Gas Absorption in Packed Columns: Liquid Phase Resistance in the Loading Region

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Data on liquid phase-controlled gas absorption in the loading regime are presented. Carbon dioxide was desorbed from water by using a 6-in. diameter tower and ½- and ¾-in. ceramic rings. Below the loading point, H_L increases approximately as the 0.25 power of the liquid rate and is independent of gas rate. In the loading regime, however, it was found that at high gas rates H_L increases less rapidly and may even decrease with increase in liquid rate, and that at low gas rates H_L increases more rapidly with an increase in liquid rate. At intermediate gas rates, the effect of liquid rate on H_L is intermediate. These effects are explained on the basis of the interaction of the gas and liquid flow rates and the effect of this interaction on k_L and a. The results suggest that in some cases tower capacity may be increased without increasing H_L.

In the design of packed towers for gas absorption, data on the transport phenomena in the individual phases are required. Because of the complexity of the fluid dynamics of the flows through irrigated packing, the designer must rely on correlations of experimental data for the prediction of the individual phases coefficients. These coefficients depend not only on the physical properties of the system, but also on the gas and liquid flow rates.

Characteristic of each packing are the limiting gas and liquid flow rates that produce flooding. These flow rates depend on the L/G ratio and on the physical properties of the fluids. At flooding, the holdup of liquid in the packing is sufficient to make the system inoperable. At flow rates immediately below flooding, liquid holdup decreases with a decrease in gas rate until the loading point is reached, below which a further decrease in gas rate has a negligible effect on liquid holdup. The gas rate at which loading begins is approximately 50 to 60% of the flooding gas rate for the common packings under usual operating conditions.

Most experimental studies of packed column performance have been concerned with columns operating below the loading point. Thus design correlations have been based upon data taken below loading. However, economic considerations often dictate the design or operation of a packed column between the loading and flooding points, and hence absorber performance in this region is of considerable interest.

Various studies of liquid phase-controlled mass transfer in packed columns have confirmed that H_L is independent of gas flow rate below the loading point. The few data in the literature on performance in the loading regime present an unclear picture. At low gas rates, Sherwood and Holloway (5) found H_L to increase as the 0.25 power of the liquid rate up to approximately the loading point and then to increase very rapidly with further increase in liquid rate. Data at constant liquid rate, however, indicated that H_L dropped sharply as the gas rate was increased beyond the loading point. Cooper, Christl, and Perry (1) obtained data at very high liquid rates and low gas rates and found H_L to decrease with increasing gas rate. At low gas rates, Vivian and King (7) found H_L to increase as flooding was approached. Eckert (2) reported data on the performance of rings and saddles in distillation which indicated H.E.T.P. to be independent of gas and liquid rate except near flooding where the H.E.T.P. first decreases slightly and then rises abruptly. However, since both gas and liquid phase resistances are probably important in these systems, it is not clear what the behavior of H_L is in this case.

In view of these anomalies, a brief study of liquid phase absorption performance in the loading regime was undertaken as the initial phase of an experimental study of the effect of gravity on the mass transfer coefficient (6).

EXPERIMENTAL PROCEDURE

Carbon dioxide was desorbed from water in a 6-in. diameter column containing packing approximately 1 ft. deep. One-half- and three-quarter in. ceramic Raschig rings were used as packing. The temperature was 25°C. and the total pressure was 1 atm.

The apparatus and procedure, including precautions to minimize and allow for accumulation of excess bicarbonate ion in the liquid, were the same as described in reference 6.

EXPERIMENTAL RESULTS

The experimental results for the desorption of carbon dioxide from water are reported in Figures 1 and 2, which show the variation of H_L with liquid rate at constant gas rate for the two sizes of packing used. Note that at low liquid rates H_L is proportional to approximately the 0.25 power of the liquid rate and is independent of gas rate, in agreement with the results of previous investigators. However, at higher liquid rates and depending on the gas rate, H_L is found to increase less rapidly and even to decrease with increasing liquid rate. Pressure drop measurements indicate that these deviations occur at flow rates corresponding approximately to the loading region.

The nature of the behavior of H_L above the loading point depends on the gas rate. At high gas rates H_L

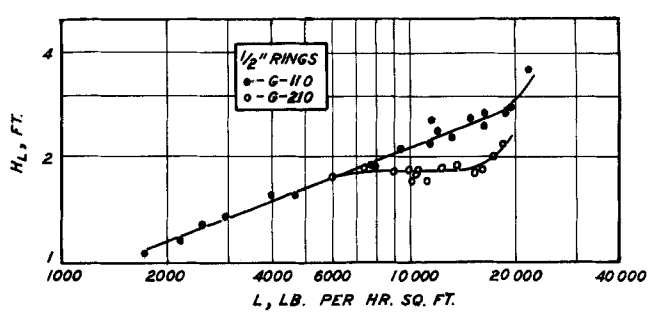

Fig. 1. Effect of liquid and gas rate on the desorption of carbon dioxide (½-in. rings).

reaches a maximum near the loading point and then decreases with a further increase in liquid rate. At intermediate gas rates H_L remains approximately constant with liquid rate above the loading point and then increases sharply as the flooding point is reached. At low gas rates H_L continues to increase above the loading point and rises sharply as flooding is approached, as indicated by the data in Figure 1 and clearly shown by Sherwood and Holloway (*5*). Figure 3 illustrates this overall behavior qualitatively.

DISCUSSION

The observed behavior of H_L as a function of liquid and gas rates is undoubtedly the result of the interaction of these rates on k_L and a, on which H_L depends. At low liquid rates the packing is incompletely wetted and the wetted fraction of the packing area increases with increasing liquid rate. Some of the data available on the wetted area suggest that the wetted area increases approximately as the 0.3 power of the liquid rate at low liquid rates (*3, 4*). Assuming a penetration theory model in which the average liquid surface exposure time is given by the packing dimension divided by the surface velocity of the liquid layer, one would expect the average coefficient k_L to be proportional to the 0.33 power of the liquid rate (*8*). Thus the combined effect of L on k_La would be expected about the 0.7 power, giving a variation of H_L with the 0.3 power of L, in close agreement with the experimental data below loading. Under these conditions fluid dynamic interaction between the liquid and gas phases is negligible and variation of H_L is due solely to liquid phase fluid dynamics.

In the loading regime, where the gas and liquid flow rates are between those at the loading and flooding points, the gas and liquid phases interact fluid dynamically. In this regime there is sufficient momentum transfer from the gas to the liquid to restrict the normal flow of liquid through the packing. Consequently, the downward velocity of the liquid is decreased and the holdup of liquid on the packing is increased. The effect of these fluid dynamic phenomena on the mass transfer process can be expected to be different at low and high liquid rates.

At low liquid rates, relatively high gas rates are required to produce loading. Since the packing is normally incompletely wetted at these liquid rates, the increase in liquid holdup produced by the drag of the gas increases the wetted area a. In addition, the drag of the gas probably introduces surface turbulence which increases k_L as well. Both of these effects tend to increase k_La relative to what would be expected for normal liquid flow through the packing, and thus H_L decreases as either L or G is increased past the loading point. Presumably at sufficiently high gas rates, that is, incipient flooding, entrainment of liquid by the gas would overshadow these effects, causing H_L to increase in the flooding region.

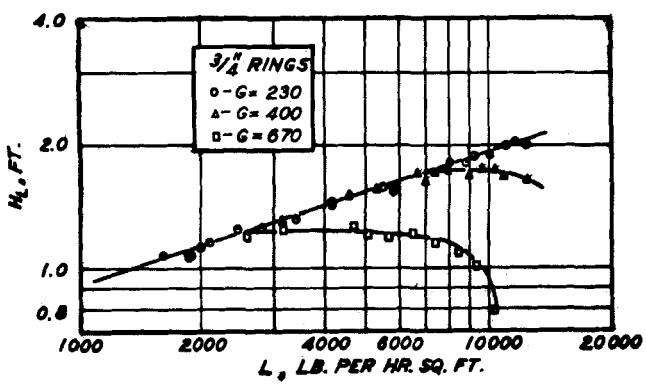

Fig. 2. Effect of liquid and gas rate on the desorption of carbon dioxide (¾-in. rings).

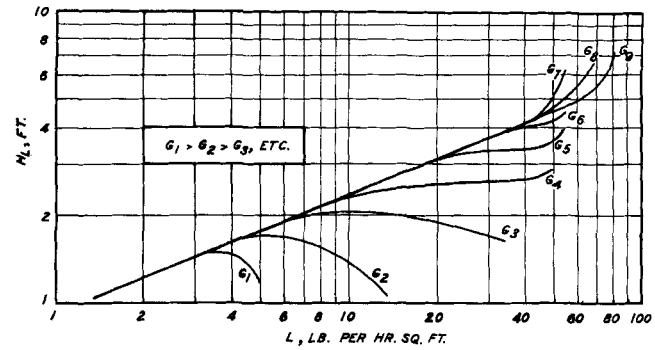

Fig. 3. Effect of loading on gas absorption (qualitative).

At high liquid rates, relatively low gas rates are required to produce loading. In these cases the packing is nearly completely wetted and any increase in holdup due to drag of the gas is achieved by filling voids in the packing, thus decreasing the interfacial area. This effect causes k_La to lie below the value expected without the drag of the gas and H_L increases faster than expected with liquid rate. At higher gas rates entrainment would also be expected to contribute to increasing H_L.

At intermediate liquid rates performance would be expected to show a combination of these effects. Thus it is not surprising to find the H_L leveling off with liquid rate and then increasing rapidly as flooding is approached.

An interesting consequence of the phenomena in the loading region is the increased capacity which may be available in some absorbers which were designed to operate near the loading point. Since in certain ranges of gas and liquid rates H_L decreases with increasing gas rate and liquid rate, it is possible to effect an increase in throughput at constant L/G ratio without sacrificing purity or recovery.

These considerations point to the desirability of sometimes designing and operating packed-column absorbers in the loading region, especially when the L/G ratio is not very high. They also point out the need for more performance data on packed-column absorbers in the loading region.

NOTATION

a = interfacial area, sq. ft./cu. ft.
G = gas rate, lb./(hr.)(sq. ft.)
H.E.T.P. = height equivalent to a theoretical plate, ft.
H_L = height of a transfer unit for liquid phase, ft.
k_L = liquid phase absorption coefficient, ft./hr.
L = liquid rate, lb./(hr.)(sq. ft.)

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