STUDIES on the dynamics of liquid-solid and gas-solid semifluidization can be broadly divided as (i) the prediction of the onset and the maximum semifluidization velocities, (ii) the prediction of packed bed formation, and (iii) the prediction of pressure drop across a semifluidized bed. Although the first two aspects have been extensively studied, the third has not been explored in detail. The available correlations either indicate wide deviations between the calculated and the experimental values of pressure drop or involve laborious calculations. They are neither handy for the designer to use nor very accurate. An attempt has, therefore, been made to develop a simplified working correlation for the prediction of the pressure drop across a liquid-solid semifluidized bed in terms of system parameters.

Fan and Wen have measured the total pressure drop across liquid-solid semifluidized beds. In semifluidization, the total pressure is ideally the algebraic sum of the pressure drop across the fluidized and the packed sections. Hence,

\[ \Delta p_T = \left( \frac{\Delta p}{L} \right)_f (h - \epsilon_{pa}) + \left( \frac{\Delta p}{L} \right)_{pa} \]  

Using Leva's equation for fluidized section and Ergun's equation for packed section, one can rewrite Eq. (1):

\[ \Delta p_T = \frac{1}{g} \left[ \frac{150 (1 - \epsilon_{pa}) \mu u}{\epsilon_{pa}^3 d_p^2} + 1.75 \frac{(1 - \epsilon_{pa}) G}{\epsilon_{pa}^3 \rho_p} \right] \times \left[ \left( h_f - h \right) \frac{1 - \epsilon_f}{\epsilon_f - \epsilon_{pa}} + \left( h_f - \frac{(1 - \epsilon_{pa})(h_f - h)}{\epsilon_f - \epsilon_{pa}} \right) \right] \]

\[ \left( 1 - \epsilon_f \left( \rho_f - \rho_p \right) \right) \]  

(2)

Fan and Wen measured the pressure drop in fixed and fluidized beds separately and obtained the total pressure drop using Eq. (1). This was compared with the observed bed pressure drop and also with that calculated using Eq. (2). The experimental values were nearer to those calculated using Eq. (1), whereas Eq. (2) gave lower values.

Kurian and Raja Rao found the overall pressure drop in a liquid-solid semifluidized bed obtained using Eq. (2) to be valid for spherical particles of large diameters. For small and irregular shaped particles, the observed pressure drop was greater than that given by Eq. (2). This additional pressure drop was given as

\[ \Delta p_a = 2 \times 10^{-3} G_{st} d_p^{-0.94} h_{pa}^{-0.59} \]  

(3)

The resulting equation was

\[ \Delta p_T = \left[ \frac{150 (1 - \epsilon_{pa}) \mu u}{\epsilon_{pa}^3 d_p^2} + 1.75 \frac{(1 - \epsilon_{pa}) G}{\epsilon_{pa}^3 \rho_p} \right] \times \left[ \left( h_f - h \right) \frac{1 - \epsilon_f}{\epsilon_f - \epsilon_{pa}} + \left( h_f - \frac{(1 - \epsilon_{pa})(h_f - h)}{\epsilon_f - \epsilon_{pa}} \right) \right] \]

\[ \left( 1 - \epsilon_f \left( \rho_f - \rho_p \right) \right) \]  

(4)

Comparison between the experimental and calculated values showed an average deviation of 12% and a maximum deviation of 20%.

In order to overcome wide discrepancies between the experimental and calculated values of liquid-solid semifluidized bed pressure drop, a correction factor was suggested by Roy and Sarma in terms of system parameters which is as follows:

\[ c = \frac{\Delta p_T}{\Delta p_T \text{ actual}} = \frac{\Delta p_T}{\Delta p_T \text{ calculated}} = \frac{150 (1 - \epsilon_{pa}) \mu u}{\epsilon_{pa}^3 d_p^2} + 1.75 \frac{(1 - \epsilon_{pa}) G}{\epsilon_{pa}^3 \rho_p} \times \left[ \left( h_f - h \right) \frac{1 - \epsilon_f}{\epsilon_f - \epsilon_{pa}} + \left( h_f - \frac{(1 - \epsilon_{pa})(h_f - h)}{\epsilon_f - \epsilon_{pa}} \right) \right] \times \left( 1 - \epsilon_f \left( \rho_f - \rho_p \right) \right) \]

(5)

The calculated values were obtained using Eq. (2). As it appears from above, the equations involve very laborious calculations for the prediction of semifluidized bed pressure drop.

Experimental Procedure

The experimental set-up used is shown in Fig. 1. The semifluidizer was a perspex column, 2.54 cm internal diam. and 100 cm long, inserted between two flanges and provided with an inclined feeder at a height of 21 cm from the base for intermediate addition and
removal of materials. A movable restraint made up of 100 mesh stainless steel screen was placed between two perspex rings, the outside diameter of which was very nearly equal to the inside diameter of the column. With the help of a 3 mm diam. brass rod, this restraint was moved to any position within the column. A rotameter was included in the liquid line and the fluid was recirculated by a pump. Two pressure taps, one just below the bottom screen and the other at the top of the column, were provided to record the bed pressure drops. While taking a run, the sample was introduced into the column and the fixed bed height was noted. The movable restraint was adjusted for a particular bed expansion ratio. Pressure drop across the bed was noted with the increase of air flow rate. When semifluidization set in, the top bed formations were constantly recorded.

Results and Discussion
Physical properties of materials and ranges of variables studied are given in Table 1. Typical data showing nature of the variation of pressure drop and packed bed formation with fluid mass velocity are presented in Figs 2 and 3 respectively.

The Correlation
Fan et al. reported that the accurate measurement of porosity of the packed and fluidized sections of the semifluidized bed was difficult. This led to a wide deviation between the calculated and the experimental values of pressure drop. Hence, an attempt has been made to report the semifluidized bed pressure drops
as a dimensionless ratio and relate it to various system parameters.

A relation between the group, \( \frac{\Delta P_T}{\Delta P_{off}} \) and the other parameters can be written as follows:

\[
\frac{\Delta P_T}{\Delta P_{off}} = f \left( \frac{D_c}{d_p}, \frac{\rho_s}{\rho_f}, \frac{h_s}{h_{pa}}, \frac{h_{pa}}{h_s} \right)
\]

(6)

We observe that the height of initial static bed has no appreciable effect on the semifluidized pressure drop. Also the column diameter has not been altered. Hence, the effect of \( h_s/D_c \) is not relevant. Eq. (6), therefore, reduces to:

\[
\frac{\Delta P_T}{\Delta P_{off}} = A \left( \frac{D_c}{d_p} \right)^{a_1} \left( \frac{\rho_s}{\rho_f} \right)^{a_2} \left( \frac{h_{pa}}{h_s} \right)^{a_4} \]

(7)

where \( A \) is a constant and \( a_1, a_2, a_3 \) and \( a_4 \) are exponents of the system variables.

The effect of individual parameters can be seen from Table 2. By plotting the pressure drop ratio against each of the system variables on log-log coordinates, the exponents of Eq. (7) are evaluated. After substitution of these exponents, the equation becomes:

\[
\frac{\Delta P_T}{\Delta P_{off}} = A \left( \frac{D_c}{d_p} \right)^{-0.218} \left( \frac{\rho_s}{\rho_f} \right)^{0.610} \left( \frac{h_{pa}}{h_s} \right)^{-1.130} B
\]

(8)

where \( A \) is the coefficient and \( B \) is the exponent of the overall product. The pressure drop has been plotted against the overall product in Fig. 4. A straight line fit has been obtained by the method of least squares as \( ^{12} \)

| No. | Operating parameter, \( \frac{D_c}{d_p} \) | kg/M² | \( \frac{\Delta P_{off}}{\Delta P_{off}} \) | kg/M² | \( \frac{\Delta P_T}{\Delta P_{off}} \) | Constant parameters
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10·42</td>
<td>60·4</td>
<td>734·0</td>
<td>12·15</td>
<td>( \frac{\rho_s}{\rho_f} = -2·83 )</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>23·00</td>
<td>73·6</td>
<td>639·0</td>
<td>8·68</td>
<td>( R = 2 )</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>46·15</td>
<td>74·7</td>
<td>630·0</td>
<td>8·43</td>
<td>( h_s/D_c = 2·36 )</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>65·50</td>
<td>85·6</td>
<td>675·0</td>
<td>8·11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>93·00</td>
<td>80·2</td>
<td>620·0</td>
<td>7·73</td>
<td>( \frac{h_{pa}}{h_s} = 0·5 )</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 — Relation of \( \frac{\Delta P_T}{\Delta P_{off}} \) with system variables
Fig. 5 — Comparison of semifluidized bed pressure drop

### Table 2b — Influence of Density Ratio on the Pressure Drop Ratio

<table>
<thead>
<tr>
<th>No.</th>
<th>Operating parameter, ( \frac{\rho_s}{\rho_f} )</th>
<th>( \Delta P_{osf} ) kg/M²</th>
<th>( \Delta P_T ) kg/M²</th>
<th>( \Delta P_T ) ( \Delta P_{osf} )</th>
<th>Constant parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.83</td>
<td>73.6</td>
<td>639.0</td>
<td>8.68</td>
<td>( D_d/d_{df} = 2.3 )</td>
</tr>
<tr>
<td>2</td>
<td>3.72</td>
<td>81.6</td>
<td>870.0</td>
<td>10.66</td>
<td>( R = 2 )</td>
</tr>
<tr>
<td>3</td>
<td>4.45</td>
<td>123.4</td>
<td>1680.0</td>
<td>13.61</td>
<td>( h_s/D_e = 2.36 )</td>
</tr>
<tr>
<td>4</td>
<td>5.25</td>
<td>143.8</td>
<td>1605.0</td>
<td>11.16</td>
<td>( h_{ps}/h_s = 0.5 )</td>
</tr>
</tbody>
</table>

### Table 2c — Influence of Bed Expansion Ratio on the Pressure Drop Ratio

<table>
<thead>
<tr>
<th>No.</th>
<th>Operating parameter, ( R )</th>
<th>( \Delta P_{osf} ) kg/M²</th>
<th>( \Delta P_T ) kg/M²</th>
<th>( \Delta P_T ) ( \Delta P_{osf} )</th>
<th>Constant parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>73.6</td>
<td>639.0</td>
<td>8.68</td>
<td>( D_d/d_{df} = 2.3 )</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>80.4</td>
<td>670.0</td>
<td>8.33</td>
<td>( \rho_s/\rho_f = 2.83 )</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
<td>77.1</td>
<td>720.0</td>
<td>9.34</td>
<td>( h_s/D_e = 2.36 )</td>
</tr>
<tr>
<td>4</td>
<td>3.5</td>
<td>82.2</td>
<td>830.0</td>
<td>10.10</td>
<td>( h_{ps}/h_s = 0.5 )</td>
</tr>
</tbody>
</table>

### Table 2d — Influence of Packed Bed Formations on the Pressure Drop Ratio

<table>
<thead>
<tr>
<th>No.</th>
<th>Operating parameter, ( h_{ps}/h_s )</th>
<th>( \Delta P_{osf} ) kg/M²</th>
<th>( \Delta P_T ) kg/M²</th>
<th>( \Delta P_T ) ( \Delta P_{osf} )</th>
<th>Constant parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.250</td>
<td>73.6</td>
<td>326.0</td>
<td>4.44</td>
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<td>2</td>
<td>0.400</td>
<td>435.0</td>
<td>5.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.500</td>
<td>639.0</td>
<td>8.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.666</td>
<td>775.0</td>
<td>10.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.800</td>
<td>1033.0</td>
<td>14.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.916</td>
<td>1360.0</td>
<td>18.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{\Delta P_T}{\Delta P_{osf}} = 19.50 \left( \frac{D_d}{d_f} \right)^{-0.17} \left( \frac{\rho_s}{\rho_f} \right)^{-0.48} \left( R \right)^{0.28} \left( \frac{h_{ps}}{h_s} \right)^{-0.89} \quad \text{...(9)}
\]

The values of the pressure drop calculated using Eq. (9) have been compared with the experimental values in Fig. 5. Though it can be said that in general there is no appreciable deviation of the calculated values from the experimental, a few points deviate considerably from the diagonal line. These refer
particularly to particles of large size and of higher
density and to the two extreme regions of semifluidization operation, viz. the onset and the maximum
semifluidization conditions. Similar discrepancies
have been observed by Kurian and Raja Rao. The
possible explanations for the discrepancy are:
(i) The screen configuration,
(ii) The orientation of the particles to the screen;
(iii) Opening when they approach the screen;
(iv) Influence of particle shape; and
(v) Certain degree of instability existing at the
extreme regions of semifluidization operation.
A better explanation cannot be given without
making more detailed studies.

Acknowledgement
The authors are thankful to the Board of Scientific
and Industrial Research, Orissa, for financial assistance.

Nomenclature

\[
\begin{align*}
\Delta P_{of} & = \text{pressure drop across bed corresponding to the onset} \\
\Delta P_T & = \text{overall pressure drop across the semifluidized bed,} \quad \text{FL}^{-2} \\
\eta & = \text{bed expansion ratio in semifluidization, dimensionless,} \\
\beta & = \text{density of solid, ML}^{-3} \\
\varepsilon_f & = \text{porosity of fluidized bed or fluidized section of} \\
\varepsilon_{pa} & = \text{porosity of packed bed or packed section of semi} \\
& \quad \text{fluidized bed, dimensionless} \\
\mu & = \text{viscosity of fluid, ML}^{-1} \theta^{-1}
\end{align*}
\]

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