Solid-phase distribution in an airlift reactor with an enlarged degassing zone

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The distribution of the solid-phase in an airlift reactor of the concentric draught tube type, with an enlarged degassing zone, has been determined. Samples were taken at eight points of the reactor for various airflow rates, solids loading and density. Hold-up of solids varied considerably within the reactor. The highest value, for all tested experimental conditions, was obtained immediately above the top of the riser and the lowest value near the wall of the degassing zone.

Introduction

Three-phase airlift reactors are used in a variety of industrial applications where intimate contacting of gas-liquid-solid phases is desirable, such as in the chemical, petrochemical, minerals processing and biochemical industries (Livingston and Zhang, 1993).

Extensive studies of the airlift reactor have been made on the effect of geometry of the reactor, gas and liquid flow rates, power input on the mass transfer rate between the gas and the liquid-phases and on the fundamental hydrodynamic characteristics (Kawase *et al.*, 1994; Koide *et al.*, 1983). However, little is known regarding the airlift reactor when operated in the presence of solid particles and only few reports to solids hold-up (Assa and Bar, 1991; Freitas *et al.*, 1997; Ijichi *et al.*, 1994; Kochbeck, *et al.*, 1992; Siegel *et al.*, 1988).

Unlike the gas hold-up, which is known to vary continuously along the riser and the downcomer and, consequently, is referred as local gas hold-up, it is a common assumption that the distribution of the solids in the liquid throughout the airlift vessel is uniform (Assa and Bar, 1991). Siegel *et al.* (1988) anticipated that the solids hold-up in the riser is different from the solids hold-up in downcomer but did not present experimental data. Kochbeck *et al.* (1992) measured the local solids hold-up along the riser of two airlift reactors with outer loop and volumes of 80 l and 800 l. They used particles of polycarbonate and polybutyleneterephthalate with densities considerably higher than the liquid-phase. Ijichi *et al.* (1994) also measured solids hold-up (iron powder as solid-phase) through the draft tube of an airlift reactor. Nevertheless, solids suspended in biological processes include cells of

microorganisms immobilised on solid-support particles, microbial, plant or animal cells and filamentous organisms that, in general, have a density very close to that of the liquid medium. Assa and Bar (1991) verified the degree of biomass homogeneity in the airlift bioreactor by investigating the axial distribution of yeast and plant cells at various aeration rates. However, none of the mentioned studies was performed in an airlift reactor with an enlarged degassing zone. This zone represents a great fraction of the reactor total volume; thus, the amount of solids and their distribution along the degassing zone contribute decisively for the performance of the system.

In this study, experiments were performed to obtain the solid-phase distribution through an airlift reactor, of the concentric draught tube type, with an enlarged degassing zone. Solids hold-up was measured in eight points of the reactor, for different airflow rates and solids loading and for two solids densities, using Calcium-alginate beads as solid-phase. Calcium-alginate is a widely used matrix for the entrapment of enzymes and biomass in continuous fermentation, in order to achieve higher productivity (Vicente and Teixeira, 1995). Its physical properties allows for a good simulation of the typical solid-phase occurring in fermentation processes and the use of solids with two densities attains for the fact that, as cells grow, small changes in particles density are also expected to take place.

An aqueous solution of ethanol was used as liquid-phase since it represents reasonably well the liquid-phase behaviour in bioreactors (Kelkar *et al.*, 1983), being the surface tension the only physical property that differs significantly from water.

Figure 1 Schematic diagram of the airlift reactor. The reactor is divided in eight sections for sampling purposes (sections S_1 to S_5 correspond to the degassing zone and section S_6 is a transition section between the downcomer – S_7 – and the riser – S_8). The arrows indicate the fluid flux.

Materials and methods

The 60 l airlift bioreactor with an enlarged degassing zone described by Freitas *et al.* (1997) was used (see Fig. 1).

Gas-liquid-solid system

An aqueous solution of 10 g ethanol /l was used as liquid-phase.

Volumetric airflow rates studied were 1.9, 5.5, 9.1, 13.6, 30.3, 58.8 and 90.2 l/min. The riser superficial gas velocity (v_{gr}) was calculated as the ratio between the air volumetric flow rate and the riser cross-section area.

Ca-alginate beads were used as solid-phase and were prepared according to the procedure described by Vicente and Teixeira (1995). Calcium-alginate beads with two different densities were used. The mean diameter and density of the "low density beads" were 2.131 ± 0.102 mm and 1023 ± 1 kg/m³, respectively, and the values for the "high density beads" were 2.151 ± 0.125 mm and 1048 ± 1 kg/m³. For each type of solids, solids loading applied was 5%, 10%, 20% and 30% (v/v).

Local solids hold-up determination

Local solids hold-up was determined at eight different points, each one representing a different section of the reactor – S_1 to S_8 (Fig. 1), using the procedure developed by Freitas *et al.* (1997).

Results and discussion

It is observed in Figure 2 that, for all solids loading and airflow rates studied, there is a radial and an axial distribution of the solid-phase.

In the degassing zone (S_1 to S_5), solids hold-up increases from the wall to the middle of the reactor (from S_1 to S_5 and, in general, from S_1 to S_5). This is especially true for low airflow rates because the rising force is weak. Consequently, the solids that leave the riser enter the centre of the degassing zone – S_5 and S_6 , do not spread throughout the degassing zone and are recirculated immediately to the downcomer. For higher values of airflow rate, solids rise in higher amounts to section S_5 and, on their way down, pass through sections S_1 , S_2 and S_3 . The behaviour of sections S_1 and S_5 is not very well defined. These are sections of connection of the upper (S_1 , S_2 and S_3) and the lower (S_6 , downcomer – S_7 and riser – S_8) parts of the reactor, where solids that leave the riser are mixed with the ones that are in the way down, to enter the downcomer and, thus, a great turbulence is observed. So, solids hold-up presents intermediate values and only for an airflow rate of 1.9 l/min it is clearly lower in S_1 than in S_5 . For higher airflow rates, as a result of a better mixing induced, solids hold-up in sections S_1 and S_5 have almost the same values.

Solids hold-up is always higher in the lower parts of the airlift reactor, since the higher values of local gas hold-up obtained are in one of the following sections: S_6 , riser (S_8) or downcomer (S_7), regardless of the solids loading, the density of the solids and the airflow rate. This proves the efficiency of the degassing zone while acting as a solids settler. Nevertheless, section S_6 presents, in almost every situation, the highest value of solids hold-up. This is the result of being one of the sections with the lower cross-section area associated to the fact that solids leaving the riser mix with solids coming from sections S_4 and S_5 .

Siegel *et al.* (1988) compared solids hold-up in the riser and in the downcomer. They found that for solids with densities greater than the liquid-phase the hold-up of the solids is greater in the riser; for solids with densities lower than the liquid-phase the opposite happens. In the present work, where solids densities are slightly higher than the density of the liquid-phase, it can be seen that riser and downcomer solids hold-up presents similar values (Fig. 2). The small differences observed depend on solids loading

Figure 2 Solids hold-up variation (low density solids) along the sections of the reactor (ϵ_{si}), for different airflow rates and solids loading (ϵ_s) (sections in Fig. 1).

and airflow rate. For low solids loading, if airflow rate is low, solids hold-up in the riser is higher than in the downcomer and, if airflow rate is high, riser solids hold-up

is lower or equal to downcomer solids hold-up. This happens because low airflow rate results in a low rising force and solids remain more in the riser. However, when

Figure 3 Solids hold-up in each section of the reactor (ϵ_{si}) versus superficial gas velocity (v_{gr}), for different solids loading and densities (Low density solids: $\diamond$ – 5%, $\blacksquare$ – 10%, $\bullet$ – 20%, $\blacktriangle$ – 30%; High density solids: $\diamond$ – 5%, $\square$ – 10%, $\circ$ – 20%, $\triangle$ – 30%).

airflow rate is high, solids rise more easily to the top of the riser and then, even if they get to the degassing zone, they enter the downcomer, increasing its solids hold-up. When solids loading is high, solids distribution through the reactor is more uniform and there is not a great difference between riser and downcomer solids hold-up. Solids density does not influence the distribution of solids between riser and downcomer. The increase of solids density leads to similar increases of riser and downcomer solids hold-up.

Figure 2 also shows that, increasing the airflow rate, the distribution of solids becomes more uniform since solids hold-up in each section converges to similar values: solids hold-up decreases in sections S_6 , in the downcomer (S_-), in the riser (S_8) and, slightly, in section S_5 and increases in sections S_1 , S_2 , S_3 and S_4 (as can be seen in Fig. 3). In sections S_3 , S_4 and S_5 , however, the variation of solids hold-up is very small.

Figure 3 shows the influence of solids loading and density on solids hold-up. As expected, in all sections of the reactor, solids hold-up increases (almost linearly) with the increase of solids loading. Analysing, for each solids loading and airflow rate, the effect of solids density on solids hold-up, it can be seen that there are different behaviours depending on the section: with the increase of solids density, solids hold-up increases in sections S_6 (ϵ_{s6}), in the downcomer (ϵ_{s-}) and in the riser (ϵ_{s8}) and decreases in almost every section of the degassing zone. The increase of solids density leads to a higher difference between the density of liquid and solid phases, being more difficult to the high density solids to rise to the upper sections of the reactor. Section S_5 presents almost the same value of solids hold-up (ϵ_{s5}) for both solids densities because, increasing solids density, solids do not rise so easily to the top but still reach section S_5 .

To confirm the validity of the determinations of the local solids hold-up, a balance to the solid-phase, for each set of experimental conditions, was made in order to determine the overall solids hold-up. Comparing overall solids hold-up calculated using the local solids hold-up (ϵ_{si}) with the solids loading (ϵ_s), relative errors less than 10% were found. The higher deviation was obtained for the lowest airflow rate (superficial gas velocity of 0.01 m/s), probably because, in this case, values of riser and downcomer solids hold-up are far from the real ones. As suggested by Kochbeck *et al.* (1992), an axial distribution of the solid-phase along the riser should have been taken in account for airflow rates up to 0.02 m/s, which was not the case. In the present work, samples were taken only at the top of the riser and of the downcomer, being assumed that

solids hold-up in these sections is uniform and presents similar values to those found at the sampling point. This hypothesis is valid for all the airflow rates studied except for 1.9 l/min (riser superficial gas velocity of 0.01 m/s).

Conclusions

A series of experiments was carried out to determine the distribution of the solid-phase and the influence of the airflow rate, solids loading and density, in an airlift reactor with an enlarged degassing zone. Samples were taken in eight sections of the reactor.

It can be concluded that there is an axial and a radial distribution of the solid-phase, depending on the experimental conditions. Solids hold-up increases, in general, from the wall to the middle of the degassing zone and from the top to the bottom of the reactor. In all cases, solids hold-up in the degassing zone is lower than in riser or in downcomer. Increasing airflow rate, solids hold-up decreases in riser (S_8), in downcomer (S_-) and in the section between these two sections (S_6) while increases in almost every section of the degassing zone. A slight increase in the density of the solid-phase causes the opposite effect, that is, an increase of solids hold-up in S_6 , riser and downcomer and a decrease in the degassing zone. Solids loading influence is the same in all sections: increasing solids loading, solids hold-up in each section increases.

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