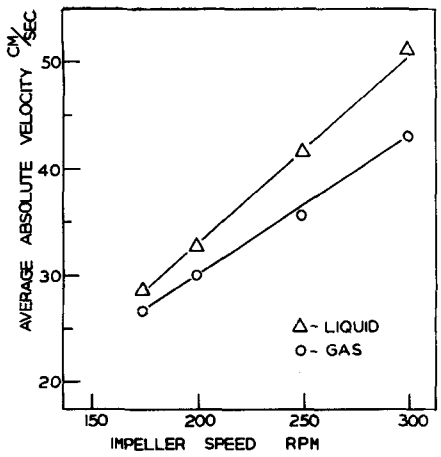

Fig. 2. Average bubble and liquid velocity as function of impeller speed.

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.

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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

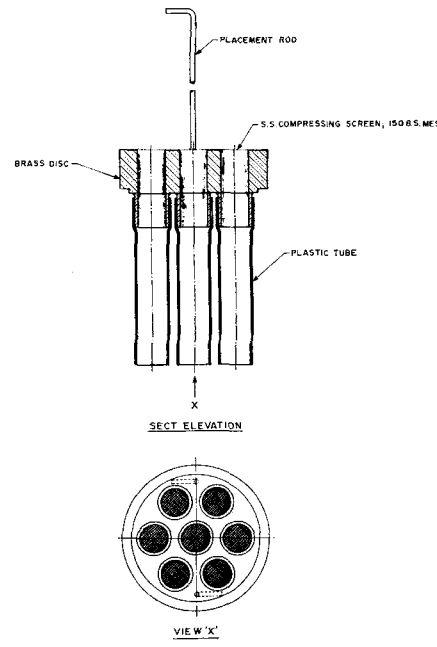

Fig. 1. Details of tubular reactor assembly.

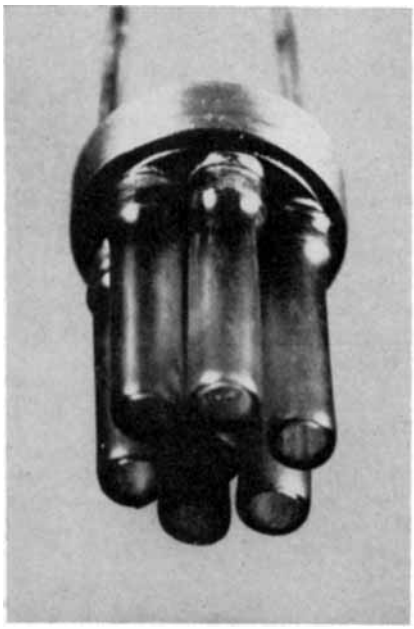

Fig. 2. Photograph of the tubular reactor bundle.

bed, fluidized bed, or a combination of these beds in any proportion.

In the course of studies on the mechanics of semifluidization in our laboratory, a novel method was developed for achieving an MT combination in the semifluidized bed. A bundle of rigid transparent plastic tubes was fixed to a perforated plate, details of which are shown in Figures 1 and 2. When this bundle is inserted into a fluidized bed reactor and placed at a convenient height, it is possible to form fixed beds in the tubes, while at the same time retaining a portion of the solids in fluidized state at the bottom of the reactor. This is shown schematically in Figure 3. The proportion of solids in the tubular fixed beds and in the fluidized bed can be varied, both by varying the velocity of the fluid and the position of the tubular bundle.

Experiments were carried out with sand particles in the size range −36 +52 B.S. mesh, and it was found that

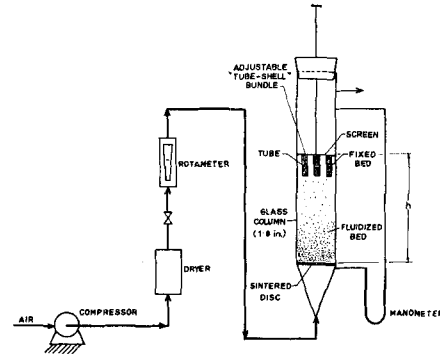

Fig. 3. Semifluidized bed as an MT reactor system.

fixed beds of nearly equal heights were formed in each of the tubes. The tubes used were transparent to enable visual observation of the fixed beds. Some typical results are shown in Table 1.

The semifluidized bed will operate between the limits G_{ms} and G_t. G_t was determined from the Stokes Einstein equation. G represents the actual mass velocity at which the fraction of solids in the packed bed was determined. This was done by noting the height of the packed bed in the transparent plastic tubes and by assuming that $\epsilon_s = \epsilon_p$. G_{ms} represents the velocity for the on set of semifluidization. A curve of ΔP vs. G shows an abrupt rise at $G = G_{ms}$ (Figure 4), thus enabling G_{ms} to be easily determined.

Clearly, therefore, it is possible to operate this kind of reactor as an MT combination, the lower fluidized bed providing the mixed reactor and the top *tube-shell* bundle the tubular reactor. The fluidized portion can be made fully mixed by appropriate choice of L/D ratio and introduction of baffles. The fraction of the bed that should act as a C.S.T.R. (in this case the fluidized bed) can be calculated from the equations developed by Aris (*1*). Then, with this conversion as the starting point, the length of the tubular reactor can be calculated from known methods for achieving a given conversion.

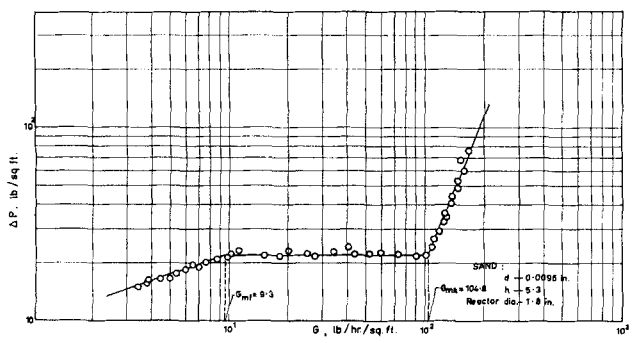

Fig. 4. A typical semifluidization curve.

Table 1. Some Typical Results in an MT Reactor (Without Reaction)

Sr. No.	d	h	Fraction of solids in packed bed	G	G_{ms}	G_t
1	0.01385	5.0	0.5	742	152.4	2261
2	0.00960	5.3	0.4	441	104.8	1375
3	0.00960	7.0	0.5	632	131.0	1375
4	0.02118	5.0	0.5	830	196.0	3550
5	0.02118	7.0	0.3	808	228.0	3550

The proposed reactor is advantageous for fast exothermic reactions such as vapor phase oxidation and chlorination of hydrocarbons, and particularly for oxidation since the large quantities of air used (20:1 ratio) for this reaction make the semifluidized reactor more practical.

It is proposed to carry out certain reactions in this type of reactor (oxidation of naphthalene) after studying the mechanics of semifluidization more fully, and the results will be communicated in a more comprehensive paper.

NOTATION

D = diameter of the reactor, in.
d = geometric mean diameter of particle, in.
G = mass rate of the fluidizing fluid (air), lb./(hr.)(sq.ft.)
G_{mf} = mass rate for the onset of fluidization, lb./(hr.)(sq.ft.)
G_{ms} = mass rate for the onset of semifluidization, lb./(hr.)(sq. ft.)
G_t = mass rate based on terminal velocity of the particle, lb./(hr.)(sq.ft.)
h = total height of the semifluidized bed, in.
L = length of static bed, in.
ΔP = pressure drop, lb./sq.ft.
ϵ_p = void fraction in the packed tubular bed
ϵ_s = void fraction in the static bed before fluidization

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