INTRODUCTION

The fluid flow phenomena in two-phase and three-phase conditions are more often met with as important applications in the industry. These problems have been studied uptil now as detached units for point application to a specific process. It was therefore felt necessary, first to make a rational classification of the various flow patterns of two-phase and three-phase flows and evolve a notational nomenclature representing these systems (Tables I and II). Secondly, it was required to put together at one place, the informations regarding the momentum transfer considerations for the appropriate systems only, critically appreciating the methods of approach to these problems, before undertaking experimental work for the physical design of batch three-phase bubble-bed reactors.

At present, chemical reactors are designed mostly on the basis of informations derived from kinetic studies, for which quite a lot of data are available both from literature and from industrial practices. A successful design of a reactor should not only be based on kinetic data but also on the relevant transport phenomena of momentum, heat and mass, which significantly affect the process. Now, the momentum transfer considerations that are taken into account in a three-phase reactor design, are as yet based on too much empericism. While emperical methods are followed under certain unavoidable circumstances, constant effort should be put in to find out the necessary fundamentals to interpret the phenomena. Hence, a project was started in this laboratory to study some aspects of momentum transfer in two-phase and three-phase fluid flow systems, with the ultimate aim of incorporating these findings with the already available other transport phenomena and kinetic data for the design of a three-phase reactor.

It is recognised that transformations taking place in a system, whether it is momentum, heat or mass transfer, should be understood through building up of the total picture of the phenomena from elemental components which contribute to the system. In a three-phase gas-liquid-solid batch bubble-bed reactor, the momentum transfer from the gas phase to the solid-phase takes place via the liquid medium. Hence it was thought advisable to break up the problem into simpler gas-liquid and liquid-solid systems and then to integrate the findings of these studies towards a three-phase system.

Part-I of the project approaches the problem fundamentally from the solid-liquid side and part-II from the gas-liquid angle and these findings have been synthesised for momentum transfer considerations in a three-phase system. The investigations carried out by earlier workers on momentum transfer studies relevant to the present work, may be classified under the following main heads :

A. Solid-liquid systems (onset of fluidization)

B. Gas-liquid systems (Gas bubble dynamics)

C. Miscellaneous studies in three-phase gas-liquid-solid systems.

PART - A

SOLID-LIQUID SYSTEMS (ONSET OF FLUIDIZATION)

A survey of privious works reveal that the approach has been made in two general ways, from a fixed bed to a fluidized bed and onwards, or from a fluidized bed to a fixed bed via sedimentation.

Fixed Bed

Literature is full of references with respect to researches in this field and a number of investigations have sought to derive correlations of the friction factor. However, the variables of particle shape, roughness, distribution, manner of packing, and several other not clearly definable parameters like geometry and characteristic of the flow path have made the task quite involved. There are at present several well-recognised correlations which permit reasonably accurate prediction of pressure drop through a bed of spherical or non-spherical materials.

Several other investigators while dealing with the motion of particles in fluids or of fluids past particles brought in a number of intriguingly detailed analyses of boundary-layer theory in laminar and turbulent flow, wakes and vortices, skin friction, profile drag, mixing length and mean free path, pick up or suspension velocity, etc. Each of these topics has its major area of significance and constant efforts are being made to interrelate these with commonly observed process phenomena in order to strengthen the fundamental approach to design problems.

But no instances are found in literature, where in the analysis of flow mechanics, the effect of solid surfaces with respect to liquid phase has been taken into account. Perhaps the magnitude of the influence of solid-liquid interfacial phenomenon was not considered significant compared to more commonly observed pressure and energy effects.

Fluidized Bed

The earlier investigators [1-4] who have developed correlations for onset of fluidization from the fixed bed approach, extended the pressure drop equations in a fixed bed, to the fluidized bed with proper alterations incorporated. Basic similarity between flow through fixed and fluidized beds was recognised and most correlations aimed at giving a reasonable prèdiction of the critical velocity of the fluid at the point of initial bed expansion when the loss in pressure energy experienced by the fluid became equal to the weight of the bed in the fluid stream.

The second phase of development in this field was connected with the prediction of the state of bed expansion which is an important parameter for specifying the height of the fluidized bed chamber. Attempts were made to relate average bed voidage with bed expansion in a manner identical with the function contained in the Kozeny-Carman equation. The validity of the assumption as far as application to flow through porous structures was concerned rested on the assumptions that a modified channel flow prevailed and that the flow pattern was thoroughly tortuous. This model was quite satisfactory in dense structures and to a less extent in liquid fluidized beds upto about 80% free space. Failure of the voidage function in the generalised expression for the pressure drop to apply in the range of bed voidage $>$ 0.80 was indicated [5 - 7]. Analysis of data for the transition and turbulent flow region became still complicated since the state of flow factor was no longer constant. Attempts were then made to predict expansion behaviour of liquid-solids columns through the entire laminar to turbulent flow range by some generalised correlation; notable amongst which are those of Richardson and Zaki [8]. Simultaneously, some kind of unified theory was sought aiming at clarifying the behaviour of solid particles [9]. In continuous fluidization studies, which is a logical extension of the batch process, constant search was made to get a generalised correlation between bed expansion and fluid velocity [10 - 12].

For the expanded bed, the phenomenon of stratification was also reported when a greater portion of fines were found in the upper bed region than in the lower strata [6, 13]. In an attempt to partially restrict the expansion of a fluidized bed the technique of 'semi-fluidization' was developed [14].

Sedimentation

In extension of fluidization studies with concentrated suspensions and bed porosity, the data appeared to confirm the equality between settling velocity of a suspension in quiescent fluid and the counter-flowing fluid velocity necessary to maintain the same concentration in continued suspension [2, 8] and the analogy between sedimentation and fluidization especially for systems exhibiling particulate characteristics became more apparent.

Major investigations in this field was aimed at incorporating suspension properties in Stoke's law either for measuring resistance or to predict settling rates [15 - 20] as functions of size and shape of particles or flow spaces. Interference phenomena and the instability brought about by increased volume fraction of solids were also studied with simultaneous settling of particles of different densities [21].

Other approach to the problem of the behaviour of suspending particles in a turbulent flow system was through mathematical treatment for getting expressions for residence time and eddy diffusivity [22, 23].

Graphical methods for calculating the sedimentation rates of concentrated suspensions have recently been reported [24].

While one staggers at the amount of data collected and comprehensive studies made by numerous workers on intriguingly diverse aspects of fluidization and sedimentation, one wonders how the solid surfaces could manage to avoid attracting the attention of investigators.