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COMPUTATIONAL SIMULATIONS OF HYDRODYNAMICS OF EXTERNAL LOOP AERLIFT REACTOR

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In the current work a computational simulations of hydrodynamics of external loop airlift reactors have been presented. The simulations were carried out using ANSYS 12.0.1 CFX solver. The numerical results have been depicted in the form of contours, linear graphical trends and axial distributions of the gas holdup. The numerical simulations data have been compared to the experimental measurements and good agreement was achieved.

ANSYS CFX, simulation, hydrodynamics, airlift reactor, gas holdup
Introduction

Over the last years external loop airlift reactors (EL-ALRs) have drawn much more attention due to their simple construction, good heat and mass transfer, and good mixing characteristics as the gas phase in a reactor serves the dual functions of aeration and agitation [1, 2]. EL-ALRs have been used in many industries where intimate contact of gas-liquid phases is necessary, for example, in chemical, petrochemical industries and biological wastewater treatment processes [3, 4]. The special feature that distinguishes EL-ALRs from bubble columns is the liquid circulation flow through a downcomer which is connected with the riser by horizontal connections at the top and the bottom of the reactor. In the EL-ALRs, the density difference due to different gas holdups in the riser and in the downcomer induces circulation flow of the liquid. The circulation creates good mixing in all phases and provides good mass transfer. The interfacial area and the 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 the flow field in the reactor, turbulence characteristics in the individual phases and the energy dissipation rates.

The two key hydrodynamic parameters of airlift reactors are the gas holdup and liquid circulation velocity. Several literature studies have focused on the estimation of these hydrodynamic parameters [5-7]. These factors are affected by the geometry of the reactor, the riser to the downcomer cross-sectional area ratio, the liquid height and the operational conditions which include superficial gas velocity, liquid velocity and gas bubble size. Thus a study of gas holdup is important for scaling up and design of airlift reactors.

Simulations of gas–liquid two phase flows in airlift columns by computational fluid dynamics (CFD) started about two decades ago. This subject has been reviewed by Jakobsen et al. [8], Joshi [9] and Sokolichin et al. [10]. Computational fluid dynamics (CFD) is one of the most powerful tools for analyzing of flow pattern and the gas holdup in EL-ALRs. CFD method has been used as a useful tool for
understanding flow behaviors in airlift reactors. The reports of CFD modeling on
two-phase flows in external loop airlift reactors are rather limited. CFD simulations
of the flow pattern and the gas holdup in such reactors were performed only by Wang
et al. [11], Roy et al. [12], Cao et al. [13] and Karcz et al. [14].

The aim of the numerical investigations presented in this paper was to determine
the average and local gas holdup, fluid velocity of a two-phase flow in the external
loop airlift reactor.

**Numerical simulations**

The computational model of the airlift reactor, operating with air-water system,
was created with the program product Design Modeler on the basis of work sketches
of external loop airlift reactor (Fig. 1). The reactor consists of two tubes (riser and
downcomer) connected to each other by horizontal connections at the top and the
bottom of the reactor. The riser (r) has an inner diameter Dr = 0.055m and height Hr =
1.87m, whereas the dimensions of the downcomer (d) are Dd = 0.048m and Hd =
1.47m, respectively. The sparger of the column is in the form of perforated plate with
41 orifices each of which with hydraulic diameter do = 0.002m, while the mean
bubble diameter was set to be constant and equal to dp = 0.004 m for the whole
numerical domain. The sparger was defined as gas inlet, while the top of the riser was
defined as gas outlet with implemented degassing condition.

The mesh grid consists of 74 984 tetrahedral elements (Fig. 2) and was created
by the commercial package ANSYS Workbench 12.0.1. Euler-Euler numerical
approach which assume the gas and liquid phases to be interpenetrating continua was
used for the unsteady simulation of flows in the EL-ALR. The Euler-Euler approach
is more economical than the Euler-Lagrange approach and hence more popular. The
turbulence equations were resolved by the $k$-$\varepsilon$ model for the liquid phase and by the
zero equation model for the dispersed phase [15].
Experimental measurement methods

In our previous work the experiments were carried out for a pilot – scale external loop airlift plexiglas column of identical geometry as used in the numerical simulations on Fig. 1. All experimental runs were carried out at atmospheric pressure and a temperature of 25°C with air and tap water as gas and liquid phases, respectively. Air flow rates were measured by a rotameter.

The overall gas holdup was measured by the volumetric expansion method under operating conditions and for different superficial gas velocities. This method is based on the fact that, in the case of increasing gas flow rates, the liquid in the reactor is expanded by the gas phase. The hold up was found out by the difference between level with \( H_g \) and without aeration \( H \) (1):

\[
\varepsilon = \frac{H_g - H}{H_g}
\]  

(1)

At low superficial gas velocities, the dispersed liquid levels can be clearly defined and well measured. At high air flow rate the liquid surface became very turbulent with the level changing and a mean dispersion height was estimated.
The usual manometric method was applied to measure the average gas holdup and the holdup in the different regions of the riser. In airlift reactors the friction pressure drop is usually negligible compared with the static pressure drop [16]. The local static pressure drop $\Delta P$ between the two tapping ports with vertical space of $\Delta h$ is (2)

$$\Delta P = \rho_l g \Delta h (1 - \varepsilon_g)$$  (2)

where $\rho_l$ is the liquid density and $\varepsilon_g$ is the gas holdup and respectively (3):

$$\varepsilon_g = 1 - \frac{\Delta P}{\rho_l g \Delta h}$$  (3)

The pressure drop was measured by four reverse U-tube manometers placed 23, 63, 103, 163 cm above the gas distributor on the height of the riser. In the downcomer four different ports were located 10, 60, 100, 140 cm. above the gas sparger. A series of experiments were performed by varying the superficial gas velocity over the range of $5,3 \times 10^{-3} \div 7,1 \times 10^{-2}$ [m/s] to create a characteristic velocity curve of airlift reactor.

Experimental values of gas holdup were based on the arithmetical average from 15 data for each gas flow and by the two methods. The two discussed measurement methods yield comparable results.

**Numerical results and discussion**

In our numerical simulations, the input gas mass flow rate was varied within the range $V_{g \text{mass}} = 1,5 \times 10^{-5} \div 20 \times 10^{-5}$ [kg/s] which corresponds to superficial gas velocity range $U_{gr} = 5,3 \times 10^{-3} \div 7,1 \times 10^{-2}$ [m/s]. The results of the numerical simulations have been elaborated in the form of contours and axial distribution of the gas holdup in the airlift reactor.

1. Gas holdup

One of the most important parameters of EL-ALRs – the gas holdup was investigated with respect of the superficial gas velocity. Gas holdup in the reactor is found to increase with increasing superficial gas velocity. Linear trend of gas holdup
is observed and shown in Fig. 4. In such form it is easier to compare the experimental data and the CFD numerical data. Experimental results and numerical simulations were compared and good agreement was found for gas holdup especially for small inlet gas volumetric flows. At lower superficial gas velocities the difference between the simulation and the experiment for the lowest gas holdups was < 10% and it was increasing slowly and reaching difference of 19%.

**Fig. 3** Results of the numerical simulations for the gas hold up in EL-ALR for superficial gas velocity $U_{gr} = 2.05 \times 10^{-2} \text{ m/s}$

**Fig. 4** Results of the numerical simulations for the liquid velocity in EL-ALR for superficial gas velocity $U_{gr} = 2.05 \times 10^{-2} \text{ m/s}$

![Graph showing comparison between experimental and numerical data for total gas holdup]
Fig. 5 Comparison of the values of gas holdup from numerical simulations and from experimental measurements

2. Axial distribution of gas holdup in the riser

Axial distribution of gas holdup for various superficial gas velocities is shown in Fig. 5. The distance between the different regions in the riser is 20cm. The gas holdups within the riser section for the axial levels do not change much. However, there is a clear trend for the gas holdup to increase monotonically with the increase of the height of the riser. This tendency is observed for both superficial gas velocities.

Fig. 6 Axial distribution of gas holdup
Conclusions

1. ANSYS CFD has been used to simulate the hydrodynamics in external loop airlift reactor and a comparison of measured and numerical gas holdup data has been presented. The agreement has been shown to be good.

2. The CFD model was successfully extended for prediction of axial distribution of gas holdup. However, more experimental data should be obtained in order to evaluate the agreement.

3. The collected data presented the linear trend of increasing the gas holdup with increasing superficial gas velocity.

4. The future objective is to validate the CFD simulation with experimental data in order to determine an appropriate set of model parameters for future design analyses.

Nomenclature

\[ d_o \ [m] \] hydraulic diameter of the orifices
\[ d_p \ [m] \] mean bubble diameter
\[ D_d \ [m] \] inner diameter of the downcomer
\[ D_r \ [m] \] inner diameter of the riser
\[ H_d \ [m] \] height of the downcomer
\[ H_r \ [m] \] height of the riser
\[ k \ [m^2 \cdot s^{-2}] \] turbulent kinetic energy per unit mass
\[ U_{gr} \ [m/s] \] superficial gas velocity
\[ V_{g \ mass} \ [kg/s] \] superficial gas velocity

Greek Symbols

\[ \varepsilon \ [m^2 \cdot s^{-3}] \] turbulent energy dissipation rate per unit mass
\[ \varepsilon_g \ ] \] gas holdup

References


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