Wet scrubbing of acidic gases

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Wet scrubbing is a tried-and-true method for treating toxic gas discharges. This article describes how certain acidic gases are treated using wet scrubbing techniques.

Even before air pollution regulations existed for controlling toxic gases, the treatment of acidic gas emissions from industrial processes and facilities was relatively commonplace. These types of emissions produce immediate and troublesome problems for the environment and for the people living in the plants vicinity.

When these corrosive acidic gases attack buildings, vehicles, or plants, the results can be devastating. Similarly, when these gases are inhaled or come into contact with human skin, the harmful results are quickly noticeable and can be extreme. The means to remove acidic gases from process or facility emissions have been in use for many decades, but the most common and effective way to capture acidic gases is still through the use of wet scrubbers.

A wet scrubber is a device that uses a liquid—typically water or a water-based solution—to capture the acidic gas by absorbing it from the carrier gas stream. The subsequent gas stream emitted from the scrubber contains such a low residual amount of the acidic gas that it no longer poses a threat. The scrubbing liquid typically contains a reactive agent that "neutralizes" the acid absorbed, making the small liquid effluent from the scrubber relatively easy to dispose of or treat in existing wastewater treatment facilities.

In this article, several acidic gases are discussed in terms of how they are generally treated using wet scrubbing techniques.

Hydrogen chloride

By far the most common nonsulfurous acid gas emitted by industry is hydrogen chloride (HCl). As with many acidic gases, sources of HCl vary widely. A common source is the exhaust during the filling or "breathing" of holding or storage tanks. These tanks generally contain up to 35 percent to 36 percent aqueous HCl solution. Many chemical processes emit HCl, and the emissions may be with or without other toxic gases and at different concentrations. In addition, combustion processes in which chlorinated substances are thermally oxidized emit HCl.

Under many circumstances, HCl is scrubbed using an ejector venturi gas scrubber (Fig. 1a, b). An ejector venturi gas scrubber is an "eductor"-type design. It makes use of the scrubbing liquid as the motive fluid to pull the gas stream into and through it without the need of another device, such as a fan, to move the gas. The liquid and gas streams thoroughly mix, and the HCl transfers from the gas phase to the scrubbing liquid phase. A single-stage ejector venturi gas scrubber can typically achieve 95 percent HCl removal.

A countercurrent packed tower (Fig. 2a, b) is used to achieve even higher HCl removal efficiencies, up to and exceeding 99.9 percent, if necessary. This device is a vertical tower in which the scrubbing liquid flows downward countercurrent to the upward gas flow over a bed of packing pieces that function primarily to provide a surface area on which the two streams come into contact.

Figure 1

a. Ejector venturi gas scrubber

b. Ejector venturi gas scrubber components

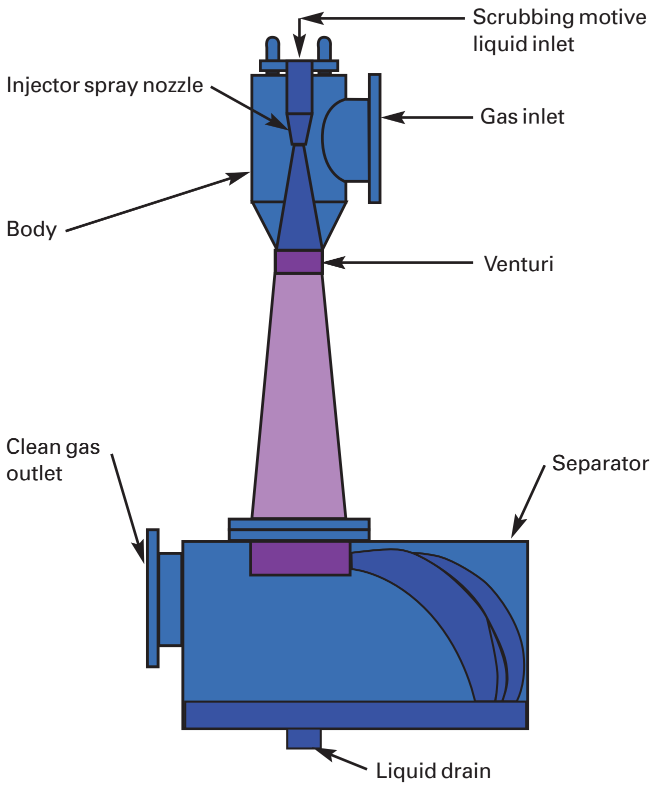
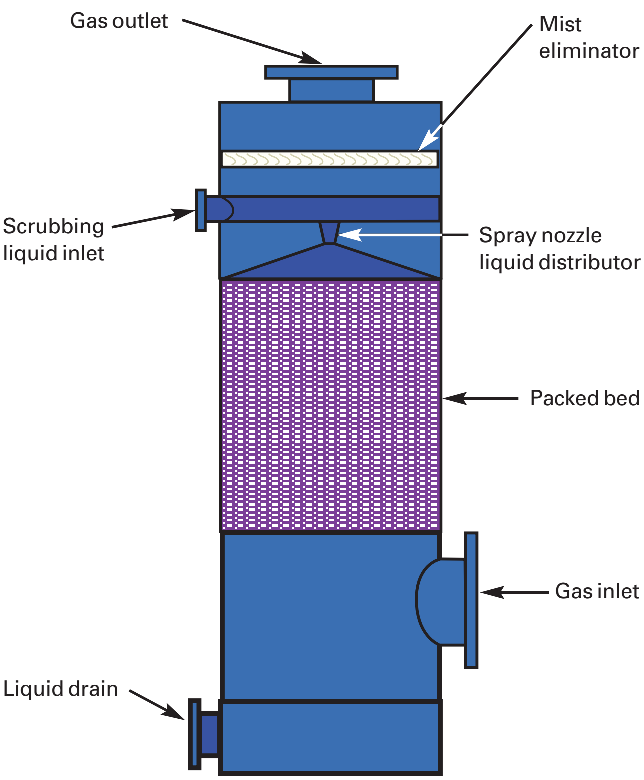


Figure 2

a. Countercurrent packed tower

b. Packed tower scrubber components



For applications in which the HCl is at relatively high levels in the gas stream and the removal efficiency must be very high, often a combination of a first-stage ejector venturi gas scrubber and a second-stage packed tower is ideal. In those cases, the ejector venturi gas scrubber removes the bulk of the HCl and the packed tower “polishes” the remainder so that an extremely low discharge concentration can be attained.

To neutralize the HCl, it is very common to use an aqueous sodium hydroxide (NaOH) solution as the scrubbing fluid. The reaction between NaOH and HCl produces sodium chloride (NaCl), otherwise known as ordinary table salt.

On the other hand, if the HCl is relatively concentrated in the gas stream, it may be practical to recover most of the HCl in aqueous solution, which can then be reused or sold. To accomplish this, a multiple-stage system is usually required, consisting of one or more ejector venturi gas scrubbers and a packed tower as the final stage (Fig. 3). HCl solution is recirculated as the scrubbing fluid in the initial stages, typically absorbing and recovering more than 90 percent of the HCl. The final stage may then utilize aqueous NaOH to meet low-ppm discharge concentrations exiting the packed tower. This arrangement not only saves most of the cost of the NaOH, but also may generate a salable product.

Figure 3

Multiple-stage system

Hydrogen fluoride

Generally speaking, the methods described above for scrubbing HCl would also apply to hydrogen fluoride (HF). However, because of HF's vapor pressure characteristics, the probability of recovering it in a usable or salable form is lower than that for HCl.

While NaOH solution can also be used to scrub and neutralize HF, the product of HF and NaOH is sodium fluoride (NaF), which has limited solubility in water. Therefore, it is usually more practical to neutralize HF with potassium hydroxide (KOH) solution. In that case, the product of its reaction with water is potassium fluoride (KF), which is very soluble in water.

Hydrogen bromide and hydrogen iodide

Again the methods just described for scrubbing HCl would apply to the acidic gases hydrogen bromide (HBr) and hydrogen iodide (HI). However, their chemical properties make them somewhat more difficult to scrub than HCl or HF. Although scrubbing these gases can be very effective, knowledge of their mass transfer characteristics and the chemistry of their neutralization is important for successful design of treatment equipment. Also, the recovery of these acidic gases in a usable or salable aqueous form is very unlikely.

Chlorine

Chlorine (Cl2) is scrubbed in a countercurrent packed tower using aqueous NaOH solution. The resulting products are NaCl and sodium hypochlorite (NaOCl), which is a bleaching agent. NaOCl is stabilized in the scrubbing solution by being maintained at relatively high alkalinity. When the presence of NaOCl is undesirable, chemical additives can be used in the scrubbing solution. Scrubbing with water alone is impractical because of the very limited solubility of Cl2 in water.

An ejector venturi gas scrubber may be useful for Cl2 scrubbing in cases of high Cl2 gas concentrations. But a single-stage ejector venturi gas scrubber is seldom used because its performance is limited.

Bromine and fluorine

Countercurrent packed tower designs are generally used for scrubbing bromine (Br2) and fluorine (F2) using aqueous alkali solutions to achieve optimum removal efficiencies. As with other acidic gases, if the concentrations of Br2 or F2 are high, an ejector venturi scrubber may be used as a first stage to absorb the bulk of the acid gas, with a packed tower polishing stage to follow.

Specifically for F2 scrubbing, it is very important to maintain adequate levels of excess alkali (typically NaOH or KOH) to eliminate the generation of certain undesirable by-products. As with HF scrubbing, KOH is the preferred scrubbing reagent because the product of neutralization is considerably more soluble in water than when NaOH is used.

Hydrogen cyanide

Hydrogen cyanide (HCN) is usually scrubbed with an aqueous solution of NaOH. The methods used are similar to those described for HCl scrubbing. Recovery as a usable by-product is not practical. Also, in some cases, the addition of NaOCl to the scrubbing solution is used to increase removal performance or to produce more desirable reaction products.

Nitric acid

Scrubbing nitric acid (HNO_3) is very similar to scrubbing HCl. Not only are the methods the same, but there is also good potential for recovering aqueous HNO_3 in a usable form in those applications in which high concentrations exist in the gas stream and other contaminants are not present that might contaminate the product.

However, in some processes that produce HNO_3, nitrogen oxides (NO_x) are also produced. The effective scrubbing of NO_x is much more complicated than acid gas scrubbing. It depends greatly upon which species is present, if mixed species are present (which often occurs), at what absolute levels they exist, and at what relative levels they exist. Nonconventional and special proprietary methods of scrubbing are often required.

Chemical storage tank exhaust scrubbing

Many of the acids discussed in this article may be kept as aqueous solutions in bulk storage tanks in industrial facilities because of their uses as major ingredients in numerous chemical and pharmaceutical products. These tanks are vented and therefore emit hazardous toxic gases that require treatment.

One of two processes generally results in the emission of these gases: (1) so-called "breathing" of the tank during changes in ambient temperatures, resulting in very low rates of emissions and (2) tank filling that displaces gaseous volumes equal to the volumes flowing into the storage tank. Tank breathing is typically not a factor in the design of treatment equipment because it results in emission rates far exceeded by tank filling operations.

One key to properly determining the design of the treatment equipment is the type of filling operation that occurs. If the storage tank is filled using a mechanical pump, then the design capacity of the treatment equipment (scrubber) is simply equivalent to the volume of the displaced gas as the tank is being filled. For example, if the tank is being filled at the rate of 100 gallons per minute, the equivalent gas rate being emitted is approximately 13.4 cubic feet per minute. This would result in a relatively small scrubber size.

On the other hand, if the filling is done from a pressurized tanker truck or rail car, then a different, much larger, gas rate must be the basis of the design. At the end of the normal filling process as the pressure in the source tanker truck or rail car has "pushed out" the acidic liquid, eventually no more liquid will be present and the pressurized gas will surge out and through the filling lines for a short time, but at a gas rate many times the normal filling rate. It is common that, whereas the normal filling rate is only 13.4 cubic feet per minute, this surge gas rate is several hundred to a few thousand cubic feet per minute. This rate depends upon the specific pressure at the source as well as the frictional losses as the gas flows through the piping to the tank being filled.

This surge rate becomes the required design condition for the treatment (scrubbing) equipment, resulting in a considerably larger and costlier scrubber than required otherwise. The gas concentration condition upon which the scrubbing design is based will change as well.

The concentration of acidic gases is directly related to the vapor pressure of the acid in aqueous solution. However, it is also related to the pressure of the gas space above the stored liquid. This then differs between the gas stream simply exiting the atmospheric storage tank or the gas resulting from the surge gas coming from a pressurized source. This is another factor to be carefully examined and accounted for. **APC**

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