Wet ESP for the Collection of Submicron Particles, Mist and Air Toxics

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Abstract: New regulations are restricting particulate, acid gas and organic emissions to extremely low levels. Wet tubular electrostatic precipitators, with their ability to generate strong electrical fields in a wet, cooled atmosphere have demonstrated particulate emissions less than 0.0003 gr/dscf, with toxic organic, heavy metals and acid mist collection exceeding 99%. Designing parameters, field test data and operating data from installations on these processes are discussed in the paper

Keyword: wet ESP submicron particles electrical field

1 INTRODUCTION

New and proposed regulations are restricting particulate, acid gas and organic emissions to extremely low levels; with emphasis on heavy metal and toxic organic concentrations. Conventional scrubbing systems (wet or dry) are generally not effective in controlling sub micron emissions, consisting primarily of acid gas mists, condensed heavy metals and condensed organics. Wet tubular electrostatic precipitators, because of their ability to generate strong electrical fields in a wet, cooled atmosphere, have been shown effective in “polishing” the flue gas. The net results are demonstrated particulate emissions as low as 0.0003 gr/dscf; overall heavy metals collection efficiencies exceeding 99% and toxic organic removal greater than 99.9999%.

These units have been used as the primary air pollution control systems, or as retrofits to up-grade existing Air Pollution Control (APC) systems.

2 DESIGN DESCRIPTION

Beltran Technologies has developed a unique wet tubular precipitator as a result of considerable research and development. The typical Beltran wet ESP is a vertical-flow, hexagonal or rectangular tube type precipitator. The schematic is shown in Fig. 1. Typically the flue gases enter at the bottom and rise through the precipitator. There are generally two sets of spray headers. The first set continually cools and saturate the flue gases. The spray header set at the top and directly below the collector washes down the collector and electrodes. These are operated on a periodic as needed basis.

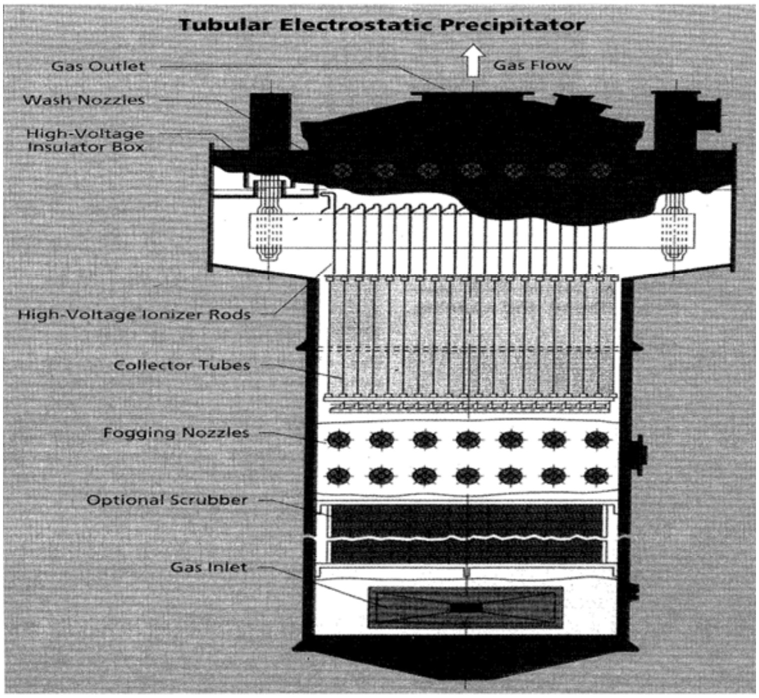


Fig. 1 This design of a wet precipitator, originally employed for the collection of fine particulates, oil, smoke and acid mist, has been shown extremely cost effective for the collection of sub-micron particulates

The tubular precipitator consist of a ionizing section and a collection section. The discharge electrode is in the form of a rod or tube with a number of sharp corona generating discharge points. Various collecting tube geometries have been utilized over the years, the most common being the round. The square configuration and/or the hexagonal shape is chosen because of ease in manufacturing and higher collection area per square foot of the cross-section. These geometries are much more space efficient than the round shape.

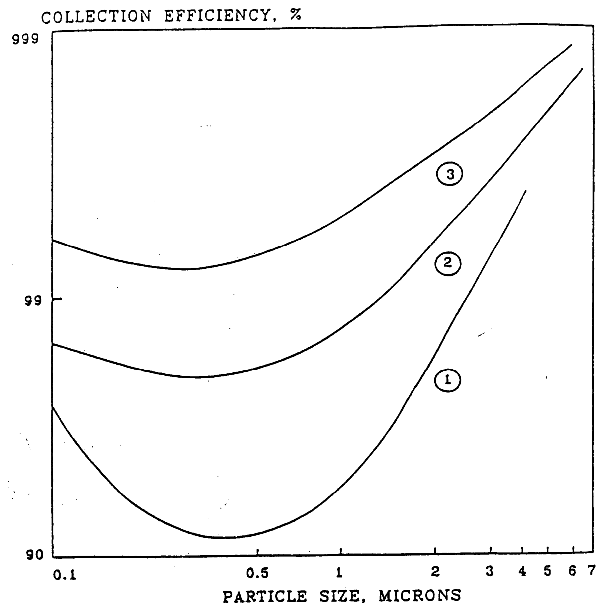
The precipitator uses solid ionizing rods instead of wires. The unique electrode design with ionizing stars is capable of attaining higher average electric field strengths than any other plate and wire or tube and wire designs. This higher field strength results in higher particle migration velocities that translate into a reduced collector area.

Entrained particulate matter and fog droplets that enter the electrostatic section are charged by the high voltage produced by the electrode and collected on the grounded plates. Most of the particulates are flushed into the bottom of the housing. The high voltage insulators are kept clean continuously using a purge-air system. These features result in very low maintenance. Optional internal scrubbers to remove acid gases, can be installed in the lower part of the housing.

3 WHY WET ESP

The wet ESP is the most efficient sub-micron particulate collector. Its' collection mechanism is electrical charging as opposed to inertia in cyclones and scrubbers.

Since fine particles do not have a significant mass, they generally go through cyclones and scrubbers with minimal collection. Also, high pressure drop is associated with cyclones, scrubbers and baghouses. The wet ESP has only a one-inch water column drop and is low in maintenance.



The unique electrode design allow for generation of a corona field 4 to 5 times more intense than standard wet or dry ESP's (Fig. 2). The Wet ESP provides low energy collection of sub-micron particles which is not greatly influenced by the physical or chemical nature of the collected material.

A major benefit of wet operation is that it eliminates particle re-entrainment. Re-entrainment occurs when a highly conductive or resistive particle detaches itself from the collector and rejoins the gas stream.

There are other benefits to wet operation:

(1) Gas adsorption can take place;

(2) Water provides a continuous cleaning action;

(3) Lower gas stream temperatures are possible, allowing particulate to form by condensation or gas phase reaction;

(4) Water is available as a quenching medium in case of duct fires;

(5) Collection section acts as a demister;

(6) Wet precipitators are easily integrated with scrubbers.

Fig. 2 Tubular electrostatic precipitator, Performance Corona Power Levels of ① 200, ② 400, ③ 1000 watts per 1000CFM

.4 INDUSTRIAL APPLICATIONS

Beltran wet ESP have been installed on a variety of industrial emissions:

(1) Incineration;

(2) Alternate Energy Sources;

(3) SO_2 Scrubbing Processes;

(4) Primary and Secondary Non-Ferrous Metals Industry;

(5) Steel Industry;

(6) Chemical Industry.

All of these applications involve heavy concentrations of sub-micron particles. Sub-micron particles are formed by condensation phenomena or by gas phase reaction, where the product of reaction has very low vapor pressure at the reaction temperature.

Generally, particles larger than one micron in diameter scatter light by true reflection. Thus, the loss of light is proportional to the projected surface area. For sub-micron particles, the relationship is more complex, since the particle diameter is comparable to or less than the wavelength of visible light spectrum (.4 micron to .7 micron range). Total number of particles increases inversely as the cube of the diameter. The total projected surface area increases as the reciprocal of diameter. Thus, for the same concentration of particulates, viewed through the same linear distance, plume density increases with decreasing particle size.

In many applications described in this paper, serious corona quenching (current suppression) situations are encountered. When particle density approaches ion density, corona quenching occurs. When the particle concentration is mainly in the sub-micron range, such conditions arise even with particulate loading of a few tenths of a grain/CF. The particles are charged to the same polarity as the unipolar corona ions. Thus, the electric field gradient near the discharge electrode decreases, reducing the flow and mobility of ions. Since for sub-micron particles, diffusion charging is the principal means of particle charging, reduction in ion mobility affects particle charging. In multi-stage ionizers, higher ion densities are obtained than is possible in conventional single stage ionizers. Corona current is a measurement of rate of deposition of corona ions on the grounded electrode. Since the charged particle mobility is order of magnitude lower than the corona ions, contribution of the charged particles depositing on grounded electrode to the corona current is minimum. This explains, in part, why even in heavy current suppression situations where current is suppressed by a factor of 40 or more, very high precipitator efficiencies are possible. To combat corona suppression type situations, high intensity ionizers, positive corona, and several electrical fields in series are generally required.

The electrostatic force exerted on the particle depends on the electrostatic field, particle diameter, and dielectric constant. The residence time and the vertical distance needed for the particle to migrate from the discharge electrode to the grounded electrodes increases with decrease in particle diameter and with lower dielectric constant (good electric insulators). For these reasons condensed hydrocarbons (dielectric constant of 2-5 and sub-micron size) have very low migration velocities. Water droplets (dielectric constant of 78) are thus very easy to collect compared to organic mist.

In summary, heavy concentration of sub-micron particles: 1) create corona suppression; 2) decrease migration velocity; 3) create higher plume densities.

5 INCINERATION EMISSION CONTROL

The incineration of waste materials, especially plastics, can generate hydrochloric acid, hydrofluoric acid and sulfur oxides. The corrosive nature of these flue gases demands that special attention be given to the materials of construction. A reasonable alternative to corrosion resistant metals is to use fiberglass reinforced polyester (FRP). The electrically conductive sections of the ESP can be made from special conductive FRP.

The wet ESP has been used with great success in many industrial applications where fine particulate emissions are the major concern. Overall collection efficiencies in excess of 99% have been demonstrated on a consistent and reliable basis.

Three successful case histories are supplied using three different types of pre-scrubbing prior to the wet electrostatic precipitator. Case 1 (Fig. 3) can burn solid and/or liquid hazardous waste and utilizes a spray dryer/bag house followed by a saturator/wet scrubber ahead of the WESP. To minimize equipment corrosion, the WESP housing was constructed of veiled FRP. The collector was fabricated of electrically conductive FRP. All metal surfaces exposed to the flue gas, including the ionizing rods, are constructed of Hastelloy. This system has achieved extremely low particulate emissions and heavy metal concentrations during test burns. By injecting the WESP bleed-off into the spray dryer, a zero liquid discharge is obtained. Particulate emissions as low as 0.0003 gr/dscf were obtained.

Case II burns solid and/or liquid hazardous waste and only utilizes a quench/packed tower absorber ahead of the WESPs. (Fig. 4) In this instance a rubber lined, carbon steel housing was used to reduce corrosion. The WESP collector, ionizing electrodes and remaining flue gas exposed surfaces were constructed of Hastelloy. No inertial type prescrubbing is used primarily because particulate sizing after the incineration is predominantly sub-micron. By using two WESPs in series, particulate levels as low as 0.002 gr/dscf were achieved. The cleanest water is circulated through the WESPs to the packed tower where the bleed off solids are concentrated and removed by a filter press for disposal.

5 ALTERNATE ENERGY SOURCES

5.1 Retort Oil Shale

Oil shale is a fine grained, compact, sedimentary rock containing an organic material called kerogen. Heating the oil shale to about 900℉ decomposes this material to produce oil shale. Commercially, in situ combustion and surface retorting methods have been tried. Exhaust gases from oil shale retort contain a considerable amount of water (4- to 50 grain), and hydrocarbons (304 grain/SCF). Some dust as shale fines, and carbon is also present. The carrier gas is combustible and has high heating value. Very high tar mist removal efficiencies are required. Since hydrocarbon mist is formed by condensation, the majority of particles are below one micron in size. Low dielectric constant combined with very high loading of sub-micron particles create very tough conditions for efficient precipitation. Two Tubular precipitators in series have a 99% plus collection efficiency. Since the carrier gas is combustible, every flange connection is sealed tightly to prevent inleakage of oxygen. The method of insulator purging is of paramount importance and inert gas and cleaned process gas was used successfully. Also, advanced designs incorporate insulating oil-type seal seals to eliminate purging requirements altogether.

5.2 Coal/Wood Gasification

Coal gasification has received much attention in recent years. Similar processes have also been developed for wood gasification and municipal refuse gasification. Precipitators used in these processes are for gas clean up rather than for pollution control. Coal tar, fine unburned carbon, char ash, and volatilized heavy hydrocarbons are present in the gasifier exhaust. The gas cleaning train generally consists of a cyclone or some mechanical pre-filter after the gasifier, then a heat exchanger to recover heat, a medium or low energy scrubber to cool the gas and remove heavy tar particles, and a wet Tubular ESP to remove fine hydrocarbons. The particulate loading after the gasifier can be as high as 9-10 grains/CF of char (in case of wood gasification) and almost as much of hydrocarbons. The particle size distribution is generally bimodal with the char and carbon particles in 2-15 micron range and the condensed hydrocarbons in the sub-micron range. Outlet loadings from the precipitator of 0.003 grain/CF or less are required. The presence of H_2S, ammonia and water creates fairly active corrosive conditions.

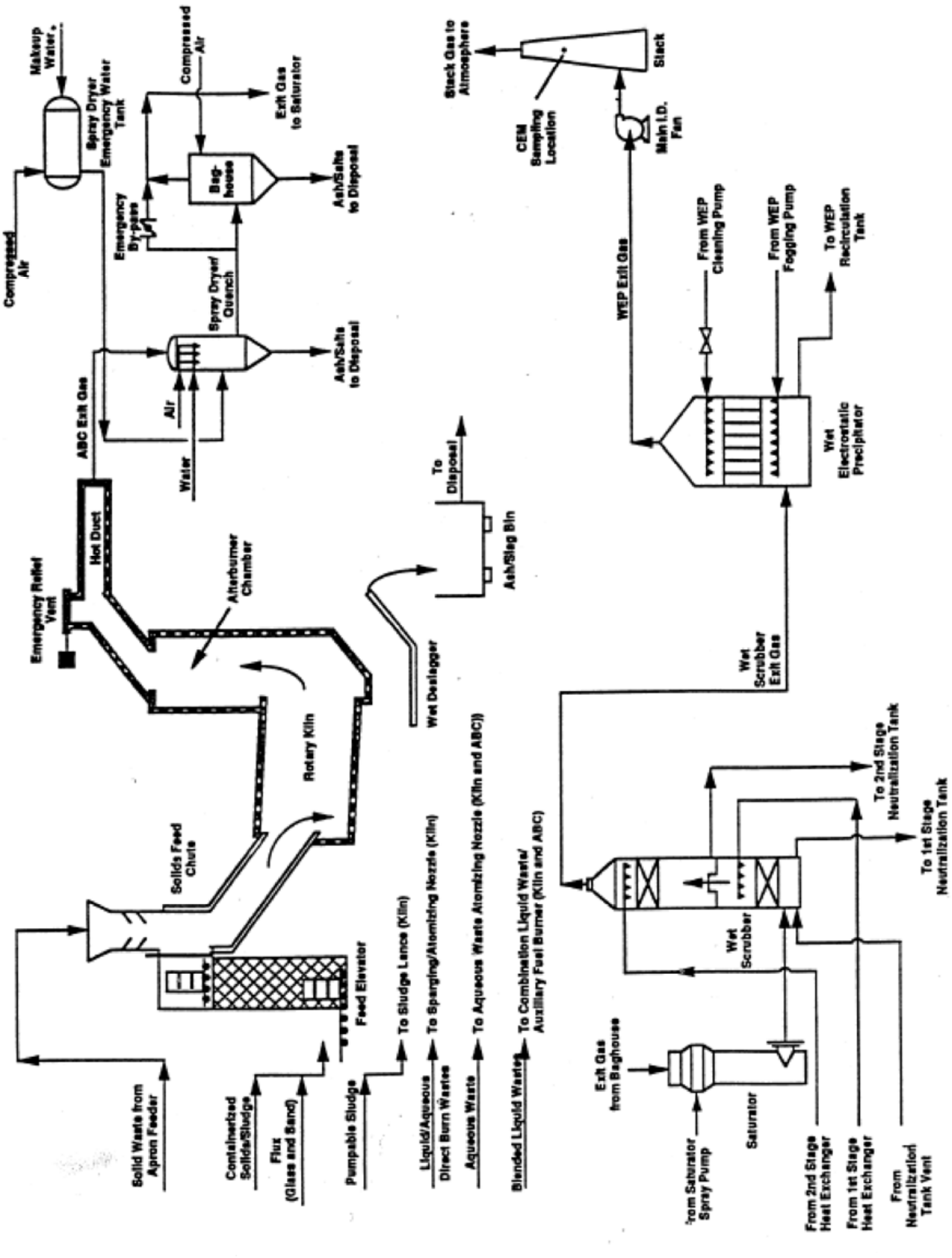


Fig. 3 APTUS Environmental Services (Case 1)

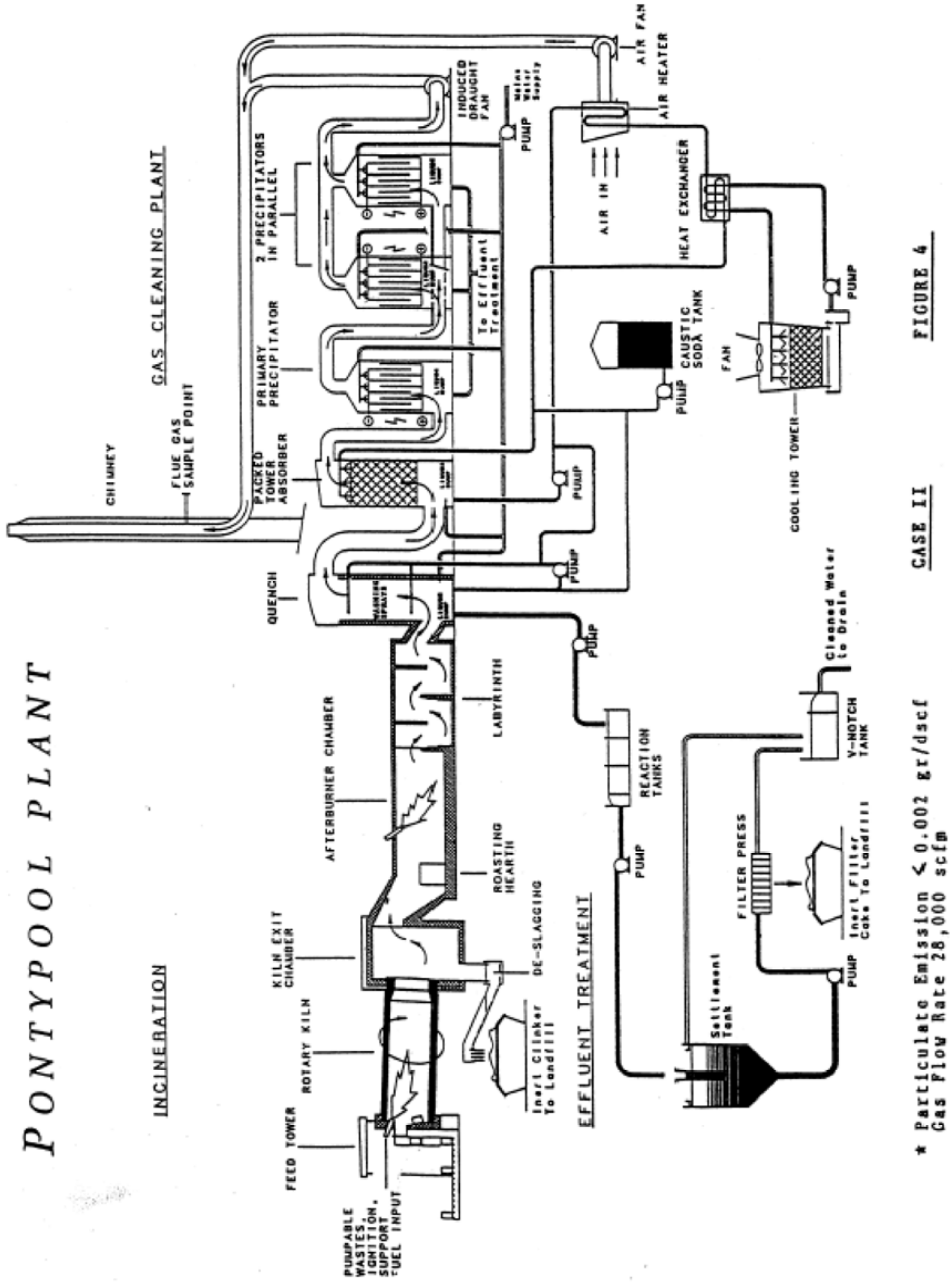


Fig. 4 Pontypool Plant (Case II)

6 SO_2 SCRUBBING PROCESSES

Many processes generate SO_2 in concentrations that are too low to be handled effectively in acid plants, but are high enough to violate air quality regulations. Scrubbing of SO_2 gases is generally accomplished using one of the following process:

(1) Lime/Limestone Slurry Systems;
(2) Soda Ash/Caustic Scrubbing;
(3) Soluble Alkali Processes;
(4) Ammonia Scrubbing.

Major industrial sources where these desulfurization techniques have been utilized are:

(1) Utility plants;
(2) Recovery boiler off gases in pulp and paper industry;
(3) Cogeneration using petroleum coke;
(4) Tail gases from some metal smelting operations;
(5) Tail gases from single absorption type acid plants.

Since FGD systems for utility plants is a topic for a separate paper by itself, the remaining four processes will be addressed in this paper.

6.1 Paper Industry

In paper making, large quantities of steam are required at three stages. First for cooking the wood chips, then to separate the individual cellulose fibers from the binding material lignin, and finally for evaporation of water in which cellulose fibers are dispersed for paper making. Economic considerations have led to development of some special type of boilers using pulp mill by-products. These include sand impregnated salt water borne bark and hogged wood fired boilers and recovery boilers using black kraft liquor and spent sulfite liquor.

In ammonia based acid sulfite pulping processes, recovery boiler off gases are passed through an ammonia absorber. In the absorber, Ammonium sulfite and Ammonium bisulfite are produced by the following reactions:

$2NH_3 + H_2O + SO_2 = (NH_4)_2 SO_3$ Ammonium Sulfite
$NH_3 + H_2O + SO_2 = NH_4 HSO_3$ Ammonium Bisulfite

These reactions take place in the liquid phase and the ratio of the sulfite to bisulfite produced depends on the pH of the solution. To maximize absorption of SO_2 and to minimize ammonia partial pressures, the absorber is operated at minimum practical temperatures. A very dense plume is observed at the absorber stack. The particle size is extremely fine, between 0.1 and 0.5 microns in diameter and the particles are not completely soluble in water. In the past, fiber bed filters have been used to control these emissions. However, pluggage and gradually increasing pressure drop through the fiber bed plagued these systems. Moreover, when pH control is not very accurate, free ammonia is generated, causing corrosion of the glass fiber.

Tubular precipitators used on these applications are constructed of fiberglass. A specially conductive fiberglass resin was developed for this application. This eliminates the need for, and also the problems associated with, maintaining water film on the collecting electrode. The high voltage discharged electrode is made of graphite and high molybdenum stainless steel. Carpenter-20 discharge discs have also been used. The particulate concentration is generally in 0.4 to 0.6 grain/CF range for properly operated units. Increase in absorber temperature or in pH of the scrubbing liquor can significantly increase particulate concentration. Two pass Tubular precipitators have collection efficiencies in excess of 99 percent under the entire range of process conditions. The collection efficiencies were measured using modified EPA method 5 and forward light scattering photometer. Excellent agreement was found between these two measurements. Heavy current suppression was encountered. Which is believed to have been caused by heavy concentration of extremely fine particles and enormous moisture loading (saturated stream at 160 ℉).

6.3 Cogeneration

Cogeneration using petroleum coke feedstock has been investigated. The exhaust from tangentially fired pulverized coke boiler is first cleaned by a Dry ESP. Ammonia scrubbing or Double alkali processes are used fro SO_2 scrubbing. The presence of heavy metal impurities in the fuel act as a catalyst to promote further oxidation of SO_2 to SO_3. Tubular precipitators are used to collect fine acid mist and fine sulfite-bisulfite emissions. The SO_2 concentration has to be reduced to 5 ppm-10 ppm level to comply with opacity regulations.

6.4 Metal Smelting

Primary and second metal production usually involves smelting of the ore in a reduction furnace. Sulfur oxides generated during this operation are generally cleaned and taken to the acid plant if the concentration is above 5 percent. Weak gases are generally scrubbed using lime/limestone slurry processes and emissions are collected using a baghouse. However, in some applications where caustic/soda ash or Ammonia scrubbing is used and/or where appreciable quantity of acid mist is present, Tubular precipitators are used to control emissions. These precipitators are operated wet. Particulate loadings of about 0.3 to 0.4 grain/CF are common and heavy moisture load is usually present. Corrosive conditions dictate use of plastic or special alloy construction.

6.5 Acid Plants

In older acid plants in single absorption plants, 98% SO_2 conversation efficiency can be achieved. Tail gases from these plants require SO_2 scrubbing systems to comply with Federal regulations on allowable SO_2 emissions. Ammonia scrubbing is widely used. Tubular precipitators are used to control acid mist and sulfite-bisulfite emissions.

7 NON-FERROUS METALS INDUSTRY

Tubular Precipitators have been used in following the Non-Ferrous Metal operations:

(1) Zirconium Calcining;
(2) Silver/Gold Refining;

(3) Molybdenum Roasting;

(4) Nickel Recovery using Electric Arc Furnace.

7.1 Zirconium Calcining

Zirconium and hafnium are used in the nuclear industry for the fuel rod casings. These metals are immune to corrosion attack from most of the chemicals and can withstand very high temperatures. Neutrons pass through Zirconium, whereas they are absorbed in Hafnium. Thus the nuclear reaction can be controlled by use of Zirconium and Hafnium tubes. Zirconium and Hafnium are mined as Zircon sand. The ore is chlorinated, selectively precipitated, passed through a separation operation, chlorinated again, and then reduced. The exhaust from the calciner contains Zirconium oxide, Hafnium oxide, a trace amount of elemental sulfur, some chlorides and sulfuric acid mist and sulfur dioxide. The exhaust is first treated in a caustic packed bed scrubber. The two-pass Tubular precipitator made of FRP is used to remove fine particulates and acid mist. High moisture loading and high concentration (0.4 to 0.5 grain/CF) of sub-micron particulates cause severe current suppression. Two passes in series are effective in combating the suppression effects. Collection efficiencies in 97 to 99 percent range are observed.

7.2 Silver/Gold Refining

In the bisulfate slime fusion process, filtered slime obtained from the tank house electrolytic refining operations is fused in two rotary batch kilns. The typical charge for the rotary kiln consists of about 46% by weight slime. 41% by weight sulfuric acid and remaining sodium sulfate. The slime consists of appreciable quantitities of Copper, Silver, and Selenium. Silica, Lead, Tellurium, Arsenic, gold and other organic materials are also present. The fusion of slime in the rotary kiln is a batch process and requires approximately six hours. The fume laden gases pass through a primary spray quench type scrubber followed by a venturi scrubber and finally through a tubular wet ESP. The size of particles entering the precipitator is thus in the sub-micron range. Selenium in the crystalline form sticks tenaciously to solid surfaces, so collecting tubes are continuously flushed. Mild current suppression conditions are present. Generally, the particulate loading is in 0.1 to 0.2 grain/CR, but at times can go as high as 0.4 to 0.5 grain/CF. Since the exhaust volumes are small from these processes, a low throughput velocity (high SCA) single pass unit is used for this application. Collection efficiencies of 98%-99% are obtained on this application.

Tubular precipitators have also been used on photographic film incinerator exhausts from recovering silver halides. Carbon and other finely divided impurities are also present in the exhaust gases. The gases are first passed through a quencher/scrubber and then through the Tubular precipitator. FRP construction is used to prevent chloride corrosion attack. Two passes are used to obtain extremely high collection efficiency.

7.3 Molybdenum Roaster

Molybdenum disulfide is oxidized in the multilevel hearth furnace to Molybdenum trioxide and sulfur dioxide. The exhaust is first passed through a baghouse and then through a lead lined quench scrubber. The exhaust stream entering the precipitator contains organic compounds and sulfuric acid mist with some oxides of Molybdenum, Selenium, Rhenium, and Mercury. Chlorides and trace amounts of fluorides are also present in the air stream. Fiberglass reinforced plastic with synthetic veil on the inside surface is used as a material of construction. A high SCA, two pass Tubular precipitator system has collection efficiency in excess of 99 percent. The cleaned gases are then taken to an acid plant.

7.4 Nickel Recovery

Variety of wastes are generated during steel making process. These wastes are generally contaminated with slag, oil, and water. Wastes from specialty steel making processes contain appreciable amounts of Nickel, and Chromium. Baghouse dust, mill scale, and high alloy grit. The mixture is palletized, dried , and then reduced in a rotary hearth furnace. Nickel and Iron oxides are completely reduced. The hot reduced pellets are mixed with additional fluxes and coarse metallics for adjustment of slag and metal chemistry. This is then fed into an electric arc furnace where Chromium oxide is reduced. The exhaust from electric arc furnace is taken to a high pressure drop (45″ w.c.) venturi scrubber. The sub-micron particulate emission from Venturi was still very high (0.1 to 0.2 grain/CF). Apart from causing opacity problems, the particulate carryover was causing maintenance problems for the high pressure fan. Two pass Tubular precipitators installed on this process completely eliminated this problem and plume opacity is reduced to almost zero. The unit is operated continuously wet to prevent accumulation of lead and zinc on the collector plates. Current suppression was of order of two to threefold.

8 STEEL INDUSTRY

Typical applications where Tubular precipitators are used in the steel industry are:

(1) Scarfing;

(2) Sintering;

(3) Coke Oven Exhaust.

8.1 Scarfing

Very fine Iron oxide particulates are created during scarfing operations. Particulate loadings of 1 grain/CF and greater are commonly encountered. The particle size is mainly in the sub-micron to 2 micron range. The exhaust stream coming from the scarfer is generally completely saturated. Wet Tubular precipitators are used in this application. Collection efficiency of 99 percent and higher are required to meet the opacity regulations. ASTM 304 L stainless steel construction is used. The collected particulates are very easy to wash off. Tubular precipitators used on this application have very high collection efficiencies even at high throughput velocity.

8.2 Sintering

Sintering is generally used to beneficiate ores by a high temperature agglomeration process. Sintering process transforms raw ore into a product which is uniform in size, has not many fines, is convenient to handle, and has better chemistry. Particulate loading from these processes range from 0.1 to 0.5 grain/CF. Very high amounts of condensable organic matter is also present (0.05 to 0.3 grain/CF). Sintering machines using recycle draft and strand cooling have lower emissions and lower exhaust volumes. Tubular units using stainless steel construction have been used in this application.

8.3 Coke Oven Exhaust

Exhausts from coke oven batteries are cooled in a quencher and then cleaned in a Tar mist type Tubular precipitator. The exhaust contains tar, fine unburned carbon, ash, etc. The coke oven gas, after being cleaned, can be used as a fuel source. Part of the cleaned gas is further cleaned in a fuel gas precipitator to be used to fire coke oven batteries. Since the carrier gas is combustible, all the precautions required for oil shale precipitators are also applicable here. Insulator purging is done using cleaned gas from the fuel gas precipitator.

9 CHEMICAL INDUSTRY

The Tubular precipitators are used as acid mist precipi-tators in:

(1) Sulfuric Acid Plants;

(2) Sulfonation Plants.

9.1 Sulfuric Acid Plants

Tubular precipitators have been used in metallurgical type acid plants to clean up smelter gases before they can be taken to the acid plant. Tubular precipitators are also used in sulfuric acid plants using H_2S or spent sulfuric acid as a feed material. Lead and FRP construction have been used in this service. In some applications, Hastelloy has been used. Conductive FRP construction, square tube two stage Tubular precipitators have several advantages over conven-tional lead tube type units. Both sides of the tubes are used for collection so height of the unit is reduced by a factor of two. The FRP housing encloses the entire unit, thus this type of precipitator can be designed for more than –20 inches w.c. The units are eaning.

shipped as modules, thus significantly reducing installation costs. Two stage, two pass Tubular precipitators used on Copper smelter off gases and on Gold and Arsenic roaster off gases have achieved 99.5% plus efficiency. The normal criteria used in the acid industry, to check the precipitator efficiency, is to have a 10 meter run of ductwork after the precipitator. This length of duct should be optically clear if the precipitator is performing satisfactorily.

9.2 Sulfonation Plants

Surfactants are organic compounds that have both a water soluble (hydrophilic) and a water insoluble (hydrophobic) group. The hydrophilic group for the most commercial available anionic surfactants is either a sulfonate or a sulfate. The hydrophobic portion is generally a hydrocarbon (C_8-C_{18}) in a straight or slightly branched chain. Oleum is most frequently used for sulfonation reaction. The reaction can be given by:

$$RH + H_2SO_4 = RSO_2OH + H_2O$$

Very dense white plume is generated during transfer of oleum to the storage tank. Fiber bed filters with absorption spray type devices have been used for control of these emissions. The emissions from the sulfonation reactor have also been handled using filters. However, pluggage problems are encountered during manufacture of some detergents. Two stage wet type Tubular precipitators have been used in this application quite successfully. The acid mist loadings are generally 0.25 to 0.3 grain/CF. Very fine size distribution (0.1 to 0.3 micron) is encountered. Low throughput velocities are required to achieve high collection efficiencies (99.5%).

Tubular precipitators have also been used on the detergent spray tower emissions. Detergent slurry is sprayed from the top of the detergent spray tower. Hot gases are drawn countercurrently upwards. The organic oils are evaporated creating dense plume. The exhaust also contains carryover detergent fines and a high moisture load. Wet Tubular precipitators are used to control opacity of the exhaust stream.

10 CONCLUSIONS

Wet Tubular electrostatic precipitators are ideally suited in applications involving high concentrations of fine particulates or for control of organic and acid mists. Further, they are suitable for difficult and highly corrosive applications in gas Cl.