AIR STRIPPING IN INDUSTRIAL WASTEWATER TREATMENT

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Keywords: Air stripping, Ammonia, VOC, Design, Packed tower.

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Summary

In the past, the major objectives of wastewater treatment were the removal of suspended solids, biochemical oxygen demand and coliform bacteria. It is only very recently that the removal of inorganic nutrients, such as nitrogen has been brought into focus. Municipal wastewater and many industrial wastes are among the principal contributors of these nutrients to surface waters. The presence of organic compounds that are potentially hazardous or toxic in water bodies is made increasingly evident by advances in analytical methods. This has resulted in the development of new technologies for the removal of these compounds from raw potable surface and groundwater supplies, as well as from process stream wastewater. The removal of substances having reasonable equilibrium vapor pressures at ambient temperatures, including ammonia, and many

volatile organic compounds (VOCs), by any of the processes known as air or gas stripping has proven to be efficient. The countercurrent packed-tower type air stripper offers greater interfacial surface area for mass transfer of volatile organic compounds than other gas-stripping processes. This method therefore offers significant advantages in efficiency and overall cost when used for the removal of ammonia and volatile organic compounds from wastewater streams.

1. Introduction

Air stripping is a process by which a liquid, usually wastewater, is brought into intimate contact with a gas, usually air, so that some undesirable volatile substances present in the liquid phase can be released and carried away by the gas. Processes such as mechanical surface aeration, diffused aeration, spray fountains, spray or tray towers, and countercurrent packed towers are encompassed by the term air stripping. These procedures produce a condition in which a large surface area of the water to be treated is exposed to air, which promotes transfer of the contaminant from the liquid phase to the gaseous phase.

2. Process Description

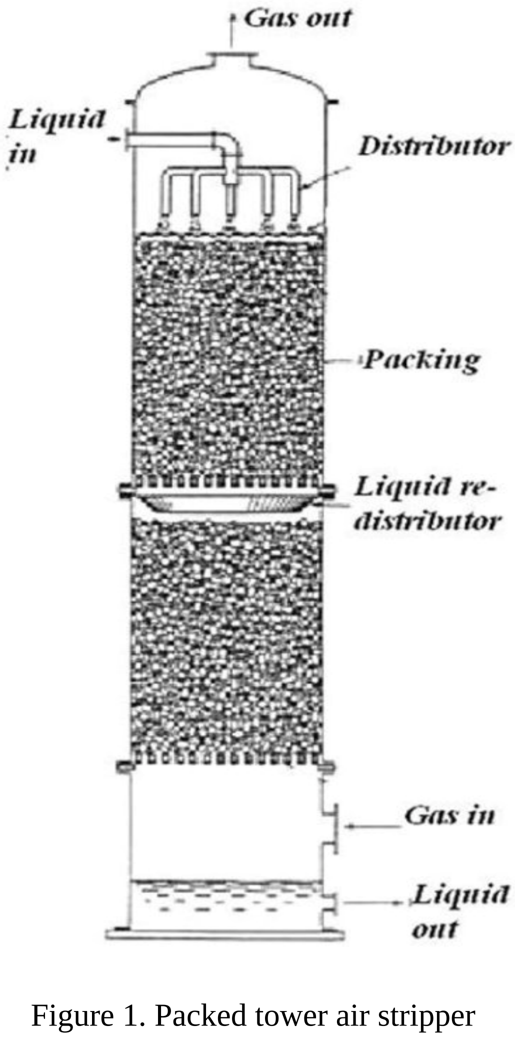

Figure 1. Packed tower air stripper

The process consists of counter-current flow of water and air through a packing material. The packed tower consists of a cylindrical drum equipped with a gas inlet and distributing space at the bottom; a liquid inlet and distributor at the top; gas and liquid outlets at top and bottom, respectively; and a supported mass of inert solid shapes, called tower packing (Figure 1). In the traditional system, water is pumped to the top of the tower, and is allowed to flow down over the inert packing, while air is pumped countercurrent from the bottom of the tower. The contaminants of interest such as ammonia or volatile organic compounds (VOC) are stripped out of the water into the air stream. In practice, two methods are used to achieve contact between phases so that mass transfer can occur: (1) continuous contact and (2) staged contact. Different flow patterns used in practice include countercurrent, co-current and cross-flow. The most common flow pattern is countercurrent mode.

3. Stripping Theory

The ratio of the contaminant at equilibrium in the liquid phase, C_L , to the contaminant in the gaseous phase, C_G, is a relationship known as Henry's law:

$$H = \frac{C_G}{C_L} \quad (1)$$

where H is Henry's constant. Henry's constant is a property of the solute/solvent system and the temperature, and follows Van't Hoff's relationship.

$$\log H = \left(\frac{-H^o}{RT} \right) + k \quad (2)$$

where $H°$ = enthalpy change resulting from the dissolution of the compound in water;
R = the universal gas constant;
T = the absolute temperature; and
k = a compound dependent constant.

The general form of the equation for the rate of mass transfer across the gas-liquid interface in a gas stripper is given by the equation:

$$\frac{1}{V}\frac{dm}{dt} = K_L a(C_L^{*} - C_L) \quad (3)$$

where V = the liquid volume, m^3;
m = the mass of the solute, kg;
t = time, s;
K_L = the overall liquid mass transfer coefficient, m/s;
a = the specific interfacial area, m^2/m^3;
C_L = the bulk average concentration in the liquid phase, kg/m^3;
C_L^* = the liquid concentration in equilibrium with the gas phase concentration, C_G, kg/m^3; and
K_La = the transfer rate constant.

The rate constants for the local liquid and gas phase transfers, k_L and k_G, respectively, are related to the overall transfer rate constant by

$$K_L a = \left(\frac{1}{K_L a} + \frac{1}{K_G a.H} \right)^{-1} \quad (4)$$

4. Design Considerations

Stripping towers have diameters of 0.5 to 3 m and heights of 1 to 15 m. The height of the packed tower will affect the removal efficiency of the contaminant. The desired rate of flow of the liquid to be treated will determine the diameter of the air stripping column. The type of packing material will have an impact on the mass transfer rate, because the surface area of the packing provides the air-to-water interfacial area. The air-to-water ratio ranges from as low as 5 to several hundred and is controlled by flooding and pressure drop considerations. The ratio of air-to-water flow through the air stripper will control the removal rate of the contaminant. An increase in the air-to-water ratio will usually result in greater removal rates, up to a point at which entrainment of the liquid by the air flow occurs, resulting in a sharp increase in the air pressure drop through the stripping column. This phenomenon is known as flooding. The opposite condition occurs when the liquid flow rate is increased until the tower begins to fill with liquid. This is also referred to as flooding. The pressure drop in the tower should be between 200 to 400 N/m^2 per meter of tower height to avoid flooding. The designer must choose a gas velocity far enough from flooding velocity to ensure safe operation. The flooding velocity depends on the type and size of packing and liquid mass velocity. Lowering the design velocity increases the tower diameter without much change in required height, since lower gas and liquid velocities lead to a proportional reduction in mass-transfer rate. Channeling occurs when water flows down the tower wall rather than through the packing. Distribution plates must be placed approximately every 5 to 10 m in the tower immediately above each packing section to avoid this. Channeling is severe in towers filled with stacked packing than in dumped packings. Using a smaller size packing will reduce the tendency of flow to channel. In towers of moderate size channeling can be minimized by having diameter of the tower at least 8 times the packing diameter. A packing material that offers a large surface area for mass transfer will usually present more resistance to countercurrent air flow, causing a higher gas pressure drop. Different materials offer better resistance to corrosivity, encrustation, or unfavorable water conditions. Initial packing material selection can be made with one offering a very low gas pressure drop that allows an increase in removal efficiency.

5. Design of Stripping Tower

The design procedure for a stripping tower consists of following steps:

1. Evaluation of equilibrium data;
2. Estimation of operating data;
3. Selection of column;
4. Column diameter and pressure drop calculation; and
5. Estimation of column height or number of plates.

5.1 Evaluation of Equilibrium Data

The equilibrium relationship is given by a plot of C_0', mole fraction of solute in the liquid that is in equilibrium with the gas leaving the tower, against y_e, the mole fraction of solute in gas leaving the top of the tower.

Using Henry's law, y_e is defined as follows:

$$y_e = \frac{H}{P_T} C_0' \tag{5}$$

where, y_e=concentration of solute in gas leaving the top of the tower, moles of solute per mole of air

H = Henry's law constant, $\frac{atm(mole\,gas)/(mole\,air)}{(mole\,gas)/(mole\,water)}$

P_T = total pressure

C_0' = concentration of solute in liquid that is in equilibrium with the gas leaving the tower, moles of solute per mole of liquid.

5.2 Estimation of Operating Data

The operation data for isothermal system are the liquid rate and the terminal concentrations or mole fractions. The operating conditions in the column are described by an operating line which is obtained by a mass balance around the column.

5.3 Mass Balance Analysis

The mass balance analysis for a continuous stripping tower is given by (Figure 2):

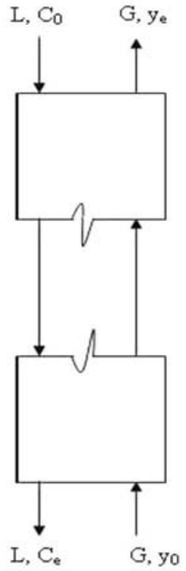

Figure 2. Continuous countercurrent flow gas stripping tower.

Total moles in = Total moles out

Moles of solute entering in liquid stream **+** Moles of solute entering in gas stream **=** Moles of solute leaving in liquid stream **+** Moles of solute leaving in gas stream

$$LC_0 + Gy_0 = LC_e + Gy_e \qquad (6)$$

where, L =moles of liquid per unit time
G=moles of incoming gas per unit time
C_0=concentration of solute in liquid entering at the top of the tower, moles of solute per mole of liquid
C_e=concentration of solute in liquid leaving the bottom of the tower, moles of solute per mole of liquid
y_0=concentration of solute in gas entering the bottom of tower, moles of solute per mole of solute-free gas
y_e=concentration of solute in gas leaving the top of the tower, moles of solute per mole of air;

$$\Rightarrow (Gy_0 - Gy_e) = (LC_e - LC_0)$$

$$\Rightarrow G(y_0 - y_e) = L(C_e - C_0)$$

$$\Rightarrow (y_0 - y_e) = L/G(C_e - C_0)$$

$$\Rightarrow \frac{L}{G} = \frac{(C_e - C_0)}{(y_0 - y_e)} \qquad (7)$$

This is the equation of straight line known as operating line. On (x, y) coordinate it has a slope of (L/G) and pass through the point (C_0, y_0) and (C_e, y_e).

5.4 Selection of Column

Parameter	Packed column	Plate column
Pressure drop	√	×
Flooding	×	√
Channeling	×	√
High foaming liquid	√	×
Liquid hold-up	×	√
Corrosive atmosphere	√	×
Sediment deposition	×	√
Temperature change problem	×	√
Total weight	×	√
Small column	√	×
Large column	×	√

Note # √: more favored; ×: less favored;

Table 1. Comparison of packed and plate column

Packed column and plate columns are generally used in industrial stripping operations. Although packed columns are used more often in air pollution control, both have their special area of usefulness. Their relative advantages and disadvantages are presented in Table 1.

5.5 Column Diameter and Pressure Drop Calculation

The minimum possible diameter of stripping tower is determined from flooding velocity. Generally the column design velocity ranges from 60 to 80 % of the flooding velocity. For liquids having foaming tendency the maximum allowable velocity will be lower than the estimated flooding velocity, especially for plate tower. Pressure drop for packed column can be correlated with the column operating data, packing type, and physical properties of the constituent involved. The maximum allowable pressure drop can be determined by the cost of energy for compression of the feed gas. Figure 3 shows the correlation of flooding and pressure drop in a packed tower.

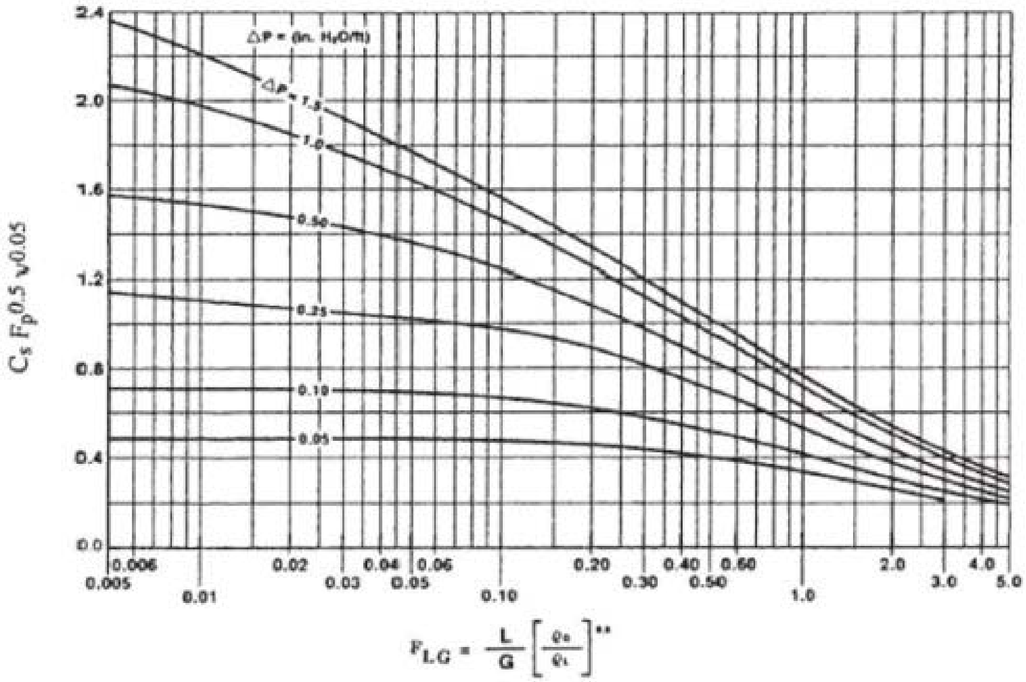

Figure 3. Flooding and pressure drop correlations for packed towers. [C_s=capacity parameter, F_p=packing factor, ν=kinemetic viscosity of liquid, ρ_G, ρ_L=gas and liquid density]

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Biographical Sketches

A. Srinivasan is presently pursuing her doctoral degree in Environmental Engineering at the University of Regina, Regina, Saskatchewan, Canada. She graduated in Chemical Engineering from the University of Madras in 2003. She obtained a Master's degree in Environmental Management from Anna University, Chennai in 2005 through the Centre for Environmental Studies, College of Engineering, Guindy.

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