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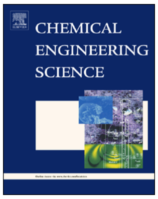

Experiments and modelling of a draft tube airlift reactor operated at high gas throughputs

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HIGHLIGHTS

- Study and modelling of an annular sparged draft tube airlift at high gas throughputs.
- Strong influence of collective effects and flow pattern on the riser hydrodynamics.
- Weak effect of gas volume fraction increase on bubble's mass transfer coefficient.
- Volumetric mass transfer coefficient is proportional to the gas superficial velocity.

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ABSTRACT

One-dimensional modelling of global hydrodynamics and mass transfer is developed for an annulus sparged draft tube airlift reactor operating at high gas throughputs. In a first part, a specific closure law for the mean slip velocity of bubbles in the riser is proposed according for, in one hand, the collective effects on bubble rise velocity and, in the other hand, the size of the liquid recirculation in the airlift riser. This global hydrodynamics model is found to well explain the global gas volume fraction measurements in the airlift riser for a wide range of superficial gas velocity ($0.6 \leq J_G \leq 10$ cm s^{-1}). In a second part, mass transfer in the airlift has been studied by using the gassing-out method and a dual-tip optical probe to measure the bubble size distributions. As for bubble columns, in such airlift, the volumetric mass transfer coefficient appears to be quite proportional to the gas superficial velocity. Finally, as in Colombet et al. (2011), mass transfer at the bubble scale seems to be weakly influenced by an increase of gas volume fraction.

1. Introduction

Airlift reactors are widely used in many processes, like absorption or desorption operations for water treatment or chemical industry applications. At low gas volume fraction, the behavior of internal or external airlifts has been thoroughly studied and modeled (Bello, 1981; Jones, 1985; Wachi et al., 1991; Kushalkar and Pangarkar, 1994; Chisti et al., 1995; Cockx et al., 1997; Gourich et al., 2005; Talvy et al., 2005; Luo and Al-Dahhan, 2008). However at high gas volume fraction, the understanding and the modelling of global hydrodynamics and mass transfer stays clearly a challenge. In chemical industry, the use of high gas volume fraction contactors is particularly interesting for mass transfer operations coupled with a chemical reaction in the liquid phase. Dense bubbly flows provide a mixing of reactants in the liquid phase and a high interfacial area that appears to be very useful when mass transfer limits the chemical reaction.

The difficulty increases also for complex geometries as it can be found in annulus sparged draft tube airlifts (Fig. 1a). Many studies have focused on draft tube airlifts with the gas injection located in the center of the reactor (Jones, 1985; Wachi et al., 1991; Merchuk et al., 1994; Kushalkar and Pangarkar, 1994; Pironti et al., 1995; Kojima et al., 1999; Reza Mehmia et al., 2005; Shariati et al., 2007; Luo and Al-Dahhan, 2008). But to our knowledge only a few works exist on draft tube airlift with the injection located in the annular volume (Botton et al., 1978, 1980; Chisti et al., 1995; Wongsuchoto and Pavasant, 2004; Zhang et al., 2010). With such gas injection, a large liquid recirculation is progressively formed in the airlift

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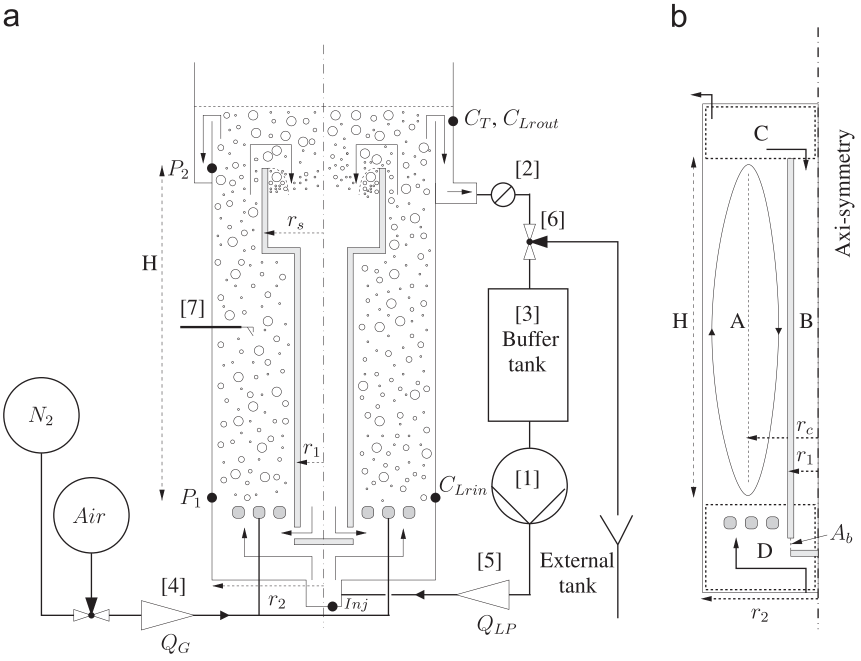

Fig. 1. (a) Pilot plant and (b) axisymmetric airlift representation.

riser (Wongsuchoto and Pavasant, 2004). This liquid recirculation is similar to those formed in conventional bubble columns if the gas injection is not uniformly distributed on the column cross section (Lockett and Kirkpatrick, 1975; Molerus and Kurtin, 1986; Becker et al., 1994; Vitankar and Joshi, 2002). Consequently, compared to standard airlift reactors, the study of annulus sparged airlift is made difficult because of the complexity of gas–liquid hydrodynamics in the riser, especially in the case of high gas throughputs.

The aim of this article is to contribute to global modelling of hydrodynamics and mass transfer process in an annulus sparged draft tube airlift reactors by means of experimental investigation as well as 1D modelling.

In a first step, experimental set-up and measurements techniques are described. Then, hydrodynamic experimental results are presented focusing on bubble size and gas volume fraction measurements. In a third step, a global hydrodynamic model is proposed to explain the evolution of the riser global gas volume fraction. In a last step, using the plug flow with axial dispersion model so-called Axial Dispersion Model (ADM), the liquid-side volumetric mass transfer coefficient $k_L a_l$ is measured by adjusting the ADM prediction on experimental dissolved oxygen concentration time evolution. To perform mass transfer measurements, axial dispersion in the riser is also measured independently. Mass transfer experimental results are then analyzed considering recent works on mass transfer in bubbly flows.

2. Experimental set-up

2.1. Reactor design and gas–liquid system

The experimental installation is depicted in Fig. 1a. The whole installation includes an airlift reactor, a centrifugal pump ([1]) and a buffer tank ([3]) of volume V_{Tank} ($\approx 8V_{Airlift}$). The reactor is made of two vertical concentric tubes of radii r_1 and r_2. At the top of the draft tube, a separator of radius r_s ensures bubbles disengagement. The gas phase is introduced through pierced toroidal gas spargers, at the riser bottom. Bubbles are formed in a jet regime. Gas and liquid inlet flow rates (Q_G and Q_{LP}) are monitored by flow controllers ([4-5]). The airlift volume is about 0.13 m^3 and, as shown in Fig. 1b, its geometry can be divided in four main parts:

- a riser corresponding to the annular volume between the two concentric tubes [*A*],
- a downcomer corresponding to the internal smallest inner tube volume [*B*],
- an upper connecting domain [*C*],
- a lower connecting domain [*D*].

The pilot plant can run closed to the liquid ($Q_{LP}=0$) or open to the liquid ($Q_{LP}>0$). In that last case, a valve ([2]) in Fig. 1a) is placed at the reactor liquid outlet to maintain the liquid level in the airlift.

In conventional airlift contactor, the downcomer can be aerated or not, depending on whether or not the liquid velocity is strong enough to entrain bubbles coming from the riser into the downcomer. At the top of the downcomer, if the liquid downward velocity U_{Ls} is lower than the single bubble relative velocity V_z^∞, no bubble can be trapped in the downcomer. Otherwise, the downcomer is aerated. In our experimental plant, the gas-liquid separator was specially designed (by controlling the separator radius r_s) to avoid downcomer aeration whatever the gas throughput ($U_{Ls}<V_z^\infty$). Moreover, the clearance distance above the draft tube has been chosen to avoid strong curvature of the free surface (vortex formation). As a result, in the downcomer, gas and liquid volume fractions are respectively $R_{Gd}=0$ and $R_{Ld}=1$.

The gas–liquid system is composed of air and water with 0.1% of butanol (v/v) at ambient temperature and pressure. A small amount of butanol was added to tap water in order to increase easily gas volume fraction by decreasing the surface tension from 73 mN down to 65 mN (Habrdova et al., 2004). It results in smaller bubbles with slightly lower terminal rising velocities than in pure water (Camarasa et al., 1999; Veera et al., 2001). Meanwhile, the addition of alcohol in water is not considered as a contamination of the bubble surface, since it is known to decrease homogeneously the surface tension. The main fluid properties are summarized in Table 1.