in Packed Beds," paper presented at AIChE Annual Meeting, Chicago, Ill. (Nov., 1976).

Hirose, T., M. Toda, and Y. Sato, "Liquid Phase Mass Transfer in Packed Bed Reactor with Cocurrent Gas-Liquid Downflow," *J. Chem. Eng. Japan*, **7**, 187-192 (1974).

Larkins, R. P., R. R. White, and D. W. Jeffrey, "Two-Phase Cocurrent Flow in Packed Beds," *AIChE J.*, **7**, 231-239 (1961).

Oshinowo, T., and M. E. Charles, "Vertical Two-Phase Flow, Part I, Flow Pattern Correlations," *Can. J. Chem. Eng.*, **52**, 25-35 (1974).

Sato, Y., T. Hirose, F. Takahashi, M. Toda, and Y. Hashiguchi, "Flow Pattern and Pulsation Properties of Cocurrent Gas-Liquid Downflow in Packed Beds," *J. Chem. Eng. Japan*, **6**, 315-319 (1973*a*).

Sato, Y., T. Hirose, F. Takahashi, and M. Toda, "Pressure Loss and Liquid Holdup in Packed Bed Reactor with Cocurrent Gas-Liquid Downflow," *ibid.*, 147-152 (1973*b*).

Scatterfield, C. N., "Trickle-Bed Reactors," *AIChE J.*, **21**, 209-228 (1975).

Sylvester, N. D., and P. Pitayagulsarn, "Radial Liquid Distribution in Cocurrent Two-Phase Downflow in Packed Beds," *Can J. Chem. Eng.*, **53**, 599-605 (1975*a*).

————, "Mass Transfer for Two-Phase Cocurrent Downflow in a Packed Bed," *Ind. Eng. Chem. Process Design Develop.*, **14**, 421-426 (1975*b*).

Taitel, Y., and A. E. Dukler, "A Model for Predicting Flow Regime Transitions in Horizontal and Near Horizontal Gas-Liquid Flow," *AIChE J.*, **22**, 47-55 (1976).

Turpin, J. L., and R. L. Huntington, "Predictions of Pressure Drop for Two-Phase, Two-Component Concurrent Flow in Packed Beds," *ibid.*, **13**, 1196-1202 (1967).

Weekman, V. W., Jr., and J. E. Myers, "Fluid Flow Characteristics of Concurrent Gas-Liquid Flow in Packed Beds," **10**, 951-957 (1964).

Manuscript received April 25, 1977; revision received July 22, and accepted August 11, 1977.

Part II. Pulsing Regime Pressure Drop

Surveys of local and overall pressure drop in partially pulsing 29.2 cm diameter beds show the overall pressure drop steady but elevated, while local pressure drops across various sections of the bed oscillate in correspondence with the local pulse frequency. The increase in overall pressure drop due to pulsing varies between 0 and 100%, depending on the extent of pulsing and liquid holdup within the bed.

In foaming systems, the overall bed pressure drop can be higher than for pulsing alone, depending on liquid holdup and (apparently) the type of foam and its intensity. In some cases, pulsing appears to be the starting point for low frequency foaming pressure drop surges which are associated with cyclic foam formation and breakup within the bed.

SCOPE

Pressure drop oscillations are often associated with pulsing, and a correspondence between local pulse frequency and local pressure drop oscillation frequency has been observed in beds up to 29.2 cm in diameter and particle sizes in the range of 0.350 to 0.801 cm (Part I of this study; Sato et al., 1973*a*). Yet, the transition into the pulsing flow regime is reported to have no abrupt effect on pressure drop in beds of 5.08, 10.2, and 15.2 cm in diameter packed with 0.762 to 0.823 cm particles (Turpin and Huntington, 1967), whereas manometer fluctuations were greatest at transition into pulsing in 7.62 cm diameter beds packed with 0.378, 0.475, and 0.648 cm beads and spheres (Weekman and Myers, 1964), all operating in the same range of air/water flow rates. Apparently, particle size or some other bed related property controls the extent to which pulsing affects pressure drop. Therefore, the objective of Part II of this study is to determine the extent to which pulsing affects overall bed pressure drop using data from the 30.5 cm OD column system of Part I.

CONCLUSIONS AND SIGNIFICANCE

In the pulsing flow regime, the overall bed pressure drop is not in correspondence with the frequency of pulses leaving the bed. Overall bed pressure drop is relatively steady but elevated, while local pressure drops across various sections of the bed are oscillating in correspondence with local pulse frequency (Figures 1 and 2). The increase in overall pressure drop due to pulsing depends on the extent of pulsing within the bed and the liquid holdup (Figure 3). For fully pulsing beds (Figure 4), the increase in pressure drop goes through a maximum of approximately 100% at liquid holdups [defined by Equation (3)] between 0.5 and 0.6.

When foaming accompanies pulsing, the pressure drop may be higher than for pulsing alone, depending on liquid holdup and (apparently) the type of foam and its intensity (Figure 5).

While foaming may form and exist without pulsing, the latter appears to trigger foaming, which may lead to low frequency foaming pressure drop surges between a pulsing level and a higher pulsing and foaming level. However, the bed pressure drop is not affected by foaming when the liquid holdup [defined by Equation (3)] is below 0.5. In that range, the effect of pulsing per se prevails; that is, pressure drop increases between 0 and 100%, depending on liquid holdup.

While keeping liquid holdup below 0.5 is suggested as a means of avoiding a potential foaming problem in a catalyst bed, it is no substitute for advancing the present state of knowledge of foams, foaminess, and foam breakage. Because universal methods for characterizing foam are not available, we cannot presently quantify the various foaming pressure drop levels possible with hydrocarbon systems, nor can we distinguish among various forms of foam or foam intensity in the correlation of foaming and pulsing/foaming flow regimes (Part I, Figure 3). The time of collapse after shaking (Bikerman, 1973) used in this study to characterize the slight foaming observed with air/33 to 46% glycerine solutions is not sufficient nor meaningful, as it depends on individual definitions of shaking and collapse. Some other parameter combining surface tension, viscosity, vapor pressure, and gas-to-liquid ratio is needed. Another area of needed research is foam control through antifoam agents which are stable at high temperatures and do not affect catalyst activity.

LOCAL AND OVERALL PRESSURE DROP IN PULSING BEDS

Figure 1 shows a survey of local and overall pressure drop as sensed and recorded by pneumatic instruments (Part I, Figure 1). During this run, the lower 61 cm of the bed were visibly pulsing, and a pulse frequency gradient was visible along the bed. The pressure drop traces for the middle 30.5 cm sections and the top and bottom 15.2 cm sections of the bed are in good correspondence with the visual observations; that is, the frequency of the local pressure drop oscillation decays toward the top of the bed. However, while the pressure drop across the middle 91.5 cm section of the bed is oscillatory, the drop across the lower 106.7 cm of the bed is less oscillatory, and the overall bed pressure drop (with and without the distribution plate) is barely oscillating. The overall pressure drop is not in correspondence with the frequency of pulses leaving the bed as reflected by pressure drop oscillations across the bottom 15.2 cm section of the bed. Furthermore, comparison of pressure drops across nonpulsing and pulsing bed sections, for example, 2 239 N/m^2 for the top 15.2 cm section of the bed vs. 3 484 ± 498 N/m^2 for the bottom 15.2 cm section of the bed, suggests that pulsing increases pressure drop.

To amplify these observations, the liquid rate for the run of Figure 1 (7.595 kg/m^2s) was kept constant, and the air rate was doubled for another survey of local and overall pressure drop. The results are given in Figure 2.

During the run (Figure 2), the lower 91.5 cm of the bed were visibly pulsing, and compared to Figure 1, the pulse frequency was noticeably higher. Again, the local pressure drop traces are consistent with visual observations, and the overall bed pressure drop, while somewhat more oscillatory than in Figure 1, is not in correspondence with the frequency of pulses leaving the bed. In fact, if the column were not transparent and if only the overall pressure drop were available (as in commercial trickle-bed reactors), it would be very difficult to suspect that the beds were pulsing in Figures 1 and 2.

The overall pressure drop is the algebraic sum of local oscillatory pressure drops of different frequencies and amplitudes. The oscillations appear to cancel when added but not the increase in pressure drop due to pulsing, which is very pronounced in Figure 2. The pressure drop across the barely pulsing top 15.2 cm section of the bed is 2 986 N/m^2 compared to 5 226 ± 746 N/m^2 for the fully pulsing bottom 15.2 cm section. Also, the pressure drop across the middle 91.5 cm section of the bed is nonlinearly distributed among its three 30.5 cm subsections. This is worth noting because existing pressure drop correlations predict one value per unit height of bed for a given flow regime, and linearity is assumed when the overall bed pressure drop is calculated.

EFFECT OF PULSING ON OVERALL BED PRESSURE DROP

Figures 1 and 2 suggest that pulsing may increase overall pressure drop by factors anywhere between 1 and 2,

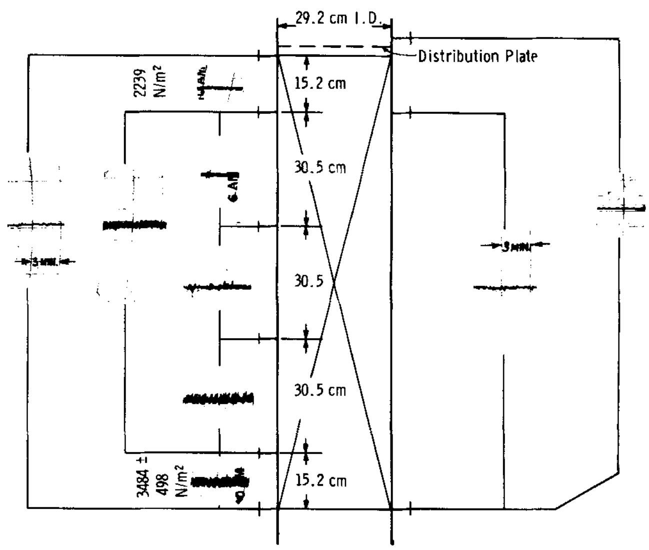

Fig. 1. Local and overall pressure drops as sensed by pneumatic *d/p* cell transmitters and recorded by a pneumatic consotrol receiver at a chart speed of 0.635 cm/min; lower 61 cm of bed were visibly pulsing; $L = 7.595$ kg/m^2s, $G = 0.106$ kg/m^2s (run 331).

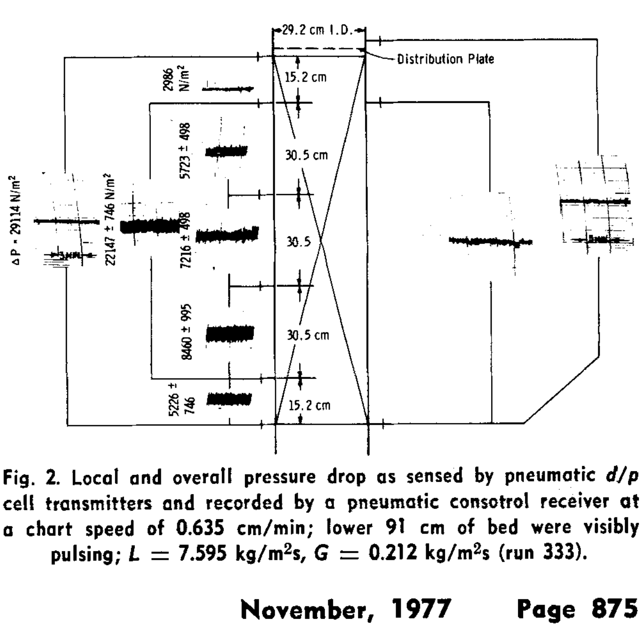

Fig. 2. Local and overall pressure drop as sensed by pneumatic *d/p* cell transmitters and recorded by a pneumatic consotrol receiver at a chart speed of 0.635 cm/min; lower 91 cm of bed were visibly pulsing; $L = 7.595$ kg/m^2s, $G = 0.212$ kg/m^2s (run 333).

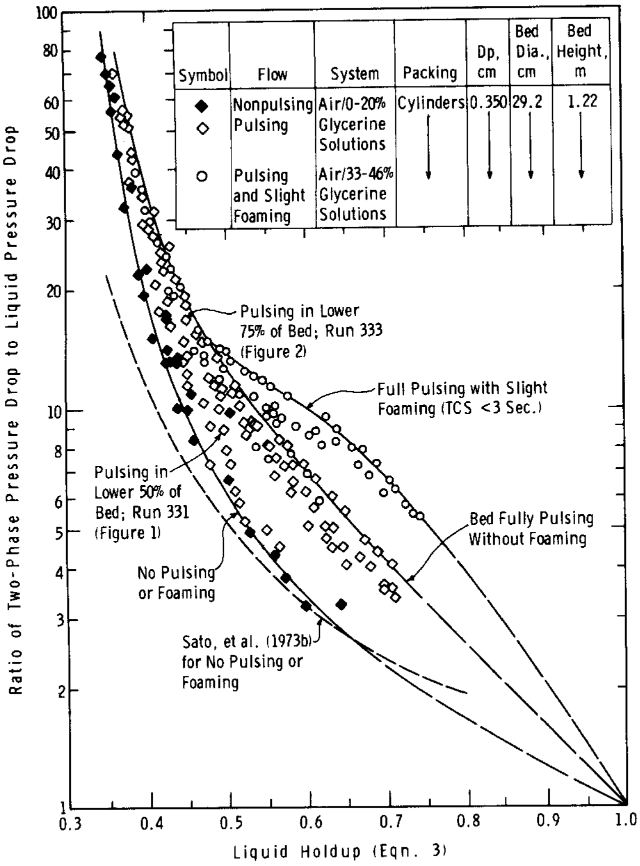

Fig. 3. Effect of pulsing on overall pressure drop in nonfoaming and slightly foaming (TCS <3 s) two-phase downflow through a catalyst bed; pressure drops for partial pulsing fall between the curves for no pulsing and full pulsing.

depending on the extent of pulsing within a bed or variables which affect and extent of pulsing and its frequency. It is of practical importance to determine the maximum increase in pressure drop that can be attributed to pulsing and the conditions for which the increase is maximum.

To correlate the increase in pressure drop due to pulsing, a fundamentally sound method is required for plotting pulsing and nonpulsing pressure drop data over a wide range of variables. Starting with fundamentals, Larkins et al. (1961) showed that for a given packing and a given flow regime, the two-phase pressure drop when normalized by the pressure drop due to liquid flow alone should correlate with the liquid holdup within the bed; that is

$$\Delta P_{lg}/\Delta P_l = f(H_l) \tag{1}$$

Similarly, the two phase pressure drop when normalized by the pressure drop due to gas flow alone should correlate with gas holdup within the bed, or

$$\Delta P_{lg}/\Delta P_g = f(1 - H_l) \tag{2}$$

Larkins et al. (1961) tested and confirmed Equation (1) using their liquid holdup data for air/water flowing downward through 0.952 cm Raschig rings. In fact, their curve shows two distinct slopes, which is characteristic of a change from one flow regime to another; that is, the form of Equation (1) fits more than one flow regime. However, Larkins et al. (1961) did not pursue this form of correlation because liquid holdup was considered unknown in design calculations. Instead, they combined Equations (1) and (2) so as to eliminate the liquid holdup per se from their pressure drop correlation.

Since the work of Larkins et al. (1961), a considerable amount of liquid holdup data has been generated and reviewed (Sato et al., 1973*b*; Satterfield, 1975; Charpentier and Favier, 1975). Differences among correlations have been attributed to different methods of holdup measurement (Sato et al., 1973*b;* Satterfield, 1975) and insufficient accounting for the effect of packing characteristics (Sato et al., 1973*b*). The more recent data show a significant dependence of liquid holdup on packing properties (Charpentier and Favier, 1975; Clements and Schmidt, 1976; Goto and Smith, 1975; Schwartz et al., 1976), so that with a proper choice of a liquid holdup correlation, the form of Equation (1), already proven for more than one flow regime (Larkins et al., 1961), can also be made applicable to more than one packing.

Charpentier and Favier (1975) obtained liquid holdup data with twenty gas/hydrocarbon systems, three cobalt/molybdenum/aluminum oxide catalysts, and glass spheres. They compared the fit of different correlations with their data and concluded that for design purposes, either their correlation or that of Sato et al. (1973*b*) may be used to determine liquid holdup for foaming and nonfoaming hydrocarbons and for any flow regime with catalyst packings. As the correlation of Sato et al. (1973*b*) is easier to use, it was chosen for application in Equation (1). For consistency, the recommendation of Sato et al. (1973*b*) for calculating single-phase pressure drop was also used, so that

$$H_l = 0.40a^{1/3}\,(\Delta P_l/\Delta P_g)^{0.11} \text{ for } 0.01 < (\Delta P_l/\Delta P_g) < 400 \tag{3}$$

where

$$a = 6(1-\epsilon)/d', \quad \text{in mm}^{-1}$$

$$d' = \frac{D_p}{1 + \dfrac{2D_p}{3D(1-\epsilon)}}$$

and

$$\Delta P_{l \text{ or } g} = (150 + 4.2Re^{5/6}{}_{l \text{ or } g})\frac{(1-\epsilon)^2 (L \text{ or } G)\mu_{l \text{ or } g} Z}{g_c\,\epsilon^3\,\rho_{l \text{ or } g}\,d'^2} \tag{4}$$

where

$$Re_{l \text{ or } g} = \frac{d'\,(L \text{ or } G)}{\mu_{l \text{ or } g}\,(1-\epsilon)}$$

For a given run of this study, liquid holdup and single-phase pressure drops were calculated for the packing, flow rates, and fluid properties of the run using Equations (3) and (4). The observed two-phase pressure drop for the run was normalized by the calculated liquid-phase pressure drop, and the ratio $\Delta P_{lg}/\Delta P_l$ was plotted vs. H_l as suggested by Equation (1).

Applying this procedure to nonpulsing runs, the solid points in Figure 3 are obtained. A best curve, labeled no pulsing or foaming, is shown drawn through the data, extrapolating to $\Delta P_{lg}/\Delta P_l = 1.0$ at $H_l = 1.0$. To show a typical comparison of this curve to published pressure drop correlations, the two-phase pressure drop correlation of Sato et al. (1973*b*), that is

$$\sqrt{\Delta P_{lg}/\Delta P_l} = 1.30 + 1.85\,(\Delta P_l/\Delta P_g)^{-0.425} \quad \text{for} \quad 0.01 < (\Delta P_l/\Delta P_g) < 400 \tag{5}$$

is superimposed as a dotted curve in Figure 3. Equation (5) shows reasonable agreement with the data in some range of liquid holdup but appears to deviate systematically away from (and below) the data as the liquid holdup is reduced.

While the no pulsing or foaming curve is based strictly on air/0 to 20% glycerine solution data, it has been found to fit pressure drop data from several reactors in hydroprocessing service. It can, therefore, be considered a realistic reference for pulsing bed data.

Applying the above-mentioned procedure to pulsing runs of this study, the open points in Figure 3 are obtained. Beds with incipient pulsing at the bottom fall close to the no pulsing curve, and as the point of incipient pulsing moves up the bed and a state of full pulsing is approached, the points fall considerably above the no pulsing curve. For example, a run with pulsing in the lower half of the bed (Figure 1) and a run with pulsing in the lower 75% of the bed (Figure 2) are identified in Figure 3.

As interest centered on the maximum increase in pressure drop due to pulsing, a best curve was drawn through the air/0 to 20% glycerine solution points representing fully pulsing beds. This curve is labeled bed fully pulsing without foaming in Figure 3.

The air/33 to 46% glycerine solution data points representing full pulsing and slight foaming (TCS < 3 s) deviate from the rest of the pulsing points when liquid holdup exceeds 0.50. A separate curve was thus drawn through the highest air/33 to 46% glycerine solution data. The curve is labeled full pulsing with slight foaming (TCS <3 s) in Figure 3, taking off at a liquid holdup of 0.5 and extrapolating to the same focal point as the nonpulsing and pulsing curves.

The difference between the full pulsing and nonpulsing curves in Figure 3 represents the increase in pressure drop due to pulsing. That difference is highest at intermediate liquid holdups disappearing toward either end of the liquid holdup scale. Indeed, as single-phase flow is approached ($H_l = 0$ or 1), the effect of pulsing being a two-phase flow phenomenon should disappear; that is, the pressure drop increase due to full pulsing goes through a maximum with respect to liquid holdup or variables affecting liquid holdup.

To amplify this observation, the ratio of the curves labeled bed fully pulsing without foaming and no pulsing or foaming is plotted vs. liquid holdup in Figure 4. The solid portion of the curve represents the range of data in Figure 3, and the dotted portions of the curve represent reasonable extrapolations to single-phase flow at either end of the liquid holdup scale.

As shown (Figure 4), the fully pulsing-to-nonpulsing pressure drop ratio goes through a maximum of 2.1 at liquid holdups between 0.50 and 0.60. For partially pulsing beds, the increase in overall pressure drop is proportionately lower. For example, two points representing partially pulsing beds (Figures 1 and 2) at liquid holdups of 0.45 to 0.50 are superimposed on Figure 4. For the case of pulsing in the lower 50% of the bed, the increase in overall pressure drop is by a factor of 1.44, and for the case of pulsing in the lower 75% of the bed, the increase is by a factor of 1.77. For full pulsing, the increase is by a factor of 2.0 to 2.1. Furthermore, the increase in pressure drop when partially pulsing at lower liquid holdups may not be noticeable. This may explain why earlier investigations with Raschig rings and relatively large diameter TCC beads and spheres did not report any increases in pressure drop due to pulsing (Larkins et al., 1961; Weekman and Myers, 1964).

The results presented in Figure 4 should not be considered biased by the choice of liquid holdup and liquid pressure drop correlations used in Figure 3. Any consistent and valid set of such correlations could be used to present the data in the form of Figure 3 and derive the pressure drop increase due to pulsing as in Figure 4. However, a major requirement in the choice of a liquid holdup correlation is that it should cover data from pulsing and nonpulsing beds with and without foaming. Presently, only two correlations (Sato et al., 1973*b*; Charpentier and Favier, 1975) meet this requirement, and one of them (Sato et al., 1973*b*) is used in this study.

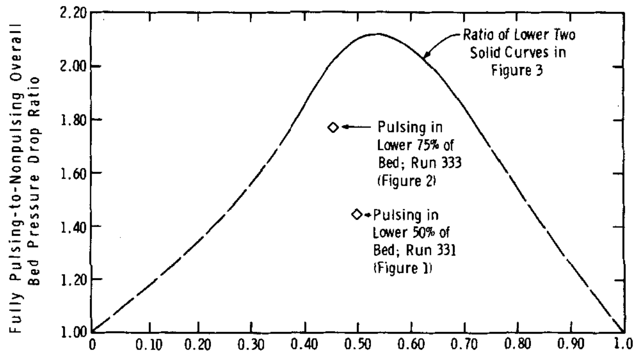

Fig. 4. Pressure drop increase due to full pulsing in nonfoaming two-phase downflow through a catalyst bed.

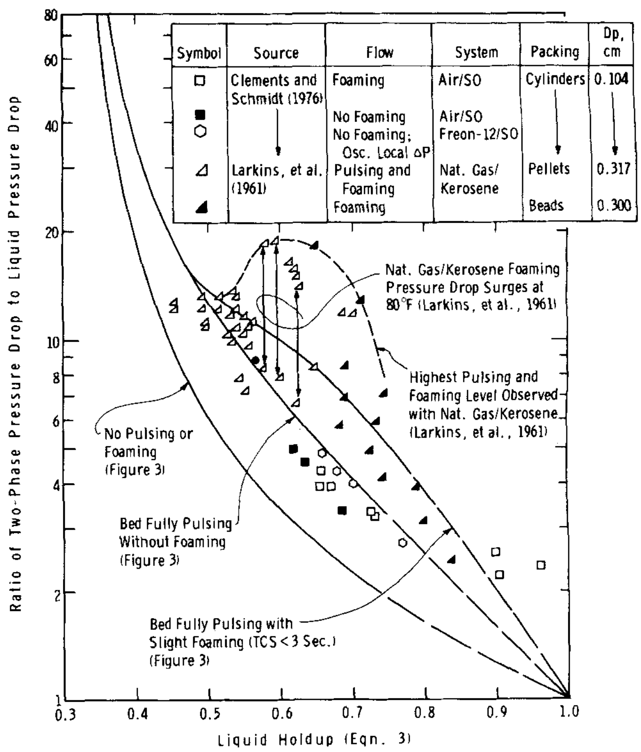

Fig. 5. Effect of pulsing and foaming on overall pressure drop in two-phase downflow through catalyst beds.

EFFECT OF PULSING/FOAMING ON OVERALL BED PRESSURE DROP

Figure 3 suggests that slight foaming (TCS <3 s) within a fully pulsing catalyst bed may lead to a significant increase in pressure drop beyond and the level for full pulsing, particularly as liquid holdup is increased beyond 0.5. This calls for examination of other pulsing and foaming pressure drop data.

As may be expected from investigations of pressure drop in well-behaved foaming systems (Weekman and Myers, 1964), various pressure drop levels are possible depending on the type and amount of surfactant added to a nonfoaming pure liquid, and the pressure drop may increase from five to fortyfold (Weekman and Myers, 1964). This means that when the foaminess of a foaming system cannot be characterized, a wide scatter of pressure drop data is obtained, and several curves can be drawn through the data. Such is the case with natural gas/kerosene data (Larkins et al., 1961) presented in Figure 5, where the pressure drop levels for no pulsing or foaming, full pulsing without foaming, and full pulsing with slight foaming (Figure 3) are superimposed as solid curves for comparison.

Most of the natural gas/kerosene data points, whether reportedly foaming or foaming and pulsing, fall above the level for full pulsing without foaming. Some foaming and pulsing natural gas/kerosene points and some foaming and nonfoaming air/silicone-oil points (Clements and Schmidt, 1976) fall between the levels for no pulsing and full pulsing, which is indicative of partial pulsing. This shows that foaming may accompany partial and full pulsing or may exist by itself, which is consistent with the flow map presented in Figure 3 of Part I.

The dotted curve in Figure 5 connects the highest visually pulsing and foaming or foaming natural gas/kerosene points. As for the case of pulsing and slight foaming with air/33 to 46% glycerine solutions, the curve takes off at a liquid holdup of approximately 0.5, but it goes through a maximum closely where the effect of pulsing is maximum (Figure 4). This suggests that pulsing could be a trigger mechanism for foaming when the liquid has a tendency to foam.

Another phenomenon observed with natural gas/kerosene is occasional low frequency, high amplitude overall pressure drop oscillations in combination with visual observations of cyclic foam formation and breakup (Larkins et al., 1961). The bed voidage appeared to fill up with foam as the pressure drop was observed to increase. At some point, the foam seemed to collapse and sweep from the column with a corresponding decrease in pressure drop. The cycle then repeated itself.

Figure 5 shows a cluster of three natural gas/kerosene foaming pressure drop surges as observed by Larkins et al. (1961) at 80°F. These are denoted by two-way arrows connecting the high and low points of the surge. As shown (Figure 5), the surges are between the curve for full pulsing without foaming and the curve representing the highest pulsing and foaming natural gas/kerosene points; that is, full pulsing is the starting point for foaming pressure surges in this case.

We do not know what parameter to associate with the various foaming pressure drop levels. Qualitatively, such a parameter would have to be a combination of at least surface tension, viscosity, vapor pressure, and gas-to-liquid ratio. To make this quantitative, the present state of knowledge of foams and foaminess has to be advanced.

Meanwhile, one way to assure no foaming pressure surges in catalyst beds is through foam control, for example, addition of antifoam agents, provided they are stable at the temperature considered. However, Figure 5 suggests a way of designing around the problem by keeping liquid holdup [as defined by Equation (3)] below 0.5. Bed pressure drop appears unaffected by foaming in that region, but the effect of pulsing per se prevails in accordance with Figure 4; that is, pressure drop increases between 0 and 100%, depending on liquid holdup within the bed.

APPLICATION TO COMMERCIAL REACTORS

If pressure drop data from existing reactors are available, their superimposition on Figure 5 may reveal internal foaming within the bed, provided that other reasons for high pressure drop, for example, dirty feed or a fouled bed, are eliminated. Certainly, overall pressure drop increases by more than 100% over normal cannot be attributed to pulsing alone (Figure 4).

For new reactors, Figure 3 can be used to predict overall bed pressure drop when not pulsing, and Figure 4 can be used to determine the increase in pressure drop due to pulsing. But, if also foaming, the effect on pressure drop cannot be determined if liquid holdup exceeds 0.5 (Figure 5).

NOTATION

a = external catalyst surface per unit volume of bed, in mm^{-1} when used in Equation (3)
a_p = external surface of a catalyst particle
D = bed diameter
D_p = effective particle size = $6\, v_p/a_p$
G = superficial mass velocity of gas
g_c = conversion constant
H_l = liquid holdup within the bed, fraction of bed voidage occupied by liquid [Equation (3)]
L = superficial mass velocity of liquid
ΔP = pressure drop
Re = Reynolds number
TCS = time of collapse after shaking (Bikerman, 1973)
v_p = volume of catalyst particle
Z = bed height
ϵ = void fraction of catalyst bed
μ = viscosity
ρ = density

Subscripts

l = pertaining to liquid alone
g = pertaining to gas alone
l or g = liquid or gas
lg = pertaining to two-phase flow

LITERATURE CITED

Bikerman, J. J., *Foams*, p. 104, Springer-Verlag, New York (1973).

Charpentier, J. C., and M. Favier, "Some Liquid Holdup Experimental Data in Trickle-Bed Reactors for Foaming and Nonfoaming Hydrocarbons," *AIChE J.*, **21**, 1213-1218 (1975).

Clements, L. D., and P. C. Schmidt, "Two-Phase Pressure Drop and Dynamic Liquid Holdup in Co-Current Downflow in Packed Beds," paper presented at AIChE Annual Meeting, Chicago, Ill. (Nov., 1976).

Goto, Shigeo, and J. M. Smith, "Trickle-Bed Reactor Performance, Part I. Holdup and Mass Transfer Effects," *AIChE J.*, **21**, 706-713 (1975).

Larkins, R. P., R. R. White, and D. W. Jeffrey, "Two-Phase Concurrent Flow in Packed Beds," *ibid.*, **7**, 231-239 (1961).

Sato, Y., T. Hirose, F. Takahashi, M. Toda, and Y. Hashiguchi, "Flow Pattern and Pulsation Properties of Cocurrent Gas-Liquid Downflow in Packed Beds," *J. Chem. Eng. Japan*, **6**, 315-319 (1973*a*).

Sato, Y., T. Hirose, F. Takahashi, and M. Toda, "Pressure Loss and Liquid Holdup in Packed Bed Reactor with Cocurrent Gas-Liquid Downflow," *ibid.*, 147-152 (1973*b*).

Satterfield, C. N., "Trickle-Bed Reactors," *AIChE J.*, **21**, 209-228 (1975).

Schwartz, J. G., Eric Weger, and M. P. Duduković, "Liquid Holdup and Dispersion in Trickle-Bed Reactors," *ibid.*, **22**, 953-956 (1976).

Turpin, J. L., and R. L. Huntington, "Predictions of Pressure Drop for Two-Phase, Two-Component Concurrent Flow in Packed Beds," *ibid.*, **13**, 1196-1202 (1967).

Weekman, V. W., Jr., and J. E. Myers, "Fluid Flow Characteristics of Concurrent Gas-Liquid Flow in Packed Beds," *ibid.*, **10**, 951-957 (1964).

Manuscript received April 25, 1977; revision received July 22, and accepted August 11, 1977.