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The Effects of Viscosity and Surface Tension on the Hydrodynamics of Air-Lift Reactor

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Abstract **-** The objective of this work is the hydrodynamic characterization of an airlift reactor. The main parameters obtained are the void fraction and superficial velocities of the continuous and dispersed phases. Different liquid solutions covering a range of viscosity and surface tension values are employed, with an air phase. This work aims to study the effect of liquid phase viscosity and surface tension on the performance of air-lift reactors

Keywords**:** Air-lift reactor, Gas holdup, superficial velocity, viscosity, surface tension

1. Introduction

Air-lift reactors are multiphase reactors where a gas phase is dispersed into a continuous phase (e.g. gas/liquid reactions, agitation by gas injection, refining, fermentations, etc.), are widely used in industrial gas–liquid operations, in chemical, petrochemical and biochemical process industries. Air lift reactors are characterized by their simple design, low operating cost and high-energy efficiency and performance. Despite the simplicity of the design, they are characterized by a very complex fluid interactions and coupling between the deferent phases.

The hydrodynamics in an air-lift reactor can be mainly summarized in three different flow regimes: homogeneous regime, vortical-spiral flow regime and heterogeneous/turbulent regime [1]. Each one of the three regimes has different hydrodynamic and transport characteristics, and their stability are strongly influenced by the Air-lift geometry, operation conditions and physico-chemical parameters of the liquid phase [2], [3], [4], [5], [6], [7], [8], [9].

The effect of liquid phase proprieties such as viscosity and surface tension on the hydrodynamics of multiphase flow has been the subject of many studies in the literature. Zahradnı´k et al. [7] examined the effect of many parameters on gas holdup ε_G and the stability of homogenous and heterogenous regimes $U_{G,trans}$, reporting a significantly enhanced stability of the homogeneous bubbling regime (e.g. Increase of $U_{G,trans}$) in the presence of surface-active solutes and a decrease in gas holdup for moderate and high viscosity. More recently Olivieri et al. [10] observed a stabilization of the homogeneous regime up to μ = 4.25 mPa·s, and then for higher μ, a destabilization of the homogeneous regime. He also observed that the decrease of the surface tension decreases abruptly the stability interval of the homogeneous regime and the existence region of the vortical-spiral flow regime. these results were confirmed by Rabha et al. [11] in a study of the effect of liquid viscosity ($1 \leq \mu_L \leq 1149$ mPa-s) on local flow phenomena of the gas phase in a small diameter bubble column performed using ultrafast electron beam X-ray tomography.

This work aims to investigate the effect of liquid phase's viscosity and surface tension on the hydrodynamic of Air-lift reactor to provide an extensive study that can explain deferent mechanisms of bubble formation, break-up, coalescence, etc. The Air-lift that is the subject of this study is based on the principle of air-lift and flotation, under vacuum. The technology has been patented by the French Research Institute for the Exploitation of the Sea (IFREMER) and the National Institute of Applied Science (INSA) Lyon [12]. The column combines in its operation the functions of hydraulic pumping, solute transfer and particulate phase separation and minimizing energy costs [13].

2. Materials and Methods

The experimental study of the hydrodynamics of the Air-lift was carried out on a test bench shown schematically in Figure 1 below. The system consists a vertical column (two concentric Plexiglas tubes of 80 mm and 150 mm diameter), a storage tank and a vacuum pump. The vertical column consists of a two-cone placed at the head and connected to a vacuum pump; two sections of 1 m of concentric tubes; a 25 mm section equipped with a plug for the optical bi-probe; a base equipped with a ceramic bubble diffuser and connected to a water recirculation basin. This basin is connected to the column by two parallel PVC pipes (50 mm in diameter). A suction pipe connected to the inner tube and a discharge pipe, to the outer tube. A harvesting tank which acts as a suction chamber of the vacuum pump and a collection tank for the particles trapped by the bubbles is appended to the air-lift. The injection of air is made in the central tube at the bottom of the column through the ceramic bubble diffuser. The compressed air used is that of the collective air supply system of the laboratory. It is supplied under a maximum pressure of 6 bar. A pneumatic circuit has been designed for our device in order to be able to filter the air and to control its pressure using a pressure switch. The compressed air is filtered and then passed through a pressure switch before entering a mass flow meter to record the effective air flow for the air-lift. Tap water is used at room temperature, distilled water is alternatively be used. The liquid flow rate of the air-lift is measured by an ultrasonic flow meter. The gas and liquid temperatures have been checked and maintained constant at room temperature during all the experiments (295 ± 1 K).

The characterization of the continuous (liquid) phase flow was made using an ultrasonic flowmeter. Differential pressure sensor is used to determine global parameters: pressure, holdup. The density of the gas is defined from the pressure at mid-height of the column.

In this work, we are interested in the study of the global performances of an airlift system. we are interested in the evolution of the hydrodynamics of the flow as a function of the properties of the dispersed phase. In this presentation, we are particularly interested in the impact on the void ratio and the pumping capacities of the airlift represented by the superficial velocity of the liquid phase.

Table1 summarizes the main features of the investigated liquids: Water and aqueous Alginate and Glycerol solutions. Alginate solutions were characterized by viscosity μ ranging between 1 and 27 mPa.s, and constant superficial tension σ and density ρ. The glycerol solution and Alginate 0.2% were characterized by the same viscosity and different surface tensions.

Table1 Continuous phase solutions proprieties

	$\rho(kg.m^{-3})$	$\mu\ (Pa.s)$	$\sigma(N.m^{-1})$
Water	997	1×10^{-3}	73×10^{-3}
Alginate 0.2%	997	4.8×10^{-3}	72×10^{-3}
Alginate 0.5%	997	7.5×10^{-3}	71×10^{-3}
Alginate 1%	997	26.75×10^{-3}	70×10^{-3}
Glycerol 38%	1083	4.7×10^{-3}	61×10^{-3}

2.1. Liquid phase velocity

The liquid velocity of the two-phase mixture of the bubble column is initially estimated from the liquid flow obtained by direct measurement using an ultrasonic flow meter. The velocity is obtained by the following expression:

$$U_L = \frac{Q_L}{A_c} \tag{1}$$

U

Where :

Q_L : liquid flow measured in $m^3.S^{-1}$

U_L: liquid velocity in $m.S^{-1}$

A_c: total section of the inner tube of the column in m^2

2.2. Superficial gas velocity

The superficial gas velocity in the air-lift column takes several expressions. We are going in a first approach to determine a superficial gas velocity. This is a global gas velocity used very often in the hydrodynamic study of bubbly flows. This superficial gas velocity is obtained from the volumetric flow and the cross-sectional area of the bubble column. The superficial gas velocity is thus given by the expression:

$$U_G = \frac{Q_v}{A_c} \tag{2}$$

A_c $[m^2]$ is the area of the total section of the inner tube of the column

$Q_v = \frac{Q_m}{\rho_G}$ is the volumetric gas flow at the column section

Q_m is the mass gas flow obtained by direct measurement with the mass flowmeter

$\rho_G = \frac{P}{RT}$ is the gas density

T is the temperature and P is the pressure.

2.3. Global gas holdup

The global gas holdup is defined as the volume of dispersed gas relative to the total volume of the two-phase mixture. It is obtained by pressure measurement using the differential pressure sensors placed on the air-lift (see figure 1). To determine the gas holdup relation with the measured pressure, we have two hypotheses:

- there is conservation of gas velocity;
- the pressure losses in the column are negligible because of smooth Plexiglas column walls.

The differential pressure is given by the expression:

$$\Delta P = \rho_L\, gh\alpha_L + \rho_g\, gh\alpha_G \tag{3}$$

With $\alpha_L = 1 - \alpha_G$ the volumetric fraction of the liquid, we will have the expression:

$$\Delta P = \rho_L\, gh(1 - \alpha_G) + \rho_g\, gh\alpha_G \tag{4}$$

The contribution of the mass of gas in the mixture is negligible. It is in the order of 1.13×10^{-4} and is practically within the margin of error made by the pressure sensor. So, we could very well neglect the term $\rho_g gh\alpha_G$ in the calculation of the gas holdup. We will then have the following relationship:

$$\Delta P = \rho_L \, gh(1 - \alpha_G) \tag{5}$$
$$\alpha_G = 1 - \Delta P / (\rho_L g h) \tag{6}$$

Where:

g: acceleration of gravity

h: is the mixture height between two successive pressure taps

ρ_L: liquid density

ΔP: measured differential pressure

α_G : global gas holdup

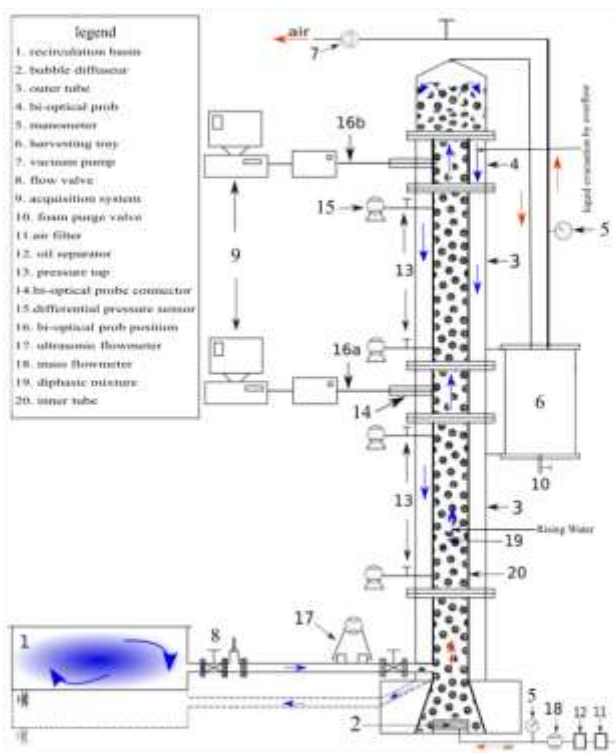

Fig. 1. Experimental setup

3. Results and discussion
3.1. Effect of viscosity

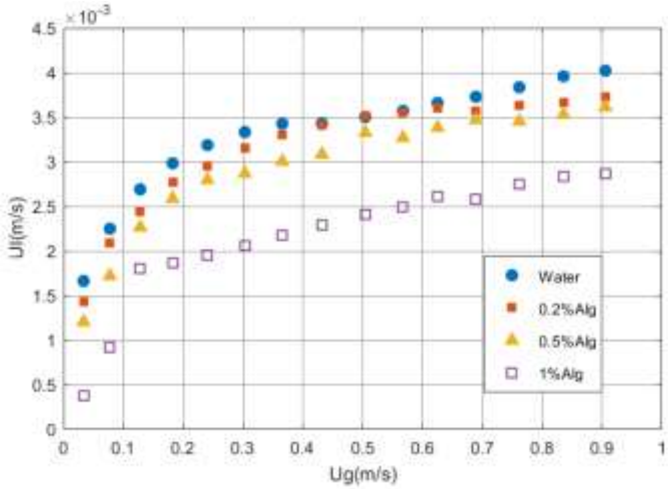

Fig. 2: Liquid phase velocity evolution as function of superficial gas velocity

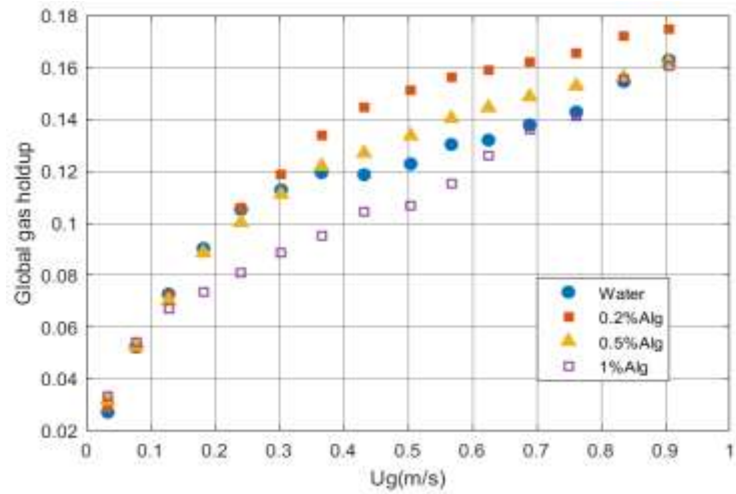

Fig. 3: Gas holdup evolution as function of superficial gas velocity

Figure 2 shows the results of the liquid phase velocity evolution as function of superficial gas velocity for air-water system and air-Alginate solutions. For all cases we observe an increase of the liquid velocity while increasing gas velocity. As shown in Figure 3 this is accompanied by an increase of gas holdup, more rising bubbles in the inner tube lead to larger liquid flow.

The experimental results show, that the increase in viscosity leads to a drop in the liquid phase velocity, therefore a reduction in the pumping function of the Airlift system. These results, are explained by the fact that for the low viscosities coalescence is limited and the bubbles size is reduced causing an increase in gas holdup. However, in liquid of moderate viscosity bubbles have lower rise velocity due to large drag force thus slowing the upward movement of the liquid phase. For higher viscosities, the tendency to coalescence increases resulting in large bubbles and lower gas holdup (Fig. 4).

At low viscosities there is a tendency to increase the gas holdup with increasing viscosity (Fig. 4), therefore favouring the bubble regime with the appearance of finer bubbles and a delay in coalescence. The low viscosities stabilize and increase the thickness of the boundary layer between the bubbles (the amount of movement bubbles cannot exceed the thickness of the layer). Nevertheless, whatever the superficial velocity of the gas, the void content reaches a maximum for a viscosity of order between 4 and 5 to begin to decrease for higher viscosities. this result is consistent with the majority of observations made in a bubble column where a critical value of μ in the order of 4.25 is reported [10].

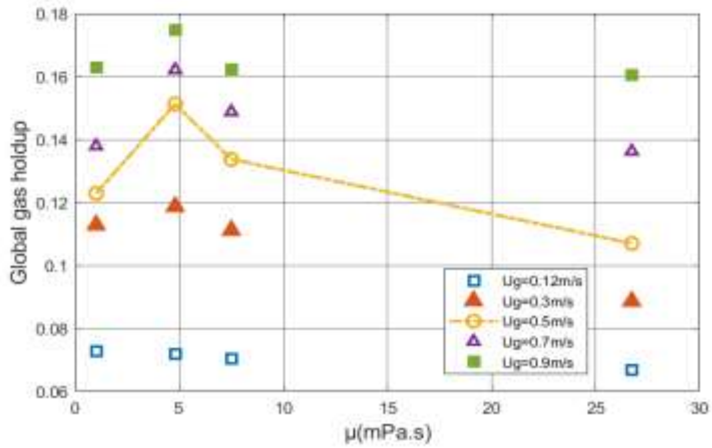

Fig. 4: dispersed phase viscosity effect on the gas holdup

3.2. Effect of surface tension

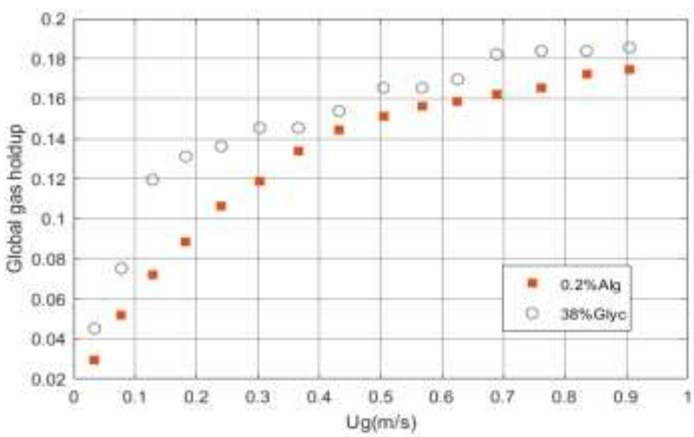

Fig. 5: Gas holdup evolution as function of superficial gas velocity

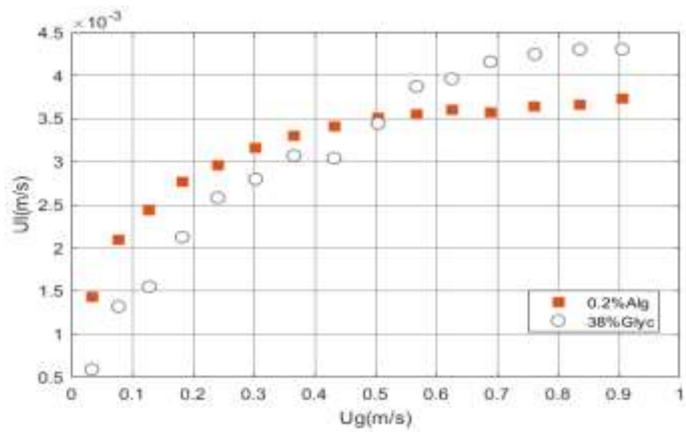

Fig. 6: Liquid phase velocity evolution as function of superficial gas velocity

Figures 5 and 6 present a comparison of the results for the 0.2% Alginate and 38% Glycerol solutions. These two solutions have almost the same viscosity 4.7 mPa.s but have different surface tension as reported in Table 1.

The gas holdup is always higher for the glycerol solution. When considering surface tension decrease, gas holdup increases mainly as a consequence of homogeneous flow regime stabilization, small bubble formation and demoting coalescence.

In contrast we observe smaller liquid superficial velocity until Ug =0.5m/s (Fig. 6) This phenomenon is explained by the appearance of a counter air-lift effect in the outer tube (discharge tube) of the air-lift. The presence of air bubbles at the outer tube causes the liquid flow to slow down this slow the return of the liquid to the recirculation basin of the column and decreases the velocity of hydraulic circulation and therefore the liquid flow.

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4. Conclusion

During this study we were able to explore the impact of the properties of the liquid phase on the performance of an air-air-lift system. During this work we were able to observe the influence of the viscosity for different aqueous solutions of of alginate. The advantage with these solutions is that only the viscosity is modified. which makes it possible to clearly identify its influence on the behaviour of the airlift. For the same viscosity but with a lower surface tension, tests with a mixture of water and glycerine show that the impact of the surface tension seems to depend on the superficial velocity of the gas. For low velocities, a lower surface tension increases the void ratio but limits the liquid flow. For higher gas velocities, a transition from the homogeneous regime to a heterogeneous regime limits the growth of the void ratio but increases the flow rate.

It is important to note that the viscosity does not only affect the diameter and the shape of the bubbles, but it also influences the behaviour of the dispersed phase such as the upward and horizontal velocities and the trajectories of the bubbles, due to the balance between viscous and inviscid forces. A better understanding of the operation of air-lift systems and the influence of the properties of bubbles, requires access to the distribution of their size and shape as well as their rising velocity. This approach is of fundamental importance to understand and model the dynamics of flow and mass transfer.

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References

[1] Chen, R.C., Reese, J., Fan, L.-S., 1994. Flow structure in a three-dimensional bubble column and three-phase fluidized bed. American Institute of Chemical Engineering Journal 40 (7), 1093–1104.

[2] Baker, G. (1954). Simultaneous flow of oil and gas. Oil and Gas, 53 :185–190

[3] Wilkinson, P.M.; Spek, A.P.; van Dierendonck, L.L. Design parameters estimation for scale-up of high-pressure bubble columns. AIChE J. 1992, 38, 544–554. [CrossRef]

[4] Hewitt, G. F. and Roberts, D. (1969). Studies of two-phase flow patterns by simultaneous X-ray and flash photography. ATOMIC ENERGY RESEARCH ESTABLISHMENT HARWELL (UNITED KINGDOM)

[5] Taitel, Y. and Dukler, A. E. (1976). A model for predicting flow regime transitions in horizontal and near horizontal gas-liquid flow. AIChE Journal, 22(1) :47– 55. [6] R. E. Kalman, "New results in linear filtering and prediction theory," *J. Basic Eng*., vol. 83, no. 4, pp. 95-108, 1961.

[7] Zahradnik, J., Fialova, M., Ruzicka, M., Drahos, J., Kastanek, F., and Thomas, N. H. (1997). Duality of the gas-liquid flow regimes in bubble column reactors. Chemical Engineering Science, 52(21) :3811–3826

[8] Shah, Y. T., Kelkar, B. G., Godbole, S. P., and Deckwer, W.-D. (1982). Design parameters estimations for bubble columnreactors. AIChE Journal, 28(3) :353–379

[9] Furukawa, T., Fukano, T., 2001. Effects of liquid viscosity on flow patterns in vertical upward gas-liquid two-phase flow, Int. J. Multiphase Flow 27, 1109-1126.

[10] Olivieri, G.; Elena Russo, M.; Simeone, M.; Marzocchella, A.; Salatino, P. Effects of viscosity and relaxation time on the hydrodynamics of gas–liquid systems. Chem. Eng. Sci. 2011, 66, 3392–3399.

[11] Rabha, S.; Schubert, M.; Hampel, U. Regime transition in viscous and pseudo viscous systems: A comparative study. AIChE J. 2014, 60, 3079–3090.

[12] Rene, F.; Lemarie, G.; Champagne, J.Y.; Morel, R. Procédé et Installation de Traitement d'un Effluent Aqueux, en vue d'en Extraire au Moins un Composé Gazeux Dissous; Application à L'aquaculture en Milieu Aqueux Recirculé. FR0702308A. 29 mars 2007. (In French)

[13] Barrut, B. Etude et Optimisation du Fonctionnement d'une Colonne Airlift à Dépression: Application à L'aquaculture. Ph.D. Thesis, Université Montpellier, Montpellier, France, 2011