The Uselessness of Total Reboiling

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It has been shown (*1*, *2*) that solvent extraction and rectification are analogous operations. The operation analogous to raffinate reflux discussed in the previous note is total reboiling (*3*). In this operation a liquid stream from the bottom of a rectifying tower is split into two streams; one is vaporized and sent back to the tower, and the other is a bottoms product. Total reboiling also is subject to the same objections; it does not aid the degree of separation and requires one extra plate in a tower. It is not widely claimed as being useful and is not discussed in any authoritative works on distillation.

In constructing a McCabe-Thiele diagram for a desired separation it may be noted that the intersection of the lower operating line with the diagonal has physical significance only for the total reboiling operation. This significance has been obtained at the expense of an extra theoretical plate. The McCabe-Thiele diagram is identical for the case of partial reboiling, which is advantageous with regard to equipment. However in this case this same intersection of the operating line with the diagonal has no physical meaning. The use of total reboiling to give a meaning to this intersection should not lead one to believe that it has practical usefulness.

ACKNOWLEDGMENT

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Semifluidization: Mass Transfer in Semifluidized Beds

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It is the purpose of this communication to report the preliminary performance data of a new and unique type of fluid-solid contact operation which may be termed "semifluidization."

A state of fluidization results when the flow rate of fluid passing upward through a bed of solid particles becomes sufficiently high to buoy the solid particles, provided a sufficient space of free board is available for free expansion of the bed.

The characteristics of fluidization, especially its advantages over fixed-bed operation, are extensively discussed elsewhere. However the fluidization process is not immune from some serious defects of its own, such as loss of driving potential for the transport processes within the bed due to the back mixing of the solid particles, attrition and elutriation of the solid particles, necessity of considerable free board above the bed, and erosion of the containing vessel.

The present authors have speculated about the possibilities of eliminating those defects and attaining a type of solid-fluid contactor which compromises the features of both fixed and fluidized beds by partially restricting expansion of the fluidized bed.

Such possibilities are hinted from many of the correlations of transport processes (*1*, *4*) within the solid-particles-fluid contactors, which are claimed to be equally applicable both to the fixed bed and to the fluidized bed. For instance the mass transfer factor of J_d factor correlation of Chu and his co-workers (*1*) suggests that, irrespective of the type of operation (fixed bed or fluidization), the rate of mass transfer can be altered if the porosity of the bed can be changed.

However expansion of the bed, and consequently the porosity of the conventional fluidized bed, is a function of the geometrical characteristics of the solid particles, the physical properties of the solid particles and fluid, and the flow conditions of the fluid and is not subject to arbitrary control. In other words the porosity of the fluidized beds must be treated as a dependent variable rather than an independent variable.

A typical set of available data on bed expansion is plotted in Figure 1, in which the porosity of the beds is plotted against the rate of fluid flow (*2*).

While the expansion in a conventional fluidized bed is allowed freely, in a semifluidized bed the bed expansion is restricted by a porous or sieve plate introduced above the expanding bed, thus forcing formation of a fixed bed above the fluidized bed. By adjusting the position of the movable top sieve plate one can vary the over-all bed porosity. Therefore the desired heights of fixed and fluidized sections for optimum driving potential for mass, heat, and momentum transfer can be obtained.

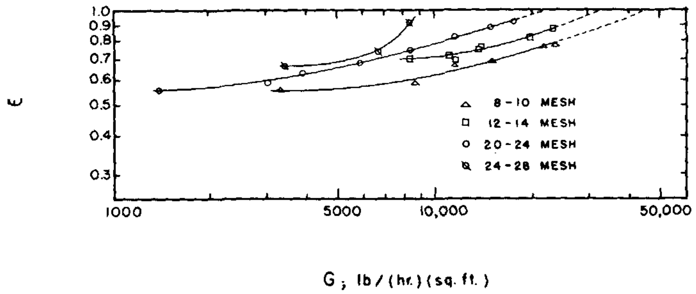

Fig. 1. Porosity of bed of benzoic-acid particle fluidized with water (*2*).

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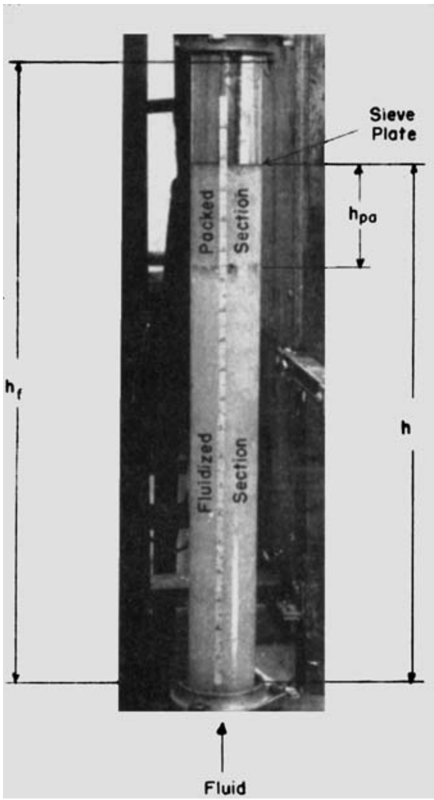

Fig. 2. Semifluidization of benzoic acid-water system.

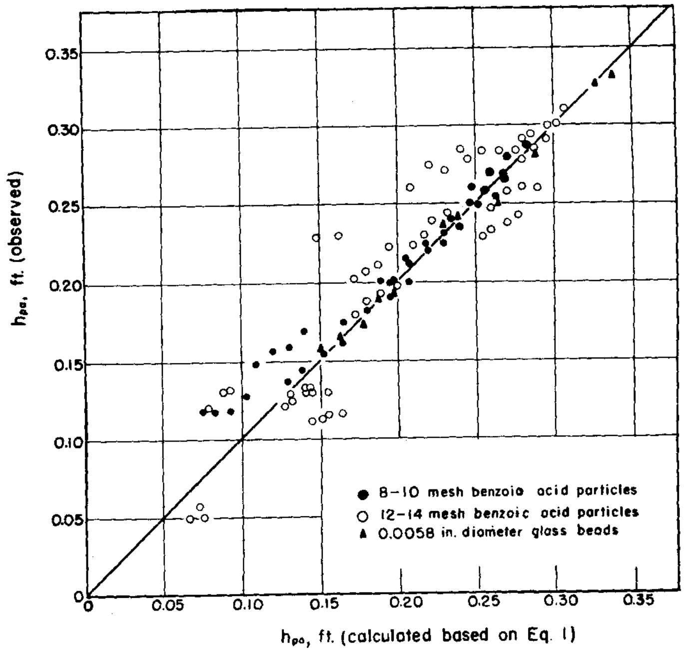

Fig. 4. Heights of packed-bed section whose calculation is based on Equation (1) and compared with that experimentally observed.

EXPERIMENTAL

The benzoic acid-water system was employed in the present investigation. The mass transfer in the fixed and fluidized beds of the system has been investigated by various researchers (*2*, *3*).

The experimental apparatus, procedure for preparing solid particles, and the operating procedure employed by Evan and Gerald (*2*) were closely followed with the exception of the following modifications:

1. A movable top sieve plate was installed within the column containing the solid particles so that the expansion, and consequently the over-all porosity, of the bed could be controlled.

2. To minimize the change in geometry of the particles during the experimental runs none of the individual runs exceeded 80 sec. This resulted in a decrease of less than 3% of the initial weight of the solid particles for a single run.

A few preliminary test runs indicated that reproducibility of the Evan and Gerald data are excellent.

RESULTS OF EXPERIMENTS AND DISCUSSION OF RESULTS

As the picture in Figure 2 indicates it was found that a definite fraction of the solid particles formed a fixed bed immediately below the top sieve plate. The remainder of the particles remained in fluidized condition below the packed section. The name of "semifluidization" was taken from this phenomenon.

The segregation of the particles depended on factors such as the particle and fluid characteristics, flow conditions, and the expansion of the bed allowed. This is illustrated in Figure 3. The bed-expansion ratio is the height between the top sieve plate and the bottom of the expanded bed divided by the height of the bed before expansion.

Based on a simple material balance the height of the packed-bed section in the semifluidized bed can be derived. If the behavior of the particles in a column is assumed to be independent and uniform as is the case in a particulate type of fluidization, when one refers to Figure 2

$$h_{pa}\rho_s(1 - \epsilon_{pa}) = [h_{pa} + (h_f - h)]\rho_s(1 - \epsilon_f)$$

or

$$h_{pa} = (h_f - h)\,\frac{1 - \epsilon_f}{\epsilon_f - \epsilon_{pa}} \qquad (1)$$

The relationship concerning these quantities and operating conditions have been reported in literature (*5*). Figure 4 indicates the height of packed section calculated based on Equation (1) and that obtained from the experiments.

The weight fraction of solid in packed section can be calculated from

$$X = \frac{\rho_s A(1 - \epsilon_{pa})(h_f - h)}{W} \cdot \frac{1 - \epsilon_f}{\epsilon_f - \epsilon_{pa}} \qquad (2)$$

The agreement indicated in Figure 4 is good considering that the large-and irregular-size particles of benzoic acid were employed and that the data include $\epsilon_f > 0.8$ where the measurements of

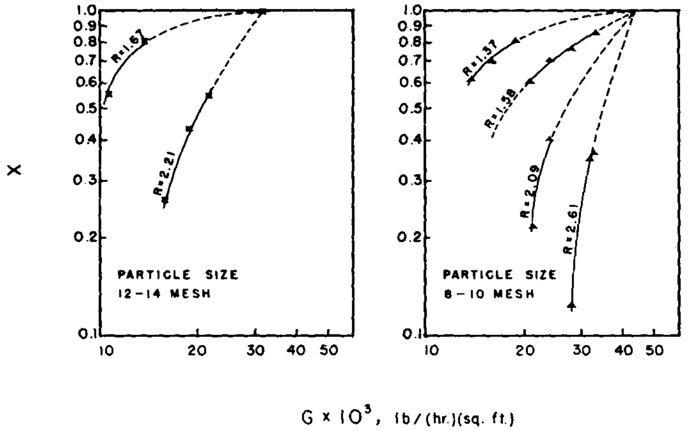

Fig. 3. Weight fraction of packed particles.

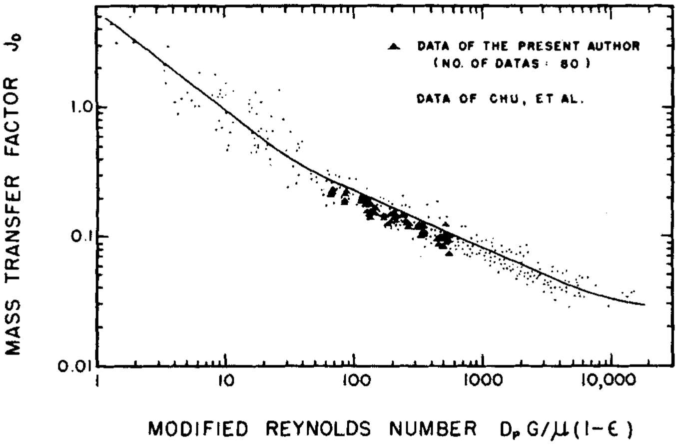

Fig. 5. Generalized correlation of mass transfer data (*1*).

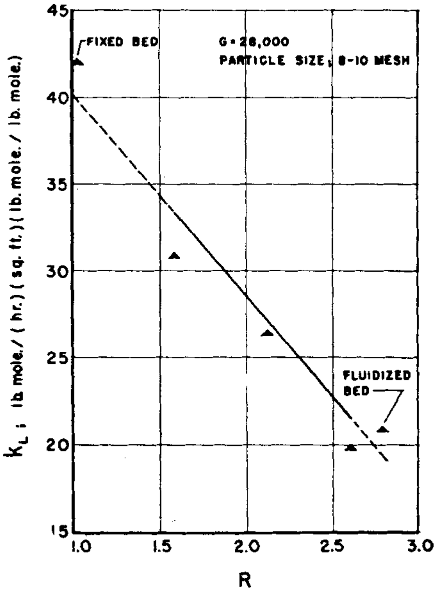

Fig. 6. Expansion ratio vs. mass transfer coefficient.

bed height could not be made accurately.

As indicated in the figure the deviation for the larger particles is greater than for the smaller ones.

The mass transfer data were correlated in terms of the J_d factor and the modified Reynolds number (*1*) (Figure 5). The mass transfer coefficients were calculated on the basis of the over-all logarithmic mean driving force, as was done by other investigators (*1*, *2*) for both packed- and fluidized-bed mass transfer. The solid line in Figure 5 is a line of a generalized correlation used by Chu and his co-workers (*1*) to correlate the mass transfer data in both the fixed beds and the fluidized beds. The magnitude of the deviations from the line of the data by the present authors is of the same order as that of the data used by Chu, *et al.*

The axial concentration gradient within the semifluidized bed is being investigated.

To illustrate the effect of controlled expansion the mass transfer coefficients under approximately constant operating conditions are plotted against expansion ratios in Figure 6.

For a given fluid-flow rate a desired mass transfer coefficient can be selected by adjusting the position of the top sieve plate. The values of k_L for semifluidized bed lie between the limits corresponding to the fixed bed at one end and the fluidized bed (*2*) at the other. For a given expansion ratio the mass transfer coefficient was found to increase as the fluid flow rate is increased.

CONCLUSIONS

The following significant conclusions could be drawn from the results of the present investigation:

1. The segregation of the solid particles into two distinct sections, the fixed bed (upper section) and the fluidized bed (lower section), is caused within a fluidized bed by denying it full expansion. In other words it is possible to carry out the fixed bed and fluidization operations simultaneously within a single vessel.

2. The depth of the packed section, and consequently the fluidized section, are a function of the flow conditions, particle and fluid characteristics, and the expansion of the bed allowed.

The ratio of the depth of the fixed bed to the depth of the fluidized bed can be fixed arbitrarily for certain particles and fluids by controlling the expansion of the bed with the upper sieve plate.

3. The rate of mass transfer is also affected not only by the characteristics of the particles, fluids, and flow rate but also by the amount of expansion of the bed allowed. The magnitudes of mass transfer coefficients can be controlled approximately linearly and within the limits of a completely fixed bed and a fully fluidized bed by means of bed expansion alone.

The expansion of the bed can be introduced as an independent factor, in addition to such factors as temperature, pressure, and flow rate, in controlling the rate of mass transfer for any solid particles-fluid system.

The preliminary phase of the present investigation was concerned with the heights of fixed and fluidized sections and the aspect of mass transfer. However the result has very significant implications to the other aspects of this new operation, such as momentum transfer, heat transfer, and chemical reaction rate in the semifluidized beds. A comprehensive study of these phases of operation in semifluidized bed shall be reported in a paper to follow this communication.

The great possibility of the practical application of this new operation of semifluidization is beyond the need of much description since both fixed beds and fluidized beds are extensively employed in industry as catalytic reactors, ion exchange columns, heat exchangers, driers, solvent extractors, and other process equipments.

It is difficult to predict the occurrence of semifluidization for a large diameter column (of the order of 2 ~ 3 ft.) based on the evidence from the small laboratory-scale column. However it is believed that such phenomena are quite possible in a particulate fluidization but may not be possible in an aggregative fluidization.

NOTATION

D = diameter of particle, ft.
G = mass velocity of fluid, lb./(hr.)(sq. ft.)
J_d = mass transfer factor, dimensionless
h = depth or height of particle bed, ft.
k_L = mass transfer coefficient in liquid phase, lb. mole/(hr.)(sq. ft.)
R = bed expansion ratio, the height between the top sieve plate and the bottom of the expanded bed divided by the height of the bed before expansion, dimensionless.
X = weight fraction of particles in fixed bed, dimensionless
ϵ = void fraction or porosity in the bed of particles, dimensionless
μ = viscosity, lb./(hr.)(ft.)

Subscripts

f = fluidization
L = liquid
S = solid particle
pa = packed bed

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