Electrostatic Fly Ash Precipitation for Municipal Incinerators
A Pilot Plant Study

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Abstract

Pilot plant tests on a 220 ton-per-day continuous feed municipal incinerator demonstrates the technical feasibility of electrostatic precipitation for control of stack emission. Data on the nature of the furnace stack gases and the physical characteristics of the dust as well as performance of a pilot unit treating approximately 600 cfm are presented.

Part I Trends in Refuse Disposal by Incineration and Air Pollution Control

Introduction

In a study for the Capitol Region Planning Agency, East Hartford, Conn., Goodkind and O’dea, and Leonard S. Wegman [1] have reported that production of refuse, which is closely related to population, has grown over twice as fast as the population due largely to the increased per capita consumption of paper products. For example, total refuse production in the Capitol Region in 1950 was 292,000 tons; in 1962 it was 489,000 tons, an increase of 67 per cent during a period in which the population increased from 469,000 to 611,000, an increase of only 30 per cent. The present typical value of 1600 pounds per capita per year consists of 1150 pounds combustible refuse and 450 pounds noncombustibles.

Just as striking as this trend on increased per capita production of refuse is that indicated for rapid exhaustion of available disposal land within practical limits of population centers. Of the 28 communities in the Capitol Region, 8 towns will have exhausted disposal land by 1965; 18 by 1975; and by 1985, 21 of the 28 will have disposal land deficiencies. But a reduction of 65 per cent in these land deficiencies could be achieved by shifting present open dump and similar operations to incineration – the controlled reduction of combustible refuse by burning at high temperatures without nuisance.

The increase in the general population, the increasing rate of refuse generation per capita, and the decreasing availability of suitable disposal land, all combine to indicate little doubt that incineration will become more and more the dominant method of disposal of refuse over the available alternates of open dumps, open burning and sanitary landfill. Further, it appears that the trend in incineration will be toward larger efficient operations located close to population centers, on either a municipal or regional basis, in order to reduce operating and hauling costs. European practice appears to give strong support to these conclusions. Effective control of this source of atmospheric pollution is thus an important goal.

Present Methods of Control and Their Effectiveness

Three methods of control have been in use in the United States for the control of air pollution emanating from large (in excess of 50 tons per day) moving grate incinerators: 1) Underfire air, 2) settling chambers
or combined settling chamber-spray coolers, and 3) mechanical collectors. To these may be added a fourth, electrical precipitators, which are used commonly in Europe [2], [3] but not in the United States.

Stenberg, et al. [4] have reported emissions from a 250 ton per day traveling grate continuous feed municipal incinerator were reduced from 4.5 pounds per 1000 pounds flue gas corrected to 50 per cent excess air (#/1,000 PGEA) to approximately 3.0 #/1000 PFG 50 per cent EA by reducing underfire air from 40 SCFM/sq ft grate to 20 SCFM/sq ft. It is interesting to note, however, that even at considerably reduced underfire air, these loadings taken at the furnace exit, and before any settling chambers and/or spray coolers, are considerably in excess of most codes in the country today. It is also important to note that the levels of underfire air required for efficient combustion in the large, modern traveling grate incinerator appear to be on the higher end of the range studied by Stenberg and thus could result in loadings of 3 to 4 #/1000 PFG 50 EA even after the settling and/or spray chambers [5]. It thus appears that the use of reduced underfire air as a means for air pollution control is quite limited and cannot be relied upon as the only means for effective air pollution control.

The use of settling chambers, or combined settling chamber-spray coolers, is almost universal in the large traveling grate furnace installation. The real function of these devices as dust collectors is obscure at present. It appears that their primary function is to provide additional combustion time for entrained particles and that dust collection is a minor and contingent benefit. Some estimates have indicated loadings leaving the furnace may be reduced as much as 50 per cent in systems using many baffles and substantial water in the form of sprays for cooling. However, Stenberg [6] reports a collection efficiency based on actual tests of only 11 per cent in a two pass baffle/spray chamber on a 50 ton per day unit. Thus, even with the most optimistic viewpoint on the collection efficiency of settling and/or spray chambers, it is clear—and generally conceded—that they are not a satisfactory solution from the standpoint of quantitative emission code requirements.

Although the use of mechanical collectors for control of air pollution from municipal incinerators is fairly common, the paucity of reliable published information on their effectiveness is striking. Lenihan [7] has implied successful use of involute collectors and wetted-wall cyclones for municipal incinerators in a general paper, but no performance figures are given. Hayden [8] reports on the use of a centrifugal collector on a pair of 75 ton/day Morse-Boulger cylindrical furnaces, where efficiencies of 99 per cent on all entrained matter are indicated. Test data presented in support of this performance appears to indicate that the total dust entering the collector from the furnace was in the range of 0.196 #/1000 PFG 50 EA which, on the basis of data from all other sources, would not be a reasonable value for larger continuous feed multiple chamber incinerators.

Information from unpublished sources would appear to indicate that mechanical collectors of the involute or multiple vane-type cyclone type are less than satisfactory for control of this source to meet existing codes. For example, in a study for the City of New York, Battelle Memorial Institute [9], reported efficiencies of only 13 to 23 per cent from tests on a typical vane-type multitube collector installed on a large continuous feed incinerator.

It is apparent that the combination of expressing stack emissions or codes in terms of pounds per thousand pounds flue gas corrected to 50 per cent excess air, and the high temperatures and cooling excess air associated with this combustion process, tend to lend validity to the assertions of effective control which is apparently based upon stack appearance. Thus, if we assume a reasonable loading entering the collector of 2.0 #/1000 PFG 50 EA, when one corrects this value to actual concentration at stack air conditions of 700°F and 400 to 500 per cent excess air, one comes up with a loading of approximately 0.10 grains/ft² at stack conditions. This loading of particulates having a size consisting of approximately 45 per cent less than ten microns, will not appear to be a very bad stack even with no collection of ash whatever. As a result, collectors of even minimal performance may be presented as effectively meeting the requirements of dust loading codes, when actually they are not. The fact that this situation has been allowed to exist is more related to the question of whether quantitative emission codes for other combustion processes are applicable to the incinerator, than to the purely technical question of whether the actual incinerator emission does or does not exceed an existing quantitative emission code. On this latter purely technical basis, it appears that because of the lack of published data, one cannot reach a firm conclusion on the adequacy of mechanical collectors to meet typical emission codes of 0.85 #/1000 PFG 50 per cent EA. However, there is a strong suggestion that their use, even under the most optimistic circumstances, is marginal.

Potential Methods of Control

Three technically feasible alternatives to present methods of control suggest themselves as potential, practical solutions to the inevitable demand for higher dust collection efficiencies in the municipal incinerator: Electrostatic precipitation; bag filtration; and wet scrubbing. Of these, wet scrubbing is probably the
least attractive primarily because of the psychological aspects of condensate plumes from structures located close to residential areas. Present day systems, for this reason, utilize relatively inefficient cooling with ambient air in order to limit stack gas moisture content to a point where condensate plumes are minimized, except under the most severe atmospheric conditions.

Part II The Pilot Plant Study
Purpose and Objective of Study

In addition to confirming the conclusions on the increased use of incineration as the primary means of refuse disposal, European practice seems to point to electrostatic precipitation as an effective means of air pollution control from these sources. However, differences in practice with regard to generation of steam and the use of auxiliary fuels make direct application of European experience to United States problems somewhat questionable. For this reason the pilot plant investigation to be reported was undertaken. In January, 1962, Research-Cottrell, Inc., Bound Brook, New Jersey, under contract to the Department of Public Works of the City of New York undertook to perform a pilot plant study on the use of electrostatic precipitation for control of particulate emissions from large continuous feed municipal incinerators. The objectives of the program were: 1) to establish the effectiveness of electrostatic precipitation for this process, 2) to establish the necessary parameters for the design of full-scale installations.

Description of Installation and Test Techniques

Fig. 1 is an elevation of the general furnace arrangement. The furnace upon which the tests were run has a rating of 220 tons per day. It is a continuous feed incinerator equipped with traveling drying stoker and traveling burning stoker. Both forced draft and induced draft are utilized. Combustion air is primarily automatically controlled forced draft below the burning stoker, although manually controlled overfire air is utilized for furnace temperature control. The gas cooling system consists of automatically controlled air dilution ports and spray nozzles. Louvre damper control of air dilution and spray nozzle bank operation are controlled on the dust collector inlet temperature at approximately 600°F. Operation of the furnace is continuous, 24 hours per day, over the normal weekly operating cycle of five days per week.

The pilot plant was installed to treat approximately 500 to 1000 ACFM of gas leaving the cooling chamber before it entered the existing multiple tube mechanical dust collector. A sampling manifold was installed in the cooling chamber outlet duct at Plane AA of Fig. 1. It consisted of three inlet nozzles located in the center of three areas of equal cross section sized for isokinetic conditions at the mid-point of the gas volume range to be studied. Gasses passed through a vertical flow, multiple pipe type pilot precipitator, a centrifugal fan, and then re-entered the cooling chamber outlet duct at a point downstream of the inlet nozzles in the sampling header. The system was equipped with flow control dampers, sampling stations, etc.
necessary for obtaining desired operating conditions and test data.

A general arrangement of the pilot plant is shown in Fig. 2. Gas volumes were determined by pitot tube traverses at points A and B of Fig. 2. Sampling for determination of dust concentration and pilot precipitator collection efficiency was carried out simultaneously at points C and D of Fig. 2. The extraction technique was utilized for establishing dust concentration. This method consists of isokinetically drawing a sample of dust laden gas through a nozzle into a pre-dried and pre-weighed alundum extraction thimble and monitoring the quantity and conditions of the gas passing through the extraction thimble with a suitable positive displacement gas meter equipped with thermometer and mercury manometer. From the accumulated weight of extracted dust, and quantity and condition of sampled gas, the concentration in weight per unit volume of gas sampled is obtained. Moisture determinations were made by the condensate method. These techniques all conform to ASME Power Test Codes 21 and 27.

Results of dust concentration tests on both pilot precipitator inlet and outlet were calculated in terms of grains/CF dry gas at standard conditions (32°F and 29.92 in. hg), as well as in terms of pounds per thousand pounds flue gas corrected to 50 per cent excess air (e/1000 eFG 50 per cent EA). These latter values were calculated from the former on the basis of an average actual excess air of 358 per cent at the cooler outlet as determined in previous tests on this furnace and the average actual gas temperature measured at the pilot precipitator inlet. Dust samples for subsequent laboratory analysis of physical characteristics were obtained using high volume samplers in order to provide sufficient dust for the analyses. These high volume samplers, which were operated at isokinetic conditions via the null method, consisted of a one inch nozzle, a small high performance cyclone, and a cloth bag filter in a commercially available integrated assembly complete with exhaust blower. This method and apparatus also conforms to ASME Power Test Codes 21 and 27.

Laboratory analyses for particle size distribution, specific gravity, loss on ignition and bulk electrical resistivity were performed in conformance with methods presently under consideration as future ASME and APCA Standards [10].

FIG. 2. GENERAL ARRANGEMENT OF PILOT PLANT

(A) Inlet Pitot Tube Station
(B) Outlet Pitot Tube Station
(C) Inlet Dust Sampling Station
(D) Outlet Dust Sampling Station
(E) Dust From Cooling Chamber (Plane AA-Fig. 1)
(F) Sampling Manifold
(G) HV Rectifier and Controls
(H) Dust Hopper
(I) Pilot Electrostatic Precipitator
(J) Flow Control Damper
(K) Return Duct
(L) Fan & Motor Assembly
Results

A total of 24 tests were completed during the period from May 9, 1962 to June 6, 1962. During this period the average daily refuse incineration rate was 220 tons/day; the maximum rate was 240 tons/day and the minimum rate 160 tons/day. Incineration occurred at the average rate of 65 per cent of the total days tested and dropped below the average rate only one day during this period. Refuse consisted of combined material from private and Department of Sanitation sources. Over the test period, the percentage of refuse from private sources averaged 44 per cent, with a maximum of 58% and a minimum of 14 per cent.

Table I summarizes results obtained on temperatures in the combustion chamber (Point B on Fig. 1), temperatures leaving the cooling chamber (Point C on Fig. 1), and humidity and dust concentration leaving the cooling chamber as determined by sampling in the pilot precipitator inlet flue (Point A on Fig. 2). These figures represent the stack conditions in the absence of any dust collector.

Dust samples obtained with the high volume sampler were examined visually and microscopically. The ash is quite heterogenous and consists of a rather typical fly ash fraction combined with large (approximately 1/16 in.) low density carbonaceous flakes apparently resulting from incomplete combustion of paper products. Attempts to make resistivity determinations and particle size analyses yielded unsatisfactory results until dust samples were pre-sieved on a 300 micron screen. Results of this pre-sieving showed 92.5 per cent by weight of the total ash to be less than 300 microns in size.

Terminal velocity analysis of the minus 300 micron fraction was determined using a Balco centrifugal classifier and converted to particle size distribution on the basis of the actual specific gravity of the total sample of 3.01 grams/cc. The results of these analyses are shown in Figs. 3 and 4. Fig. 3 indicates the cumulative size distribution by weight of the total sample. It will be noted that approximately 45 per cent of the ash is less than 10 microns, a figure closely approximating fly ash from a typical pulverized coal fired boiler. Fig. 4 indicates the bulk electrical resistivity of the minus 300 micron fraction of the ash as a function of temperature at a constant humidity of 10 per cent by volume which approximates the conditions at the cooling chamber outlet.

A total of 17 complete tests for pilot precipitator efficiency were completed in the examination of the principle other fundamental variables affecting precipitator operation. These tests were run in three groups according to average operating voltage for the test series. Results are shown in Table II.

As can be seen, the capability of electrostatic precipitation to function at efficiency levels in excess of 90 per cent on fly ash from large continuous feed municipal incinerators has been demonstrated. This level of performance makes technically feasible the reduction of stack effluents to levels well within any quantitative emission codes now in existence.

Pilot plant data were analyzed in terms of the generally accepted equation for single stage electrical precipitators,
FIG. 4. LABORATORY BULK ELECTRICAL RESISTIVITY OF MINUS 300 MICRON DIAMETER FRACTION OF ASH LEAVING COOLING CHAMBER AT CONSTANT HUMIDITY OF 10% BY VOLUME.

Table II
SUMMARY OF ELECTROSTATIC PRECIPITATOR PILOT TEST RESULTS

<table>
<thead>
<tr>
<th>Test Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Tests</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Precipitator Inlet Temp. °F</td>
<td>491</td>
<td>500</td>
<td>493</td>
</tr>
<tr>
<td>Precipitator Inlet Moisture-% by Volume</td>
<td>15.0</td>
<td>17.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Precipitator Inlet Dust Concentration - Grains/CFNTP</td>
<td>0.210</td>
<td>0.221</td>
<td>0.217</td>
</tr>
<tr>
<td>Precipitator Inlet Dust Concentration - #/1000 # FG 50% EA</td>
<td>1.10</td>
<td>1.17</td>
<td>1.14</td>
</tr>
<tr>
<td>Precipitator Outlet Dust Concentration - Grains/CFNTP</td>
<td>0.0125</td>
<td>0.0127</td>
<td>0.0224</td>
</tr>
<tr>
<td>Precipitator Outlet Dust Concentration - #/1000 # FG 50% EA</td>
<td>0.066</td>
<td>0.066</td>
<td>0.118</td>
</tr>
<tr>
<td>Precipitator Collection Efficiency - per cent</td>
<td>94.0</td>
<td>94.4</td>
<td>89.5</td>
</tr>
<tr>
<td>Precipitator Operating Voltage-KV Peak</td>
<td>47</td>
<td>45</td>
<td>35</td>
</tr>
</tbody>
</table>

\[ E = 1 - e^{-\frac{A}{\nu} w} \]  
(1)

where \( E \) = fractional collection efficiency

\( A \) = total surface area of collecting electrodes

\( \nu \) = total volume throughput at actual conditions

\( w \) = theoretical particle drift velocity

(or effective precipitation rate parameter)

and the effective precipitation rate parameter established for the conditions of this application.

Practical and Economic Aspects

While the duration of the pilot plant operation was insufficient to allow any firm conclusions, there were indications that proper engineering of ash removal systems, and attention to material selection from the standpoint of corrosion, are important factors in the practical design of precipitators for this service, at least until such time as auxiliary fuels are used during periods when refuse is unavailable. However, experience gained in the pilot plant appears to indicate that nominal practice with respect to electrode rapping, ash transport, heat insulation, material selection, etc., will suffice for application of electrostatic precipitators to the larger incinerators where close control of combustion conditions and exit temperatures is utilized.

As is evident from (1) the value of the rate parameter \( w \) determines the precipitator size required to obtain a desired collection efficiency on a given quantity of gas. And since precipitation size is obviously related to cost, the rate parameter \( w \) establishes the economics of this mechanism of cleaning.

As a general orientation to anticipated capital investment for uninstalled equipment of this type, approximate costs based on the rate parameter \( w \) established in the pilot tests and a collection efficiency of 90 per cent are shown in Fig. 5.

Conclusions

1) Incineration will become more and more the dominant means of refuse disposal in the United States.

FIG. 5. APPROXIMATE INITIAL UNINSTALLATED COST OF 90% EFFICIENCY-ELECTROSTATIC PRECIPITATORS FOR CONTINUOUS FEED MUNICIPAL INCINERATORS AS A FUNCTION OF FURNACE SIZE.
2) Methods now used for control of air pollution from this source are, at best, marginal for meeting quantitative emission requirements of present day air pollution codes.

3) Trends in incinerator design and in air pollution legislation will place even greater demands on performance of air pollution control equipment.

4) The feasibility of operating an electrostatic precipitator in excess of 90 per cent collection efficiency has been demonstrated on straight refuse incineration.

5) Practical design parameters for the application of the electrostatic precipitator to large continuous feed incinerators have been established.

Acknowledgment

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References


"Specifications for the Design of Electrostatic and Combination Fly Ash Collectors: Methods of Analysis of Physical Chemical and Electrical Characteristics of Fly Ash," proposed.