CHAPTER - 5  
CORRELATION

5.1 GENERAL

Nakamura et al. [1985] stated that since fluidized beds are extensions of fixed beds, correlations can be developed from the relationships for fixed beds, setting the pressure drop equal to the buoyant weight of the particles at the onset of fluidization. Darton [1985] had stated that the theory and correlations developed for two-phase mixtures (liquid-solid or gas-liquid) can still be applied when a third phase is added. Darton [1986] listed some of the phenomena used in two phase fluidized bed systems to be modified and can be applied to three-phase fluidized beds. Such of the phenomena are listed in Table 5.1.

TABLE 5.1 DARTON'S CORRELATION PHENOMENA.

<table>
<thead>
<tr>
<th>TWO-PHASE FLUIDIZATION</th>
<th>GAS/LIQUID BUBBLE COLUMNS</th>
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<tr>
<td>Porosity (bed expansion)</td>
<td>Bubble rise velocity</td>
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<td>Particle mass transfer</td>
<td>Regimes of bubbling</td>
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<td>Heat transfer at surfaces</td>
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<td>Mass transfer from bubbles</td>
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<td>Mixing</td>
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<td>Heat transfer at surfaces</td>
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</tbody>
</table>
5.2 HYDRODYNAMICS

A number of correlations for the predicting the hydrodynamic behaviour of three-phase fluidized bed countercurrent system are available in the literature. The hydrodynamic behaviour includes the phenomena such as minimum fluidization velocity, $U_{mf}$, pressure drop, $\Delta p$, liquid hold up, $\epsilon_l$, gas hold up, $\epsilon_g$, relative bed expansion, $H/V$, etc...

5.3 MASS TRANSFER

Various correlations on mass transfer phenomena on three-phase fluidized bed cocurrent system are also available in the literature. Mass transfer occurs simultaneously with the transfer of heat, either as a result of an externally imposed temperature difference or because of the absorption or evolution of heat which generally occurs when a substance is transferred from one phase to another. For a bubble column systems, the volumetric mass transfer coefficient depends on the operating parameters, physical properties of fluids & fluidizing particles, gas distributor design, particle concentration etc... These properties affect the bubble behaviour and hence the interfacial area, 'a'.

In cooling tower, cooling of water occurs by transfer of sensible heat and also by evaporation by contact with atmospheric air. Although this sort of operation is simple in the sense that mass transfer is confined to the air, they are nevertheless complex owing to the large heat transfer effects which accompany evaporation. Here no heat is added to, or removed from, the air-water system except by the water and air being
contacted. From the preceding chapters, it is seen that the outlet air from the test section is fully saturated for which the performance characteristics are optimum. Hence, a correlation for mass transfer phenomena need not be proposed.

5.4 HEAT TRANSFER

Little has been reported on heat transfer behaviour of countercurrent fluidization. Simultaneous heat and mass transfer takes place between liquid droplets/film & air which can be analysed by considering the dominant transport mechanism based on the convective mass transfer.

In developing a correlation for the heat transfer coefficient in bubble columns, a reasonable hypothesis is that the hydrodynamic conditions in bubble agitated systems may be satisfactorily represented by the liquid & gas velocities, density, specific heat and thermal conductivity. The heat transfer coefficient, 'h', may be expressed in terms of these variables as:

\[ h = f(U_l, U_g, \rho_g, c_{pg}, k_g) \]  \hspace{1cm} (5.1)

or simple by an empirical power function as:

\[ h = K U_l^a U_g^b \rho_g^c c_{pg}^d k_g^e \] \hspace{1cm} (5.2)

where,

a, b, c, d, e & K are variables employed in setting up the correlation which depends upon the applications.
Published data on heat transfer coefficients in three-phase fluidized beds are extremely limited. The limited investigators had worked on co-current three-phase fluidized bed system. Baker et al. [1978] having worked on cocurrent fluidized bed system in lesser diameter column with higher density particles proposed a correlation for heat transfer coefficient, 'h', as:

\[ h = 1977 U_l^{0.070} U_g^{0.059} d_p^{0.106} \]  \hspace{1cm} (5.3)

in which,

- 'h' is expressed in W/m²K,
- 'U_l' is in mm/s,
- 'U_g' is in mm/s and
- 'd_p' is in mm.

Based on the above preceding paragraphs, an attempt has been made to formulate a correlation for heat transfer coefficient, 'h', in three-phase fluidized bed countercurrent system.

Typical plots of overall heat transfer coefficient, 'h', against the bed voidage is shown in Fig. 4.40. It may be seen from Fig. 4.39 to 4.40, the heat transfer coefficient in three-phase fluidized beds increases with gas velocity for all velocities of gas & liquid and bed voidage. The increase was initially quite rapid. However, at higher gas rates, it becomes less marked and 'h' appeared to approach a maximum.

The heat transfer data are obtained at various liquid flow rates while holding the gas flow rate
constant. The experimental values of heat transfer coefficient is correlated by the equation:

\[ h = 30245 \ U_1^{1.1849} \ U_g^{0.06238} \ dp^{-0.186548} \]  

(5.4)

Regression Coefficient = 0.975
Standard Deviation = 0.1232

where,

- \( h \) is the heat transfer coefficient in kW/m\(^2\)K,
- \( U_1 \) is the liquid velocity in m/s,
- \( U_g \) is the gas velocity in m/s and
- \( dp \) is the diameter of fluidizing particle in mm.

The data fit has an average error of 7.7% in predicting the heat transfer coefficient. The maximum error is 9.6% and minimum error is 0.4%.

Fig. 5.1 shows the comparison of heat transfer coefficient, \( h_{\text{expt}} \), with the value of heat transfer coefficient obtained using the correlation (5.4). The prediction of the proposed correlation is compared with values of overall heat transfer coefficient obtained in the experimental investigation for 2404 data points.
FIG. 5.1 CORRELATION FOR HEAT TRANSFER COEFFICIENT