# CFD SIMULATIONS IN AN INTERNAL CIRCULATION AIRLIFT OPERATING UNDER HOMOGENEOUS REGIME

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**Abstract.** Multiphase airlift reactors have been widely used for decades in chemical engineering, biochemical fermentation and wastewater treatment. The advantages of theses reactors include simple construction, an absence of moving parts, efficient mixing and mass transfer with low energy consumption per unit volume. The objective of the present work is to study, using CFD (Computational Fluid Dynamics) simulations, the hydrodynamics behaviors (liquid circulation velocity and gas holdup) in an internal circulation airlift reactor with air injection between the cylinders. In these simulations the conditions adopted were dispersed phase (gas) - air; continuous phase (liquid) – water; drag model – Grace; and different air superficial velocities ($U_g$). In the liquid phase, the turbulence can be described using the k-ε model. Through this study, it was possible to obtain useful and essential information about the design and operation of this equipment.

## 1. INTRODUCTION

Airlift reactors and bubble columns are the two main types of pneumatically agitated reactors. Because of many operational advantages, airlift devices are far more significant than bubbles columns and bioprocessing and bioremediation. Airlift reactors are pneumatic agitated gas-liquid and gas-liquid-solid contacting devices that are used in the chemical process industry bioprocessing and waste treatment. All the pneumatically devices possess good mixing, mass and heat transfer characteristics, simplicity of construction, absence of moving parts, and low energy consumption. Other advantages of these equipment in biochemical processes are easiness of long term sterile operation, and a hydrodynamic environment suitable for fragile biocatalysts, which are susceptible to physical damage by fluid turbulence or mechanical agitation (Chisti, 1998).

Airlift reactors are one of the most important types of modified bubble columns (BCs) and there are two types of ALR: internal and external loop. Internal loop reactors consist of concentric tubes or split vessels, in which a part of the gas is entrained into the downcomer, whereas external loop reactors are two conduits connected at the top and the bottom, in which little or no gas recirculates into the downcomer. The part in which the sparger is located is called the riser, and the other is the downcomer. The driving force, based on the static pressure difference, or the mixture density difference, between the riser and the downcomer generates the loop liquid circulation. Compared with conventional reactors, such as stirred tank reactors or bubble columns, shear stress is relatively constant and mild throughout the reactor. For design of an airlift reactor, it is necessary to have accurate estimates of the phase holdups and velocities in the riser and downcomer (van Baten *et al.*, 2003; Ebrahimifakhar *et al.*, 2011).

Thus, two key hydrodynamic parameters of airlift reactors are the gas holdup and liquid circulation velocity. The hydrodynamic and other relevant parameters such as the airlift geometry are interrelated and their relationship can be quite complex and they directly or indirectly influence each other in sometimes not so obvious ways (Chisti, 1998), e.g. the driving force for the liquid circulation is the difference in gas holdups between the riser and the downcomer. This driving force is balanced by friction losses in the riser and the downcomer and in the bottom and top parts of the reactor (influence of bottom and top clearances in the case of internal loop airlifts or losses in connecting pipes in the case of external airlifts and of the airlift geometry in general). However, the resulting liquid circulation in turn affects the riser and downcomer gas holdup and thus the driving force. The gas holdup depends also on bubble slip velocity, which depends on the bubble size. Bubble size is influenced by the gas distributor, coalesce properties of the involved fluids and by turbulence. Turbulence is influenced by liquid circulation, etc (Simcik *et al.*, 2011).

Computational fluid dynamics (CFD) is one of the most powerful tools for analyzing and optimizing results and can save a great deal of time and expense (Ebrahimifakhar *et al.*, 2011). Several recent publications have established the potential of computational fluid dynamics (CFD) for describing the hydrodynamics of bubble columns and airlifts (Simcik *et al.*, 2011; Ebrahimifakhar *et al.*, 2011; van Baten *et al.,* 2003; van Baten and Krishna, 2003; Wasewar *et al.*, 2008; Zhang *et al.*, 2012).

The objective of the present work was to study, using CFD (computational fluid dynamics) simulations, the hydrodynamics (liquid circulation velocity and gas holdup) in an internal circulation airlift reactor.

## 2. MATERIAL AND METHODS

### 2.1 Reactor configuration and operating conditions

The simulations were done in an with air injection between the cylinders (annulus) (Figure 1). The total volume of the apparatus was 5 L. The outer cylinder has a diameter of 0.115 m and a height of 0.6 m, and the inner cylinder, or the draft tube (downcomer), has a diameter of 0.08 m, a height of 0.35 m and this is mounted into the column 0.03 m above at the bottom. At the bottom of the column, the gas phase is introduced through a circular holes arranged near the outer cylinder.

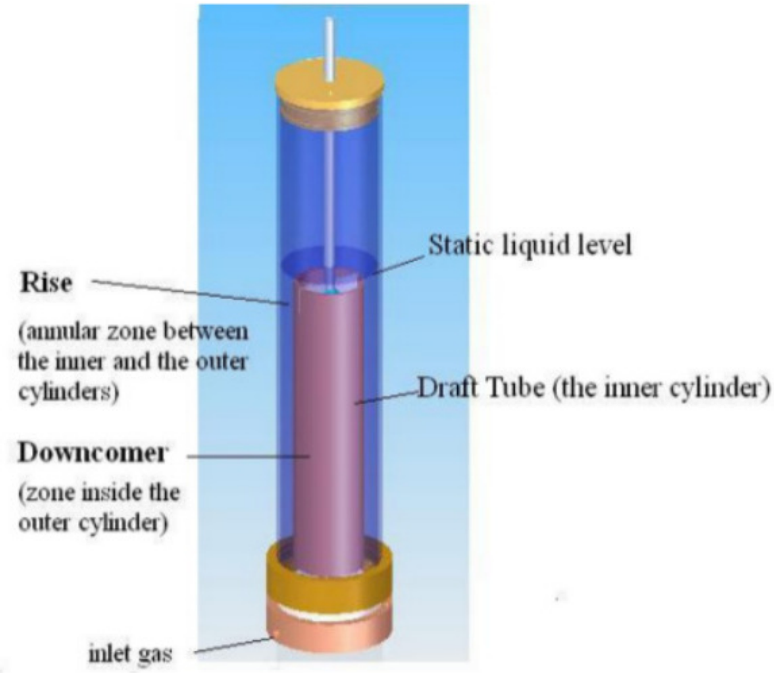



Figure 1. Schematic representation of the airlift reactor used this work.

## 2.2 Mathematical modeling

In the present work, an Euler–Euler two-fluid model was employed to investigate the hydrodynamics of gas–liquid phases in the internal circulation airlift reactor. In this model, liquid is considered to be the continuous phase, and gas bubbles are considered to be the dispersed phase. Two fluids are considered to be incompressible, and the uniform pressure field is assumed to be shared by both phases. Simulations were performed for transient state, the simulation time of 120 s and time step of 0.001s. The physical properties of the gas and liquid phases (at 25 $^oC$) are specified in Table 1.

Table 1 – Physical Properties of the fluids used in the CFD simulations

| | **Liquid (water)** | **Gas (air)** |
|---|---|---|
| Viscosity [cP] | 8,9 x $10^{-1}$ | 1.831 x $10^{-2}$ |
| Density (ρ)[kg/m] | 997 | 1.185 |
| Surface tension (σ) [N/m] | 0.072 | |

The drag model used was from Grace and liquid phase turbulence was modeled using the k-ε model. The governing equations of mass and momentum balance are solved for each phase and can be written as follows.

In this work, the entire internal airlift reactor was employed as the computational domain. At the inlet, the boundary conditions were specified by the superficial gas velocity.

Superficial gas velocities ($U_{GR}$) were varied from 0.004 - 0.22 m.s$^{-1}$ for the simulation. The outlet was considered to be at atmospheric pressure. The boundary conditions were a no-slip condition for liquid and a free-slip condition for the gas phase on all reactor walls. Isothermal conditions are assumed in the computational domain, so the energy equation is not calculated. Mass transfer and chemical reactions were neglected. In this work, simulations were performed using the program commercial computational fluid dynamics (CFX 13.0 - ANSYS).

**2.3 Gas hold up (ε) (gas void fraction) -** Gas holdup is an important hydrodynamic parameter and it is a basic measure of gas-liquid contacting airlift reactor. Gas hold up is governed by average bubble size, population of bubbles and bubble velocity (Chisti e Moo-Young, 1988). Bubble size and holdup in the column strongly depend on the properties of the gas-liquid system and on the type and design of the gas distributor. The interfacial area and mass transfer rate are dependent on holdup. Holdup also indicates the volume fraction of gas phase and mean residence time of the gas phase in the vessel. It also governs the velocity or flow field in the vessel, turbulence characteristics in the individual phases and the energy dissipation rates. Thus a study of gas holdup is important for scaling up and design of airlift reactors (Chisti, 1989).

In this work, the gas holdup was determined experimentally by measuring the increase in height of the dispersion upon aeration as follows Equation 1 (Chisti, 1989).

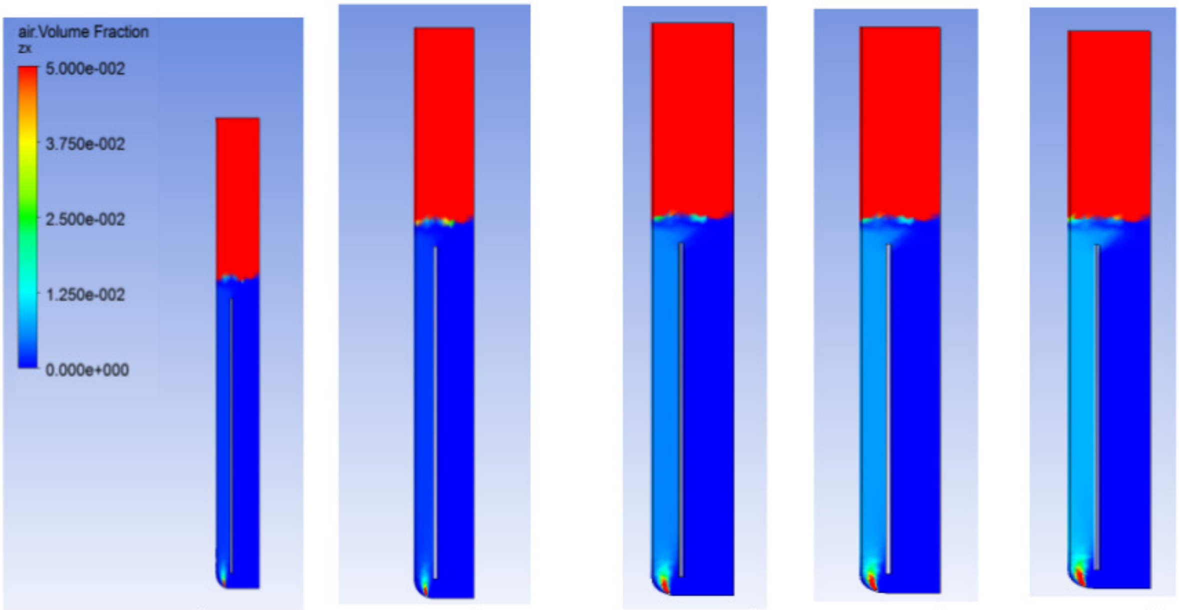
$$\varepsilon = \frac{h_D - h_L}{h_D} \tag{1}$$

where $h_D$ is the height of the gas-liquid dispersion and $h_L$ is the height of gas free liquid.

## 3. RESULTS AND DISCUSSIONS

The hydrodynamics simulation results at different superficial gas velocities for the airlift reactor are presented in this section.

Figure 2 shows the volume fraction of air at superficial velocities in riser ($U_{GR}$) in the reactor. The gas was injected homogeneously over the bottom region. The air bubbles move upwards due to the differences of density between the gas and liquid phases. The simulation time, represented in the figure, is 120 s.




(0.4 m s$^{-1}$) (0.8 m s$^{-1}$) (1.3 m s$^{-1}$) (1.7 m s$^{-1}$) (2.2 m s$^{-1}$)

Figure 2. Volume fraction of gas at various superficial velocities in riser.

Through Figure 2 shows that for low $U_{GR}$ values, the entire volume fraction of gas present the reactor is in the riser region defining the arrangement type I. In this type of arrangement, the gas is not present in the downcomer region. This regime occurs only at low volumetric flow rates of gas supply ($Q_G$), when the liquid velocity is not sufficient to drag bubbles to the downcomer region (van Benthum *et al.*, 1999). In Figure 3 are illustrated the results of the experimental gas hold-up (ε), and the ones obtained by simulation as a function of the superficial gas velocity ($U_{GR}$).

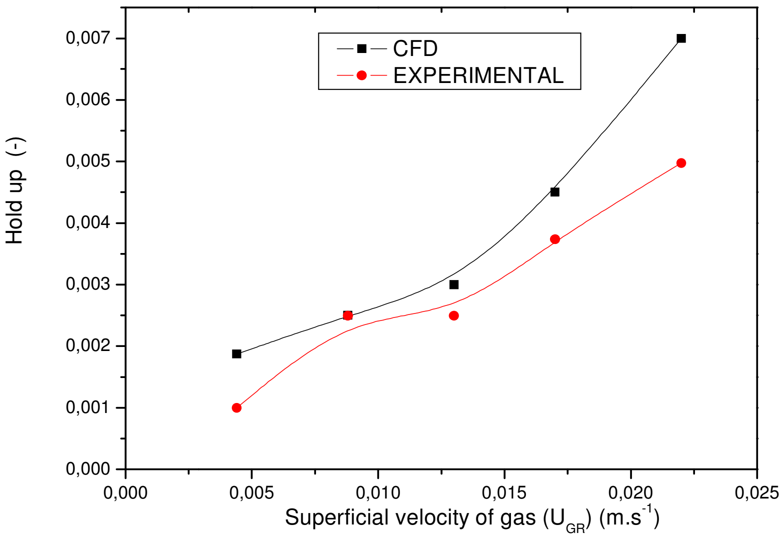



Figure 3. Effects of superficial gas velocity ($U_{GR}$) in gas hold-up.

It can be observed in Figure 3 that ε increases with the increase of $U_{GR}$ in the experimental range investigated (0.004 - 0.22 m.s$^{-1}$). This fact occurred because there is a higher amount of gas entering the system and increased drag of the liquid by the gas. The difference in gas retention values obtained in this study with those found in the literature, occurs due to the geometry of the air sparging system, the number of holes in the base of the reactor and the air flow rate employed.

Figures 4 and 5 illustrated the liquid velocity ($U_L$) at superficial velocities in riser ($U_{GR}$) in the reactor.

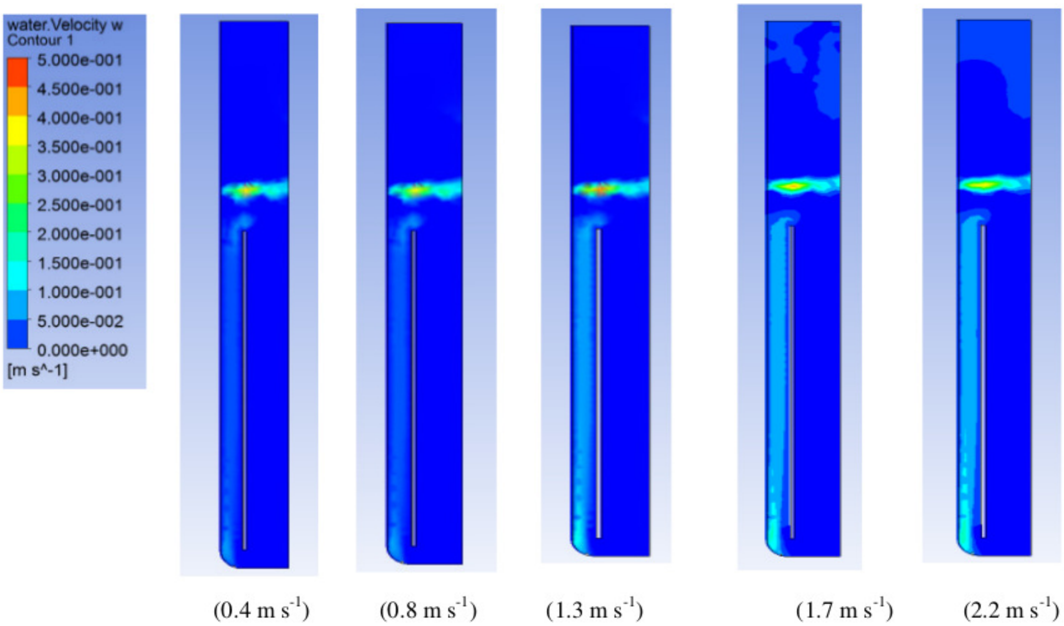



Figure 4. Comparison of the liquid velocity (m s$^{-1}$) at various superficial velocities in riser.

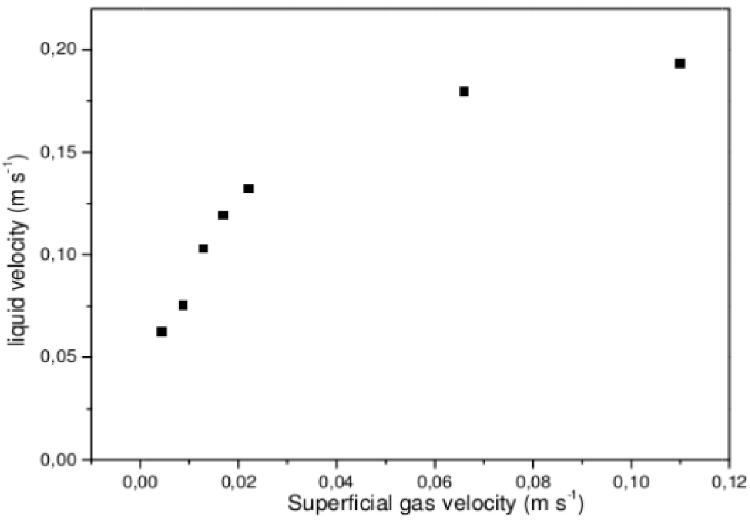



Figure 5. Effects of superficial gas velocity ($U_{GR}$) in liquid velocity.

From the results obtained (Figures 4 and 5) it was verified that at low superficial gas velocities ($U_{GR}$ < 0.02 m.s$^{-1}$), the velocity ($U_L$) increased significantly with increase of $U_{GR}$. $U_{GR}$ values greater than 0.02 m.s$^{-1}$, the increase $U_L$ with $U_{GR}$ was less intense. This is due to the fact that the gas does not achieves more momentum transfer to the liquid, as well as difference between the gas retention in regions of riser and downcomer decrease with increasing $U_{GR}$. Thus, there is no more a difference significant densities between these two regions, which is the driving force for circulating the liquid.

Similar results were reported by Zhang *et al*., (2012) and Chisti e Haza, (2002). Zhang *et al*., (2012) observed that when superficial gas velocities are less than 1 cm.s$^{-1}$, the liquid velocity increases rapidly with the increasing superficial gas velocity. However, when the superficial gas velocity is beyond 1 cm.s$^{-1}$, the increasing rate of liquid velocity becomes slow, probably because, at low superficial gas velocity ranges, the gas holdup in the riser increases rapidly while the gas holdup in the downcomer does not increase in an obvious manner because bubbles can hardly be entrained into the downcomer. The increased difference in gas holdup between the riser and the downcomer leads to the increasing liquid velocity in the downcomer. As the superficial gas velocity is over 1 cm.s$^{-1}$, bubbles begin to be increasingly entrained into the downcomer. This phenomenon can also be observed in the experiment.

## 5. CONCLUSIONS

In the present study, the effects of reactor geometry on the hydrodynamic parameters in an internal airlift reactor were investigates theoretically using CFD. Special attention was given to the liquid circulation velocity and the gas holdup in the riser. An important parameter in airlift reactors is the location and type of sparger used to introduce gas into the reactor. With the results obtained, it can be concluded that the location of the sparger, in the gap between the cylinders, possible to obtain adequate values of gas holdup close to those found in the literature. Experiments are being conducted in order to compare the results of these simulations with those obtained in the reactor benchtop.

## 6. ACKNOWLEDGEMENTS

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