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Shear-thinning fluids flow in fixed and fluidised beds

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Abstract

In the paper the results of experimental studies directed on the effect of liquids' properties (aqueous solutions of polymers and surfactants) on resistance of the flow through porous and fluidised beds, are presented. It was shown that the determination of the values of minimal fluidisation velocity on the basis of an analysis of pressure drop related to the current two-phase system height gives the more accurate values than the method based on the initial bed height. Independently of the Newtonian or shear-thinning properties of the liquid flowing through motionless or fluidised bed, the relation of the friction factor on well-defined Reynolds number (related to real rheological parameters of a liquid studied) is analogous. It has been shown that the diagram proposed by Koziol et al. can be stated as the generalized one, not only for the determination of the solid particles motion in Newtonian fluids, but for the shear-thinning liquids too. In the last case it should be taken into account that the critical value of porosity cannot be taken equal to 0.4, but should be appropriate to the real porosity in the critical conditions for a given system solid particle–liquid. The generalization of both, the map of Bi and Grace related to the characteristic fluidisation ranges and the diagram of the classification of particles fluidised proposed by Goossens for gas-fluidisation, on any systems of solid particles–power law fluids, has been proposed.

Keywords: Solid–liquid systems; Power-law fluids; Polymers; Surfactants; Friction factor; Minimum fluidisation velocity

1. Introduction

Many processes are enhanced by the successful application of fluidisation, which compared to other processes, offers improved fluid–solids contact, near isothermal conditions, and improved heat and mass transfer. Fluidisation starts at a point when the bed pressure drop exactly balances the net downward forces on the bed packing, thus in that point the system of solid particle–Newtonian fluid obeys the force balance relations:

$$\frac{\Delta P}{H} = g \cdot (\rho_{\mathrm{p}} - \rho_{\mathrm{L}}) \cdot (1 - \varepsilon_{\mathrm{crit}}), \tag{1}$$

$$\frac{150 \cdot w_{0,\mathrm{crit}} \cdot \eta_{\mathrm{L}} \cdot (1 - \varepsilon_{\mathrm{crit}})}{\varepsilon_{\mathrm{crit}}^3 \cdot d_{\mathrm{p}}^2} + \frac{1.75 \cdot \rho_{\mathrm{L}} \cdot w_{0,\mathrm{crit}}^2}{\varepsilon_{\mathrm{crit}}^3 \cdot d_{\mathrm{p}}} = g \cdot (\rho_{\mathrm{p}} - \rho_{\mathrm{L}}), \tag{2}$$

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where ΔP is the pressure drop, H is bed height, g is gravity acceleration, ρ_p is particle density, ρ_L is fluid density, ε_{crit} is current porosity corresponding to so-called minimum fluidisation velocity, $w_{0,crit}$ is superficial velocity of a fluid defined as the volumetric flow divided by the cross sectional area corresponding to minimum fluidisation velocity, η_L is Newtonian fluid viscosity, d_p is particle diameter. Therefore the result is the relation

$$\frac{\Delta P}{H} = \frac{150 \cdot w_{0,crit} \cdot \eta_0 \cdot (1 - \varepsilon_{crit})^2}{\varepsilon_{crit}^3 \cdot d_p^2} + \frac{1.75 \cdot (1 - \varepsilon) \cdot w_{0,crit}^2 \cdot \rho_0}{\varepsilon_{crit}^3 \cdot d_p}. \tag{3}$$

The two terms on the right hand side of Eq. (3) can be recognized as viscous and inertial contributions. In most industrial applications involving fluidised beds, the solid particles diameters and also their total volume V_s in two-phase system are small. In these cases, the second term in Eq. (2) is negligible compared to the first one, so that

$$\frac{150 \cdot w_{0,crit} \cdot \eta_L}{g \cdot (\rho_p - \rho_L) \cdot d_p^2} = \frac{\varepsilon_{crit}^3}{1 - \varepsilon_{crit}}. \tag{4}$$

For a given bed the above equation can be used for both, the unexpanded (of porosity ε_0 and for superficial velocity w_0) and the expanded, states. As total volume of two-phase system increases ε may increase and hold the pressure drop ΔP constant (H will also increase but its effect is much less than the effect of change in porosity ε). At velocities w_0 less than the minimum fluidisation velocity $w_{0,crit}$ the bed behaves as a packed bed. However, as the velocity is increased above $w_{0,crit}$, not only the bed does expand (H increases), but also the particles move apart, and ε also increases to keep the ΔP constant. The equations derived for minimum fluidisation velocity can be applied to liquids as well as gases, but beyond the minimum fluidisation velocity $w_{0,crit}$, the appearance of beds with liquids or gases is quite different.

The fundamental tasks of fluidised-bed dynamics are to determine the condition of transition from a fixed-bed into a fluidised-bed state and the prediction of bed expansion in relation to rheological properties of liquid media. In some publications (Richardson, 1971; Dullien, 1975; Rietema, 1982; Joshi, 1983; Kunii and Levenspiel, 1990; di Felice, 1995; Jamialahmadi and Muller-Steinhagen, 2000) the previous findings have been reviewed where Newtonian liquid fluidisation is a specific case, such as the problem of flow in porous media, dispersed two-phase systems as well as particulate fluidisation. In papers of Kemblowski et al. (1989) and Chhabra et al. (2001) most experimental and theoretical studies concerned with pressure drop determination for non-Newtonian fluid flow through porous media have been reviewed. In a paper by Chhabra and Srinivas (1991) an attempt has been made to reconcile and critically analyse the voluminous literature available on the flow of rheologically complex fluids through unconsolidated fixed bed and fluidised bed. Chhabra (1993) has demonstrated that non-Newtonian liquid fluidised beds in literature have received limited attention. The representative summary on the variety of packings and non-Newtonian fluids used as well as the representative studies on fluidisation of particles with non-Newtonian fluids was presented in paper of Chhabra et al. (2001). The bulk of the information available in the literature relates to the beds of spherical particles fluidised by power-law inelastic polymer solutions. Little is known about the role of fluid viscoelasticity – due to mobility of particles in a fluidised bed, the viscoelasticity manifests itself in different ways in fixed and fluidised beds. While in the creeping flow through fixed bed of particles the viscoelasticity gives rise to excess pressure drop, in the flow through fluidised beds it can lead to segregation of particles. The last review paper of Chhabra et al. (2001) suggests that the knowledge is very scant about the detailed kinematics of flow including flow patterns, residence time distribution, micro-level phenomena such as polymer adsorption, retention and wall effects. The current literature has not failed to give special attention to the solutions of surface-active agents flowing through fixed and fluidised bed.

The present study is concerned with the experimental comparison of the liquid phase properties effect on both, friction factors for the flow of the rheostable fluids through porous and fluidised bed, and on minimum fluidisation velocities for Newtonian and non-Newtonian (both surfactants and polymers) aqueous solutions.

2. Experimental

Fig. 1 illustrates the schematic diagram of the experimental set-up. The main element of the test installation was an apparatus constructed from organic glass pipe with an inside diameter of $T = 0.090$ m and a height of