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Effect of gas liquid separator and liquid height on the global hydrodynamic parameters of an external loop airlift contactor

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Abstract

This study is devoted to the measurement of global hydrodynamic characteristics (gas hold-up and liquid circulating velocity) of an external loop airlift contactor filled with tap water, with different conditions for phase separation and for liquid height. It is shown that these two operating parameters have a great influence on the behaviour of the airlift reactor. These parameters generally are not specified for the use of the relations proposed in the literature, despite their importance. However, this study reveals that two openings in the top junction between the riser and the downcomer are able to generate doubling of the liquid circulation velocity and a decrease in the gas hold-up of about 30% for high gas throughputs. Furthermore, under these conditions, the liquid circulation velocity is multiplied by a factor of 2.7 with little change in the liquid height before aeration, and the gas hold-up is decreased about 27%. © 1997 Elsevier Science S.A.

Keywords: Gas liquid separator; External loop airlift contactor; Global hydrodynamic parameters

1. Introduction

In recent years, the use of airlift contactors for industrial applications has increased slowly but continuously. They are encountered in the fields of aerobic fermentations, waste water treatment [1], three phase contacting and other multiphase operations requiring low shear stresses [2,3]. They are often chosen because of their very simple design [4] and because of the low power input requirements for given gas–liquid transport rates [1]. Moreover, the absence of stirrer shaft, seals and bearings facilitates the establishment of conditions of asepsis [2].

In order to be able to design this type of apparatus, it is necessary to know the hydrodynamic behaviour and in particular the gas hold-up and the circulation velocity of the liquid. These two parameters have been studied extensively because of their influence on transfer phenomena.

Two categories of airlift can be encountered: airlifts are built with an internal or with an external loop. External loop airlifts allow the possibility of fixing easily the liquid velocity by a simple valve settled at the bottom connecting section. However, the important external transfer area of the external loop enables the user to heat or cool the liquid and so to control the temperature inside the reactor.

Many empirical and semi-empirical relationships have been proposed in the literature to link the two hydrodynamic parameters, that is to say ϵ_r, the gas hold-up in the riser, and U_{lr}, the superficial liquid velocity. They have been tabulated by Chisti and Moo-Young [2] and Kemblowski et al. [5]. All these relationships can be applied in determined ranges of operating conditions and cannot be generalized to any geometry. This is due to the fact that, for a given value of the superficial gas velocity, any variation of the following parameters modifies the liquid velocity and the gas hold-up:

(i) the physical properties of gas and liquid [6–10];
(ii) the ratio between the cross-sections of the downcomer and the riser (A_d/A_r) [11,12];
(iii) the geometry of the top and bottom connecting sections between the riser and the downcomer [3,13];
(iv) the conditions for phase separation [14];
(v) the height of non-aerated liquid, that is to say the liquid level before aeration;
(vi) the height of the reactor [15];
(vii) the gas sparger [16].

Most relations only take into account the gas flow rate and the geometrical parameter A_d/A_r. In this work, we intend to show the important effects of the conditions for phase separation and of the height of non-aerated liquid.

In order to predict the liquid circulation velocity, it has to be pointed out that the general momentum balance equation for water-like media, which is written as follows [2],

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$$U_{lr}=\left[\frac{2gh_d(\epsilon_r-\epsilon_d)}{K_t/(1-\epsilon_r)^2+K_b(A_r/A_d)^2[1/(1-\epsilon_d)^2]}\right]^{0.5}$$

presents drawbacks, essentially because the correct values of the gas hold-up in the riser and in the downcomer as well as the coefficients K_t and K_b must be known. Until now, these parameters have had to be evaluated using empirical correlations.

Furthermore, in many studies concerning external loop airlift reactors the dispersion height is situated above the top pipe connecting the riser to the downcomer. In this case, the dispersion height h_d in the equation should not be the experimental value but it should be limited to the height of the upper level of the connecting pipe.

2. Experimental equipment

The external airlift reactor used for the measurements in this work is shown schematically in Fig. 1. It consists of a riser (0.194 m in diameter and 1.40 m in height) and of a downcomer (0.092 m in diameter and 1.00 m in height) made of Altuglass. The length of the connecting sections between the riser and the downcomer is 0.50 m. The gas sparger is settled inside the riser and just above the level of the lower connection tube as shown in Fig. 1. It consists of a ring (0.17 m in diameter) and a cross pierced with 64 holes of 0.8 mm diameter. The liquid passes through the gas sparger to ensure a good distribution of gas and liquid in the whole section of the riser. The airlift is equipped with two openings in the top connecting section between the downcomer and the riser, which are used to avoid air accumulation in this part. These openings can be closed.

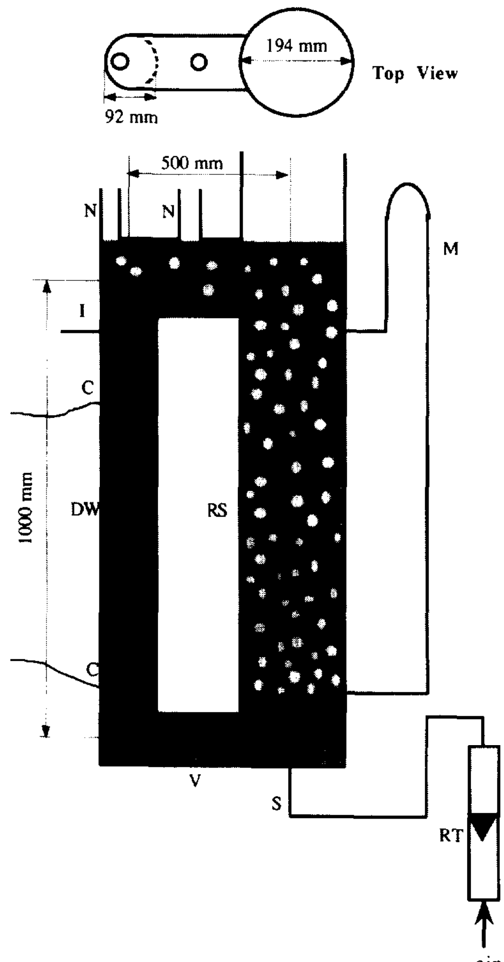

Fig. 1. Scheme of the experimental apparatus: C conductivity probes, S sparger, DW downcomer, RS riser, I tracer injection point, M manometer, N nozzle, R rotameter, V valve.

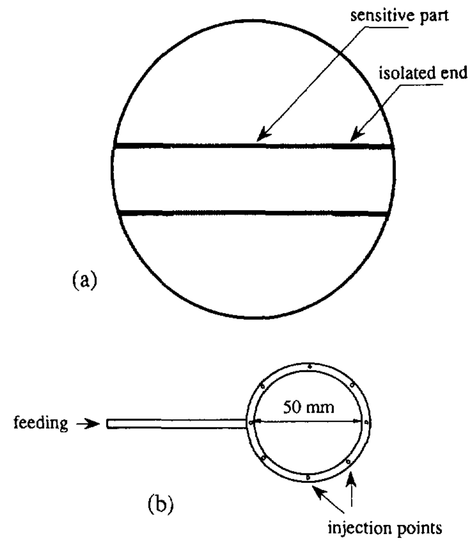

Fig. 2. Details of the experimental apparatus: (a) a conductivity probe, (b) system of injection for the tracer.

All measurements are carried out batchwise with respect to the liquid. The flow rate of gas is determined with a calibrated rotameter and the superficial gas velocity U_{gr} is based on the cross-section of the riser. The average volumetric gas hold-up is calculated from manometric measurement of hydrostatic pressure. Two identical conductimeters equipped with conductivity probes enable us to calculate the liquid circulation velocity in the downcomer. The conductivity probes are settled at a distance of 0.52 m from each other (see Fig. 2). The probes are isolated (non-sensitive) at the vicinities of the wall in order to avoid disturbance of the measurements due to wall phenomena which can occur especially with highly viscous non-Newtonian media. The tracer (concentrated sulphuric acid) is injected through a special sparger in order to obtain a rapid distribution of the tracer in the liquid. This is done at 0.22 m above the first probe. The responses of the two probes are registered and treated by a microcomputer.

3. Conditions for phase separation

The gas–liquid separator is constituted by the whole upper part of the airlift and is a key factor of the design. It controls the disengagement of gas and consequently the gas hold-up in the downcomer. The liquid circulation is controlled by the difference between the gas hold-up in the riser and in the downcomer, which depends on the efficiency of the separator. In industrial equipment, the connecting sections between the riser and the downcomer in many external loop airlifts are constituted by a simple tube.

In a previous study concerning an internal loop airlift, Siegel and Merchuk [14] established a relation which links the liquid superficial velocity in the downcomer to the liquid circulation time as a function of the geometrical characteristics of the special separator. They carried out experiments with different lengths of the separator (entirely opened, at atmospheric pressure), which leads to different values of the gas hold-up in the downcomer, depending on the bubble disengagement and residence times. In our study, the geometrical characteristics remain unchanged, only the pressure conditions are modified at the top junction through the opening or closing of nozzles, the separator being closed, as in most industrial cases.

As can be observed in Fig. 3, when the openings are closed, the separation of phases is not perfectly achieved and accumulation of air generates a supplementary resistance to the liquid circulation. In fact, in this case, beyond a critical value of the gas flow rate, the liquid velocity reaches a maximum value and then decreases. The maximum corresponds to the value of gas superficial velocity generating a dispersion height above the upper pipe connecting the riser to the downcomer. At the same time, when the openings are closed the gas hold-up is increased (Fig. 4) because of a less important entrainment of the bubbles by the rising liquid. When the openings allow the complete evacuation of gas in the separator, we note a significant increase in the liquid circulating velocity.

Fig. 3 also presents values of the liquid circulating velocity calculated from the momentum balance equation. The value of the coefficients K_t and K_b is taken to be equal to 5 [3] and the gas hold-up in the downcomer is neglected. A good agreement with experimental results is obtained in the case of opened nozzles, while when the nozzles are closed, the predicted values of U_{lr} are very different from those obtained

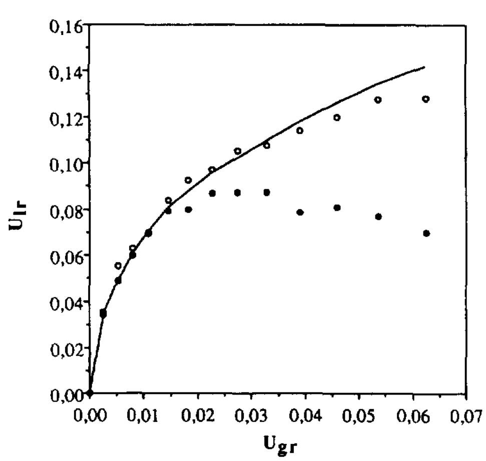

Fig. 3. Influence of the conditions for phase separation on the liquid circulation velocity, $h_l = 0.97$ m: ○ opened nozzles, ● closed nozzles, ——— momentum balance equation.

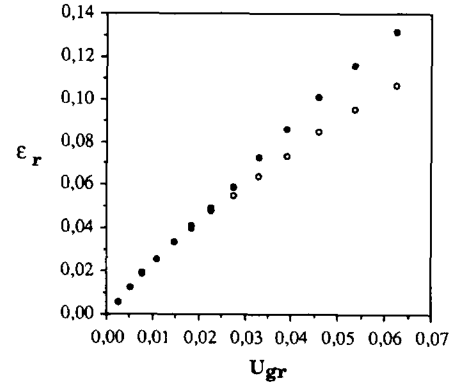

Fig. 4. Influence of the conditions for phase separation on the gas hold-up, $h_l = 0.97$ m: ○ opened nozzles, ● closed nozzles.

experimentally. This is due to the air accumulated in the phase separator which generates a decrease in the liquid velocity and an increase in the gas hold-up.

Depending on the requirements of a selected operation, it may be interesting to operate under conditions generating a higher liquid circulating velocity or a higher gas hold-up. In fact, a compromise must always be chosen between enhancing homogenization of the liquid and obtaining high gas hold-up. A given plant offering the possibility of modifying phase separation conditions can be suitable for the different systems encountered. It appears to be simpler to change the conditions for phase separation than to modify the geometry of the airlift (for example reducing A_d/A_r). Consequently, it has to be pointed out that special care must be taken in using relations proposed in the literature.

4. Height of liquid before aeration

The influence of the height of liquid before aeration is quite important on the hydrodynamic characteristics, but is not taken into account in the literature. Nevertheless, the difference between the hydrostatic pressure in the riser and the downcomer which generates the liquid circulation is controlled in part by this parameter. In the case of an internal loop airlift, Russell et al. [15] carried out experimental measurements and proposed a relation to calculate the liquid velocity in the riser. This study takes into account the change in the height of the internal draft tube which is a geometrical characteristic of the pilot but not the operating parameter which is the level of non-aerated liquid. The latter is fixed equal to the height of the internal draft tube, which does not obviously correspond to the best operating condition, but to a particular case. In the present work, on the contrary, the geometry of the plant is given, and the consequences of a change in operating conditions, that is to say the liquid volume, are studied. This means that we are essentially focused on the fact that with a given pilot, it is possible to obtain various hydrodynamic behaviour by changing only the operating conditions related to the liquid phase.

In the case of our external loop airlift, Figs. 5 and 6 enable us to note that both the liquid velocity and the gas hold-up largely depend on the height of non-aerated liquid. Two regimes can be identified.
(i) The first corresponds to a level of the dispersion below the top connecting section between the riser and the downcomer, that is to say that it remains a free surface all along the phase separator. When the height of non-aerated liquid increases, it is characterized by a very important increase in the liquid velocity due to the increase in the difference between the hydrostatic pressures in the riser and the downcomer and generating a strong decrease in the gas hold-up.
(ii) In the second regime, an increase in the liquid height no longer modifies the circulation of the liquid or the gas hold-up because there is no variation in the difference between the hydrostatic pressures in the riser and in the downcomer.

The minimal value of the liquid height before aeration is fixed to reach the lower part of the top pipe connecting the riser to the downcomer. The maximal value is located at about 3 cm above the upper part of the connecting pipe. Figs. 5 and 6 also include the values of liquid height beyond which liquid circulation begins to be induced.

The transition between these two regimes depends on the gas flow rate, because the dispersion in the riser reaches the top connecting section between the riser and the downcomer much more easily when the gas velocity is high. The higher the gas flow rate, the lower is the limiting value of the height of non-aerated liquid. This means that the limit between the two operating regimes is controlled by the height of the dispersion, and not by the volume of the liquid phase.

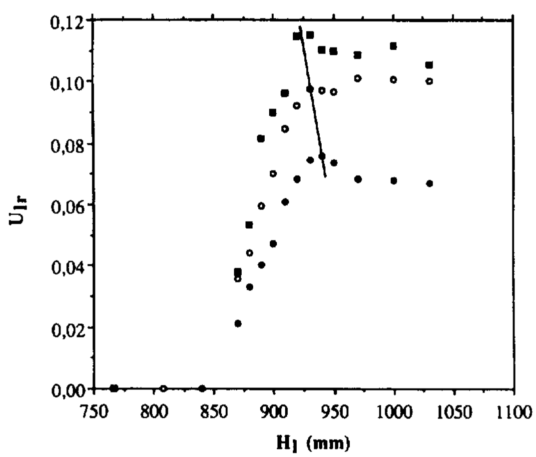

Fig. 5. Effect of the height of non-aerated liquid on the liquid circulation: ● $U_{gr}=0.011$ m s^{-1}, ○ $U_{gr}=0.023$ m s^{-1}, ■ $U_{gr}=0.039$ m s^{-1}.

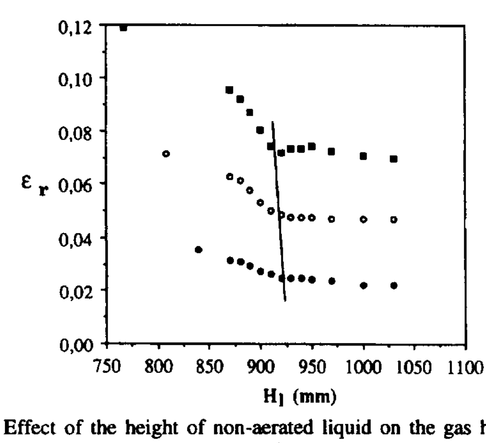

Fig. 6. Effect of the height of non-aerated liquid on the gas hold-up: ● $U_{gr}=0.011$ m s^{-1}, ○ $U_{gr}=0.023$ m s^{-1}, ■ $U_{gr}=0.039$ m s^{-1}.

5. Conclusions

This study has been devoted to the global hydrodynamic characteristics of an external loop airlift contactor filled with tap water, and operating with different operating conditions.

It has been pointed out that the height of non-aerated liquid is an important parameter. The increase in height of non-aerated liquid leads to an increase in the circulating velocity of the fluid and consequently to a decrease in the gas hold-up. The influence of this parameter is a function of the geometry of the top connecting section between the riser and the downcomer. The pressure in the closed gas–liquid separator is an important parameter which has to be taken into account for the separator design, since it has been pointed out that it controls the hydrodynamic behaviour of the reactor.

Consequently, we would like authors and users to be aware of the necessity of taking into account these operating parameters before estimating the hydrodynamic parameters of their airlift contactor.

6. Notation

A_d	Cross-sectional area of the downcomer (m^2)
A_r	Cross-sectional area of the riser (m^2)
g	Gravitational constant (m s^{-2})
h_d	Dispersion height (m)
h_l	Liquid height before aeration (m)
H_{dt}	Height of the draft tube (m)
K_b	Friction loss coefficient of the bottom connecting section
K_t	Friction loss coefficient of the top connecting section
U_{gr}	Superficial gas velocity in the riser (m s^{-1})
U_{lr}	Superficial liquid velocity in the riser (m s^{-1})

Greek letters

ϵ_d	Gas hold-up in the downcomer
ϵ_r	Gas hold-up in the riser

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