Simulation of Hydrodynamics in an Internal Loop Airlift Reactor

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Abstract – The simulation of air-water system is carried out in an internal loop airlift reactor with 0.44 m in the outer diameter and 2.44 m in the height with the constant length of a draft tube of 1.45 m. The Eulerian-Eulerian multiphase model with standard $k-\varepsilon$ turbulence model is utilized for all simulations. The hydrodynamics in an internal loop airlift reactor is investigated. The effects of the existence of a draft tube, cross-sectional area ratio of the riser and the downcomer ($A_r / A_d$) and the superficial gas velocity on hydrodynamics are also studied in the riser and the downcomer. The results show that the gas holdup and the axial liquid velocity are non-uniform in the riser and the downcomer. The gas holdup in the riser is higher than in the downcomer. It is maximum at the center region and decreases toward the wall region. The liquid flow is upflow in the riser and is downflow in the downcomer. The existence of a draft tube induces higher axial liquid velocity due to lower radial dispersion. As the ratio of $A_r / A_d$ increases, the gas holdup in the riser decreases but the gas holdup in the downcomer increases. The axial liquid velocity in the riser decreases with increasing the ratio of $A_r / A_d$ due to lower driving force. The gas holdup and axial liquid velocity increase with increasing the superficial gas velocity.


1. Introduction

An internal loop airlift reactor is a one type of the gas-liquid contactor and widely used in industrial processes such as chemical, petrochemical, and biochemical processes [1]. It contains excellent heat and mass transfer characteristics due to higher interfacial area. Good mixing, simplicity of construction are its attractive advantages. The hydrodynamics in the riser and the downcomer of an internal loop airlift reactor is needed for the design and scale-up. However, the hydrodynamics in this reactor is very complicate [2]. In an internal loop airlift reactor, the operating condition as superficial gas velocity has an important effect on hydrodynamics and mixing. In addition, the existence of a draft tube and cross-sectional area ratio of the riser and the downcomer ($A_r / A_d$) are the main parameter affecting gas holdup and velocity in the internal loop airlift reactor [3].

In this work, the hydrodynamics in an internal loop airlift reactor is investigated using Eulerian-Eulerian multiphase model. The effects of the existence of a draft tube, cross-sectional area ratio of the riser and the downcomer ($A_r / A_d$) and the superficial gas velocity on the gas holdup and axial liquid velocity are also studied in the riser and the downcomer.

2. Research methodology

An internal loop airlift reactor with 0.44 m in the outer diameter and 2.44 m in the height with the constant length of a draft tube of 1.45 m was used to simulate the hydrodynamics using software FLUENT V.6.2.16. The height of liquid was patched to 1.7 m with total volume of 258.51. Four different the ratios of cross-sectional area of the riser and the downcomer ($A_r / A_d$): 0.33, 0.68, 1.29, and 2.93 were used in the simulation. The draft tube was located at 5 cm above the gas sparger at the bottom. The gas sparger was placed at the center region of the reactor. The gas sparger was fixed at the same location and the same dimension for all simulations. The Eulerian-Eulerian model with standard $k-\varepsilon$ model was used in this work. The range of the superficial gas velocity used was 0-0.125 m/s. The boundary condition at the top surface was defined by the outlet pressure. This simulation was carried out in time-dependent mode with the time step of 0.005 s. The convergence criteria were set to be 0.001. In this study, the time-averaged results were presented in the range of 80-150 s.

2.1 Numerical model

In this simulation, the Eulerian-Eulerian multiphase model was used. A set of continuity and momentum...
equation is solved simultaneously. The air-water system was chosen for the case study. The turbulence model used was standard $k-\varepsilon$ model. Moreover, the mass transfer between phases and chemical reaction were neglected. Thus, the continuity and momentum conservation equation were expressed following:

The continuity equation for phase $q$ is

$$\frac{\partial}{\partial t}(\rho_q\alpha_q) + \nabla \cdot (\rho_q\alpha_q\mathbf{v}_q) = 0$$  

(1)

The momentum equation for phase $q$ is

$$\frac{\partial}{\partial t}(\rho_q\alpha_q\mathbf{v}_q) + \nabla \cdot (\rho_q\alpha_q\mathbf{v}_q\mathbf{v}_q) = -\rho_q\nabla p + \rho_q\mathbf{\tau}_q + \rho_q\alpha_q\mathbf{g} + \mathbf{F}_q$$  

(2)

The $q^{th}$ phase stress-strain tensor, $\mathbf{\tau}_q$ can be expressed as

$$\mathbf{\tau}_q = \rho_q\mu_q \left(\nabla \mathbf{v}_q + \nabla \mathbf{v}_q^T\right) + \rho_q\alpha_q \left(\frac{2}{3} \mu_q \mathbf{I}\right) \nabla \cdot \mathbf{v}_q I$$  

(3)

where $\mathbf{F}_q$ is the summation of interfacial forces between phases; drag force $\mathbf{F}_D$, lift force $\mathbf{F}_L$, and virtual mass force $\mathbf{F}_{VM}$. The effect of virtual mass force is insignificant on the simulation results [4]. Moreover, the lift force and virtual mass force have less effect [5]. Therefore only drag force was accounted for the simulation.

The drag force can be expressed below [6]:

$$\mathbf{F}_D = C_D \frac{\rho \mathbf{v}_p - \mathbf{v}_q}{\mu_q}$$  

(4)

where $C_D$ is drag coefficient and is written below

$$C_D = 24/\text{Re}(1+0.15\text{Re}^{0.887}) \ 	ext{for Re} < 1000$$  

(5a)

$$C_D = 0.44 \ 	ext{for Re} > 1000$$  

(5b)

and $\text{Re}$ is relative Reynolds number and obtained from:

$$\text{Re} = \frac{\rho_d |\mathbf{v}_p - \mathbf{v}_q| d_p}{\mu_q}$$  

(6)

2.2 Standard $k-\varepsilon$ turbulence model

The turbulence model used was a standard $k-\varepsilon$ model for mixture phase. The turbulence viscosity, $\mu_{t,m}$, is expressed as

$$\mu_{t,m} = \rho_m C_{\mu} \frac{k^2}{\varepsilon}$$  

(7)

where $k$ and $\varepsilon$ are the turbulence kinetic energy and turbulent energy dissipation, respectively and can be expressed as:

$$\frac{\partial}{\partial t}(\rho_m k) + \nabla \cdot (\rho_m\mathbf{v}_m k) = \nabla \cdot \left(\frac{\mu_m}{\sigma_k} \nabla k\right) + G_{k,m} - \rho_m \varepsilon$$  

(8)

$$\frac{\partial}{\partial t}(\rho_m \varepsilon) + \nabla \cdot (\rho_m \mathbf{v}_m \varepsilon) = \nabla \cdot \left( \frac{\mu_m}{\sigma_{\varepsilon}} \nabla \varepsilon \right) + \frac{\varepsilon}{k} \left(C_{1e} G_{k,m} - C_{2e} \rho_m \varepsilon \right)$$  

(9)

where $G_{k,m}$ is a turbulent production due to mean velocity shear and can be computed from:

$$G_{k,m} = \mu_{t,m} \left(\nabla \mathbf{v}_m + (\nabla \mathbf{v}_m)^T\right) \cdot \nabla \mathbf{v}_m$$  

(10)

The turbulent model constants were

$$C_{1e} = 1.44, C_{2e} = 1.92, C_{\mu} = 0.09, \sigma_k = 1.0, \sigma_{\varepsilon} = 1.3$$

3. Results and discussion

3.1 Gas holdup and velocity

Fig. 1a and b illustrate the contour of gas holdup and vector plot of liquid velocity in an internal loop airlift reactor at $U_g = 0.1$ m/s with $A_p/A_d$ ratio of 0.86. The gas holdup is non-uniform in the reactor. Most gas exists in the riser and a little of entrained gas appears in the downcomer. The difference of gas holdup in the riser and the downcomer is a driving force for liquid circulation in an internal loop airlift reactor. The liquid flow is upflow in the riser and is downflow in the downcomer. The radial profiles of gas holdup and axial liquid are shown in Fig. 2a and b, respectively. The gas holdup and the axial liquid velocity are maximum at the center region and decrease toward the near wall region in the riser. At $z = 0.15$ m, near the sparger the effect of the sparger is significant leading to higher gas holdup and axial liquid velocity at the center region. However, its effect is low in the upper zone. The radial profile of gas holdup and axial liquid velocity are flatter in the upper zone. The gas holdup in the riser is higher than in the downcomer. In the downcomer, the gas holdup and the axial liquid velocity insignificantly change in radial direction except for $z=1.4$ m (top zone) due to the effect of liquid entrance.
3.2 Effect of the existence of a draft tube

Fig. 3a and b show the effect of the existence of a draft tube on gas holdup and axial liquid velocity, respectively. Without a draft tube, the gas holdup is flatter. This causes more gas dispersion in radial direction, therefore axial velocity is lower. The existence of a draft tube induces higher axial liquid velocity due to lower radial dispersion.

3.3 Effect of cross-sectional area ratio of the riser and the downcomer ($A_r / A_d$)

Four different cross-sectional area ratios of the riser and the downcomer ($A_r / A_d$): 0.33, 0.68, 1.29, and 2.93 were used in the simulation. The gas holdup and axial liquid velocity profiles in the riser and the downcomer under different ratios of $A_r / A_d$ are shown in Fig. 4a and b, respectively. As the ratio of $A_r / A_d$ increases, the gas holdup decrease. The gas holdup in the downcomer increases with increasing the ratio of $A_r / A_d$. Gas can be more dragged into the downcomer when the cross-sectional area of the downcomer is lower. The difference
of gas holdup in the riser and the downcomer (driving force) decreases with increasing the ratio of $A_r/A_d$ as shown in Fig. 5. The driving force decreases with the ratio of $A_r/A_d$. Therefore, the axial liquid velocity in the riser decreases with increasing the ratio of $A_r/A_d$. In addition, the axial liquid velocity in the downcomer decreases with decreasing the ratio of $A_r/A_d$.

### 3.4 Effect of Superficial Gas Velocity

Fig. 6a and b demonstrate the effect of superficial gas velocity on gas holdup and axial liquid velocity in the riser and the downcomer. The gas holdup clearly increases with increasing superficial gas velocity in both the riser and the downcomer due to higher gas feeding. The axial liquid velocity also increases with increasing superficial gas velocity due to higher driving force (see Fig. 6a). However the increasing tendency become weaker at very high superficial gas velocity (at 0.075 m/s).

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**Fig. 5.** The different gas holdup in the riser and the downcomer under various $A_r/A_d$ ratios.

**Fig. 6.** The effect of superficial gas velocity on radial profile in the riser and the downcomer, (a) gas holdup, (b) axial liquid velocity.
4. Conclusions

The gas holdup and axial liquid velocity are non-uniform in the riser and the downcomer of an internal loop airlift reactor. The gas holdup in the riser is higher than in the downcomer. It is maximum at the center region and decreases toward the near wall region. The difference of gas holdup in the riser and the downcomer is a driving force for liquid circulation in the airlift reactor. The liquid flow is upflow in the riser and is downflow in the downcomer. Without a draft tube, the gas holdup is flatter. This causes more gas dispersion in radial direction, therefore axial velocity is lower. The existence of a draft tube induces higher axial liquid velocity due to lower radial dispersion. As the ratio of $A_r / A_d$ increases, the gas holdup in the riser decreases but the gas holdup in the downcomer increases. The axial liquid velocity in the riser decreases with increasing the ratio of $A_r / A_d$ due to lower driving force. The gas holdup and axial liquid velocity increase with increasing the superficial gas velocity.

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6. Nomenclature

$\alpha$  
gas holdup (-)

$\rho$  
density (kg/m$^3$)

$v$  
velocity (m/s)

$U_g$  
superficial gas velocity (m/s)

$p$  
pressure (Pa)

$g$  
gravitational force (m/s$^2$)

$F$  
the summation of interfacial force (N/m$^2$)

$\tau_{ij}$  
stress-strain tensor of phase $q$ (Pa)

$d_p$  
diameter of gas bubble (m)

$\mu$  
shear viscosity (Pa s)

$\lambda$  
bulk viscosity (Pa s)

$\mu_t$  
turbulent viscosity (Pa s)

$F_D$  
Drag force (N/m$^2$)

$C_D$  
Drag coefficient (-)

$k$  
turbulence kinetic energy (m$^2$/s$^2$)

$\varepsilon$  
turbulent energy dissipation rate (m$^2$/s$^3$)

$G$  
turbulent production (kg/m$^3$)

$\sigma_k$  
Prandtl number for turbulent kinetic energy (-)

$\sigma_\varepsilon$  
Prandtl number for turbulent energy dissipation rate (-)

$C_{1\varepsilon}$  
model parameter in turbulent energy dissipation equation (-)

$C_{2\varepsilon}$  
model parameter in turbulent energy dissipation equation (-)

$C_\mu$  
constant parameter in $k-\varepsilon$ model (-)

$Re$  
relative Reynolds number (-)

$A_r$  
cross-sectional area of the riser (m$^2$)

$A_d$  
cross-sectional area of the downcomer (m$^2$)

$A_r / A_d$  
cross-sectional area ratio of the riser and the downcomer (-)

References


