



Air Pollution Control Technology Fact Sheet

Name of Technology: Packed-Bed/Packed-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.”

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 inorganic fumes, vapors, and gases (e.g., chromic acid, hydrogen sulfide, ammonia, chlorides, fluorides, and SO₂); volatile organic compounds (VOC); and particulate matter (PM), including PM less than or equal to 10 micrometers (μm) in aerodynamic diameter (PM₁₀), PM less than or equal to 2.5 μm in aerodynamic diameter (PM_{2.5}), and hazardous air pollutants (HAP) in particulate form (PM_{HAP}).

Absorption is widely used as a raw material and/or product recovery technique in separation and purification of gaseous streams containing high concentrations of VOC, especially water-soluble compounds such as methanol, ethanol, isopropanol, butanol, acetone, and formaldehyde (Croll Reynolds, 1999). Hydrophobic VOC can be absorbed using an amphiphilic block copolymer dissolved in water. However, as an emission control technique, it is much more commonly employed for controlling inorganic gases than for VOC. When using absorption as the primary control technique for organic vapors, the spent solvent must be easily regenerated or disposed of in an environmentally acceptable manner (EPA, 1991). When used for PM control, high concentrations can clog the bed, limiting these devices to controlling streams with relatively low dust loadings (EPA, 1998).

Achievable Emission Limits/Reductions:

Inorganic Gases: Control device vendors estimate that removal efficiencies range from 95 to 99 percent (EPA, 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 packed-tower absorbers may achieve efficiencies greater than 99 percent for some pollutant-solvent systems. The typical collection efficiency range is from 70 to greater than 99 percent (EPA, 1996a; EPA, 1991).

PM: Packed-bed wet scrubbers are limited to applications in which dust loading is low, and collection efficiencies range from 50 to 95 percent, depending upon the application (EPA, 1998).

Applicable Source Type: Point

Typical Industrial Applications:

The suitability of gas absorption as a pollution control method is generally dependent on the following factors: 1) availability of suitable solvent; 2) required removal efficiency; 3) pollutant concentration in the inlet vapor;

4) capacity required for handling waste gas; and, 5) recovery value of the pollutant(s) or the disposal cost of the unrecoverable solvent (EPA, 1996a). Packed-bed scrubbers are typically used in the chemical, aluminum, coke and ferroalloy, food and agriculture, and chromium electroplating industries. These scrubbers have had limited use as part of flue gas desulfurization (FGD) systems, but the scrubbing solution flow rate must be carefully controlled to avoid flooding (EPA, 1998; EPA, 1981).

When absorption is used for VOC control, packed towers are usually more cost effective than impingement plate towers. However, in certain cases, the impingement plate design is preferred over packed-tower columns when either internal cooling is desired, or where low liquid flow rates would inadequately wet the packing (EPA, 1992).

Emission Stream Characteristics:

- a. **Air Flow:** Typical gas flow rates for packed-bed wet scrubbers are 0.25 to 35 standard cubic meters per second (sm^3/sec) (500 to 75,000 standard cubic feet per minute (scfm)) (EPA, 1982; EPA, 1998).
- b. **Temperature:** Inlet temperatures are usually in the range of 4 to 370°C (40 to 700°F) for waste gases in which the PM is to be controlled, and for gas absorption applications, 4 to 38°C (40 to 100°F). 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. (Avalone, 1996; EPA, 1996a).
- c. **Pollutant Loading:** Typical gaseous pollutant concentrations range from 250 to 10,000 ppmv (EPA, 1996a). Packed-bed wet scrubbers are generally limited to applications in which PM concentrations are less than 0.45 grams per standard cubic meter (g/sm^3) (0.20 grains per standard cubic foot (gr/scf)) to avoid clogging (EPA, 1982).
- 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:

For absorption applications, precoolers (e.g., spray chambers, quenchers) may be needed to saturate the gas stream or to reduce the inlet air temperature to acceptable levels to avoid solvent evaporation or reduced absorption rates (EPA, 1996a).

Cost Information:

The following are cost ranges (expressed in 2002 dollars) for packed-bed wet scrubbers of conventional design under typical operating conditions, developed using EPA cost-estimating spreadsheets (EPA, 1996a) and referenced to the volumetric flow rate of the waste stream treated. For purposes of calculating the example cost effectiveness, the pollutant used is hydrochloric acid and the solvent is aqueous caustic soda. The costs do not include costs for post-treatment or disposal of used solvent or waste. Costs can be substantially 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 much more expensive (per unit volumetric flow rate) than a large unit cleaning a high pollutant load flow.

- a. **Capital Cost:** \$23,000 to \$117,000 per sm^3/sec (\$11 to \$55 per scfm)
- b. **O & M Cost:** \$32,000 to \$104,000 per sm^3/sec (\$15 to \$49 per scfm), annually
- c. **Annualized Cost:** \$36,000 to \$165,000 per sm^3/sec (\$17 to \$78 per scfm), annually
- d. **Cost Effectiveness:** \$110 to \$550 per metric ton (\$100 to \$500 per short ton), annualized cost per ton per year of pollutant controlled

Theory of Operation:

Packed-bed scrubbers consist of a chamber containing layers of variously-shaped packing material, such as Raschig rings, spiral rings, or Berl saddles, that provide a large surface area for liquid-particle contact. The packing is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. Scrubbing liquid is evenly introduced above the packing and flows down through the bed. The liquid coats the packing and establishes a thin film. The pollutant to be absorbed must be soluble in the fluid. In vertical designs (packed towers), the gas stream flows up the chamber (countercurrent to the liquid). Some packed beds are designed horizontally for gas flow across the packing (crosscurrent) (EPA, 1998).

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, 1996a; EPA, 1996b).

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. Caustic solution (sodium hydroxide, NaOH) is the most common scrubbing liquid used for acid-gas control (e.g., HCl, SO_2 , or both), though sodium carbonate (Na_2CO_3) and calcium hydroxide (slaked lime, $\text{Ca}[\text{OH}]_2$) are also used. When the acid gases are absorbed into the scrubbing solution, they react with alkaline compounds to produce neutral salts. The rate of absorption of the acid gases is dependent upon the solubility of the acid gases in the scrubbing liquid (EPA, 1996a; EPA, 1996b).

VOC Control:

Absorption is a commonly applied operation in chemical processing. It is used 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).

The use of absorption as the primary control technique for organic vapors is subject to several limiting factors. One factor is the availability of a suitable solvent. The VOC must be soluble in the absorbing liquid and even then, for any given absorbent liquid, only VOC that are soluble can be removed. Some common solvents that may be useful for volatile organics include water, mineral oils, or other nonvolatile petroleum oils. Another factor that affects the suitability of absorption for organic emissions control is the availability of vapor/liquid equilibrium data for the specific organic/solvent system in question. Such data are necessary for the design of absorber systems; however, they are not readily available for uncommon organic compounds.

The solvent chosen to remove the pollutant(s) should have a high solubility for the vapor or gas, low vapor pressure, low viscosity, and should be relatively inexpensive. Water is used to absorb VOC having relatively high water solubilities. Amphiphilic block copolymers added to water can make hydrophobic VOC dissolve in water. Other solvents such as hydrocarbon oils are used for VOC that have low water solubilities, though only in industries where large volumes of these oils are available (e.g., petroleum refineries and petrochemical plants) (EPA, 1996a).

Another consideration in the application of absorption as a control technique is the treatment or disposal of the material removed from the absorber. In most cases, the scrubbing liquid containing the VOC is regenerated in an operation known as stripping, in which the VOC is desorbed from the absorbent liquid, typically at elevated temperatures and/or under vacuum. The VOC is then recovered as a liquid by a condenser (EPA, 1995).

PM Control:

In packed-bed scrubbers, the gas stream is forced to follow a circuitous path through the packing material, on which much of the PM impacts. The liquid on the packing material collects the PM and flows down the chamber towards the drain at the bottom of the tower. A mist eliminator (also called a “de-mister”) is typically positioned above/after the packing and scrubbing liquid supply. Any scrubbing liquid and wetted PM entrained in the exiting gas stream will be removed by the mist eliminator and returned to drain through the packed bed.

In a packed-bed scrubber, high PM concentrations can clog the bed, hence the limitation of these devices to streams with relatively low dust loadings. Plugging is a serious problem for packed-bed scrubbers because the packing is more difficult to access and clean than other scrubber designs. Mobile-bed scrubbers are available that are packed with low-density plastic spheres that are free to move within the packed bed. These scrubbers are less susceptible to plugging because of the increased movement of the packing material. In general, packed-bed scrubbers are more suitable for gas scrubbing than PM scrubbing because of the high maintenance requirements for control of PM (EPA, 1998).

Advantages:

Advantages of packed-bed towers include (AWMA, 1992):

1. Relatively low pressure drop;
2. Fiberglass-reinforced plastic (FRP) construction permits operation in highly corrosive atmospheres;
3. Capable of achieving relatively high mass-transfer efficiencies;
4. The height and/or type of packing can be changed to improve mass transfer without purchasing new equipment;
5. Relatively low capital cost;
6. Relatively small space requirements; and
7. Ability to collect PM as well as gases.

Disadvantages:

Disadvantages of packed-bed towers include (AWMA, 1992):

1. May create water (or liquid) disposal problem;
2. Waste product collected wet;
3. PM may cause plugging of the bed or plates;
4. When FRP construction is used, it is sensitive to temperature; and

5. Relatively high maintenance 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, amphiphilic block copolymer). Initially, the recycle stream may go to a 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, 1996a).

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).

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 SO₂, 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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