Fly Ash Control Equipment for Industrial Incinerators

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Abstract
A description is given of the problem facing the engineer when designing an industrial incinerator, referring especially to the treatment of particulate emissions from the incinerator between 35 and 200 microns in size, and to the choice of available commercial equipment which can attain the required results.

Introduction
As air pollution requirements become more stringent, the industrial incinerator designer will be faced with the necessity of using auxiliary equipment to meet restrictions on particulate emissions, which endanger the health and welfare of the public. At the present time, most large cities and industrial counties, have air pollution by-laws, some of which are very exacting, some lenient, and others, for want of public support and money, are not administered within their potential limits. Many councils have enacted by-laws by copying those of other authorities, complete with their errors and omissions. Once on the statute books, they are very difficult to change. There is great need for the standardization of air pollution conditions so that the industrial incinerator designer and manufacturer will not be obliged to maintain several sets of standards to meet the different requirements of many of our large cities and counties. Actually, we are all striving to attain a satisfactory end result at an acceptable price, and the designer should be free, within reasonable limits, to attain that result in the manner that he sees fit.

Most smoke abatement by-laws have a limitation as to particulate emission in relation to the amount of flue gas corrected to 50 per cent excess air, without reference to the total amount of emissions that a plant may exhaust, or a relation of the total emissions to the total area of the plant. There are also references to a limitation of smoke density on the Ringlemann Chart.

Particles of 20 micron size can be seen by some people with the naked eye, but it is more likely that those in smoke of density No. 1 on the Ringlemann Chart will include particles up to 35 microns. We might be free to consider that those particles under 35 microns in size are therefore of secondary importance, for the reason that they will remain in suspension for a very long time in a very slightly turbulent atmosphere.

Also, we must remember that most industrial incinerators are equipped with an integral combustion chamber and settlement basin. This basin has the added feature of having a large cross section at the bottom of a pass of relatively small cross-section. Particles coming down this pass have considerable inertia downwards, and therefore tend to settle out of the gas stream as it turns 90 deg from vertically downward to horizontal. In this chamber, most of the particles of 200 micron size, a large percentage of those of 100 micron size, and some of lesser size are trapped and are likely to remain on the bottom because of the low velocity of the gas. It can readily be
seen, therefore, that our main concern is in the removal of particles between 35 and 100 microns in size.

Dust Separators

One characteristic is common to all types of dust separators. Each particle must be acted upon by some force which does not act upon the entraining air, or acts upon it in a different or lesser degree, so that the particle can move from the conveying air stream to a region where the conveying forces are less effective, non-existent or counteracted by more powerful forces of retention. In all separators, the particle must move through some distance laterally across the air stream. At its destination, it must be entrapped in some manner so that it cannot again enter the cleaned air or gas. In a settling chamber, the force is gravity. In a cyclone, the force is the centrifugal force of rotation. In inertial separators, the air is bled off the stream continuously while the particles continue to flow at high speed until they reach the trap at the end of the unit, so that the force is inertia.

It is evident that for effective separation the differential force acting upon the particle must be as great as possible, and the distance through which the particle moves across the air stream must be a minimum. Since the particle must traverse the air stream laterally, the stream must be as narrow as possible or be broken into a number of streams of small dimensions.

The principal types of industrial dust-collecting devices are:

1. gravity chambers
2. inertial separators
3. centrifugal separators — dry & wet
4. filters
5. wet scrubbers
6. electrostatic precipitators.

Intermediate types may combine one or more of these, such as centrifugal wet washers, or a combination of a cyclone backed up by a filter or precipitator.

Gravity Dust Settlement

It is intended to emphasize the analysis of conditions in the gravity settlement basin, as it forms an integral part of most industrial incinerators.

The settling rate of particles of sp gr 2.0, according to Stokes’s law is approximately as follows in flue gas at 1400 F:

- 500 micron particles: 550 ft per min
- 200 micron particles: 120 ft per min
- 100 micron particles: 59.2 ft per min
- 50 micron particles: 14.8 ft per min
- 35 micron particles: 10.0 ft per min

Let us consider a typical 500 lb per hour rubbish incinerator burning Type 1 waste. The gas flow is 0.140 x 500 = 70 cfs, so at 9.0 fps the cross section of the opening under the curtain wall should be 7.77 sq ft. If the width of the unit is 3 ft 4½ in., the height would have to be 2.3 feet. The length of the chamber would have to be the square root of 7.77, or 2.76 ft. The retention time at 9.0 fps in horizontal flow, would therefore be 0.3 second. It will be seen, therefore, that a 200-micron particle leaving the underside of the curtain wall and falling at the rate of 120 ft per minute will take 1.15 seconds to reach the floor. But the retention time is only 0.3 seconds so that the particle must be heavy enough to continue its downward movement in spite of the upward flow of the gas. A particle of 100-micron size would require about 2.3 seconds to reach the floor and these might continue to be entrained in the gas stream rising at about 6.5 fps.

For the settlement chamber to be of sufficient size to settle even the 100-micron particles, the chamber would have to be 2.3/0.3 x 2.76 or 28 ft, 6 in. long, which of course is not economically feasible. It should be noted that the wide-low opening under the curtain wall is preferable to the narrow-high opening of equal cross section, because the distance of vertical fall for the particle to reach the floor is reduced. Other factors in the design must be taken into account, and a compromise struck.

The reason that so much of the fly ash of 100 microns and under is trapped in the settlement chamber is probably because of the inertial separation caused by the gas flowing downwards in the “down-pass mixing chamber” at 30 to 35 fps, then changing direction to horizontal flow at 9.0 fps, and then a much slower rate of maybe 5.0 to 6.0 fps after passing under the arch of the curtain wall.

This same 500 lb per hour incinerator will have gas flow of 4175 lb of air-gas per hour at 50 per cent excess air. Let us assume that the incinerator, is operating beyond the allowable limit, say at 1.0 lb/1000 lb flue gas. The total emission will then be 4.175 x 1.0 = 4.175 lb fly ash per hour, or 1.21 grains/cu ft at 500 F.

If the allowable is 0.85 lb/1000 lb flue gas, the emission must be reduced to 4.175 x 0.85 or 3.55 lb fly ash per hour, or if the allowable is 0.65 lb/1000 lb of flue gas, the emission must be reduced to 4.175 x 0.65 = 2.71 lb fly ash per hour.

The efficiency required in the first case is 18 per cent, and in the second case 54 per cent. However, it should be remembered that about 30 per cent of the weight of fly ash is under 30 microns in size which leaves 70 per cent between 30 and 100 microns and over. This would require the equipment to be 54/70 x 100 = 77.25 per cent efficient in the removal of particles over 30 microns.

Cyclones

Almost any manufacturer of dust collectors can supply
equipment to meet these requirements. The possible exception would be the “low pressure” or “large" cyclone whose body diameter is three to six times the diameter of the inlet pipe.

However, “large cyclones” can be used as roughing units in conjunction with a bank of V-type cloth filters, bag filters or other finishing units. Such combinations can be made into very neat packages to handle diluted flue gas from small incinerators, for example up to 500 lb per hour.

In most dust collectors, the efficiency varies as the pressure drop, a condition that also prevails with filters. The high efficiency, small diameter cyclones are available in different forms, all of which will perform the duty required for our purpose. They are generally smaller than 24 in. in diameter and therefore are limited in capacity. However, they can be grouped in 2’s, 3’s, 4’s, 6’s, etc., to handle fairly large quantities of gas. The temperature must be reduced to about 700 °F or less so as not to damage the fan. Pressure drops vary from about 3.0 to 12.0 inches W.G. and flow rates from about 1500 fpm to 4000 fpm. Efficiencies exceed 95 per cent, removal of particles over 35 microns in size.

These high efficiency, small diameter cyclones are also made in miniature sizes, such as 4, 6, 9, 10 and 12 in. diameters, and are built into casings having a common inlet, outlet and dust hopper. The cyclone units are fitted with turning vanes, which spin the gas upon entering the unit. The casings are built to accommodate large numbers of these units, the 9 in. diameter and 10 in. diameter being most economical for our purpose. The capacity of the 10 in. diameter tubes at 2.0 in. W.G. pressure drop is about 80 cubic feet per minute, and the collection efficiency of particles over 35 microns in size is over 96 per cent.

These units can, however, block up with fly ash in the small vaned openings. “When this happens the efficiency can fall off very noticeably, in fact well below our required levels. It is therefore advisable to provide access doors for inspecting the tube section regularly and provide a long handled compressed air jet to blowout blockages mentioned above.

High efficiency cyclones are probably the most practical devices for use in conjunction with industrial incinerators. When operated with an induced draft fan, it is necessary to reduce the temperature to about 600 °F by the admission of cooling air. This requires a little more than one and one half times the weight of air at 80 °F. Actually the volume to be handled is not increased as much as expected because of the drastic reduction in temperature. The 4175 lb per hour of gas at 1400 °F would be equal to a flow of 3437 cfm, whereas the 10460 lb per hour at 600 °F would only be equal to 4655 cfm, an increase by volume of 36 per cent, with a weight increase of 160 per cent. It is very unlikely that a vapor plume will be formed from such a mixture, even with heavily moisture laden air at 80 °F, exhausting into a cold northern winter atmosphere.

These units require regular cleaning, as a collection of dust in either the hopper or the tube entrances will seriously affect the efficiency. However, they require very little maintenance. Their main disadvantage is the large amount of space required; this is particularly noticeable when attempting to fit them into a crowded boiler room.

There are several dry-type dynamic precipitators on the market. These designs combine a special fan with a cyclone, which is set on top of a box for the collection of the dust. These units are available with precleaners to knock out the heavy loading, and also with after-filters to remove fine particulate matter before exhausting to atmosphere. Small package units are available with capacities which could serve a 2000 lb per hour rubbish incinerator.

Similar units are also available with integral water sprays: precleaners and after-filters. Both these combinations operate at efficiencies well above 95 per cent of particles over 35 microns in size. The efficiency of the dynamic separator by itself falls just below that of the high efficiency cyclones.

**Impingement Separators**

There are several impingement or louver-type separators available. Their operation depends upon the high speed flow of the dirty gas being maintained to carry the particles into the trap at the end of the unit; while small quantities of clean gas are successively drawn off from the inlet to the trap. These units have the advantage of operating at low pressure drop, require relatively small space and can attain efficiencies in excess of 95 per cent for separation of particles over 35 microns and 90 per cent for particles over 10 microns in size. Units can be set up for forced or induced draft. In the case of the forced draft arrangement, the dust is collected in the dust tube and falls into the dust-collecting box or hopper. The disadvantage of this arrangement is that all the dust must travel through the fan. In the case of an induced draft arrangement, a small collector is required to draw the “bleed-off air” and particulate matter, into the dust tube, and deposit it in a hopper. These, of course, can also be backed up with after-filters for improved separation. They have the advantage of requiring relatively little space and could be set on top of an incinerator under the roof of an average boiler room.

**Filters**

The two most common forms of fabric filters which are applicable to the cleaning of flue gas are the flat V type and the tubular bag type. These filters should be used
in conjunction with a cyclone or impingement unit to remove most of the dust load; otherwise they will very quickly become clogged up and will require frequent cleaning. The flow rates should be kept within the limits of the filter medium.

Various types of cleaning devices are used, the most common being a shaker that knocks the particles off the filter medium, allowing them to fall into the dust hopper. Both the V type and the tubular-type filters can also be cleaned by means of automatic air pressure cleaners.

Very high efficiencies of sub-micron particles can be obtained with this equipment. Except in special cases, filters are really too efficient for our requirements; however, open weave filter media are obtainable which will suit our designs.

**Electrostatic Precipitators**

Some interest is now being shown in the use of electrostatic precipitators, particularly in the municipal incinerator field. However, in the industrial field, these units would not be economical except for large capacity incinerators. A high voltage electrical charge is imparted to the dust particles which are then attracted to the grounded plates. Removal of the fly ash is effected by rapping or vibrating the elements. The pressure drop through the unit is low and collection efficiency is high and relatively uniform, regardless of particle size.

Space requirements are large and the relative cost is very high, especially in small units. Heavy concentrations can cause a reduction in collection of fly ash; this, however, can be offset through the use of continuous collection equipment. Operating temperatures are limited by materials of construction to 600 to 700°F, although units for higher temperatures have been built.

**Wet Scrubbers**

When dealing with hot particles of ash, it should be remembered that they are very difficult to wet. They repel water because they are so hot that a layer of steam is formed around them. This tends to insulate them from the surrounding gas until they cool to a point where a crust is formed, which continues to insulate the core of the particle from the surrounding gas. It therefore requires considerable time to wet these particles, so that they can be knocked out of the gas stream. This is the reason why the successful scrubbers require considerable retention time and anywhere from three to ten gallons of water per 1000 cubic feet of gas scrubbed. As for the dry collectors, generally speaking, the greater the pressure drop, the greater the efficiency.

Water consumption is a very important factor. Most efficient scrubbers require more than 3 gallons per 1000 cubic feet of gas treated. With quantities like this involved, recirculation is imperative, but consumption can be materially reduced by the addition of cooling air.

A factor to be remembered, is that for every twenty degree temperature rise, the moisture content of saturated air is doubled, so that it is important to balance the air and water cooling with the amount of moisture exhausted in the gas in order to obtain the most economical combination.

The wet bottom, often used in municipal incinerators, is efficient only for collecting the lumps. There is always a layer of mucky sludge on top of the water, which indicates that some degree of entrainment is affected. The sludge could be the medium that collects the finer particles as they are projected downward from the “down-pass” mixing chamber. The small additional cost might justify the burning of wood wastes or other refuse that produces a relatively heavy or large, easily trapped ash.

Single water curtains can only knock down large floating particles, such as unburned or partially burned paper, because there is not sufficient retention time to effect proper scrubbing of fine particles.

The orifice-type wet collectors consist of a basin of water with overflow, drain and make-up supply pipe, together with some type of collecting element designed to force the gas into contact with the water. The moisture laden gas then passes through a mist eliminator to trap water droplets before the gases enter the exhaust duct. Gas flow is in the range of 300 to 500 fpm and water consumption is kept near the saturation level of the exhaust gas. Pressure drops range from 5 to 10 in. depending on the design of the collecting and mist eliminating elements. Collection efficiencies exceeding 98 per cent can be expected for the removal of particles over 35 microns.

There are so many different designs of wet scrubbing towers that space does not permit their individual description. There are wet cyclones, wet centrifugal units, packed towers, floating bed scrubbers, bubble plate towers and many others, all of which operate on the same principle of intimate mixing of the gas with an ample supply of water, allowing sufficient retention time to wash down the particulate matter and to exhaust clean gas from the stack. Most of these units operate at 5 to 10 in. W. G. pressure drop with recirculated water consumption of 3 to 10 gallons per 1000 cubic of gas. Particulate reductions are in excess of 99 per cent of particles larger than 35 microns and many will remove large percentages of sub-micron particles.

The Venturi scrubber is a unit in which the gases enter the head under a negative pressure formed by a high pressure water jet. The jet pattern is designed to fill the throat of the unit below the head, into which the gas is drawn along with the water, producing very intimate mixing. Below the throat, the tail piece flares out to allow for diffusion, and the gas-water mixture is driven down into a separating box, containing a bath of water.
which is maintained at constant level. An exhaust duct is fitted to the separating box to carry the washed gas to atmosphere. For very high efficiencies these units may be installed in series. There is no pressure drop as the Venturi nozzle actually produces draft. Pressures up to 4 in. W. G. are normal, but higher pressures are available. Water and power consumption are high. At 4 in. W.G. these units require over 80 gallons of water at 100 psig per 1000 cu ft of gas. However, they can be operated at high temperature and no fan is required. Particulate reductions are above 99 per cent for particles over 35 microns in size.

In order to reduce the power consumption, similar units have been designed which derive their power from high-pressure fans, and low-pressure water is fed into the unit just before the throat. The results are quite similar — intimate mixing through pressure in the throat — and the effluent from the tail piece of the unit discharges into a separating box which is fitted with an exhaust duct. Water consumption is lower ranging from 3 to 10 gallons per 1000 cu ft of gas, but the water pressure is only 10 to 25 psig. The motive power, however, is supplied by a fan with a static head ranging from 5 to 40 in. W.G. The water, of course, is recirculated and consumption will vary with the exhaust temperature.

Venturi scrubbers can also be built in spray chambers using throats built into the dividing baffles between the passes. Each throat has its own spray nozzle, and multiple throats are used to provide the capacity required. Units can be built with two, three or four passes set upon a common water basin depending upon the efficiency required. Pressure drop is negligible or slightly positive, and water consumption is about 3 gallons of water per 1000 cu ft of gas. Flowrate through the unit should be about 200 feet per minute. The discharge duct is fitted with a mist eliminator to reduce the discharge of water droplets to a minimum. Again the quantity depends upon the final discharge temperature. Efficiencies of particulate reductions of 99 per cent of particles over 35 microns in size can easily be obtained.

The cost of these various units can vary so much depending upon what is included or excluded that it is difficult to assess. The descriptions in this paper have been arranged beginning with the simplest and least expensive to the highest-efficiency and most expensive equipment, for both the wet and dry types.

**Conclusion**

Inasmuch as the addition of water to the gas makes the problem more complex, it seems axiomatic that dry equipment should be used wherever possible. However, when temperature reduction as well as particulate reduction is required, one of the many scrubber designs should be investigated, bearing in mind that sludge removal, recirculation filtration and possibly corrosion resistant construction may need to be supplied.

Thought should also be given to the possible tightening up of restrictions by the various governing bodies. This could mean that increased efficiencies might be required. It would be wise to allow a reasonable safety factor when designing equipment that might be subjected to this hazard.