Lesson 4

Liquid-Phase Contacting Scrubbers

Goal

To familiarize you with the operation, collection efficiency, and major maintenance problems of liquid-phase contacting scrubbers.

Objectives

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

1. List two liquid-phase contacting scrubbers and briefly describe the operation of each
2. For each scrubber above, identify the range of operating values for pressure drop, liquid-to-gas ratio, as well as the collection efficiency for particles and gases
3. Describe typical operating and maintenance problems associated with each design of liquid-phase contacting scrubbers

Introduction

The previous lesson described scrubbers that use the process gas stream as energy to atomize liquid into collection droplets. Energy can also be applied to a scrubbing system by injecting liquid at high pressure through specially designed nozzles. Nozzles produce droplets that fan out into a spray in the scrubber chamber. Droplets act as targets for collecting particles and/or absorbing gas in a pollutant exhaust stream. In liquid-phase contacting scrubbers, the liquid-inlet pressure provides the major portion of the energy required for contacting the gas (exhaust stream) and liquid phases.

Two liquid-phase contacting scrubbers are the **spray tower** and the **ejector venturi**. Many other scrubber designs also incorporate sprays produced by nozzles, but in those scrubbers, the sprays are used to clean trays or to wet scrubber surfaces and orifices, and not to provide the gas-liquid contact in the system.

Spray Towers

Spray towers, or chambers, are constructed very simply—consisting of empty cylindrical vessels made of steel or plastic and nozzles that spray liquid into the vessels. The exhaust stream usually enters the bottom of the tower and moves upward, while liquid is sprayed downward from one or more levels. This flow of exhaust gas and liquid in opposite direction is called **countercurrent flow**. Figure 4-1 shows a typical countercurrent-flow spray tower. Countercurrent flow exposes the exhaust gas with the lowest pollutant concentration to the freshest scrubbing liquid.

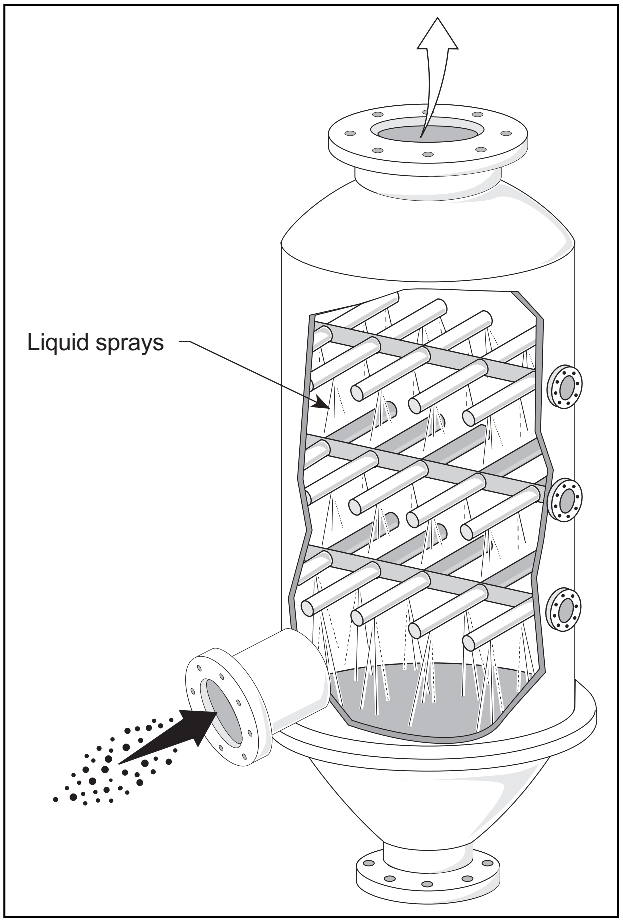

Figure 4-1. Countercurrent-flow spray tower

Many nozzles are placed across the tower at different heights to spray all of the exhaust gas as it moves up through the tower. The major purpose of using many nozzles is to form a tremendous amount of fine droplets for impacting particles and to provide a large surface area for absorbing gas. Theoretically, the smaller the droplets formed, the higher the collection efficiency achieved for both gaseous and particulate pollutants. However, the liquid droplets must be large enough to not be carried out of the scrubber by the exhaust stream. Therefore, spray towers use nozzles to produce droplets that are usually 500 to 1000 μm in diameter. Although small in size, these droplets are large compared to those created in the venturi scrubbers that are 10 to 50 μm in size. The exhaust gas velocity is kept low, from 0.3 to 1.2 m/s (1 to 4 ft/sec) to prevent excess droplets from being carried out of the tower. In order to maintain low exhaust velocities, spray towers must be larger than other scrubbers that handle similar exhaust stream flow rates. Another problem occurring in spray towers is that after the droplets fall short distances, they tend to agglomerate or hit the walls of the tower. Consequently, the total liquid surface area for contact is reduced, thus reducing the collection efficiency of the scrubber.

In addition to a countercurrent-flow configuration, the flow in spray towers can be either a cocurrent or crosscurrent configuration. In **cocurrent-flow spray towers**, the exhaust gas and liquid flow in the same direction. Because the exhaust gas stream does not "push" against the liquid sprays, the exhaust gas velocities through the vessels are higher than in countercurrent-flow spray towers. Consequently, cocurrent-flow spray towers are smaller than countercurrent-flow spray towers treating the same amount of exhaust flow.

In **crosscurrent-flow spray towers**, also called *horizontal-spray scrubbers,* the exhaust gas and liquid flow in directions perpendicular to each other (Figure 4-2). In this vessel, the exhaust gas flows horizontally through a number of spray sections. The amount and quality of liquid sprayed in each section can be varied, usually with the cleanest liquid (if recycled liquid is used) sprayed in the last set of sprays.

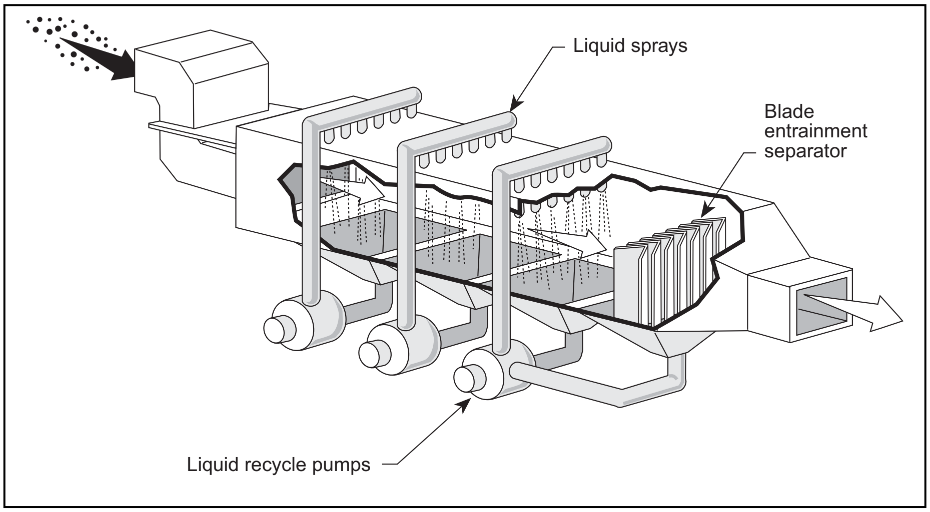

Figure 4-2. Crosscurrent-flow spray tower

Particle Collection

Spray towers are low-energy scrubbers. Contacting power is much lower than in venturi scrubbers, and the pressure drops across such systems are generally less than 2.5 cm (1 in.) of water. The collection efficiency for small particles is correspondingly lower than in more energy-intensive devices. They are adequate for the collection of coarse particles larger than 10 to 25 μm in diameter, although with increased liquid inlet nozzle pressures, particles with diameters of 2.0 μm can be collected. Smaller droplets can be formed by higher liquid pressures at the nozzle. The highest collection efficiencies are achieved when small droplets are produced and the difference between the velocity of the droplet and the velocity of the upward-moving particles is high. Small droplets, however, have small settling velocities, so there is an optimum range of droplet sizes for scrubbers that work by this mechanism. Stairmand (1956) found this range of droplet sizes to be between 500 to 1000 μm for gravity-spray (counter current) towers. The injection of water at very high pressures, 2070 to 3100 kPa (300 to 450 psi), creates a fog of very fine droplets. Higher particle-collection efficiencies can be achieved in such cases since collection mechanisms other than inertial impaction occur (Bethea 1978). However, these spray nozzles may use more power to form droplets than would a venturi operating at the same collection efficiency.

Gas Collection

Spray towers can be used for gas absorption, but they are not as effective as packed or plate towers. (Packed towers will be discussed in the next lesson.) Spray towers can be very effective in removing pollutants if the pollutants are highly soluble or if a chemical reagent is added to the liquid. For example, spray towers are used to remove HCl gas from the tail-gas exhaust in manufacturing hydrochloric acid. In the production of superphosphate used in manufacturing fertilizer, SiF_4 and HF gases are vented from various points in the processes. Spray towers have been used to remove these highly soluble compounds. Spray towers are also used for odor removal in bone meal and tallow manufacturing industries by scrubbing the exhaust gases with a solution of $KMnO_4$. Because of their ability to handle large exhaust gas volumes in corrosive atmospheres, spray towers are also used in a number of flue gas desulfurization systems as the first or second stage in the pollutant removal process.

In a spray tower, absorption can be increased by decreasing the size of the liquid droplets and/or increasing the liquid-to-gas ratio (L/G). However, to accomplish either of these, an increase in both power consumed and operating cost is required. In addition, the physical size of the spray tower will limit the amount of liquid and the size of droplets that can be used.

Maintenance Problems

The main advantage of spray towers over other scrubbers is their completely open design; they have no internal parts except for the spray nozzles. This feature eliminates many of the scale buildup and plugging problems associated with other scrubbers. The primary maintenance problems are spray-nozzle plugging or eroding, especially when using recycled scrubber liquid. To reduce these problems, a settling or filtration system is used to remove abrasive particles from the recycled scrubbing liquid before pumping it back into the nozzles.

Summary

Spray towers are inexpensive control devices primarily used for gas conditioning (cooling or humidifying) or for first-stage particle or gas removal. They are also being used in many flue gas desulfurization systems to reduce plugging and scale buildup by pollutants. Many scrubbing systems use sprays either prior to or in the bottom of the primary scrubber to remove large particles that could plug it. Spray towers have been used effectively to remove large particles and highly soluble gases. The pressure drops across the towers are very low [usually less than 2.5 cm (1.0 in.) of water]; thus, the scrubber operating costs are relatively low. However, the liquid pumping costs can be very high.

Spray towers are constructed in various sizes—small ones to handle small exhaust flows of 0.05 m^3/s (100 cfm) or less, and large ones to handle large exhaust flows of 50 m^3/s (100,000 cfm) or greater. Because of the low gas velocity required, units handling large exhaust flow rates tend to be large in size. Operating characteristics of spray towers are presented in Table 4-1.

<table>
<tr><th colspan="6">Table 4-1. Operating characteristics of spray towers</th></tr>
<tr><th>Pollutant</th><th>Pressure drop (Δp)</th><th>Liquid-to-gas ratio (L/G)</th><th>Liquid-inlet pressure (p_L)</th><th>Removal efficiency</th><th>Applications</th></tr>
<tr><td>Gases</td><td rowspan="2">1.3-7.6 cm of water
(0.5-3.0 in. of water)</td><td rowspan="2">0.07-2.70 L/m^3
(0.5-20 gal/1000 ft^3)
(5 gal/1000 ft^3 is normal; >10 when using pressure sprays)</td><td rowspan="2">70-2800 kPa
(10-400 psig)</td><td>50-90$^+$% (high efficiency only when the gas is very soluble)</td><td rowspan="2">Mining industries
Chemical process industry
Boilers and incinerators
Iron and steel industry</td></tr>
<tr><td>Particles</td><td>2-8 μm diameter</td></tr>
</table>

To test your knowledge of the preceding section, answer the questions in Part 1 of the Review Exercise.

Ejector Venturis

The ejector, or jet, venturi scrubber uses a preformed spray, as does the simple spray tower. The difference is that only a single nozzle is used instead of many nozzles. This nozzle operates at higher pressures and higher injection rates than those in most spray chambers. The high-pressure spray nozzle (up to 689 kPa or 100 psig) is aimed at the throat section of a venturi constriction. Figure 4-3 illustrates the ejector venturi design.

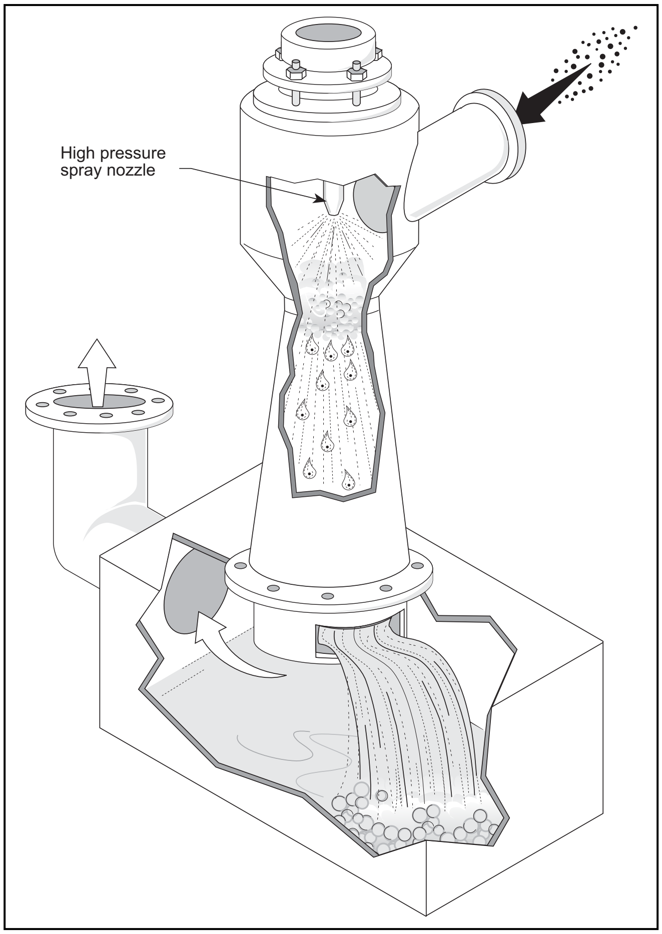

Figure 4-3. Ejector venturi scrubber

The ejector venturi is unique among available scrubbing systems since it can move the process gas without the aid of a blower or fan. The liquid spray coming from the nozzle creates a partial vacuum in the side duct of the scrubber. This has the same effect as the water aspirator used in high school chemistry labs to pull a small vacuum for filtering precipitated materials (due to the Bernoulli effect). This partial vacuum can be used to move the process gas through the venturi as well as through the facility's process system. In the case of explosive or extremely corrosive atmospheres, the elimination of a fan in the system can avoid many potential problems.

The energy for the formation of scrubbing droplets comes from the injected liquid. The high-pressure sprays passing through the venturi throat form numerous fine liquid droplets that provide turbulent mixing between the gas and liquid phases. Very high liquid-injection rates are used to provide the gas-moving capability and higher collection efficiencies. As with other types of venturis, a means of separating entrained liquid from the gas stream must be installed. Entrainment separators are commonly used to remove remaining small droplets.

Particle Collection

Ejector venturis are effective in removing particles larger than 1.0 μm in diameter. These scrubbers are not used on submicrometer-sized particles unless the particles are condensable (Gilbert 1977). Particle collection occurs primarily by impaction as the exhaust gas (from the process) passes through the spray.

The turbulence that occurs in the throat area also causes the particles to contact the wet droplets and be collected. Particle collection efficiency increases with an increase in nozzle pressure and/or an increase in the liquid-to-gas ratio. Increases in either of these two operating parameters will also result in an increase in pressure drop for a given system. Therefore, an increase in pressure drop also increases particle collection efficiency. Ejector venturis operate at higher L/G ratios than most other particle scrubbers (i.e. 50 to 100 gal/1000 ft^3 compared to 3-20 gal/1000 ft^3 for most other designs).

Gas Collection

Ejector venturis have a short gas-liquid contact time because the exhaust gas velocities through the vessel are very high. This short contact time limits the absorption efficiency of the system. Although ejector venturis are not used primarily for gas removal, they can be effective if the gas is very soluble or if a very reactive scrubbing reagent is used. In these instances, removal efficiencies of as high as 95% can be achieved (Gilbert 1977).

Maintenance Problems

Ejector venturis are subject to abrasion problems in the high-velocity areas - nozzle and throat. Both must be constructed of wear-resistant materials because of the high liquid-injection rates and nozzle pressures. Maintaining the pump that recirculates liquid is also very important. In addition, the high gas velocities necessitate the use of entrainment separators to prevent excessive liquid carryover. The separators should be easily accessible or removable so that they can be cleaned if plugging occurs.

Summary

Because of their open design and the fact that they do not require a fan, ejector venturis are capable of handling a wide range of corrosive and/or sticky particles. However, they are not very effective in removing submicrometer particles. They have an advantage in being able to handle small, medium and large exhaust flows. They can be used singly or in multiple stages of two or more in series, depending on the specific application. Multiple-stage systems have been used where extremely high collection efficiency of particles or gaseous pollutants was necessary. Multiple-stage systems provide increased gas-liquid contact time, thus increasing absorption efficiency. Table 4-2 lists the operating parameters for ejector venturis.

Table 4-2. Operating characteristics of ejector venturis

Pollutant	Pressure drop (Δp)	Liquid-to-gas ratio (L/G)	Liquid-inlet pressure (p_L)	Removal efficiency	Applications
Gases	1.3-13 cm of water	7-13 L/m^3	100-830 kPa	95% for very soluble gases	Pulp and paper industry Chemical process industry
Particles	(0.5-5 in. of water)	(50-100 gal/1000 ft^3)	(15-120 psig)	1 μm diameter	Food industry Metals-processing industry

To test your knowledge of the preceding section, answer the questions in Part 2 of the Review Exercise.

Review Exercise

Part 1

1. The liquid and exhaust gas flow in opposite directions in a ____________________ scrubber.

   a. Cocurrent
   b. Countercurrent
   c. Crosscurrent
   d. Crosshatch

2. In a spray tower, the ____________________ the droplet is, the higher the theoretical collection efficiency will be.

   a. Smaller
   b. Larger
   c. Higher
   d. Lower

3. Gas velocities in spray towers are usually kept very ____________________ to prevent excessive liquid from becoming entrained in the exhaust gas stream leaving the tower.

   a. High
   b. Low
   c. Stable
   d. None of the above

4. True or False? In general, countercurrent-flow spray towers must be larger than crosscurrent- or cocurrent-flow spray towers to accommodate the same volumetric flow rate.

5. In a spray tower, gas collection can be increased by increasing:

   a. The size of the liquid droplets
   b. The liquid-to-gas ratio (L/G)
   c. The gas velocity
   d. All of the above

6. Because spray towers contain few internal parts, they:

   a. Eliminate many potential problems due to plugging and scale buildup
   b. Have low pressure drops
   c. Are relatively simple and inexpensive
   d. All of the above

7. What are the main maintenance problems with spray towers?

   ____
   ____

8. In spray towers, the pressure drops across the tower are usually ____________________ and the liquid pumping costs can be very ____________________.

   a. High, high
   b. High, low
   c. Low, high
   d. Low, low

Part 2

9. The ejector, or jet, venturi scrubber uses ____________________ to move the process exhaust stream.

   a. Multiple nozzles
   b. A single high-pressure nozzle
   c. A compressor
   d. A fan

10. For ejector venturis, particle collection efficiencies increase with an increase in:

    a. Nozzle pressure
    b. Liquid-to-gas ratio (L/G)
    c. Pressure drop
    d. All of the above

11. Ejector venturis are subject to abrasion problems in the:

    a. Throat
    b. Nozzle
    c. Packing area
    d. a and b, only

12. True or False? Because of their open design and the fact that they do not require a fan, ejector venturis are capable of handling a wide range of corrosive and/or sticky particles.

Review Exercise Answers

Part 1

1. **b. Countercurrent**
   The liquid and exhaust gas flow in opposite directions in a countercurrent scrubber.

2. **a. Smaller**
   In a spray tower, the smaller the droplet is, the higher the theoretical collection efficiency will be. However, if the droplets are too small and the gas flow up the tower is too fast, then the droplets can be carried out of the tower.

3. **b. Low**
   Gas velocities in spray towers are usually kept very low to prevent excessive liquid from becoming entrained in the exhaust gas stream leaving the tower.

4. **True**
   In general, countercurrent-flow spray towers must be larger than crosscurrent- or cocurrent-flow spray towers to accommodate the same volumetric flow rate.

5. **b. The liquid-to-gas ratio (L/G)**
   In a spray tower, gas collection can be increased by increasing the liquid-to-gas ratio (L/G).

6. **d. All of the above**
   Because spray towers contain few internal parts, they:

   - Eliminate many potential problems due to plugging and scale buildup
   - Have low pressure drops
   - Are relatively simple and inexpensive

7. **Plugging**
   Erosion of the nozzle
   The main maintenance problems with spray towers are plugging and erosion of the nozzle.

8. **c. Low, high**
   In spray towers, the pressure drops across the tower are usually low and the liquid pumping costs can be very high.

Part 2

9. **b. A single high-pressure nozzle**
   The ejector, or jet, venturi scrubber uses a single high-pressure nozzle to move the process exhaust stream.

10. **d. All of the above**
    For ejector venturis, particle collection efficiencies increase with an increase in:

    - Nozzle pressure
    - Liquid-to-gas ratio (L/G)
    - Pressure drop

11. **d. a and b, only**
    Ejector venturis are subject to abrasion problems in the throat and nozzle.

12. **True**
    Because of their open design and the fact that they do not require a fan, ejector venturis are capable of handling a wide range of corrosive and/or sticky particles.

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