R&D NOTES

Design and Testing of a New Type of Falling Film Gas-Liquid Contacting Device

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The tube-bundle wetted-wall column, which is commonly used as an absorber-cooler, consists of a large number of metal tubes that are heavy in weight and expensive in cost. Also, the technique of uniformly distributing the liquid film to the inner wall surface of each tube often poses a difficult design problem (Sack, 1967; Brauer and Thiele, 1975; Brauer, 1981; Yih, 1986). Lefebvre (1973) has patented a device using very thin and light textile fibers arranged in a multifilament thread bundle to replace the much heavier and larger diameter metal tubes as liquid film supports in a tube-bundle wetted-wall column. This decreases the weight of the tower to a significant extent and shows much better performance. However, there are two difficulties in designing such an apparatus. One is how to arrange and tighten the thousands of thin fibers so that they can act as liquid film supports. The other is how to design liquid distributors so that every fiber receives the same amount of liquid at the top and forms a uniform liquid film enclosing the fiber. In order to simplify the design and avoid these difficulties, the present study proposes to use either square or rectangular thin sheets of lightweight material such as filter cloth or plastics as liquid film supports. Plastic film corrugated sheets have been used successfully in biological trickling filters for treatment of industrial and domestic wastewaters (Chipperfield, 1967). They have the advantages of light weight and large surface area and voidage (Eckenfelder, 1980; Grady and Lim, 1980), which permits the construction of deeper beds with the ability to handle high-strength wastes. The vertical sheet packing is usually made from PVC, with corrugated sheets bonded between alternate flat sheets to form modules typically of the size 1.2 m × 0.6 m × 0.6 m (Porter and Smith, 1979; Viessman and Hammer, 1985).

In this research, two rectangular absorbers were designed with different dimensions. Filter cloth sheets were placed in a vertical and parallel manner within the tower. Pressure drop and mass transfer measurements were made in order to test performance.

Experimental Method

The experimental setup consisted of the gas and liquid flow loops. Two absorbers were designed with different dimensions. The larger device was 1.2 m high, 1.2 m wide, and 1.2 m long, as shown in Figure 1. It was made of carbon steel with a portion of one of the surfaces made of acrylic plate. This facilitated opening the absorber, replacement of the liquid film support sheets, and visual observation of the flow behavior of the liquid film.

Several different types of materials were collected for possible use as liquid film support sheets, including filter cloth, and polypropylene, polyurethane, acrylic, polyethylene terephthalate, and polyhexamethylene adipamide sheets. After careful testing and comparison of their properties for wetting characteristics and inherent possession of a smooth vertical surface, it was found that thin filter cloth sheets made of cotton would satisfy our experimental needs as cotton has very good wetting characteristics due to its somewhat porous structure. It also has the desirable properties of heat-, acid- and alkaline-resistancy, so that it can be used in a variety of conditions and gas-liquid systems. The cloth sheets, which are number 10 100% woven cotton, were supplied from a local firm.

The thin sheets were placed inside the absorber in a vertical and parallel manner. They were 115 cm long, 100 cm wide, and 1.45 mm thick with six sheets (interspacing 16 cm) or 12 sheets (interspacing 8 cm) inserted. The smaller size absorber was 1.8 m high, 0.12 m wide, and 1 m long with nine sheets (interspacing 10 cm) of 135 cm length, 8.2 cm width, and 1.45 mm thick placed inside. In the present range of liquid flow rates of Q = 25–140 L/min, the liquid film Reynolds number in the larger size absorber was in all cases smaller than 1,600 and so must be in wavy-laminar flow. On the other hand, the flow in the smaller size absorber could achieve turbulent as well as wavy-laminar flow. The larger absorber could accommodate either counter or cross flow, while the smaller absorber's dimensions limited its flow to countercurrent only.

The liquid entered the top at one side and when it reached a certain height, it would overflow into the V-shaped liquid distributors shown in Figure 2. Each liquid distributor might accommodate one piece of thin sheet, and the width of the distributor opening was designed in such a way that its width would be slightly larger than the thickness of the sheet plus two times the liquid film thickness on each side. The liquid distributors

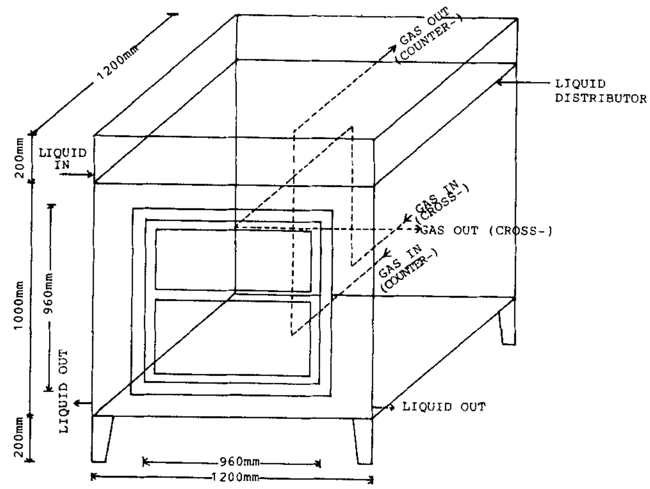

Figure 1. Absorber design.

were equidistant to each other. Holes at the upper and lower edge of the sheets enabled them to be straightened and tightened by strings and aligned in a vertical and parallel manner. This ensured uniform wetting and hence uniform liquid film thickness along the sheet height. In countercurrent flow, the gas entered the bottom of the absorber and was distributed by means of several distributor pipes with equidistant holes. The gas passed through the sheet bundle and was collected by multihole pipes. In crossflow, the gas entered through the front face and also distributed by means of a multihole distributor. After passing through the sheet bundle, the gas was collected by a collector that was of the same form as the distributor. Details of the design can be found in the thesis by Kuo (1986).

CO_2 was first passed through a liquid saturator and then entered the absorber, which was purged several times to remove air inside. The liquid, which was tap water, entered the top of the absorber and overflowed into the liquid distributor. The liquid spread as vertical liquid films on both sides of the sheet. For absorption with quiescent gas flow, the gas was supplied into the absorber at a small velocity of 0.0117 cm/s such that the pressure inside the absorber was about 3 cm H_2O greater than atmospheric. This also helped to prevent diffusion of air into the absorber. After steady operations, the liquid samples at the inlet and outlet of the absorber were withdrawn and analyzed for their CO_2 content by means of an acidic titration method. At the same time, the pressure drop across the absorber, which was measured by an inclined water manometer, was also recorded. The measured absorption rate was calculated from

$$N_{exp} = Q(C_2 - C_1)/A \tag{1}$$

and the mass transfer coefficient could be expressed as

$$k_L = (Q/A)\ \ln\,[(C_s - C_1)/(C_s - C_2)] \tag{2}$$

Results and Discussion

The measured pressure drop, for gas flow rates in the range 10–160 L/min (superficial velocity of 0.0117–0.187 cm/s), increased with increasing gas flow rate up to a maximum of 30 cm H_2O. This is quite small and is due to the large voidage in the tower. The absorption rate for CO_2 in water was investigated in the larger absorber. Six sheets with 16 cm interspacing interfacial area $A = 1.092 \times 10^5$ cm^2, and 12 sheets with 8 cm interspacing cm with twice the interfacial area were respectively inserted in the absorber. The results show that below a liquid flow rate of 25 L/min ($Re = 155$), the liquid film distribution is still visually nonuniform and discontinuous, which resulted in the experimental absorption rate N_{exp} being lower than that calculated from the penetration theory, N_p. Continuous and uniform laminar liquid film can be obtained at $Re = 186$–248, where N_{exp} agrees with N_p. For comparison with measurements in a single wetted-wall column where the falling water films formed on the outside of a stainless steel pipe of 2.72 cm OD and 183 cm absorption length (Yih and Chen, 1982), Figure 3 was constructed. All of the present data on liquid-side mass transfer coefficient from both the large and the small size absorbers are compared in this figure with the data and correlations of Yih and Chen. Yih and Chen's data agreed well with the data obtained by Lamourelle and Sandall (1972) and their correlations were derived from a fit of the data of eleven investigators. It can be seen that the present data agree well with the data obtained previously in a wetted-wall column, with the present data being slightly higher in the turbulent flow region but lower in the wavy region. The insufficient wetting of the sheets at low Re must have caused the lowering of data in the wavy region. The thin sheets have the same fixed and known interfacial area; the absorption rate and hence the mass transfer coefficient for each sheet is therefore the same. So the total absorption rate in the present apparatus can easily be predicted from the known

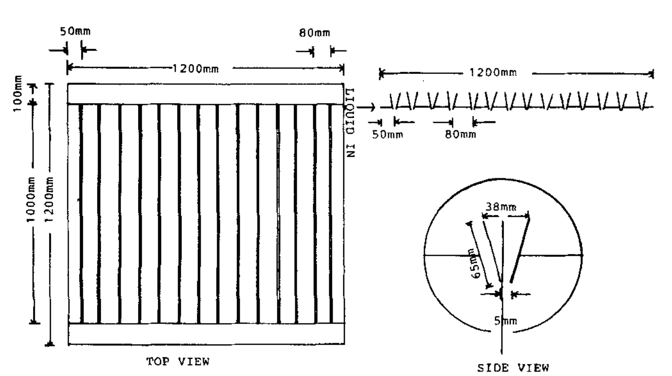

Figure 2. Liquid distributors.

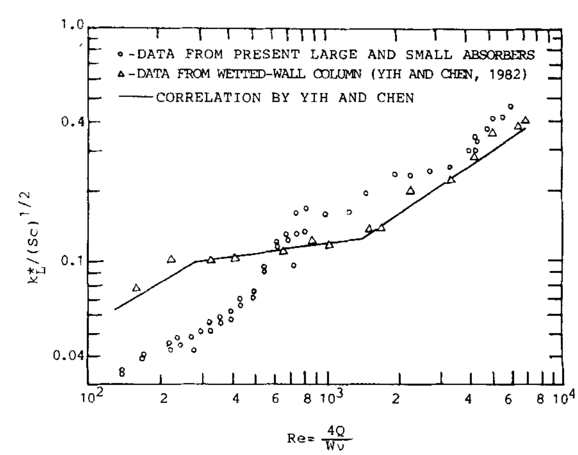

Figure 3. Data comparison.

total interfacial area of the thin sheets and the dimensionless absorption rate correlations obtained from the single-column study, such as those reported by Yih and Chen (1982).

Conclusions

The design and testing of a new type of gas-liquid contact device employing the falling film principle have been accomplished. This device has several advantages when compared with wetted-wall tube-bundle absorbers, including:

1. Minimal pressure drop
2. Larger and known mass transfer interfacial area per unit volume
3. Easily measured mass transfer coefficient, which can readily be predicted using results derived in a single long wetted-wall column
4. Much less cost and lower weight for the thin sheets than for metal tube bundles, based on the same interfacial area
5. Simple and relatively low-cost design and construction

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Notation

A = gas-liquid interfacial area, cm^2
C_1, C_2 = inlet and outlet concentration of gas in liquid, mol/L
C_s = solubility of gas in liquid, mol/L
k_L = liquid-side mass transfer coefficient, cm/s
$k_L^* = (k_L/D)(\nu^2/g)^{1/3}$
N_{exp} = CO_2 absorption rate per unit area, $mol/cm^2 \cdot s$
N_p = CO_2 absorption rate calculated from penetration theory
Q = liquid flow rate, L/min
Re = film Reynolds number, $4Q/\nu W$
Sc = Schmidt number, ν/D
W = width of sheet, cm
ν = kinematic viscosity, cm^2/s

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