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EXTERNAL-LOOP AIRLIFT MAGNETICALLY STABILIZED BED — MINIMUM STABILIZATION AND FLUIDIZATION CONDITIONS

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Abstract Experimental study of an airlift with a magnetically stabilized bed in the riser bottom has been performed. External magnetic field allows easy control of magnetized bed structure and liquid circulation rate. Minimum stabilization and fluidization conditions have been determined experimentally and by a three-line graphical method. Semi-empirical data correlations of sections of the experimental curves have been performed. Scaling relationships known from non-magnetic airlift are applicable too, but with the assumption that the magnetic field affects the loop friction coefficient only.

Keywords minimum fluidization, magnetic field, stabilized beds, gas-liquid-solid fluidization, airlift reactor

1. Introduction

Three-phase fluidization of ferromagnetic particles in the presence of an external magnetic field (Rosensweig, 1979; Liu et al., 1991; Hristov, 2002) offers possibilities to control the mobility of the solid phase and thus to achieve different hydrodynamic conditions to affect both heat (Hristov, 2003) and mass transfer processes (Hristov & Ivanova, 1999; Meng et al., 2003). Since the last two decades of the 20th century, attention has been focussed on the behaviour of liquid-solids and gas-liquid-solids beds (Liu et al., 1991; Kwauk et al., 1992) directly applicable to mass transfer processes (Al-Qodah & Al-Hassan, 2000; Al-Qodah & Lafi, 2001; Thompson & Worden, 1997) in chemical industry and environmental protection (Graham & Jovanovic, 1999). A comprehensive summary on the three-phase magnetically controlled beds and a classification scheme have been published recently (Hristov, 2005). The present work addresses an external-loop airlift reactor permitting liquid circulation control by incorporation of a magnetically controlled particle bed (Hristov, 2005). This idea is first to be briefly described in order to clarify the related analysis.

Air-lift loop reactors are commonly used in the chemical and biotechnological industry to carry out slow reactions such as oxidation and chlorination (Joshi et al., 1990). Generally, in external-loop airlift the liquid velocity depends on both the gas velocity and the hydraulic resistance of the downcomer (Chisti et al., 1988; Onken & Weiland, 1983). The latter defines the regimes and affects the stability of fluidization in the riser (Douek et al., 1995). Variation of the loop hydraulic resistance by means of a mechanical valve in the downcomer (Verlaan, 1987; Livingston & Zang, 1993; Douek et al., 1995) alters the liquid circulation velocity and the gas hold-up in the riser. Hristov (2005) proposed to replace the mechanical valve of Verlaan (1987), and Bendjaballah et al. (1999) by using a bed of magnetizable particles in an external magnetic field for remote control of liquid circulation and flow transition in the riser, i.e., between airlift and bubble column. Critical velocities for minimum stabilization and minimum fluidization of the controllable magnetic bed are the main issues of the present work.

2. Experimental Facilities

The experimental setup, described in detail by Hristov (2005), is shown in Fig. 1. It consists of a riser, 140 mm I.D. and 2 m in height and a downcomer, 50 mm I.D. Metallurgical dross (ρ_s=2100 kg·m^{-3}; d_p=0.8–1.0 mm; M_s=0.050 kA·m^{-1}), described by Penchev and Hristov (1990a), was employed as the solid phase. The particles are supported by a packed bed of ferromagnetic particles (ammonia catalyst KM-1 by Haldolrf Topsoe, ρ_s=5100 kg·m^{-3}; d_p=1.8–2.0 mm; M_s=236.4 kA·m^{-1}) as shown in Fig. 2. The gaseous and liquid phases were air and water respectively. Transverse magnetic field was generated by saddle coils (height 1500 mm, internal diameter 205 mm with an opening angle of 120°) with a maximum field intensity of about 50 kA·m^{-1} (Penchev & Hristov, 1990a; 1990b).

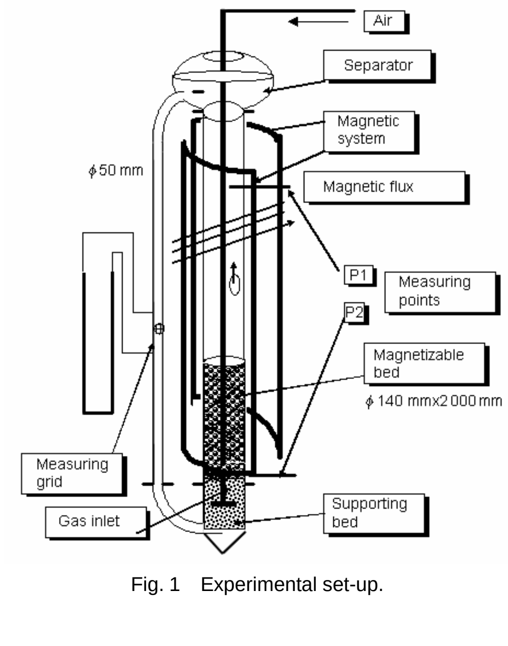

Fig. 1 Experimental set-up.

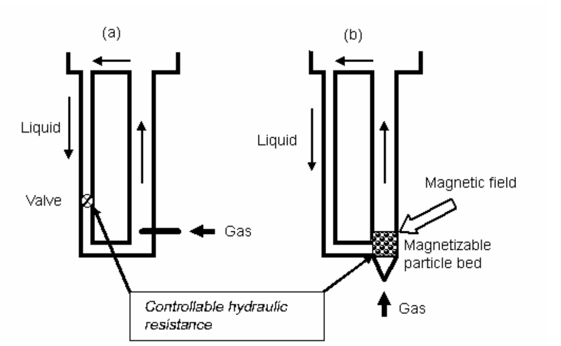

Fig. 2 Liquid circulation control by hydraulic resistances: (a) mechanical valves, after Verlaan (1987) and Bendjaballah et al. (1999); (b) magnetizable bed at riser bottom, after Hristov (2005).

The idea of the bottom supporting bed will be briefly explained while details are available elsewhere (Hristov, 2005). Fine supporting grids normally used for magnetically controlled beds (Siegel, 1987) cannot be used for three-phase fluidization, because they do not permit simultaneous passage of gas and liquid into the particle bed. The gas-liquid-solid magnetically stabilized beds need gas-liquid distributors that permit simultaneous and homogeneous distribution of the two-phase mixture at the bottom of the fluidized bed. The problem was solved by a supporting bed of ferromagnetic particles in a conical vessel at the bottom of the column (Hristov, 2005). Both the gas and the liquid enter the riser via the supporting bed. The supporting bed plays two roles: it supports the stabilized bed and produces a gas-liquid flow (like a static mixer). The particles of the supporting bed are larger and denser than those in the fluidized bed (metallurgical dross). This prevented fluidization in the conical vessel within the range of the fluid velocities employed.

Experiments were performed with the "Magnetization FIRST" mode (Siegel, 1987; Hristov, 2002), i.e. the magnetic field was applied to an initial static bed and fluidization was performed after that. That is, before starting an experiment, the bed was first fluidized in the absence of a magnetic field for 5 minutes. A slow decrease of gas flow led to an initial fixed bed to which the magnetic field was then applied. The bed behaviour was observed visually and measurements were taken to correlate with the visual observation. The transition points between regimes were detected visually too. Data processing was performed using Origin 6.0 at 0.95 confidential intervals.

3. Experimental Results and Discussion

3.1 Phase diagram and observations

As shown in the phase diagram of Fig. 3 (Hristov, 2005), two sets of transition points at issue were noted in the present study: (i) the onset of the magnetically stabilized bed (MSB); and (ii) the onset of fluidization. Generally, in an airlift the liquid velocity depends on the gas flow rate and the friction factor of the loop with respect to the liquid phase. The magnetizable bed at the riser bottom controls the overall friction factor of the loop and consequently both the liquid circulation rate and the riser hold-up without changing the gas flow rate (Hristov, 2005). A common practice in determining the critical points of bed behaviour is to control certain macroscopic characteristics such as bed height, pressure drop, fluid velocities, etc., that change in specific manners during transition between bed regimes. First attempts to do the above on the basis of bed height evolution curves (Fig. 6 of Hristov, 2005) and gas-pressure drop evolution curves as shown in Fig. 4 failed to yield satisfactory results, that is, both macroscopic values increase monotonically with gas velocity in the riser without yielding any critical point. However, these measurements did indicate that the minimum gas-fluidization velocity increases as magnetic field intensity increases, as expected (Hristov, 2002). Neither could the total gas-pressure drop evolution curves be interpreted in any other unique way (see Fig. 4) inasmuch as they exhibit opposite tendencies at low and high magnetic field intensities. The behaviour at high field intensities (the upper parts of the plots in Fig. 4) may be attributed to two main reasons: loose structure of the expanded stabilized bed and increased gas hold-up in the two-phase section of the riser above the magnetic bed.

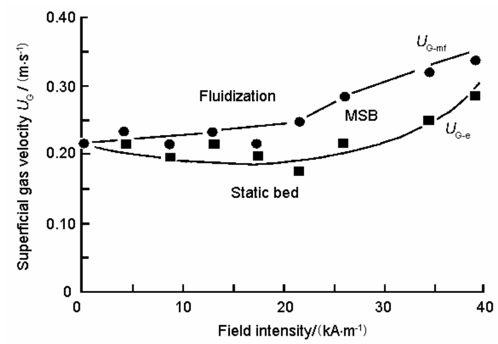

Fig. 3 State diagram of gas-liquid fluidized magnetizable solids in a transverse magnetic field. Initial bed height, h_{b0}=100 mm.

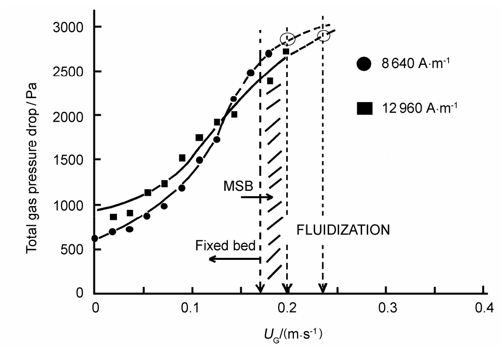

Fig. 4 Gas pressure drop across the riser, h_{b0}=100 mm.

The above unsuccessful attempts to determine the critical transition points motivated us to look for other methods employing macroscopic operating variables controlling the process instead of such resultant values as bed expansion and pressure drop, leading to the development