EPA-452/F-03-016

Air Pollution Control Technology Fact Sheet

Name of Technology: Spray-Chamber/Spray-Tower Wet Scrubber

This type of technology is a part of the group of air pollution controls collectively referred to as "wet scrubbers." When used to control inorganic gases, they may also be referred to as "acid gas scrubbers." When used to specifically control sulfur dioxide (SO_2), the term flue-gas desulfurization (FGD) may also be used.

Type of Technology: Removal of air pollutants by inertial or diffusional impaction, reaction with a sorbent or reagent slurry, or absorption into liquid solvent.

Applicable Pollutants:

Primarily particulate matter (PM), including PM less than or equal to 10 micrometers (μm) in aerodynamic diameter (PM_{10}), PM less than or equal to 2.5 :m in aerodynamic diameter ($PM_{2.5}$), and hazardous air pollutants (HAP) in particulate form (PM_{HAP}); and inorganic fumes, vapors, and gases (e.g., chromic acid, hydrogen sulfide, ammonia, chlorides, fluorides, and SO_2). These type of scrubbers may also be used to control volatile organic compounds (VOC). Hydrophilic VOC maybe absorbed by aqueous fluid, while the addition of amphiphilic block copolymers to the water can be used to absorb hydrophobic VOC. When using absorption as the primary control technique, the spent solvent must be easily regenerated or disposed of in an environmentally acceptable manner (EPA, 1991).

Achievable Emission Limits/Reductions:

PM: Spray tower scrubbers generally are not used for fine PM applications because high liquid to gas ratios (greater than 3 liters per cubic meter (l/m^3) or 22.4 gallons per thousand cubic feet (gal/1000 ft^3)) are required. Collection efficiencies range from 70 to greater than 99 percent, depending upon the application. Cyclonic spray towers generally achieve collection efficiencies at the higher end of the range (Perry, 1984; Corbitt, 1990; EPA, 1998; EPA, 1973).

Inorganic Gases: Control device vendors estimate that removal efficiencies range from 95 to 99 percent. SO_2 removal efficiencies vary from 80 to greater than 99 percent, depending upon the type of reagent used and the spray tower design. Most current applications have a removal efficiency greater than 90 percent (EPA, 1993; Sondreal, 1993; Soud, et al., 1993).

VOC: Removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Most absorbers have removal efficiencies in excess of 90 percent, and spray tower absorbers may achieve efficiencies greater than 99 percent for some pollutant-solvent systems. The typical collection efficiency range is from 50 to 95 percent. Lower control efficiencies represent flows containing relatively insoluble compounds at low concentrations, while the higher efficiencies are for flows which contain readily soluble compounds at high concentrations (EPA, 1996; Perry, 1984; EPA, 1991).

Applicable Source Type: Point

Typical Industrial Applications:

Spray tower applications include light-oil and benzene storage tank emission control using wash oil as a solvent. Spray towers do not suffer from restrictions to gas flow by accumulated residues commonly found in packed bed scrubbers. However, spray towers have the least effective mass transfer capability and thus, are generally limited to use for PM removal and with high-solubility gases (EPA, 1992).

Wet scrubbers are often used as part of FGD systems, where they are used to control emissions from coal and oil combustion from electric utilities and industrial sources. Spray towers are one of the more popular wet scrubber configurations used to bring waste gases into contact with a sorbent designed to absorb and react with the SO_2. Wet scrubbers have been applied to SO_2 emissions from the primary nonferrous metals processing (e.g., copper, lead, and aluminum), but sulfuric acid or elemental sulfur plants are more popular control devices due to the high SO_2 concentrations associated with these processes (Soud, et al., 1993).

Emission Stream Characteristics:

a. **Air Flow:** Typical gas flow rates for spray tower wet scrubbers are 0.7 to 47 standard cubic meters per second (sm^3/sec) (1,500 to 100,000 standard cubic feet per minute (scfm)) (Cooper, 1994).

b. **Temperature:** In general, the higher the gas temperature, the lower the absorption rate, and vice-versa. Excessively high gas temperatures also can lead to significant solvent or scrubbing liquid loss through evaporation. For waste gases in which the PM is to be controlled, the temperature range is generally 4 to 370 C (40 to 700 F), and for gas absorption applications, 4 to 38 C (40 to 100 F) (EPA, 1996; Avallone, 1996).

c. **Pollutant Loading:** Typical gaseous pollutant concentrations range from 250 to 10,000 ppmv (EPA, 1996). Spray tower wet scrubbers are not as prone to fouling as other wet scrubber designs, but very high liquid-to-gas ratios may be necessary to capture fine PM (EPA, 1982; Perry, 1984).

d. **Other Considerations:** For organic vapor HAP control applications, low outlet concentrations will typically be required, leading to impractically tall absorption towers, long contact times, and high liquid-gas ratios that may not be cost-effective. Wet scrubbers will generally be effective for HAP control when they are used in combination with other control devices such as incinerators or carbon adsorbers (EPA, 1991).

Emission Stream Pretreatment Requirements:

Precoolers (e.g., an additional spray chamber) may be needed to reduce the inlet air temperature to acceptable levels to avoid solvent evaporation or reduced absorption rates (EPA, 1996).

Cost Information:

The following are cost ranges (expressed in 2002 dollars) for spray tower wet scrubbers of conventional design under typical operating conditions, adapted from EPA cost-estimating spreadsheets (EPA, 1996) and referenced to the volumetric flow rate of the waste stream treated. For purposes of calculating the example cost effectiveness, the pollutant is PM at a loading of approximately 7 grams per standard cubic meter (g/sm^3) (3 grains per standard cubic foot (gr/scf)). The costs do not include costs for post-treatment or disposal of used solvent or waste.

Costs can be higher than in the ranges shown for applications which require expensive materials, solvents, or treatment methods. As a rule, smaller units controlling a low concentration waste stream will be more expensive (per unit volumetric flow rate) than a large unit cleaning a high pollutant load flow. Operating costs are much more significant than capital costs for spray towers since they are relatively simple to construct and install, and require relatively large quantities of liquid and higher water recirculation rates (EPA, 1996).

a. **Capital Cost:** \$4,200 to \$13,000 per sm^3/sec (\$2 to \$6 per scfm)

b. **O & M Cost:** \$3,200 to \$64,000 per sm^3/sec (\$1.50 to \$30 per scfm), annually

c. **Annualized Cost:** \$5,300 to \$102,000 per sm^3/sec (\$2.5 to \$48 per scfm), annually

d. **Cost Effectiveness:** \$50 to \$950 per metric ton (\$45 to \$860 per short ton), annualized cost per ton per year of pollutant controlled

Theory of Operation:

Spray scrubbers consist of empty cylindrical or rectangular chambers in which the gas stream is contacted with liquid droplets generated by spray nozzles. A common form is a spray tower, in which the gas flows upward through a bank or successive banks of spray nozzles. Similar arrangements are sometimes used in spray chambers with horizontal gas flow. Such devices have very low gas pressure drops, and all but a small part of the contacting power is derived from the liquid stream. The required contacting power is obtained from an appropriate combination of liquid pressure and flow rate (Perry, 1984).

Physical absorption depends on properties of the gas stream and liquid solvent, such as density and viscosity, as well as specific characteristics of the pollutant(s) in the gas and the liquid stream (e.g., diffusivity, equilibrium solubility). These properties are temperature dependent, and lower temperatures generally favor absorption of gases by the solvent. Absorption is also enhanced by greater contacting surface, higher liquid-gas ratios, and higher concentrations in the gas stream (EPA, 1991). Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate (EPA, 1996).

Inorganic Gases Control:

Water is the most common solvent used to remove inorganic contaminants. Pollutant removal may be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant. An example of this is using caustic solution for acid-gas absorption instead of pure water as a solvent (EPA, 1996). Amphiphilic block copolymers dissolved in the water can be used to remove hydrophobic VOC, which has much less affinity for water than hydrophilic VOC do.

Used in FGD systems, spray tower scrubbers introduce a reagent slurry as atomized droplets through the spray nozzles at the top of, or in stages within the scrubber. The SO_2-laden gas enters at the bottom of the column and travels upward through the tower in a countercurrent flow, though horizontal spray towers which use a crosscurrent design also exist. In most cases the sorbent is an alkaline slurry, commonly limestone, slaked lime, or a mixture of slaked lime and alkaline fly ash, though many other sorbent processes exist. Absorption of SO_2 is accomplished by the contact between the gas reagent slurry. The sulfur oxides react with the sorbent, forming a wet mixture of calcium sulfite and sulfate (EPA, 1981; Soud, et al., 1993).

For horizontal FGD designs, the fresh slurry (recycle and makeup streams) is often introduced at the last, or rear, stage of the absorber where the SO_2 content of the gas stream is lowest. The slurry contacted in the last stage is pumped forward to the next stage. This way, the slurry "flows" countercurrent to the gas flow. The first stage of the absorber has the highest SO_2 concentration gas stream and a slurry that has had much of its active alkalinity exhausted.(EPA, 1981).

PM Control:

In spray tower scrubbers, the PM-laden stream is introduced into the chamber where in comes in contact with the liquid droplets generated by the spray nozzles. The size of the droplets generated by the spray nozzles is controlled to maximize liquid-particle contact and, consequently, scrubber collection efficiency (EPA, 1998).

A cyclonic spray chamber is similar to a spray tower, with the exception that the is introduced in such a way as to produce cyclonic motion inside the chamber. The motion contributes to higher gas velocities, more effective particle and droplet separation, and higher collection efficiency. Tangential inlet or turning vanes are common means of inducing cyclonic motion (EPA, 1998).

VOC Control:

Absorption is applied in chemical processing as a raw material and/or a product recovery technique in separation and purification of gaseous streams containing high concentrations of organics (e.g., in natural gas purification and coke by-product recovery operations). In absorption, the organics in the gas stream are dissolved in a liquid solvent. The contact between the absorbing liquid and the vent gas is accomplished in counter current spray towers, scrubbers, or packed or plate columns (EPA, 1995).

Spray towers do not suffer from restrictions to gas flow by accumulated residues commonly found in packed scrubbers. However, spray towers have the least effective mass transfer capability and thus, are generally limited to use for PM removal and with high-solubility gases (EPA, 1992).

Advantages:

Advantages of spray towers include (AWMA, 1992; EPA, 1996):

1. Relatively low pressure drop;
2. Can handle flammable and explosive dusts with little risk;
3. Fiberglass-reinforced plastic (FRP) construction permits operation in highly corrosive atmospheres;
4. Relatively low capital cost;
5. Relatively free from plugging;
6. Relatively small space requirements; and
7. Ability to collect PM as well as gases.

Disadvantages:

Disadvantages of spray towers include (AWMA, 1992; EPA, 1996):

8. May create water (or liquid) disposal problem;
9. Waste product collected wet;
10. Relatively low mass-transfer efficiencies;
11. Relatively inefficient at removing fine PM;
12. When FRP construction is used, it is sensitive to temperature; and
13. Relatively high operating costs.

Other Considerations:

For gas absorption, the water or other solvent must be treated to remove the captured pollutant from the solution. The effluent from the column may be recycled into the system and used again. This is usually the case if the solvent is costly (e.g., hydrocarbon oils, caustic solutions). Initially, the recycle stream may go to a waste treatment system to remove the pollutants or the reaction product. Make-up solvent may then be added before the liquid stream reenters the column (EPA, 1996).

For PM applications, wet scrubbers generate waste in the form of a slurry. This creates the need for both wastewater treatment and solid waste disposal. Initially, the slurry is treated to separate the solid waste from the water. The treated water can then be reused or discharged. Once the water is removed, the remaining waste will be in the form of a solid or sludge. If the solid waste is inert and nontoxic, it can generally be landfilled. Hazardous wastes will have more stringent procedures for disposal. In some cases, the solid waste may have value and can be sold or recycled (EPA, 1998).

For FGD applications, the slurry combines with the SO_2-laden waste gas to form a waste slurry in the bottom of the scrubber. The sludge is removed from the scrubber and, depending upon the reagent or sorbent used to react with the SO_2, the waste reacted sludge is disposed of, recycled or regenerated, or, in some cases a salable product. For slurries which produce calcium sulfate and sulfite, oxidizing the waste sludge results in gypsum. Gypsum is a preferred product because it can be marketed and also because of its superior dewatering characteristics. Most scrubbers are operated without the oxidizing step and the waste sludge must be dewatered and disposed of properly. Some slurries can be regenerated and used again, but few such systems are in use due to high energy costs associated with the regeneration of the reagent (Sondreal, 1993; Soud, et al., 1993; Merrick, 1989).

Configuring a control device that optimizes control of more than one pollutant often does not achieve the highest control possible for any of the pollutants controlled alone. For this reason, waste gas flows which contain multiple pollutants (e.g., PM and SO_2, or PM and inorganic gases) are generally controlled with multiple control devices, occasionally more than one type of wet scrubber (EC/R, 1996).

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