Industrial Applications of ESPs

Goal

To familiarize you with the many ways ESPs are used by various industries to reduce emissions.

Objectives

At the end of this lesson, you will be able to do the following:

1. List five major industries that use ESPs to reduce particulate emissions
2. Describe how ESPs are used with dry flue gas desulfurization systems to reduce SO_2 emissions from boilers
3. Identify two operating problems that can occur when using ESPs on cement kilns
4. List two operating problems associated with ESPs in the steel industry
5. Briefly describe how ESPs are used along with acid gas control systems to control particulate and acid gas emissions from municipal solid waste and hazardous waste incinerators
6. Identify two processes in the lead, zinc and copper smelting industries that use ESPs to control particulate emissions

Introduction

Because ESPs can collect dry particles, sticky or tarry particles, and wet mists, they are used by many different industries, as diverse as chemical production and food processing. This lesson reviews the following industries that use ESPs to reduce air pollutant emissions: fossil-fuel-fired boilers, cement plants, steel mills, petroleum refineries, municipal waste incinerators, hazardous waste incinerators, kraft pulp and paper mills, and lead, zinc, and copper smelters.

Boilers

Particulate Matter Control System

ESPs are most widely used for the control of fly ash from industrial and utility boilers and have been used on coal-fired boilers for over 50 years. Particulate matter is generated from boilers when fossil fuels (coal and oil) are burned to generate steam for industrial processes or to produce electric power. Both hot-side and cold-side precipitators are used to control particulate emissions. Other than some construction modifications to account for the temperature difference of the flue gas handled, hot-side and cold-side ESPs are essentially the same. Cold-side ESPs are used most often for collecting fly ash from coal-fired boilers. If the dust has high resistivity, cold-side units are used along with a conditioning agent such as sulfur trioxide (see Lesson 3).

Dry Sulfur Dioxide (SO_2) Control System

One technology for reducing sulfur dioxide (SO_2) emissions from boilers is **dry flue gas desulfurization (FGD)**. In dry FGD, the flue gas containing SO_2 is contacted with an alkaline material to produce a dry waste product for disposal. This technology consists of three different FGD methods:

- Injection of wet alkaline material (slurry) into a spray dryer with collection of dry particles in an electrostatic precipitator or baghouse,
- Injection of dry alkaline material into the flue gas stream with collection of dry particles in an ESP or baghouse, or
- Addition of alkaline material to the fuel prior to combustion

Spray dryers used in dry FGD are similar to those that have been used for over 40 years in the chemical, food-processing, and mineral preparation industries. Spray dryers are vessels where hot flue gas is contacted with a finely atomized, wet alkaline spray (see Figure 5-1). Flue gas enters the top of the spray dryer and is swirled by a fixed vane ring to cause intimate contact with the slurry spray. Sodium carbonate solutions and lime slurries are the most common alkaline material used. The slurry is atomized into extremely fine droplets by rotary atomizers or two-fluid nozzles. In a rotary atomizer, slurry is broken into droplets by centrifugal force as the atomizer wheel spins at a very high speed. In two-fluid nozzles, slurry is mixed with compressed air, which forms the very small droplets. The high temperature of the flue gas, 120 to 204°C (250 to 400°F), evaporates the moisture from the wet alkaline sprays, leaving a dry, powdered product. The dry product is then collected in an ESP or baghouse (Joseph and Beachler 1981).

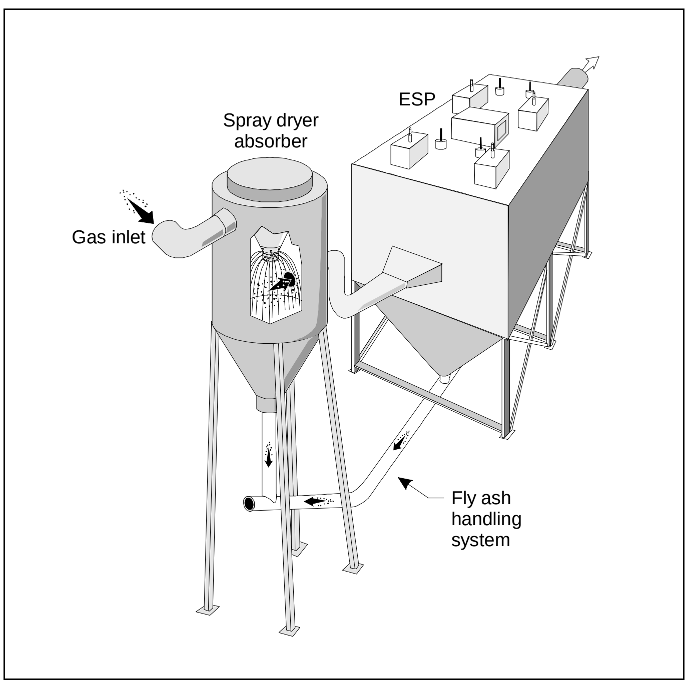

Figure 5-1. Spray dryer with ESP

A number of spray dryer FGD systems have been installed on industrial and utility boilers. They are particularly useful in meeting New Source Performance Standards (NSPS) that require only 70% SO_2 removal efficiency for utility boilers burning low-sulfur coal and as retrofit applications for units having to meet the standards required by the 1990 Clean Air Act Amendments (see Table 5-1).

Table 5-1. Commercial spray dryer FGD systems using an ESP or a baghouse

Station or plant	Size (MW)	Installation date	System description	Sorbent	Coal sulfur content (%)	SO_2 emission removal efficiency (%)
Otter Tail Power Company: Coyote Station No. 1, Beulah, ND	410	6/81	Rockwell/Wheelabrator-Frye system: four spray towers in parallel with 3 atomizers in each: reverse air-shaker baghouse with Dacron bags	Soda ash (sodium carbonate)	0.78	70
Basin Electric: Laramie River Station No. 3, Wheatland, WY	500	Spring 1982	Babcock and Wilcox: four spray reactors with 12 "Y-jet" nozzles in each: electrostatic precipitator	Lime	0.54-0.81	85-90
Strathmore Paper Co.: Woronco, MA	14	12/79	Mikropul: spray dryer and pulse jet baghouse	Lime	2-2.5	75
Celanese Corp.: Cumberland, MD	31	2/80	Rockwell/Wheelabrator-Frye system: one spray tower followed by a baghouse	Lime	1-2	85

Source: U.S. EPA February 1980.

Spray dryer absorbers systems can reduce SO_2 emissions by 60 to 90%. They have been used on boilers burning low-sulfur coal (usually less than 2% sulfur content) and are attractive alternatives to wet scrubbing technology, particularly in the arid western U.S.

In **dry injection systems**, a dry alkaline material (sorbent) is injected pneumatically into the gas stream by nozzles located in the ductwork prior to the flue gas entering the ESP. Sodium-based sorbents are used more frequently than lime for industrial coal-fired boilers but hydrated lime is prevalent for waste burning incinerators. Sodium bicarbonate is frequently used because it is highly reactive with SO_2. Sodium carbonate (soda ash), although not as reactive as sodium bicarbonate, is also used (U.S. EPA 1980). SO_2 removal efficiency for these systems is typically between 70 and 80%.

A third way to apply dry FGD is by **adding alkaline material to the fuel** (coal) prior to combustion. In fluidized bed boilers, limestone or sometimes lime is added to the coal in the fluidized burning bed. These systems are capable of removing more than 90% of SO_2 from the boiler flue gas. Alkaline material can also be injected into the furnace through ports or directly into the fuel burners. The SO_2 removal is typically greater than 70% in these systems.

Cement Plants

ESPs are used in cement plants to control particulate emissions from cement kilns and clinker coolers. In a cement plant, raw materials are crushed, ground, blended, and fed into a kiln, where they are heated. The kiln is fired with coal, oil, or gas. The material is heated to a temperature above 1595°C (2900°F), which causes it to fuse. The fused material is called cement clinker. The temperature of the hot, marble-sized, glass-hard clinker is cooled by the clinker cooler. The cooled clinker is then sent to the final grinding mills.

ESPs are frequently used to control kiln emissions because of their ability to handle high-temperature gases. These ESPs are usually hot-side ESPs with collection plates that are rapped or sprayed with water to remove collected dust. The dust generated in the cement kiln frequently has high resistivity. High resistivity can be reduced by conditioning the flue gas with moisture. Many of the newer cement plants send the high temperature kiln flue gas that contains particulate matter through a cyclone and conditioning tower (uses water to cool the gas temperature) prior to ducting the flue gas to the ESP. The ESP is then operated at a temperature of approximately 150°C (302°F).

A special problem arises during kiln startup due to the fact that the temperature of the kiln must be raised slowly to prevent damage to the heat-resistant (refractory) lining in the kiln. While kilns (especially coal-fired ones) are warming up and temperatures are below those for steady-state operating conditions, complete combustion of the fuels cannot occur, giving rise to combustible gases in the exhaust stream leading into the ESP. Electrostatic precipitators cannot be activated in the presence of combustibles, because the internal arcing of the precipitator could cause a fire or explosion. Use of a cyclone preceding the precipitator helps to minimize the excessive emissions during startup. Periods of excessive emissions during startup, malfunction, or shutdown are specifically exempted from the federal New Source Performance Standards for cement kilns.

ESPs can also be used on clinker coolers. However, the ESP must be carefully designed to prevent moisture in the flue gas from condensing. Condensed moisture can combine with clinker dust to coat the ESP internals with cement. (A case history of an ESP used on a cement kiln is given in Szabo et al. 1981.)

Steel Mills

ESPs are used in steel mills for reducing particulate emissions from blast furnaces, basic oxygen furnaces, and sinter plants.

In a blast furnace, iron ore is reduced to molten iron, commonly called pig iron. Blast furnaces are large, refractory-lined steel shells. Limestone, iron ore, and coke are charged into the top of the furnace. The gases produced during the melting process contain carbon monoxide and particulate matter. Particulate matter is removed from the blast furnace gas by wet ESPs or scrubbers, so that the gas (CO) can be burned "cleanly" in blast furnace stoves or other processes. Both plate and tube-type ESPs having water sprays to remove dust from collection electrodes are commonly used for cleaning blast furnace gas.

Basic oxygen furnaces (BOFs) refine iron from the blast furnace into steel. A BOF is a pear-shaped steel vessel that is lined with refractory brick. The vessel is charged with molten iron and steel scrap. A water-cooled oxygen lance is lowered into the vessel, where oxygen is blown to agitate the liquid, add intense heat to the process, and oxidize any impurities still contained in the liquid metal. The hot gases generated during the oxygen blow are approximately 1090 to 1650°C (2000 to 3000°F). These are usually cooled by water sprays located in the hood and ducting above the BOF. The cooled gases are then sent to an ESP or scrubber to remove the particulate matter (iron oxide dust). The iron oxide dust can have high resistivity, making the dust difficult to collect in an ESP. This problem can usually be reduced by conditioning the flue gas with additional moisture. Plate ESPs that are rapped or sprayed with water to remove dust from collection plates are commonly installed on BOFs.

In a sinter plant, materials such as flue dusts, iron ore fines (small particles), coke fines, mill scale (waste that occurs from various processing steps), and small scrap are converted into a high-quality blast furnace feed. These materials are first fed onto a traveling grate. The bed of materials is ignited by burning gas in burners located at the inlet of the traveling grate. As the bed moves along the traveling grate, air is pulled down through the bed to burn it, forming a fused, porous, red-hot sinter. The resulting gases are usually sent to an electrostatic precipitator to remove any particulate matter. If oily scrap is used as a feed material, care must be taken to prevent ESP collection plates from being coated with tarry particulate matter. Controlling the amount of oily mill scale and small scrap processed in the sinter plant can help alleviate this problem. Plate ESPs are commonly used in sinter plants.

Petroleum Refineries

ESPs are used in petroleum refineries to control particulate emissions from fluid-catalytic cracking units and boilers. In a refinery, heavy crude is broken down into lighter components by various distilling, cracking, and reforming processes. One common process is to "crack" the high-molecular-weight, high-boiling-point compounds (heavy fuel oils) into smaller, low-molecular-weight, low-boiling-point compounds (gasoline). This is usually done in a fluid-catalytic cracking (FCC) unit.

In an FCC unit, the feed stream (heavy gas oils) is heated and then mixed with a hot catalyst that causes the gas oils to vaporize and crack into smaller hydrocarbon-chain compounds. During this process, the catalyst becomes coated with coke. The coke deposits are eventually removed from the catalyst by a catalyst-regeneration step.

In the regenerator, a controlled amount of air is added to burn the coke deposits off the catalyst without destroying it. The gases in the regenerator pass through cyclones to separate large catalyst particles. The gases can sometimes go to a waste heat boiler to burn any carbon monoxide and organic emissions present in the gas stream. The boiler's exhaust gas still has a high concentration of fine catalyst particles. This flue gas is usually sent to an electrostatic precipitator to remove the very fine catalyst particles.

ESPs can also reduce particulate emissions from boiler exhausts. Oil-fired and, occasionally, coal-fired boilers generate steam that is used in many processes in the refinery. The flue gas from boilers is frequently sent to ESPs to remove particulate matter before the gas is exhausted into the atmosphere. ESPs designed similarly to those used on industrial and utility boilers are used on FCC units and petroleum refinery boilers.

Municipal Waste Incinerators

Electrostatic precipitators have been successfully used for many years to reduce particulate emissions from municipal waste incinerators. Municipal incinerators, also commonly called municipal waste combustors (MWCs) are used to reduce the volume of many different solid and liquid wastes. Generally, municipal wastes are composed of combustible materials (e.g. paper, wood, rags, food, yard clippings, and plastic and rubber materials) and noncombustible materials (e.g. rocks, metal, and glass). MWCs burn waste and produce ash residue that is disposed of in landfills.

Both dry and wet plate ESPs are commonly used on municipal incinerators. Collected dust can be removed from collection plates by rapping or by using water sprays. Plate ESPs having rigid frame discharge electrodes are currently being used on MWCs (installed after 1982). The designed collection efficiency is usually in the range of 96 to 99.6%. Dust resistivity can be a problem, particularly if the refuse contains a large quantity of paper products. The dust in the flue gas in this case usually has low resistivity. Resistivity can be adjusted by carefully controlling the temperature and the amount of moisture in the flue gas.

Since the mid-1980s a number of large MWCs (plants having a capacity of 250 to 3000 tons per day) with heat recovery devices have been built. More recent installations have been built with acid gas control systems along with an ESP or baghouse. The ESP (or baghouse) collects acid gas reaction products (mainly calcium chloride and calcium sulfate), unused sorbent material, and fly ash. ESPs are typically designed with 3 to 5 fields and are capable of meeting particulate emission limits of 0.015 gr/dscf and occasionally can achieve limits as low as 0.01 gr/dscf. These units have successfully reduced SO_2 by 80% (24 hr avg) and HCl by 90 to 95%.

The acid gas is removed by using dry sorbent injection or spray dryer absorbers. In dry injection systems sorbent is injected (usually hydrated lime) into the furnace or into the ducting prior to the flue gas entering the ESP. Acid gas removal efficiencies of 50% for SO_2 and 75% for HCl are routinely achieved (Beachler 1992).

A more commonly used acid gas control system is a spray dryer absorber placed ahead of the ESP. These systems have been able to achieve 80% removal (24 hr avg) for SO_2 and 90% removal for HCl. A wet calcium hydroxide slurry is injected into a spray dryer by a rotary atomizer or two-fluid nozzle. The slurry is made by slaking pebble lime (CaO) with water in a paste or detention slaker. The heat of the flue gas evaporates the liquid slurry in the spray dryer and the dry acid gas reaction products along with the particulate matter are collected in the ESP. Background information and data prepared as part of the promulgated NSPS and Emission Guidelines (U.S. EPA 1991) shows very good acid gas removal and particulate emission control for these systems.

Hazardous Waste Incinerators

ESPs are used in combination with a number of other air pollution control (APC) devices including wet scrubbers and dry scrubbers (also called spray dryer absorbers) to clean the flue gas generated by burning hazardous wastes. Some facilities have been designed to use spray dryers to remove the acid gases including HCl, HF, and SO_2 followed by the ESP to remove the acid gas reaction salts, any unused sorbent, and particulate matter. Other facilities have been designed with an APC system consisting of a spray dryer, baghouse, wet scrubber, and a wet ESP (Figure 5-2). The spray dryer cools the flue gas and reduces some of the acid gas components. The baghouse collects the particulate matter (including metals) and the wet scrubber removes HCl (> 99%) and other acid gases. The wet ESP collects any particulate matter not removed by the baghouse. The wet scrubbing system is a closed loop. The effluent produced in the scrubbers is ultimately sent to the spray dryer to evaporate the liquid, therefore eliminating the need for a waste water treatment system. A number of facilities using this APC system configuration are permitted to burn PCBs and other Toxic Substance Control Act (TSCA) and Resource Conservation and Recovery Act (RCRA) wastes.

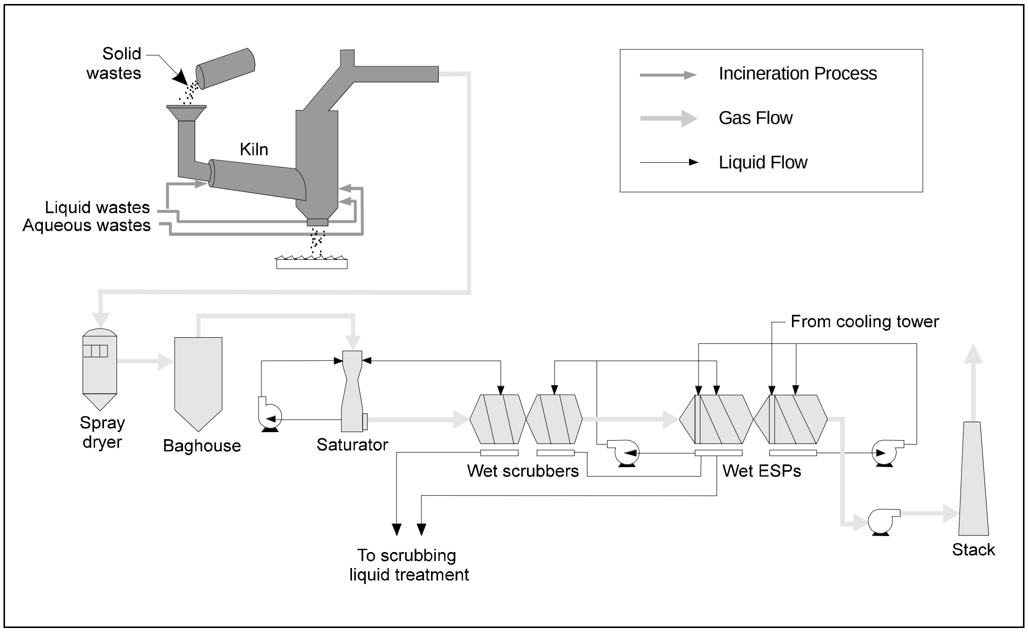

Figure 5-2. APC system for a hazardous waste incinerator consisting of a spray dryer, baghouse, wet scrubbers, and wet ESPs

Kraft Pulp and Paper Mills

Plate or tube-type ESPs are used in the kraft pulp and paper industry to reduce particulate emissions from the recovery furnace. In the kraft process of making pulp and paper, chemicals are recovered by using evaporators, recovery furnaces, and reaction tanks. As part of the pulping process, a waste product, black-liquor, is produced. After it is concentrated, the black-liquor concentrate is burned in the recovery furnace to provide heat and steam to various processes in the plant. The recovery furnace is essentially a boiler designed to effectively burn the black-liquor concentrate. The resulting flue gas contains particulate matter that is usually removed by an ESP before it is exhausted into the atmosphere. Dust can be removed from collection electrodes by rapping or by using water sprays.

Lead, Zinc, and Copper Smelters

Plate ESPs are used to reduce particulate emissions from a number of processes in the smelting of lead, zinc, and copper metals. Since lead, zinc, and copper are found in sulfide ore deposits, the release of sulfur compounds is a problem during the smelting process. Before being smelted, ore concentrates are often treated, or prepared, by two processes called sintering and roasting. **Sintering** changes the physical form of a material, usually by taking an ore mixture of large and fine pieces and fusing them into strong, porous products that can be used in the smelting processes. ESPs are commonly used to reduce emissions from lead and zinc sinter plants. ESPs are also effective in reducing emissions from zinc and copper roasters. **Roasters** prepare zinc and copper ores by removing unwanted materials such as sulfur. The roasted ore is then sent to other refining processes to produce zinc and copper metals.

Other Industries

ESPs are used in many other large and small industrial processes including glass melting, sulfuric acid production, food processing, and chemical manufacturing. Glass melting furnaces usually use hot-side ESPs because the flue gas temperature in this process is approximately 230 to 260°C (450 to 500°F). Sulfuric acid plants usually use plate or tube-type ESPs to collect sulfuric acid mists. Collected mists are removed from collection electrodes by water sprays. Some smaller industries that produce coatings, resins, asphalt, rubber, textiles, plastics, vinyl, and carpet frequently use a small two-stage precipitator to control particles and smoke. The two-stage ESPs use liquid sprays to remove collected particles, smokes, and oils from the collection plates.

Summary

Table 5-2 summarizes the information presented in this lesson for various industries that use ESPs to reduce emissions.

Table 5-2. Summary of typical ESP applications (by industry)

Industry	Process	Material Collected by ESP	ESP Collection Efficiency	ESP Features	Potential Problems
1. Industrial & utility boilers	Burning fossil fuels	Fly ash	> 99%	Hot-side and cold-side ESPs	Fly ash from low sulfur coals has high resistivity
	Dry SO_2 control systems	Dry, alkaline product	> 99% (particles); 70-80% (SO_2)	Cold-side ESP (usually rigid electrode or rigid frame)	
2. Cement plants	Cement kilns	Particulate emissions	> 99%	Usually hot-side ESPs with collection plates. Rapped or sprayed with water.	Dust often has high resistivity. Combustible gases are present when kiln is warming up.
	Clinker coolers	Particulate emissions	> 99%	Hot-side or cold-side depending on gas temperature.	Must prevent moisture in flue gas from condensing
3. Steel mills	Blast furnaces	Carbon monoxide and particulate matter	> 99% Particulate matter	Wet ESPs. Both plate and tube with water sprays.	
	Basic oxygen furnaces	Iron oxide dust	> 99%	Wet or dry plate ESPs	Iron oxide dust can have high resistivity

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Table 5-2. *(continued)*
Summary of typical ESP applications (by industry)

Industry	Process	Material Collected by ESP	ESP Collection Efficiency	ESP Features	Potential Problems
3. Steel mills (cont'd)	Sinter plant	Particulate matter	> 99%	Wet or dry plate ESPs	Oily scrap used as feed material can coat plates with tarry substance
4. Petroleum refineries	Fluid-catalytic cracking Boiler operations	Catalyst particles Particulate matter	> 99% > 99%	Usually dry ESPs Usually dry ESPs	
5. Municipal waste incinerators	Incineration and heat recovery Acid control systems (spray dryer along with ESP)	Particulate matter Acid gas reaction products, unused sorbents	96-99.6% > 99.5 (0.015 gr/dscf) for particulate matter. SO_2 and HCl reduced 80 and 90% respectively	Wet and dry plate ESPs Usually rigid-electrode systems (newer facilities)	Low resistivity of dust from paper products
6. Hazardous waste incinerators	Acid control systems (1) Spray dryer and baghouse followed by wet ESPs (2) Spray dryer followed by an ESP	Acid gas reaction products, unused sorbents	> 99% (0.015 gr/dscf) HCl removal efficiency > 95%	Wet ESPs or dry ESPs when used with spray dryer	
7. Kraft pulp and paper mills	Recovery furnace boilers	Particulate matter	> 99%	Wet or dry ESPs	
8. Lead, zinc, copper smelters	Sinter plants Roasting	Particulate matter Particulate matter	> 99% > 99%	Usually plate ESPs Usually plate ESPs	

Suggested Reading

For more information about the specific industries discussed in this lesson see:

Beachler, D. S., J. A. Jahnke, G. T. Joseph and M. M. Peterson. 1983. *Air Pollution Control Systems for Selected Industries, Self-Instructional Guidebook*. (APTI Course SI:431). EPA 450/2-82-006. U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 1985. *Operation and Maintenance Manual for Electrostatic Precipitators*. EPA 625/1-85/017.

U.S. Environmental Protection Agency. 1981. *Inspection Manual for Evaluation of Electrostatic Precipitator Performance*. EPA 340/1-79-007.