Flyash Control Equipment
for Municipal Incinerators

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Abstract

A description is given of settling chambers with sprays, cyclone types and electrostatic precipitators as used in municipal incinerators. Special emphasis is placed on selection and duct design especially to inlets of collectors which affects efficiency. Importance is stressed on preventing leaks and overfilling of hoppers and proper maintenance of equipment in order to obtain optimum efficiency. Control of air pollution is best accomplished by thorough burning in combustion chamber and thus decrease load to flyash control equipment.

Introduction

The municipal incinerator designer is confronted more than ever with the problem involving greater care in the selection of collection equipment for municipal incinerators due to more stringent air pollution codes and regulations. For example, in the new code being proposed by the Department of Air Pollution Control of the City of New York emission in refuse burning equipment shall not exceed 0.65 lb for each thousand pounds of dry gas. This is as measured in the flue and adjusted to 50 per cent excess air or calculated to 13 per cent carbon dioxide. There is a further stipulation that not more than 250 pounds of particulate matter be emitted in any 60 minute period.

Part of the above proposed code is taken from the model ASME air pollution control ordinance. All codes based on this model place a limit on the concentration (not the total quantity) of dust which may legally be entrained in the gases emitted to the atmosphere. This limiting concentration in the model code is set at 0.85 pounds of dust per 1000 lb of gas or some mathematically equivalent concentration. This code concentration is approximately equivalent to a concentration of 0.25 grains per cubic foot of flue gas at 500 F.

The ASME model air pollution ordinance was originally intended to apply to coal burning boiler plants. For that reason, the limiting dust concentration is tied to a flue gas composition of 12 per cent carbon dioxide. The purpose of tying in the phrase “adjusted to a certain percentage of excess air or having the excess calculated from the percentage of the carbon dioxide of the flue gas” is to refer tests to common bases. As test sampling is on a volumetric basis, the combustion gases must be calculated by reducing everything to a comparable basis in order that the result be to a common standard.

An entirely different type of code, from the dust emission standpoint, was promulgated by Los Angeles County. This code defines the total quantity of dust which may legally be emitted to the atmosphere. This varies according to the total quantity of solid material entering the process. The allowable percentage decreases on a sliding scale so that the allowable discharge runs from 0.24 lb/hr for a process weight of 50 lb/hr to a maximum allowable discharge of 40 lb/hr for process weights of 30 tons/hr and greater. This is very strict and is due to Los Angeles special requirements as there are a great number of inversions.

In order to cover the subject it will be necessary to
briefly explain the basic types of dust collectors. These are gravity settling chambers with or without sprays, cyclone collectors, wet scrubbers and finally bag type and electrostatic precipitators. It is unfortunate that few municipal incinerators in this country have installed commercial dust collecting equipment supplied by reputable dust collector manufacturers. Many have water sprays in settling chambers and are called scrubbers. If they are not properly designed they cannot do an efficient dust collecting job as the dust in the flue gas has very little contact with the water spray.

**Gravity Settling Chambers**

These are very inefficient devices and application is limited to the collection of particles larger than 200 microns which are called **brick bats**. The analysis of flyash consist from a large incinerator will show approximately 50 per cent of particles of 50 microns, so it is evident that this type of device cannot meet present day codes.

A definition of a micron might be in order at this time. A micron is a linear dimension equal to one millionth of a meter. This is equivalent to 1/25,000 of an inch. The smallness of a micron can best be visualized by noting that a human hair is approximately 80 microns and the point of a sharp needle is 20 microns in diameter. To most persons, a 20 micron particle cannot be seen by the naked eye.

A simple gravity settling chamber is shown (Fig. 1) with pertinent flow data. A dust particle near the top of smooth air stream in order to be entrapped must fall at least to the lower level of the outlet pipe. For example, a 30 micron particle will settle in air at approximately 10 ft/min, a 10 micron particle approximately 1.2 ft/min. In the illustration it is assumed that a 200 micron particle is involved and traveling in a forward velocity of 375 ft/min or 6-1/4 ft/sec. The falling velocity of this 200 micron particle is 68 ft/min according to Stokes Law which states “The terminal velocity of finely divided particle under the action of gravity in still air quickly attains a definite velocity and then continues to fall at this velocity.” From this sketch, it is evident that every foot of vertical drop requires 5-1/2 ft of length.

The dry baffle (Fig. 2) or inertia separation chamber depends on the reversal of gases around or under baffles. The abrupt change of gas direction at the baffles can cause separation of the dust by impingement. However, the velocity of the gas will pick up and carry along with it any particle which has a lower settling velocity. The efficiency of settling chambers varies between 30 and 40 per cent in collection unless the dust is very coarse.

**Scrubbers**

The simplest type of scrubber is a water curtain. Sprays of water in either the settling chamber or in special chambers cannot be called scrubbers unless the spray pattern captures all the particles in the full area of the gas stream. This condition is difficult to obtain in practice as a very fine spray at high pressures is required. Unfortunately, the droplets tend to unite into a larger body or mass after leaving the spray nozzle, thus reducing the effectiveness in collection.

To remove fine flyash particles a fine spray through fog nozzles is required which in turn requires high pressure atomization of the water to form a fog rather than droplets of water. The most efficient type of scrubber is the venturi type which draws the water and gases through narrow venturi sections at high velocities. This
type is not practical for municipal incinerators as the volumes to be handled are high. This means a high initial cost and high operating cost due to high draft loss.

Another type of commercial scrubber is the flooded type as shown in Fig. 3. The flue gases pass upward through holes in the first plate and impinge on the grid directly above which has a water seal over the holes and the ash is separated by a combination of impingement and wetting. Fig. 4 shows a commercial scrubber in which the incoming gas is jetted into a scrubbing bath, then is passed over spray-eliminator baffles before being discharged. This would seem to be practical as a typical New York City incinerator handling 250 tons per day has a volume of 160,000 CFM at 700 F. To handle this quantity would require three units as shown, each handling 64,000 CFM. There would be an 8 in. pressure drop and it would require 1/2 gallon per minute of water per 1000 CFM handled. This represents 95 gallons per minute for the 250 ton unit.

Although the ash laden water is cleaned by settling, make up water must still be used. The saturated exhaust gases leaving the scrubber in cold weather have a long white plume which is many times complained about since some people believe that this is smoke. On the other hand, the scrubber has the benefit of partially absorbing odors and some oxides of nitrogen and sulphur dioxide.

The collection efficiency of an efficient wet scrubber designed and installed by a commercial organization, comprising of steel shells with suitable baffles and sprays can reach 97 per cent. For wet baffles where the dust laden air impinges only on the wetted surface and is carried away by flumes the efficiency may vary between 60 to 80 per cent. It is surprising to see a chamber in which nozzles or shower heads are installed in a haphazard manner called scrubbers. In most of these so called homemade designs the water does not even come in contact with more than 10 per cent of the dust laden air in the stream.

**Cyclone Collectors**

Cyclone or mechanical collectors usually consist of a number of small tubes from 6 to 10 inches in diameter contained in a common housing with a common dust collection hopper, or of large diameter up to 48 in. in size for high efficiency type with long cones designed by reputable dust collector manufacturers. This does not mean the tin cyclone type used by wood working industries which would be unsuitable for the collection of flyash as each tinsmith has his own ideas on cyclone design with the help of a how-to-do-it book.

This paper will deal more with the cyclone types and will point out some of the pertinent facts that may be helpful in understanding cyclone operation. It is the writer's opinion that the large diameter varying from 26 to 40 inches will be used to a greater extent in the future in large municipal incinerator applications and followed by an electrostatic precipitator when extremely high efficiency is required. A combination mechanical electrical collector could have an efficiency of over 99 per cent and would have a nearly invisible plume leaving the stack.

The small diameter cyclones are known as axial inlet (Fig. 5) type. With this type, it is practically impossible to achieve uniform distribution to the individual cyclones. It can be seen that the rear cyclones have a tendency to carry a disproportionately heavy share of the dust loading. Due to the close nesting a reverse flow can very easily be set up in some cyclones and funnel dust into the clean gas exhaust of adjacent cyclones if there is a difference in pressure at the cyclone dust outlets due to mal-distribution of gases to the inlets. The particular cyclone having the lower pressure at the dust outlet will discharge more gas from the hopper than enters through that cyclone. Unless this type of cyclone handles dry
dust which does not have any tendency to stick, trouble can be expected. For this reason, the axial or small diameter cyclone should not be used on incinerators where water sprays are used for cooling due to the tendency of plugging at the inlets.

The plugging of spinner vanes due to build-up of flyash deposits can become a major maintenance problem. The ease with which spinner vanes can plug, will be appreciated by noting the small area of the individual openings as shown in the upper left-hand side of Fig. 5 of the multiclone collectors.

In the proceedings of the conference on the Mechanical Engineers Contribution to Clean Air in 1958, investigations (Fig. 6) were made on the effect of individual tubes plugging in a multitubular type unit with regard to that unit's efficiency. The information was obtained from an 16 tube unit and the test points were with no tubes plugged, 1, 2, 4, and 8 tubes blocked. The data is contained in the attached curve. The basic efficiency of the test unit with no tubes blocked was 89.8 per cent. It will be noted that if one half of the tubes are blocked the efficiency falls to 17 per cent.

Large diameter efficient cyclones (Fig. 7) manufactured by commercial dust collector manufacturers are recommended for municipal incinerators as they are virtually plug proof. For example, a cyclone handling 8000 CFM (equivalent to 15 – 10 in. multi-tubes) would have an inlet with an inside dimension of 13 in. wide by 29 in. high. The diameter of the top would be 44 in. with the lower cone diameter of 15 in. Openings of this size are hard to plug especially with the velocities involved of 3600 ft/min. or 60 ft/sec inlet velocities.

The advantages of locating the gas inlet on side of the cyclones with split-duct manifold permits each cyclone to handle its proportionate share of the dust loading (Fig. 8) so that the inlet velocity is equal to the velocity within the individual cyclone. Due to the large size of the individual cyclones the cones and other wearing parts can be refractory lined. This is usually accomplished by enlarging the section and using hexsteel with refractory abrasion resistant concrete as a lining to minimize wear in the cone section.

Properly designed cyclones would have no difficulty in meeting a typical code if properly installed and operated. For example, a test was made on a New York incinerator which has a 250 ton per day rating. The Emission Rate Potential was established at 427 pounds. The Current Guides for Prevention of New Air Pollution, dated June 1962, issued by the Council of Technical Advisors to the New York State Air Pollution Control Board, established flyash as a Class F Contaminant. Under such conditions the collection efficiency required would be from 80 to 90 per cent.

The inlet loading from an incinerator of this type will vary up to 1 grain per cu ft. A collector having an efficiency of 85 per cent would then collect 0.85 grain with 0.15 grain per cu ft of gas escaping to the atmosphere. This figure works out to 0.52 pounds of dust per 1000 pounds of flue gas at 500 F.
Mechanical collectors are not as sensitive to velocity changes as is generally imagined. This can best be illustrated by the curve in Fig. 9 which plots efficiency vs. inlet velocity. This is based on a collection efficiency of 90 per cent of cyclone. It will be noted that 60 ft/sec inlet velocity is the design point and there is less than 4 per cent change in efficiency when the velocity is reduced or raised by a third of the rated volume. This small change would be of no consequence so that the cyclone could be satisfactorily operated if the range is 1/3 above or below the CFM rating. In other words, a cyclone designed to handle 9000 CFM could successfully handle volumes of from 6000 CFM to 12,000 CFM.

Raising the inlet velocity increases the efficiency of the cyclone slightly but the draft loss increases as the square of the volume. Thus, if a cyclone has a draft loss of 3 in. W.G. at the design point, when velocity is doubled, the loss will increase to 12 in. W.G. Also there would be twice the wear due to the increase in amount of dust. At one half load the efficiency would drop 11 points to 79 per cent instead of the 90 per cent at normal load. With further decrease in load, the efficiency falls off sharply to the inlet velocity of 10 ft/sec in the cyclone. The efficiency then rises as the cyclone acts as settling chamber.

In order to determine the efficiency of settling chambers and cyclones the micron sizing or consist of the dust must be determined. This consist will vary from moment to moment within a certain range in dust collection work, and is broken up in per cent fractions of between 0 – 10 microns, 10 – 20 microns, 20 – 43 microns, and plus 43 microns or dust particles that will be retained on a 325 mesh screen. This is the finest commercial screen made and will hold water. The Screen Scales to equivalent micron size is shown in Fig. 10.

The equivalent micron sizing is determined by the settling velocity in accordance with Stokes Law which states, “that a falling particle under the action of gravity in still air quickly attains a definite velocity and then continues to fall at this velocity.” This differs from Newton’s Law for heavier masses which continues to accelerate. Particles under 200 microns or 60 mesh equivalent screen scale fall under Stokes Law whereas the larger particles fall under Newton’s Law.

Micron sizing is now mainly done by using the tube analyzer which uses a nitrogen atmosphere and controlled apertures for velocities. This method can analyze a dust sample in less than one half of an hour. The air elutriation method (Fig. 11) formerly used by a large dust collector manufacturer best illustrates Stoke’s Law and micron sizing.

The apparatus consists of a pump, filters, drying train and an orifice air flow gauge. Three glass settling tubes and a glass receiver for the finest dust fraction are connected in series. Assuming a dust of a specific gravity of 2.0 in which case a dust particle of 8 microns would have a settling velocity of 5.4 cm/sec in tube “A” while a dust particle of 20 microns would have a settling velocity of 2.6 cm/sec in settling tube “B” and a dust particle of 10 microns would have a settling velocity of 0.58 cm/sec in settling tube “C”. The pressure, in millimeters of oil would be used to determine the air flow necessary through the instrument for effecting settlement in tubes “A”, “B” and “C”, of fractions with a required settling velocity.
Other words, a pressure of 50 millimeters on the air flow gauge will give the following velocity:

- Tube "C" 0.88 cm/sec
- Tube "B" 3.6 cm/sec
- Tube "A" 11.2 cm/sec

After placing the weighed sample of dust in Tube "A" the air flow gauge is set for requisite pressure to give the desired velocities in the tubes. In the meantime, a fresh fabric filter will have been weighed and placed in position on the glass receiver at the outlet of the apparatus.

With everything in readiness, the air blower is started up and the flow regulated. Separation of the sizes immediately begins to take effect and dust from "A" passes to "B" to "C" and from "C" onward to the glass receiver at the outlet. Complete elutriation of an average dust sample takes about 8 to 9 hours. The fractions are then removed and weighed separately and can be broken into percentages of 30 microns, 20 microns, 10 microns and minus 10 microns.

The specific gravity of the dust must be determined as the heavier the dust the easier it is to collect by mechanical means. In dust collection work the specific gravity is the true specific gravity as opposed to bulk density. Generally speaking flyash is taken as a SG of 2.0 whereas its bulk density if computed from its bulk weight, which might be 35 lb/cu ft, would result in a figure of less than 0.6. Therefore, the main interest in dust collection work is the equivalent micron particle whether the particle is long or short and heavy.

Cyclones have fractional efficiency curves as they will collect a certain size particle of a certain specific gravity at a constant rate. A typical fractional efficiency curve of a large diameter is shown in Fig. 12. It will be noted that there is a considerable falling off in efficiency on particles of less than 20 microns. An illustration of how a curve is used for determining efficiency is shown by using an analysis for flyash suspended in a gas stream. This is taken from the specifications for the new refuse disposal plant proposed for the Town of North Hempstead, Long Island. For design purposes, the flyash is assumed to have a specific gravity of 2.0 with the data given in Fig. 12.

This efficiency can be obtained if the equipment is properly designed, installed and operated. More dust collector installations have been rendered ineffective as the result of poor inlet duct connections than for any other reason. Duct work should be designed and installed to get the dust laden gas to the dust collector inlet with minimum effect on collector performance. A gas stream entering a mechanical collector from the left (Fig. 13(a)) will cause most of the gas and dust to be handled by the individual cyclones on the right side of the dust collector.

Handling a higher proportion of the gas, the right side units will incur a higher draft loss and have a lower static pressure at their cone outlet. This in turn creates a recirculation between the units handling a lower volume of gas and those handling a higher volume of gas and thus the dust collector performance will suffer. Turning vanes (Fig. 13(b)) may be inserted in left (or right) bends. These are effective, and in fact reduce draft loss across the bend, but are subject to erosion.

Overfilling of the dust hopper is another major factor which can reduce the collection efficiency of cyclone collectors. Cyclone hoppers can be filled only to a given level. If the level is at or above the cyclone vortex, then the collected dust will be discharged to the atmosphere.

**Bag Collectors**

With the advent of the high temperature bags which are woven of glass fibers and treated with Silicone, there is a good possibility of their increased use in the near future. The silicone acts as a lubricant between the fibers and makes bag collectors practical to withstand temperatures up to 600 F. There has been a tremendous increase in the use of baghouses in the cement industry and these have replaced the electrostatic precipitators as the first cost of a baghouse is considerably less.

A 12 compartment glass cloth collector has been installed in a Southern cement plant in the past few years. This unit handles 190,000 CFM and would be comparable to the volume of gases handled by a municipal incinerator. The effluent leaving the collector is so clean, that a stack was not necessary. This in itself represents quite a saving as 200 ft stacks cost a considerable amount of money.

Bag collectors strain the gas through minute openings and collection is accomplished by the physical inability of a large particle to pass through a small opening. Extremely fine particles can be collected with
FIGURE 12.  // FRACTIONAL EFFICIENCY

high efficiency. This can reach an efficiency of 99.9 per cent. With the attainment of these efficiency there is no visible plume from the stack. It has been established that in order for a plume to be invisible the exit gases must not have more than 0.05 grains per cu ft.

The gases to a high temperature glass cloth bag collector must be free of moisture and therefore a heat exchanger must be used rather than water cooling in order to prevent plugging of the pores. If the stack is to be eliminated by high temperature in the incinerator chamber prior to entering the bag collector, in order to eliminate odor complaints.

Electrostatic precipitators have been used on large installations requiring high dust collection efficiencies. They have the ability to remove fine particles with nearly 100 per cent efficiency and at a low pressure drop. The average pressure through a precipitator is in order of 1/4 to 1/2 in. W. G. This is due to the low velocity in the precipitator which will vary from 2 ft to 10 ft/sec depending on the required efficiency needed. The longer the time in the precipitator the better will be the efficiency as the particle will be under the charging influence with enough time to migrate to the collecting electrode.

As shown in Fig. 14 a precipitator operates by inducing a charge to the dust particles so that they will be attracted to the opposite charged electrodes. Cleaning of the plate is accomplished by rapping or flushing by means of weirs or sprays. Precipitators have a high cost as a large precipitator volume is required due to the low velocities involved. The required electrical equipment is expensive as the voltage must be raised to approximately 75,000 volts and then rectified to dc for operation in the precipitator.

Electric precipitators are especially designed for the particular dust being collected. The low resistance particles have a tendency to lose the charge before they can be captured and the high resistance particles are difficult to charge and escape via re-intrament. For this reason, the resistivity of the dust is important and can be classified roughly by the following groups:

1) Below about $10^5$ ohm cm
2) Between about $10^5$ and $10^8$ ohm cm
3) Above about $10^8$ ohm cm

Roughly, materials in the first group are sometimes
difficult or impossible to precipitate; materials in the second group are capable of precipitation by normal techniques, while materials in third group having a high resistivity can be brought about by conditioning which reduces the resistivity by the addition of moisture or traces of chemicals such as sulphuric acid.

The general conclusion appears that particles of low resistivity on making contact with the collector electrode, rapidly part with their charge and acquire a heavy charge of the same sign as that of the electrode, whereupon they are projected into the gas stream; if resistivity of the dust is high, back corona reverses the normal precipitating action and leads to considerable re-entrainment.

By combining a cyclone collector before the electrostatic precipitator, the cyclones will do the major part of the work and remove most of the particles not readily subject to electrostatic precipitation. Carbon particles have low resistivity which means that the particle loses its charge, before it can be captured on the collecting plates. The curve in Fig. 15 illustrates the effect of carbon on precipitator performance. If the percentage of carbon is increased from 37 to 50 per cent the precipitator size is doubled in order to obtain the same efficiency. For this reason all precipitator manufacturers limit the amount of carbon to not more than 15 per cent in making their guarantees on efficiency.

To the writer’s knowledge there have been no large municipal incinerators equipped with electrostatic precipitators in this country. A very few municipal incinerators have cyclone collectors with the majority of incinerators using so called wet bottoms which are inefficient at heat.

In Europe there are increasing numbers of municipal incinerators in which mechanical and electrostatic precipitators are used. Advantage is taken of the heat of combustion of the refuse by the use of waste heat boilers to generate steam and electricity. This would appear to be a good approach and has the advantage of reducing volume to the collectors by means of heat transfer. This is not true when water or air is infiltrated in order to cool the gases. This type of cooling adds volume to the gases going to the collector and is a detriment as it adds to the first cost of the collecting system.

One might assume that the dust collector limits the operating temperature. This is not so, as cyclone collectors have been operating at temperatures of 1200 F in pyrites plants and electrostatics can operate at temperatures up to 800 F without undue distortion. The limiting temperature in a collection system is that of the fan which is required to overcome the draft loss through the ducts and collectors. Having heavy rotating parts, fans cannot operate over 600 F without danger to the fan rotor which might collapse at high temperatures. Stainless steel fans are not economically feasible due to the large volumes of gases handled in dust collecting systems.

In any process requiring dust collectors, it is best to have the dust loading to the collector as low as possible. This can generally be accomplished by better combustion in the incinerator chamber which means that the collecting system has less quantity of flyash to handle. For example, assuming that the dust collection system has an efficiency of 80 per cent, then if the loading entering the collector is 10 grains per cu ft the collector will capture 8 grains per cu ft and 2 grains per cu ft will escape to the atmosphere. If the grain loading to the inlet of the collector is reduced to 1 grain per cu ft, then 0.8 grains per cu ft will be collected and only 0.2 grain per cu ft will escape the unit. In other words, with a lighter loading to the collector, the efficiency of the collection system can be less and still have an acceptable discharge to the atmosphere.