reference
Carbonyls	Bisulfite	12, 13
Carboxyls	Ether extraction	16
Sulfur Oxides	Modification of the Shell Development method	17
Nitrogen Oxides	Phenoldisulfonic acid	14, 15
Carbon Dioxide Carbon Monoxide	Non-dispersive infrared continuous onstream analyzers	Beckman Co. Model IR315
Hydrocarbons	Hydrogen flame ionization detector	Beckman Co. Model 109
Oxygen	Polarographic	Beckman Co. Model 96260

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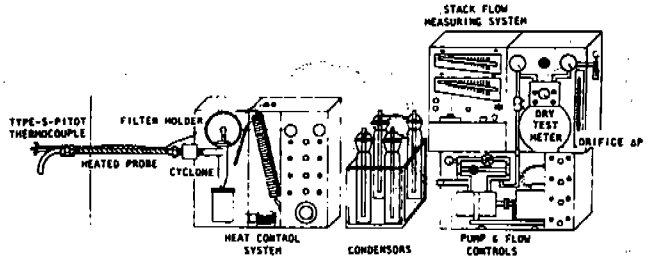

FIG. 8 PARTICULATE SAMPLING TRAIN

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THE EFFECTS OF THE OPERATING VARIABLES AND REFUSE TYPES ON THE EMISSIONS FROM A PILOT-SCALE TRENCH INCINERATOR

by J. O. Burckle, J. A. Dorsey, and P. T. Riley

DISCUSSION by W. G. Weaver, Jr., W. G. Weaver and Associates, Bloomfield, Conn.

The three gentlemen who undertook this investigation are to be commended for their attempt to evaluate the unit. This is an area that must be investigated and evaluated immediately in order that we may know the practical worth of this destructor and how it should properly be used.

The trench incinerator, since its invention by Mr. Monroe, has been billed principally as a "smokeless incinerator" and indeed has been operated at Carney Point, N.J., and other places successfully in this manner.

At the Carney Point Plant, I have witnessed the "smokeless" destruction of tires, plastic coated shutters, empty paper bags which once contained plastic powder, wood, and miscellaneous other wastes. I built a modified unit at Hartford, Conn., for the purpose of attempting to burn out car bodies and tires. We successfully destroyed tires but never had the opportunity to try cars. The Hartford unit was twice the length of the Carney Point unit, and was ramped at one end to facilitate cleanout. In spite of all these smokeless successes at the various installations, there still remains the fact that even smokeless destruction produces gases of combustions, as well as particulate emissions, which are air pollutants.

My first comment with regard to the investigation, carried on by the writers, is that they apparently tried to scale the unit down to a pilot model and in doing so could not scale all the controlling factors down, such as temperature, air pressure and air velocity. The physical dimensions of the unit were easily scaled down, but the scaling down has a direct effect on the burning rate, the air flow, air turbulance and process of combustion, etc. They could not scale down temperature and apparently could not scale down air pressure and air velocity. Therefore, they could not make a valid test of the emissions of a trench incinerator as we know it and use it. They should have tested a full-size unit in order to get a true evaluation of the particulate emission and pollutant gases.

The nozzle angle was deflected the same 30 deg for the 3 X 3 X 4 ft scaled-down unit, as it was for the 8 X 10 X 8 ft full-size unit. The resultant air flow across the two pits were, therefore, not the same and the particulate emissions, which are directly effected by the air flow, could not be comparable.

Some of the materials burned in the scaled-down model could be used in smaller volume, but a single tire would occupy practically the entire bottom area of the model. The burning of this tire would require the same heat, the same storage volume, but with the shorter distance from the combustible item to the air curtain there was far greater chance for loss of particulates. Also, the smaller total volume under the air curtain would appear to have a tendency to increase pressures and turbulance in the burning area with the resultant effect of an increase in gas and particulate emission.

I do not feel the collecting hood had any detrimental effects on the results of this experiment, either in regard to particulate emission, gas emission or the unit operation — provided, it was placed high enough over the top of the unit so as to avoid inverse pressurization.

In conclusion, I feel a start has been made in the evaluation of the Trench Incinerator but we have not given this unit a valid test, from which definite conclusions may be obtained as to its capabilities in the destruction of various types of refuse. More studies should be undertaken but on a full-size unit.

DISCUSSION by R. B. Engdahl, Battelle Memorial Institute, Columbus, Ohio

Although the values shown for particulate emissions from the trench incinerator are no surprise, they are very helpful in confirming what experience tells us: that jets of air, while important for incinerator turbulence, if aimed too close to a burning solid, will lift most of the ash from that burning surface. And once entrained in the gases, fairly elaborate means are required to remove the ash particles from the gases.

Not all waste wood is as low as 0.4 per cent ash as was the wood tested, but most of it is. Hence, in many industrial or rural areas, the trench burner can reasonably be used for many wood wastes and other low-ash solid and liquids. Furthermore, its sensible use in such areas will be a distinct step forward compared to the open burning now customary.

The comparison shown for nitrogen oxides is misleading, because cord wood undoubtedly gave a very intense fire, while the incinerators used for comparison were burning slow-burning wastes. Also, to help keep our perspective, it should be pointed out that of all the combustion devices producing NO_x, incinerators produce about the least.

Aside from the helpfulness of the data provided in this paper I feel moved to object to the growing practice of authors in not showing their experimental points on their experimental curves. ASME review practice should

require that the points be shown, so that the reader can judge at a glance whether the curves are well supported. This is a simple detail of communication.

DISCUSSION by E. S. Monroe, Jr., Engineering Service Division, E. I. du Pont de Nemours & Co., Wilmington, Del.

I cannot but agree with the authors that 10 of their 11 sets of data present a dismal evaluation of the trench incinerator. Since their results are so alien to other data available to me, I think it is proper to review their equipment and testing procedures to determine why their prototype performed so poorly. There are at least three reasons.

First, the authors did not test a trench incinerator. By covering a 3-ft sq opening with an 8-ft diam hood, the equipment tested had lost its ability to radiate heat to the sky and was no longer an open trench incinerator.

Second, a prerequisite of good incineration is good combustion. While it is possible to batch load dense materials which do not volatilize readily and obtain reasonable results, it is certainly not possible to do this with rubber. The first run with wood had a near stochiometric air quantity and probably represented food conditions of time, temperature, and turbulence — the essences of good combustion. This run incidentally met the Federal code for particulate emissions. Materials such as rubber, and to a lesser degree municipal waste, simply cannot be burned satisfactorily when overcharged in any incinerator. Rather than a 30 to 80 lb batch, we have found that, for an incineration unit this size, no more than 8½ lb of rubber should be added every 5 min. It is like the backyard grill, a teaspoon of gasoline every minute can be thrown on and burned satisfactorily, but don't throw a cupful on at once. For some overloading results that will be worse than rubber, I suggest that the authors try styrene. Until it is recognized that incineration is a combustion process and the same fundamentals are applied to it as we apply to other fuel burning processes, we will have poor results. Would the authors have tested their home heating system by pouring a gallon of oil on the floor of the furnace?

Third, and very important, there are recognized standards for various tests. Many of them are published as Power Test Codes by this Society. These codes are respected and have achieved status through years of use. I do not know of a single one of these codes that does not emphasize stability of test conditions. With solid fuel firing, PTC 4.1 recommends a minimum of 4 hr testing, after stability is reached. The authors' instrumentation techniques appear to be excellent. Their use of transient data techniques for solid fuel burning is highly questionable.

We agree, therefore, with the authors' first conclusion that their data showed particulate emissions over 1 gr/scf. We cannot agree that their data are representative or meaningful of the performance possible with full-scale trench incinerators when they are properly operated.

Another question is why the authors ignored other USPHS trench incinerator data and did not examine their test procedures to evaluate the obvious discrepancies. Table D-I is a summary of the results of three tests taken by USPHS personnel on January 10 and 11, 1967, at Carney's Point, N.J., on a full-size trench incinerator burning wood. In the authors' Table II, they chose the data from Test 3, even though the reference report clearly stated that the firebrick wall was collapsed. Runs 1 and 2 clearly show that the open-pit incinerator met USPHS' own goal.

We have no quarrel with the second conclusion that to obtain good results requires good design and good operation. What the authors fail to state is that this applies to any incinerator, including their tests.

The third conclusion is that the trench incinerator is significantly inferior to the multiple chamber incinerator in regard to particulate emission. This statement of opinion is wholly unsupported by any factual presentation or any cited references.

The last conclusion quotes Executive Order 11282 and states that this directive precludes the use of trench incinerator at Federal installations. This is not the place or time to discuss the inadequacies of the fictitious correcting of results to nonexistent conditions. We hold no brief for the 12 per cent CO_2 correction on a dry basis without benefit of auxiliary fuel. We believe that the ASME's Air Pollution Standard 1, issued in 1966, properly sets the best known units for particulate emission when it recommends pounds of particulate emission per million Btu of fuel fired. The ultimate goal of any air pollution regulation is the quality of the ambient air — not some fictitious number measured inside a piece of equipment. The Clean Air Act of 1967 clearly recognizes this principle, and I cannot emphasize too strongly that any arbitrary numbers are not proper goals. The aforementioned ASME Standard APS-1 also recognizes this goal and adjusts the in-stack particulate measurement accordingly. Table D-II should be of interest. It shows the ambient air quality with respect to suspended particles about the Carney's Point, N.J., trench incinerator when burning wood on October 21 and 22, 1966. There is no statistical evidence of any air pollution by particulate emission in these data. In fact, a comparison with Table D-III of data published by USPHS shows what a desirable neighborhood the vicinity of the Carney's Point trench incinerator is.

TABLE D-I

Run No.	Particulate Emission (grains/scf) Measured	Corrected to 12% CO_2
1	0.0202	0.124
2	0.0193	0.200
3	0.0418	0.500 (see note)

Note: Run 3 not valid. Front wall of incinerator knocked down prior to test which destroyed air flow pattern.

TABLE D-II

Sampling Station		Particulate Collected (micrograms/cu m) Run 1	Run 2	Run 3	Run 4
354 ft West	(upwind)	8.52	9.16	8.79	7.21
510 ft South	(upwind)	9.39	10.87	15.08	9.52
360 ft East S.W.	(downwind)	10.30	6.75	14.64	6.27
258 ft North	(downwind)	11.31	7.58	15.97	7.17
Incinerator Operating		No	Yes	Yes	No

Source: Leonard S. Wegman Co., Consulting Engineers

TABLE D-III

Location	Suspended Particles (micrograms/cu m) Minimum	Maximum	Mean
Wilmington, Del.	68	621	168
Philadelphia, Pa.	73	308	156
Atlantic City, N.J.	31	142	79
Kent County, Del.	23	105	56
Cape Vincent, N.Y.	12	62	30
National	5	710	108

Source: USPHS "Air Pollution Measurements – 1963"

AUTHORS' CLOSURE: In his discussion of our paper Mr. Engdahl raises a question concerning the possible misleading effect of the value given for nitrogen oxides when burning cord wood and states that it is not appropriate to compare this value with values from tests run when burning more difficult to burn waste materials. We have to agree with this point but cannot, unfortunately, provide any further information concerning the validity of his comment. Due to the nature of the sampling and analysis procedure for nitrogen oxides, it was not possible to obtain instantaneous values of the NO_x concentrations during burns; and our data is difficult to relate to other variables. We think that the emissions are probably higher than from other types of combustion units because the rapid quenching rate of the gases may tend to freeze the nitrogen oxides at a nonequilibrium value, which is higher than would be expected. We will attempt to define more accurately the nitrogen oxide emissions during our next series of burns.

We are in full agreement with his discussion concerning the particulate emissions from the trench incinerator. We would like to stress the concept that the trench incinerator can reasonably be used for low ash materials and that its sensible use will be a step forward beyond open burning, which should be emphasized. Mr. Engdahl has correctly interpreted the data as demonstrating that, as with any process, the trench incinerator is not a panacea and that its application must be carefully considered before it is decided that it is a suitable means for disposal of a particular waste material.

The discussion of our paper by Mr. Monroe raises a number of questions concerning the validity of our test procedures and data which we would like to answer as briefly as possible.

First, perhaps the most serious statement is that we ignored existing data from a series of tests on a full-scale unit at Carney's Point, N.J. We did not, in fact, ignore the available data but rather considered the entire report on the Carney's Point test series and made appropriate use of the information available to arrive at the 0.5 grain/scf value reported. Specifically, the equipment used to acquire particulate samples during this series of tests was of two different designs and, not surprisingly, produced two entirely different sets of data, as is illustrated in Table I. The train designated as NCAPC was a conventional probe, fiberglass mat, impinger-condenser train of the type normally utilized for accurate testing of emission sources. The train, identified as high volume, is less common in this type of application and, of primary significance, utilizes a woven bag having a much higher tare weight than the fiberglass mat utilized in the NCAPC train. This large tare weight makes determinations of accurate weights for small loadings of particulate extremely difficult and, as the author of the Carney's Point report states, "Accurate weights were difficult to obtain with the large bag filters . . . . When positive weights were not measurable the particulate was removed from the bag by shaking. All of the particulate could not, however, be recovered this way." As indicated in Table D-I of Mr. Monroe's discussion, the as measured loadings were in the range of 0.02 to 0.04 grains per standard cubic foot, and it is obvious that the total weight of particulate collected would be small under these circumstances.

It is also apparent that the data derived from the NCAPC trains reflects the problem relating to the collapsed firebrick wall for Test 3, which Mr. Monroe refers to in his discussion. The data from the NCAPC trains demonstrate that the effect of the collapsed wall was not as serious as indicated by him. Furthermore, the data show that emissions during Tests 1 and 2 do not meet the USPHS goal referred to in his discussion (which we assume to be the 0.2 grains per standard cubic foot given in Executive Order 11282).

It is also interesting to note that of the other parameters measured both at Carney's Point and in our pilot scale work, the measured unit temperatures and the calculated burning rates are in good agreement when burning a similar fuel, as are the particulate emission data. It can, therefore, be concluded that the two units operated under essentially similar conditions. The latter statement also has relevance to the question raised as to whether the characteristics of a true trench incinerator were retained after hooding the pilot scale unit. We have never felt that the addition of the hood significantly altered the operation of the unit, since the fairly large mass of the hood is capable of absorbing heat from the unit and reradiating it to the atmosphere. While this may not be identical to the radiation losses from an unhooded unit, the data cited indicate that for all practical purposes operation is the same.

Second, a large portion of the paper is devoted to a discussion of the requirements for good combustion

and recognized standards for testing combustion units. We agree with the theoretical discussions presented but, to our knowledge, the discussion is irrelevant to the trench incinerator and, hence, our paper. Information available to us indicates that the trench incinerator is presently being used as a batch or semibatch type process and would be expected to have emissions which are representative of this type of operation. It would, therefore, be entirely inappropriate to determine the emissions from a trench incinerator under continuous operating conditions and using procedures, which are recommended for determining the efficiency of large power boilers. Our basic philosophy is that any emission test of a process should be conducted under normal operating conditions for the unit, and that the test equipment and procedures must be adapted to get accurate results under prevailing conditions.

Third, we agree with Mr. Monroe that this was not the time or place to discuss the inadequacies of correcting results from combustion sources. While there may be questions relating to the 12 per cent CO_2 correction factor utilized in our paper, it should be noted that for the vast majority of combustion sources the correction will produce results which are consistent with other methods. For example, assuming 7500 Btu/lb of cordwood, the range of the emissions calculated as pounds of particulate per million Btu was from 0.3 to 0.8 for the pilot scale unit. When related to emission factors for other combustion sources expressed in the same dimensions, these values are equally as high as the values corrected to 12 per cent CO_2.

Finally, we do not wish to enter into an extended debate with the author concerning air quality data and its relationship to emissions from the trench incinerator. It should be obvious that the subject of atmospheric dispersion of pollutants is far too complex to be treated by placing several samplers in the immediate vicinity of an emission source and assuming that the results obtained are related to that specific source.

TABLE D-IV

Driftwood Burning Tests -- Carney's Point, N.J.

January 10 & 11, 1967

Sampling Procedure	Grain Loading @ 12% CO_2		
	1	2	3
NCAPC	0.46	0.40	0.61
High Volume	0.05	0.10	0.44