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Numerical Study of Hydrodynamics in an External-Loop Air-Lift Reactor

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The aim of the numerical investigations presented in this paper was to determine hydrodynamics in the external-loop air-lift reactor. Euler-Euler numerical approach was used for unsteady simulations of gas-liquid dispersion flow in the reactor. Calculations were carried out using solver ANSYS-CFX 12.1. The results of the numerical simulations have been worked out in the form of the contours and axial distributions of the fluid velocity fields and gas hold-up in the air-lift reactor. Good agreement was achieved by comparison of averaged results of numerical simulations with the results of experimental investigations.

1. Introduction

Air-lift column reactors are widely used in many industries, for example, chemical, biochemical or wastewater treatment, because of such advantages as: simple construction, low costs, good gas dispersion, high mixing and mass transfer performance (Chisti (1989), Jia et al. (2007)). Recently, the processes occurring in the air-lift columns are intensively analyzed using experimental and numerical methods. Jones and Heindel (2010) studied experimentally gas hold-up and superficial liquid velocity in the downcomer and riser for an external loop air-lift reactor with a downcomer-to-riser area ratio of 1:16. The results obtained showed that riser gas hold-up varied slightly with the downcomer configuration, whereas a considerable variation was observed for downcomer gas hold-up. Luo and Al-Dahhan (2010) investigated local gas hold-up, using computed tomography technique, as well as conventional techniques. Authors discussed radial and axial evolutions of gas hold-up distributions, taking into account the effects of superficial gas velocity and geometry parameters.
CFD method has been used as a useful tool for understanding flow behaviors in the air-lift reactors. Numerical simulations of two-phase flow for an internal-loop air-lift reactor carried out Oey et al. (2003), van Baten et al. (2003), Blazej et al (2004) and Hekmat et al. (2010). However, reports of CFD modeling on two-phase flows in external loop air-lift reactors are rather limited. CFD simulations of the flow pattern and the gas hold-up in such reactors were performed only by Wang et al. (2004), Roy et al. (2006), Cao et al. (2007) and Roy and Joshi (2008).

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The aim of the numerical investigations presented in this paper was to determine local hydrodynamics of a two-phase flow in the external-loop air- lift reactor.

2. Range of the simulations

External-loop air-lift column used in the numerical study is schematically shown in Fig. 1. Computational domain involved air-lift column operating with air – distilled water system. The riser (R) had inner diameter D_R = 0.1056 m and height H_{0R} = 1.932 m, whereas the dimensions of the downcomer (D) were equal to D_D = 0.0464 m and H_{0D} = 1.69 m, respectively. The sparger of the column was simulated as gas inlet in the form of perforated plate with three square orifices with hydraulic diameter equal to d_o = 0.002 m symmetrically placed on the plate.

Euler-Euler numerical approach was used for unsteady simulations of gas-liquid dispersion flow in the reactor. Unstructured computational grid was consisted of about 226 000 tetrahedral elements (Fig. 2) and it was created in commercial package ANSYS Workbench 2. Calculations were carried out using solver ANSYS-CFX 12.1. Top of the column was modeled as outlet with implemented degassing condition. Wall influence on the flow was chosen as no slip for continuous phase and free slip for dispersed phase as is recommended in literature (Ansys CFX, 2005). The turbulence was resolved by the *k*-*ε* model in the liquid phase and by the zero equation model in the dispersed phase. To model effective stress and interfacial momentum transfer of the two-phase flow, drag force and turbulent dispersion force were taken into account in computations. Two-equation *k*-*ε* model is very often used because it offers good compromise between numerical effort and computational accuracy. Application of dispersed phase zero equation model for dispersed phase is recommended (ANSYS CFX, 2005) for flows which occur in bubble columns and air-lift reactors.

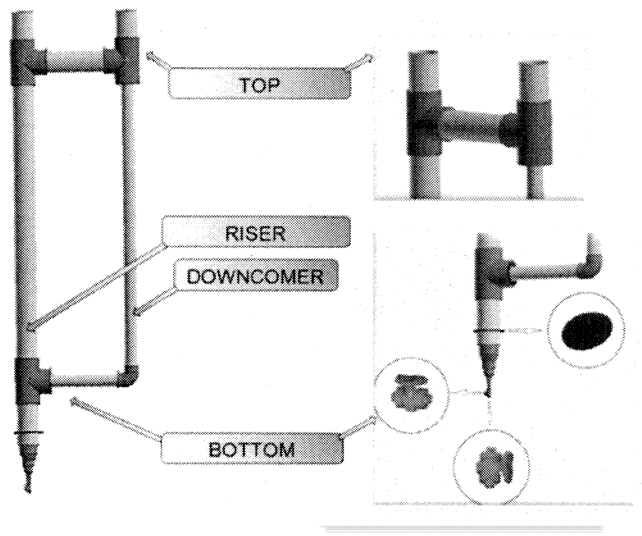


Figure 1: Details of both separation and bottom zones in external-loop air-lift column used in the study

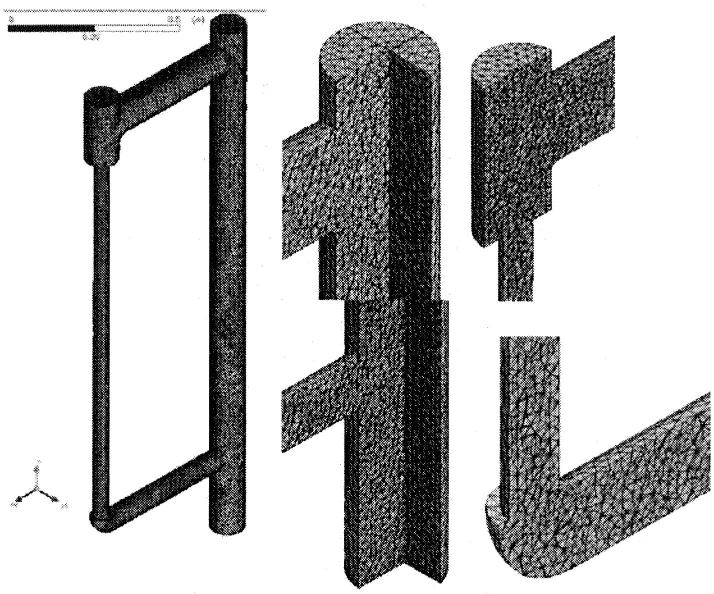


Figure 2: Numerical grid for the external-loop air-lift column used in the study

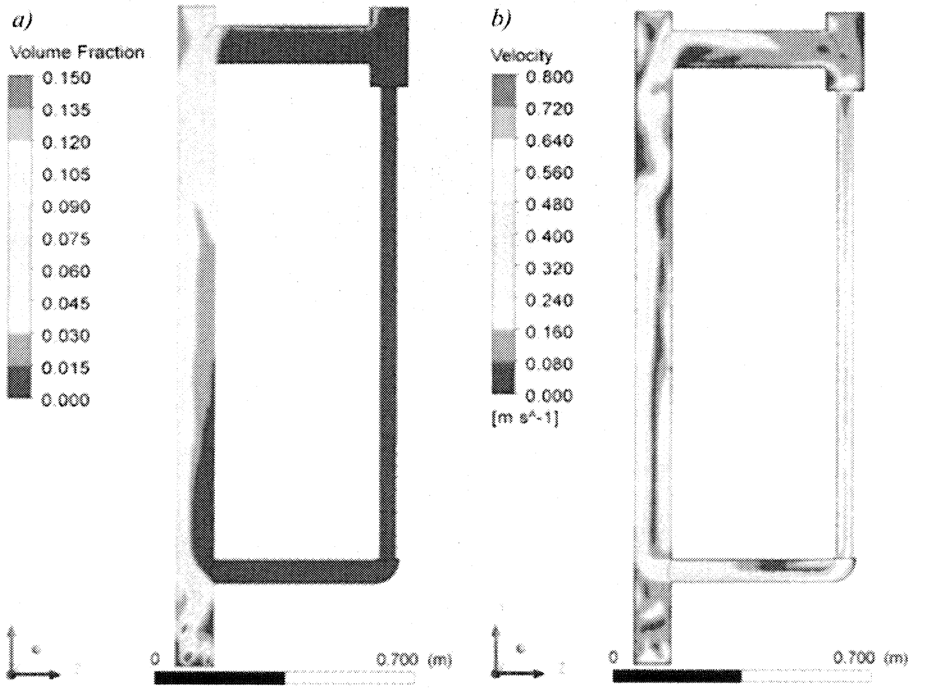


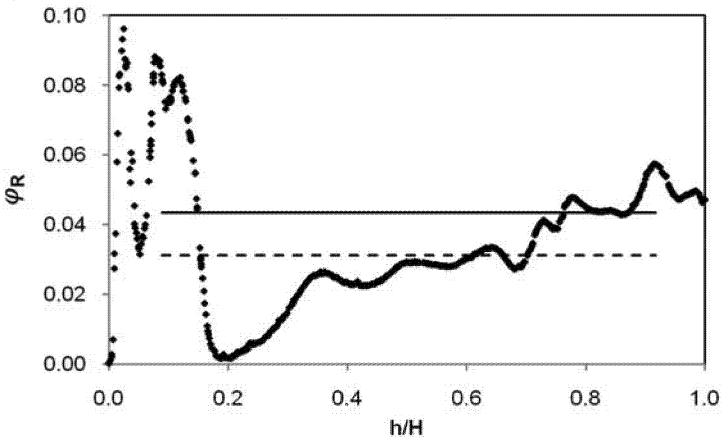
Figure 3: Results of the numerical simulations a) gas hold-up and b) liquid velocity in the external - loop air – lift column for the superficial gas velocity $w_{og} = 1.38 \times 10^{-2}$ m/s ($V_g = 1.21 \times 10^{-4}$ m^3/s) after computation time 25 s

In our numerical simulations, the input gas flow rate was varied within the range $V_g \in$ <3.64 x 10^{-5}; 3.18 x 10^{-4}> [m^3/s] (superficial gas velocity $w_{og} \in$ <4.2 x 10^{-3}; 3.63 x 10^{-2}> [m/s]), whereas constant value of mean bubble diameter equal to d_p= 0.005 m was assumed in whole numerical domain.

3. Results

The results of the numerical simulations have been worked out in the form of the contours and axial distributions of the fluid velocity fields and gas hold-up in the air-lift reactor. Fig. 3 shows the contours of the gas hold-up (Fig. 3a) and liquid velocity (Fig. 3b) obtained for the superficial gas velocity w_{og} = 1.38 x 10^{-2} m/s (V_g = 1.21 x 10^{-4} m^3/s), after computation time 25 s.

a)



b)

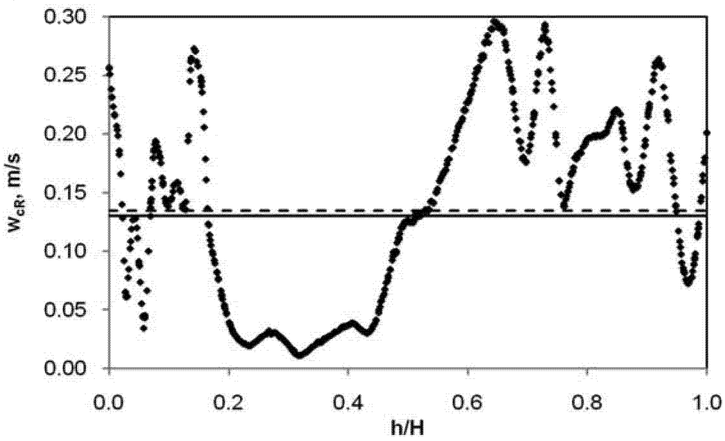


Figure 4: Axial distributions of a) gas hold-up φ_R and b) liquid velocity in the riser w_{cR} of the external - loop air – lift column for the superficial gas velocity w_{og} = 1.38 x 10^{-2} m/s (V_g = 1.21 x 10^{-4} m^3/s) after computation time 25 s; dotted line – values averaged from numerical computations; solid line – mean values from experiments (Karcz et al., 2010)

Axial distributions of the gas hold-up φ_R and liquid velocity w_{cR} in the riser of the external – loop air – lift column obtained for the data shown in Fig. 3 are presented in Fig. 4, where *h/H* denotes dimensionless axial coordinate (*H* – length of the column). In F ig. 4, the values averaged on the basis of the numerical computations (dotted line) and mean values (solid line) obtained from experiments by Karcz et al. (2010) are also given. Experiments were carried out for the column of identical geometry as used in the numerical simulations. Measuring sensors were located at the central vertical axis of the riser. Experimentally evaluated mean value of gas hold-up was based on the arithmetical average from 30 data for each superficial gas velocity. Numerical results shown in Fig. 4 were collected from the position corresponding to the distance between measuring sensors on the central vertical axis of the riser. In Fig. 4a, arithmetical average from about 600 computational local data points is presented. Underestimation in average gas hold-up values, observed in Fig. 4a, can result from complex hydrodynamic distributions in the tested air-lift column. Most complex fluid structure is observed in the bottom zone, where gas is introduced into the system and simultaneously degassed fluid flux from down horizontal pipe flows in the riser. In this section of the column, values of both gas hold-up and liquid velocity are more non-uniform than in upper part of the column. As it is shown in hydrodynamics contours (Fig. 3), rising gas flux is shifted on left wall of riser by re-circulating fluid. Because of this, average gas hold-up values determined at the vertical axis of the riser center are lower than these evaluated experimentally.

All the data of the averaged $\varphi_{R(av)}$ and $w_{cR(av)}$ values and mean experimental $\varphi_{R(exp)}$ and $w_{cR(exp)}$ values are compared in Table 1. In this Table relative mean errors Δ between numerical and experimental values of the gas hold-up φ_R and liquid velocity w_{cR} are also collected. It follows from the data presented in Table 1 and Fig. 4 that the numerical and experimental results are sufficiently agreed.

Table 1: Comparison of the values averaged from numerical computations and mean values measured experimentally by Karcz et al. (2010)

$V_g \times 10^4$, m^3/s	$w_{og} \times 10^2$, m/s	$\varphi_{R(av)}$ x10^2	$\varphi_{R(exp)}$ x10^2	$\pm\Delta\varphi_R$, %	$w_{cR(av)}$, m/s	$w_{cR(exp)}$, m/s	$\pm\Delta w_{cR}$, %
0.364	0.42	1.56	1.3	23.6	0.102	0.092	9.90
1.21	1.38	3.13	4.35	28.0	0.135	0.130	3.48
2.44	2.78	5.58	6.7	16.4	0.22	0.187	17.9
3.18	3.63	7.23	8.16	11.4	0.25	0.217	15.5

4. Conclusions

1. The results of numerical simulations enable to evaluate the structure of the fluid flow and dispersion of the gas flow in an external-loop air-lift reactor.
2. Within the range of the performed numerical computations gas hold-up and liquid velocity in the riser of the air-lift column increase about 4.6 and 2.45 times, respectively, with the increase of the superficial gas velocity from $w_{og} = 4.2 \times 10^{-3}$ m/s to $w_{og} = 3.63 \times 10^{-2}$ m/s.

3. Sufficiently good agreement was achieved by comparison of averaged results of numerical simulations with the results of experimental investigations.

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