CONTROL OF AIR AND WATER POLLUTION FROM MUNICIPAL INCINERATORS WITH THE WET-APPROACH VENTURI SCRUBBER

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ABSTRACT

This paper describes the design and operation of a medium-energy venturi-scrubber system that has been installed on a 220-ton/day municipal-refuse incinerator. It reviews technological advances over commercial gas-cleaning systems previously installed on incinerators with the objective of highlighting new and improved practices in the system design of incinerator plants for control of pollution.

INTRODUCTION

For many years, designers and operators of municipal-refuse-incinerator systems have sought improved gas-cleaning-system designs that will achieve atmospheric-pollution-control objectives with reliable system operation. Wet-scrubbing-type gas-cleaning techniques have been utilized extensively during this period because of their potential capability for high particulate-collection efficiency at minimal capital and operating cost. These wet-collector installations, including the several proprietary scrubbers put into service during the past 5 to 10 years, have had a number of significant shortcomings.

Some of these shortcomings have been excessive corrosion of metal surfaces due to diverse acid gases, including halogen compounds, in the flue gas as well as excessive erosion due to the abrasive characteristics of the fly ash. Moreover, these installations entail design complexities in conditioning and precooling high-temperature flue gases discharged from refractory-wall incinerator furnaces. They also present additional operating problems and costs in recycling and reusing turbid and acidic scrubbing liquor when necessary to curtail water use and liquid effluent flow. Furthermore, there is a possibility of pollution of receiving waterways by scrubber-liquid outfall due to the substantial quantities of particulate and volume of gaseous contaminants collected from the flue gas. There are also potential aesthetic objections to high absolute-humidity stack-gas emissions (0.5 lb water vapor/lb dry gas), particularly with higher efficiency scrubbers discharging water-saturated stack gas, in refractory-wall incinerator-furnace applications.

Being aware of these and other problems encountered in the operation of earlier wet-type incinerator gas-cleaning systems in the United States, The City of New York decided, in 1967, to install a venturi-scrubber system on a 220-ton/day furnace at the East 73rd Street, Manhattan, plant. The unit was to meet the new city incinerator fly-ash emission code, which demands 0.2 lb/1000 lb flue gas corrected to 50 percent excess air. With no previous history of the use of venturi gas-cleaning devices for municipal-refuse incinerators, this choice was made largely on the strength of the favorable experience in the application of classical Pease-Anthony type high-energy venturis to high-temperature erosive/corrosive gas-cleaning applications in industry, particularly in the manufacture of iron and steel.
Types of Venturi Scrubbers

Considering the coarse consistency of incinerator fly-ash particles (25 to 40 percent – 10 μm size)\(^\text{[1]}\) as compared to the particle-size distribution in typical industrial applications of the high-energy venturi scrubber (35 percent – 1 μm), it is apparent that only low to medium energy expenditure (less than 15-in water gage gas-pressure drop across the scrubber) is required to meet even the stringent New York City municipal-incinerator fly-ash emission code (0.2 lb dust/1000 lb flue gas corrected to 50 percent excess air). Accordingly, high-efficiency gas cleaning of incinerator flue gas may be obtained in a simplified version of the Pease-Anthony, a “wet-approach” venturi, in which all of the scrubbing liquid is used to wet the venturi converging section thoroughly prior to entering the venturi throat region for collection of fly ash (see Fig. 1). This unique wet-approach venturi converging section, designed in the configuration of a “dentist’s bowl,” eliminates high-velocity liquid jets or atomizing spray heads and lends itself to the recirculation and reutilization of scrubbing-liquid slurries containing suspended solids in excess of 5 percent by weight.
Functioning of Wet-Approach System

Figure 1 illustrates the principles of operation of the wet-approach venturi scrubber with closed-loop circulation of scrubbing-liquor slurry. The raw incinerator flue gas is introduced to the system from the furnace in a refractory-lined duct. Accelerating to over 100 ft/sec superficial velocity at the venturi throat, the flue gas fragments the descending scrubbing-liquid slurry into a mass of small droplets upon which the fly-ash particles impact and are collected. The thorough irrigation of all surfaces of the equipment “seen” by the incoming gas permits high design inlet-gas temperature and controls the buildup of wet/dry line deposits that may be encountered in high-temperature gas-cleaning services.

Downstream of the venturi throat, the clean gas decelerates, and the slurry droplets collide and agglomerate. In the liquid separator, the momentum and weight of the droplets function to remove them from the gas stream for recirculation to the converging section of the venturi.

Application to Incinerator Pollution Control

Fig. 2 is a general schematic illustration showing how the closed-loop venturi scrubbing of raw incinerator flue gas is achieved. Handling flue gas in a temperature range of 1400 to 2000°F from the last pass of the furnace, the scrubber fly-ash catch may be expected to have a wide and variable distribution of particle sizes. To prevent a periodic buildup in the concentration of coarse particles in the recirculating slurry, a liquid-cyclone classifier is installed in the recirculating piping circuit to immediately separate and discard this material. This liquid-waste stream of about 150 to 300 gal/ton of refuse burned serves also to bleed all the collected flue-gas contaminants from the scrubbing system. In a typical installation, the scrubber-liquid effluent may be limited to this relatively small design flow quantity so that waste material may be processed in a concentrated form for more convenient and simplified disposal.
Materials of Construction

The presence of substantial quantities of organic and halogen acid gases, particularly hydrogen chloride, is believed to have been an important factor in magnifying the corrosion problems of earlier incinerator scrubbing systems. Due to the susceptibility of metals – even stainless steel – to rapid deterioration in a wet-incinerator flue-gas environment, nonmetallic-lined construction of scrubbing equipment is considered the most practical engineering solution to this difficult design problem. Such construction, utilizing carbon-steel scrubber components with internal linings of fiberglass-reinforced polyester and acid brick, has gained broad acceptance in the chemical and steel industries in many abrasive and acid-gas environments. The 73rd Street scrubber has been in continuous service, 6 days a week, since its startup in June 1969, without evidence of any deterioration of these types of linings.

73rd Street Incinerator Furnaces

The East 73rd Street Municipal Incinerator (see Fig. 3) is one of 10 municipal plants serving The City of New York. It was placed in operation in 1957. Each of three 220-ton/day units receives a continuous feed of refuse onto traveling grate stokers in rectangular, refractory-lined furnaces. The lower portion of the walls is built up with air-cooled silicon carbide brick, and the balance of walls and arches, with super-duty refractory in suspended construction. The residue drops through a spray-cooled bifurcated chute to either of two wet-ash conveyors in which it is quenched and
conveyed into residue trucks for hauling. Provision was originally made in each unit for reducing the 1800 ±200°F furnace gas to 650°F by a combination of air injection and water-spray cooling, followed by a low-efficiency, dry cyclone dust collector and finally an induced-draft fan. The three fans discharge to a common breeching and stack.

73rd Street Scrubber

Figure 4 is an isometric sketch of the installation on Furnace No. 1 at 73rd Street, in an indoor 17-ft x 30-ft plot space formerly occupied by the dry-dust-collection system. Provision for tempering-air admission, shown on Figure 4, has been eliminated as has the introduction of cooling water in the spray chamber upstream of the venturi. At full load, 170,000 ft³/min, measured at 1800°F, enters the venturi through a refractory-lined duct and contacts 1100 gal/min of recirculating scrubbing-liquor slurry. In the volume of 74,000 ft³/min water-saturated at 170°F, the clean gas then enters the flooded elbow in which a flowing pool of slurry absorbs the abrasive effect of the descending scrubbing liquor. The water-saturated gas passes vertically upward in the separator and through an impingement-type mist eliminator to remove residual liquid carry-over. Separator-liquid level is maintained by continuous addition of fresh water, making up for approximately 107 gal/min of evaporation and 25 gal/min of liquid bleed. The clean, saturated flue gas flows from the separator to an induced-draft fan with a rating of 75,000 ft³/min at a static head of 15 in. water gage. The fan is driven by the same 300-hp electric motor that previously served the original dry-dust collector that handled a higher weight flow of flue gas at lower flue-gas pressure drop. The scrubbing liquor is pumped from the bottom of the separator by a slurry pump driven by a 75-hp electric motor. The liquor flows to the liquid cyclone at a pressure of 25 lb/in²/g before returning to the separator. The cyclone classifies and preferentially removes solid particles larger than 100 mesh. These solids flow from the bottom of the cyclone in a system bleed stream discharged to the wet-residue conveyor. Periodic flow measurements indicate that the bleed rate is 22 to 40 gal/min. Suspended-solids concentration has been typically less than 1 percent by weight, and measured concentrations of dissolved chlorides have ranged from 2,500 to 14,500 parts/million. The entire slurry-liquor circuit is designed for protection against both erosion and corrosion.

Minimum pH recorded is 1.8. There may seem to be an advantage in raising the pH to a more favorable level by adding an alkaline reagent to the recirculating scrubbing liquor. However, extensive experience in the application of wet-scrubbing systems to diverse industrial applications indicates that chemical feed equipment in gas-cleaning systems is subject to neglect and cannot be relied upon to provide continuous corrosion protection. Furthermore, even in incinerator scrubber systems operating on once-through scrubbing liquid, dissolved chloride levels in excess of 1000 parts/million may be reached, creating a highly corrosive liquid environment irrespective of pH.

Novel Features of 73rd Street Scrubber

The compact 73rd Street gas-cleaning installation is believed to be the first municipal refuse incinerator scrubbing system to be designed for recirculation of slurry-type scrubbing liquor without provision for liquor clarification in settling basins or clarifiers. It is also the first to be fabricated of conventional, nonmetallic-lined construction to accommodate the complex acid-gas environment unique to municipal refuse incineration. It is also unique in that it handles raw furnace gas directly at a nominal 1800°F refractory-wall furnace outlet temperature without air-tempering or spray cooling and that it utilizes a venturi.

Automatic Control of 73rd Street Scrubber Performance

An air-bleed damper is connected to the venturi gas-inlet duct, automatically positioned to control furnace draft under all incinerator-gas flow settings. At full load, the bleed damper is closed; when gas flow from the incinerator periodically decreases due to changes in combustion air flow, a compensating amount of tramp air is drawn into the scrubbing system. Thereby, approximately 9 in. water gage or more gas-pressure drop may be maintained across the scrubber during startup and shutdown and part-load incinerator-gas flow conditions. This results in sustained gas-cleaning effectiveness, making it possible to meet City emission code requirements under all modes of incinerator operation. For study purposes, the City’s specifications provided for manual adjustment of throat area. Through comprehensive stack testing with varying throat-area settings, it will be possible to fully characterize the energy requirements of the scrubbing system for code performance under all incinerator-operating conditions.
Fig. 4 Isometric View of Venturi-Scrubbing System
GAS-CLEANING PERFORMANCE

Efficiency of Wet Scrubbers

For a specific gas-cleaning application, the "contacting power," equal to the power input to the scrubber proper per unit of gasflow, will govern the efficiency of collection of particulate matter. In other words, all wet scrubbers operating under optimal conditions, designed for efficient utilization of energy, and consuming the same power, provide substantially the same degree of collection of a given dispersed dust — regardless of their collection mechanisms. Stairmand's classic paper [2] on gas cleaning provides data on dust-collection efficiency versus particle size for various types of scrubbers under conditions of energy expenditure for which they are normally designed in industrial applications (see Table 1). Considering the strong influence of dust particle size on the performance of poor- and moderate-efficiency wet-scrubber types (and the unique, wide variations in fly-ash size distribution that occur in the operation of municipal incinerators), one can begin to understand why publicized incinerator scrubber gas-cleaning efficiency data may be contradictory.

Adaptation of Dust Emission Test

The publication in 1967 of the U.S. Public Health Service's "Specifications for Incinerator Testing at Federal Facilities" has directed attention to the possible significance of condensable organic-vapor emissions in contributing to stack outlet loading. This stack-testing procedure calls for cooling of sample gas to 70°F after removal of all filterable particulates and the inclusion of condensed organics in the outlet loading score. Although detailed published test data is not yet available, it may be anticipated that wet scrubbers (particularly moderate, high-efficiency units that cool and water-saturate the flue gas to the 150 to 180°F range) will provide a mechanism for condensing and collecting the higher boiling point organic vapors.

Stack Testing of 73rd Street Scrubber

In 1969, during the early months of operation of the venturi scrubber and pending New York City's comprehensive testing of venturi-scrubber performance mentioned earlier, preliminary short-term stack-dust tests were made. The flue-gas sampling system used was similar to that prescribed by the Industrial Gas Cleaning Institute for wet-collector installations. Characteristic fluctuations in refuse feed and incinerator operating conditions were noted, adding to the complexity of gas sampling and to the difficulty in achieving repeatable test scores. Based on these tests, it was judged that 9-in. water gage venturi gas-pressure drop is required to meet New York City's incinerator emission code, 0.2 lb dust/1000 lb flue-gas corrected to 50 percent excess air. The mean outlet-dust score at this energy level was 0.05 grains/dry standard ft³ at approximately 5 percent CO₂ and 13 percent O₂, dry basis (see Table 2).

<table>
<thead>
<tr>
<th>Type of Scrubber</th>
<th>50-μm Particles</th>
<th>5-μm Particles</th>
<th>1-μm Particles</th>
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<tr>
<td>Jet-impingement</td>
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<td>83</td>
<td>40</td>
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<td>Wet cyclone</td>
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</tr>
<tr>
<td>Fluidised-bed</td>
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<tr>
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<td>80</td>
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</tr>
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<tr>
<td>High-energy venturi</td>
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<td>99+</td>
<td>98</td>
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<tr>
<th>Test No.</th>
<th>Actual Outlet Loading (Grains/st ft³ dry)</th>
<th>Orsat Readings (% CO₂)</th>
<th>% O₂</th>
<th>Lb Particulates/1000 Lb Flue Gas at 50% Excess Air</th>
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<tr>
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Gas Phase Contaminants and Their Collection

Intensive stack testing and analytic work in 1968 and 1969 by New York University under contract with the U.S. Public Health Service in conjunction with their study, “Air Borne Emissions from Municipal Incinerators,” indicates that hydrogen chloride is a principal gas-phase pollutant in municipal incinerator flue gas [3]. Average HCl emissions were about 5 lb/ton of refuse and reached higher levels at the 73rd Street Incinerator. HCl is produced primarily from the incineration of chlorinated plastic materials such as polyvinyl chloride. Extensive and growing use of such plastics in the bottling and packaging industries may be expected to bring about a continued increase in the concentration of HCl emissions. Industrial experience with low- and medium-energy scrubbers clearly indicates that such soluble and highly-ionized acid gases may be efficiently collected in low pH scrubbing liquors. SO₂, the principal insoluble acid-gas emission from municipal incineration, may be efficiently absorbed only at liquor pH of approximately 6 and above by the addition of an alkaline reagent such as lime.

CONTROL OF WATER POLLUTION FROM MUNICIPAL INCINERATORS

Disposal of Scrubber Effluent

Many of the diverse organic and inorganic contaminants emitted in municipal-refuse incineration are absorbed and/or condensed in wet-scrubber type gas-cleaning systems. Even in scrubbers of early design, appreciable concentrations of heavy metals, cyanides, phenols, and other toxicants are formed [4]. Incinerator scrubber-liquid effluent, in view of its complex waste composition, is best disposed of by discharge to a municipal waste-treatment plant. Such disposal will be particularly effective where secondary waste-treatment facilities are available for treatment of organic and other oxygen-consuming constituents of the waste.

Alternative Method

In the absence of suitable, sanitary wastetreatment facilities, the size and assimilative capacity of surface waters may permit their use as a receiver of liquid effluents after pH correction and other superficial treatment. However, increasingly stringent effluent-quality standards along regulated waterways will tend to severely restrict the disposal-by-dilution of such complex liquid wastes. It is believed that the advanced concept of the 73rd Street wet-approach scrubber with closely limited slurry-liquor bleed will serve as a forerunner of future municipal incinerator gas-cleaning system designs with no liquid outfall (Fig. 5).

Stringent mandatory control of air pollution from both gas-phase and particulate pollutants will encourage broad use of wet-scrubbers of high efficiency. In such systems, spray-cooling-chamber liquid effluents will be avoided through the elimination of spray chambers. Instead, raw furnace gas will be fed directly to scrubbers embodying the wet-approach concept. Other incidental liquid wastes from the incinerator plant, including minor cooling-water effluents, will be fed to the scrubber to meet a portion of its make-up water requirement. Cooling and quenching of incinerator residue will be achieved in residue cooler/conveyors of modified design using scrubbing-liquor-slurry bleed as the liquid medium.

Furthermore, in these new systems residue-conveyor overflow and incinerator-plant liquid outfall will be eliminated entirely by feeding the conveyor only the bleed flow volume that can be fully assimilated in the cooling and wetting of the residue. Based on estimates from published

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![Diagram of Scrubbing System](image-url)
literature [5], this exceeds 20 gal/ton of refuse burned. Liquor bleed from the scrubber will be restricted to the amount that can be processed in the residue cooler.

In addition, lime or another inexpensive alkaline reagent will be fed to the scrubbing-liquor system (to limit the vapor pressure of acid gases collected in the liquor) if the collection of soluble acid gases in the superconcentrated scrubbing liquor falls below pollution-control objectives. (Residue-quench liquor, partially neutralized by the leaching of alkali from the hot residue, may be recycled from the residue cooler to the scrubbing-liquid circuit to meet part or all of this alkali requirement.)

CONTROL OF STEAM-PLUME FORMATION FROM HIGH-EFFICIENCY SCRUBBERS

Characteristics of Scrubber Plumes

As a result of the intimate contact between gas and liquor in a high-efficiency scrubber, the gas becomes adiabatically saturated with water vapor and leaves the scrubber at approximately the wet-bulb temperature of the inlet gas. Scrubbed flue gas from refractory-wall municipal incinerators may have a saturation temperature as high as 175°F with a water-vapor content of approximately 45 percent by volume. In discharging such high-humidity gases to the atmosphere, air and gas diffuse into each other, condensing the water vapor in the flue gas and creating a dense, white steam plume, which may extend several hundred feet before dispersing and re-evaporating. Although such incinerator-scrubber steam plumes are being emitted at a number of locations in the United States and despite the fact that air-pollution-control codes invariably exclude water vapor from both emission and plume-opacity regulations, they may be considered objectionable in special localities from an aesthetic standpoint.

Water Cooling of Scrubbed Gas

A simple way to reduce the intensity and length of high-humidity water-saturated incinerator steam plumes to an insignificant level is to dehumidify the scrubbed gas by direct-contact water cooling downstream of the separator. A packed-tower cooling section served by a recirculated-cooling-water system is used in this manner to reduce the induced-draft fan weight-flow and horsepower in many high-energy gas-scrubbing applications in the iron and steel industries (see Fig. 6). Moreover, drastic reduction in the water-vapor content of the stack gas also minimizes steam-plume formation, as indicated above. The displaced heat is rejected from an atmospheric cooling tower via the cooling-water circuit. In cases where the secondary steam plume from the atmospheric cooling tower is also deemed objectionable, the displaced heat may be rejected from the cooling-water circuit using an indirect air-cooled heat exchanger. However, the added cost of going to indirect water-to-air exchange at near-ambient fluid temperatures may be expected to add greatly to the cost and complexity of this control method.

Fig. 6 Dehumidification of Scrubbed Incinerator Flue Gas Using Packed-Tower Cooling Section
Recuperative Heat Exchanger

This technique produces hot air through indirect heat exchange from the raw incinerator flue gas and achieves an incremental reduction in the saturation temperature at the scrubber outlet. Mixing the two outlet streams (hot air and saturated gas) will produce a stack gas that will not fog under warm and moderate weather conditions. Utilizing recuperative heat exchangers, such a system may be designed to prevent steam-plume formation down to a design ambient temperature in the range of 32 to 60°F and to control plume length and intensity at all temperatures below this level. Combustion-furnace recuperators of the Escher type have been used extensively in abrasive dirty-gas heat recovery services in Europe, Australia, and Japan and were newly introduced during 1969 in several large recuperative hot-blast foundry-cupola installations in the United States. This type of recuperator offers a novel compact design that is believed to be suitable for this difficult service. (See Fig. 7.) By designing for parallel flow with high cooling-air velocity inside the oblong cross-section heat-exchanger tubes, metal temperature may be held to less than 700°F at a design gas-inlet temperature as high as 1700°F. This strict limitation on metal temperature seems to be essential in view of adverse corrosion of ASTM 213 TP 22 low chrome-moly encountered in high-temperature steam superheater tubes in European incinerator service. The future introduction of this advanced type of heat recuperator in municipal incinerator practice will probably provide impetus for intermittent use of preheated combustion air during adverse wet refuse-feed conditions.

CONCLUSIONS

Incinerator system designers seek reliable operation of all gas- and liquid-handling system components and, at the same time, face continued tightening of limitations on the emission of acid gases and particulates and the discharge of complex liquid wastes.

They may be expected to look increasingly to high-efficiency wet scrubbers, which provide superior results in containing and disposing of flue-gas contaminants, as the ultimate answer to stringent environmental-quality-control requirements. The technology that has been developed in related gas-cleaning applications in the iron, steel, and chemical industries now offers a new basis for the design of reliable, heavy-duty wet scrubbers for municipal incinera tors that will meet all foreseeable performance and emission-control requirements. The City of New York's wet-approach venturi scrubber at the 73rd Street, Manhattan, Incinerator plant provides a full-scale demonstration of the applicability of experienced proprietary gas-cleaning art in achieving these objectives.

REFERENCES


