COMMUNICATIONS TO THE EDITOR

Relative Velocities of Bubbles to Liquid in an Agitated Gas-Liquid Contactor

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Although liquid flow patterns and velocities in mixing vessels have been studied extensively, usually by photographic methods, apparently no work has been reported on bubble flow patterns and velocities in agitated gas-liquid dispersions. A knowledge of the bubble velocity relative to the agitated liquid is necessary to solve the general equations for unsteady state mass transfer. In addition, information as to if and how this relative velocity changes with increasing agitation would be helpful in evaluating some theoretical models for mass transfer. As part of a more general investigation of mass transfer between bubbles and liquid in an agitated gas-liquid contactor (*1*), a photographic technique was used to provide information on bubble flow patterns and the relative velocity between the bubble and liquid.

The technique developed by Sachs and Rushton (*2*) for determining liquid velocities based on photographing tracer particles in horizontal and vertical light planes was applied to investigate the velocity of gas bubbles by photographing the bubbles themselves. Solid spherical tracer particles were introduced into the liquid and their streaks were used to determine the liquid velocity. The difference between these two velocities as measured under the same stirring conditions then gives the relative velocity between the gas and the stirred liquid.

The mixing tank was a cylindrical glass vessel with an internal diameter of 29 cm. equipped with four vertical baffles 2.9 cm. wide. Liquid depth was maintained equal to vessel diameter. A vaned-disk type impeller with sixteen radial blades was used. The impeller-to-tank diameter ratio was 0.4 and the ratios of blade width and length to impeller diameter were 0.1 and 0.35, respectively. The distance from impeller to tank bottom was 0.3 times the liquid depth. Air was introduced underneath the center of the impeller. The light source was a carbon-arc lamp and suitable lenses and slits were provided so that the vessel was illuminated by a 1-cm. wide light plane. All photographs were made with a 35-mm. reflex camera at an actual exposure time of 1/63 sec. as determined by shutter calibration.

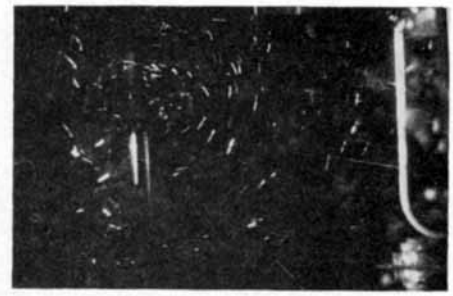

Fig. 1*a*. Gas bubble streaks obtained at 300 rev./min. impeller speed. Vertical light plane.

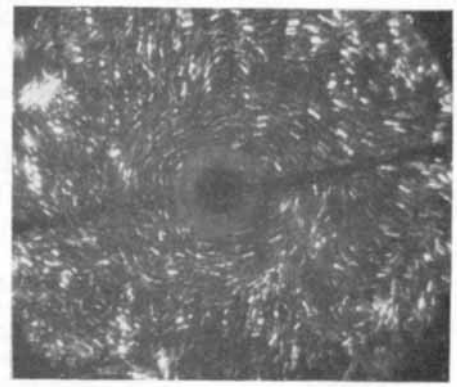

Fig. 1*b*. Gas bubble streaks obtained at 300 rev./min. impeller speed. Horizontal light plane midway between impeller and tank bottom.

Highly reflective plastic spheres consisting of a copolymer of methyl methacrylate and styrene were used as tracer particles in the determination of liquid velocities. Their density was 1.19, the same as that of the liquid used, an aqueous solution at 20°C. containing 73% glycerine. Because it is difficult to differentiate between streaks produced by the tracer particles and by the gas bubbles, the vessel was photographed first with gas bubbles alone and then with tracer particles alone. Low gas loading was used so that there would be a similarity of stirring conditions for the photographs made of the tracer particles and those of the gas bubbles at the same impeller speed.

Figures 1*a* and 1*b* are typical of the photographs obtained. The light spots on many of the streaks resulted from the varying light intensity, due to incomplete filtering of the rectifier output to the arc lamp. Over a large range of rotational speed the local bubble dispersion density did not appear to differ appreciably from the average and no fluid or bubble dead spaces existed.

The flow patterns of the bubbles and liquid were found to be essentially identical in the region of *effective agitation* and a change in impeller speed did not change the patterns. The shape approaches that of two helices, one

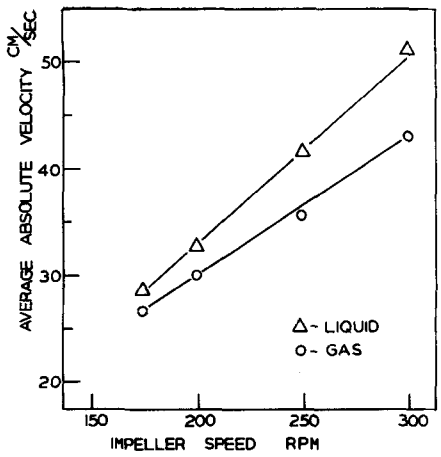

Fig. 2. Average bubble and liquid velocity as function of impeller speed.

above and one below the impeller, progressing in the direction of impeller rotation.

Quantitative information was obtained on the fluid and bubble velocities by measuring the streak lengths. Only sharp streaks that began and ended in the light plane were taken into account. The velocity vectors were converted to absolute velocity by taking the square root of the sum of the squared average velocity components in the vertical plane and the squared tangential components from the horizontal plane. The results are shown graphically in Figure 2. Each point represents the velocity as determined from the streaks from at least six photographs made at identical operating conditions, three from the horizontal plane and three from the vertical plane. From this graph it is clear that the relative velocity between the gas bubbles and the liquid increases as the impeller rotational speed increases. The data, however, are not sufficiently reliable to permit too much confidence to be placed on the numerical values.

It is hoped that this somewhat qualitative report may stimulate additional exploration in this area in the field of agitation in which practically no quantitative data are available.

LITERATURE CITED

1. Gal-Or, Benjamin, D. Sc. thesis, Israel Inst. Technol., Haifa (1964).
2. Sachs, J. P., and J. H. Rushton, *Chem. Eng. Progr.*, **50**, 597 (1954).

A New Adiabatic MT Reactor System

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Cholette and Blanchet (3, 4) have shown that a combination of mixed and tubular reactors is often theoretically more efficient than either of these reactors operated independently. It was also shown that for endothermal reactions the tubular reactor is always superior to C.S.T.R., while for exothermal reactions the C.S.T.R. is superior to the tubular reactor up to a certain conversion after which the tubular reactor is more efficient.

These observations can be explained by a simple physical model. In carrying out an exothermal reaction under adiabatic conditions in a tubular reactor, two opposite influences may be noted: increase in reaction rate due to the adiabatic rise in temperature; and decrease in reaction rate due to a decrease in reactants concentration. In the earlier part of the reactor the influence of temperature is normally more marked, leading to an increase in reaction rate. After a certain stage however the effect of concentration exerts a greater influence, leading to a decrease in the reaction rate. That portion of the reaction which occurs in the increasing rate zone can be advantageously carried out in a fully mixed reaction, that is, that occurring in the reactor is determined by the exit conditions. The subsequent part of the reaction, that is, that occurring in the decreasing rate zone, should be carried out in a tubular reactor since the average rate in this reactor is higher than the exit rate.

It is clear from the argument presented above that for an exothermal adiabatic reaction, the first reactor should be a C.S.T.R. which will give an outlet conversion corresponding to the maximum reaction rate. The products can then be led into a tubular reactor for achieving the final degree of conversion required. Aris (1) has treated this problem mathematically and has given equations for determining the outlet conversion to be achieved in the C.S.T.R. The other advantages of MT combination under adiabatic conditions have also been fully discussed (3, 4, 5).

The theoretical advantage of the MT combination can be practically realized in a simple reactor system utilizing the principle of semifluidization. Recently, Liang-Tsung Fan, Chin-Yung Wen, and co-workers (2, 6, 7) have shown that by restricting the expansion of a fluidized bed (with a perforated plate), it is possible to create a combination of fixed and fluidized beds. They have also obtained data for predicting the maximum semifluidization velocity at which all the solids in the bed will form a dense fixed bed underneath the restricting plate. Thus in between the velocities for the onset of fluidization and maximum semifluidization, it is possible to obtain a fixed

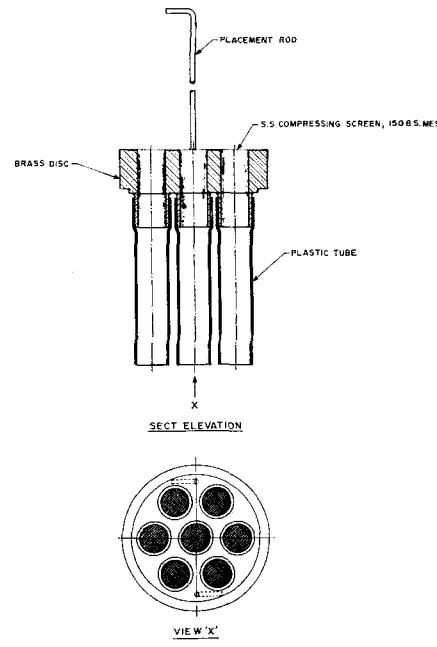

Fig. 1. Details of tubular reactor assembly.