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Computational fluid dynamics simulation of bubble coalescence and breakup in an internal airlift reactor: Analysis of effects of a draft tube on hydrodynamics and mass transfer

Abtin Ebadi Amooghin [a,*], Somaye Jafari [b], Hamidreza Sanaeepur [c], Ali Kargari [c]

[a] Young Researchers and Elites Club, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Young Researchers and Elites Club, North Tehran Branch, Islamic Azad University, Tehran, Iran
[c] Membrane Processes Research Laboratory (MPRL), Petrochemical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Mahshahr Campus, Mahshahr, Iran

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ABSTRACT

Two-dimensional computational fluid dynamics (CFD) simulations of internal airlift reactors were considered to predict hydrodynamic and mass transfer in unsteady state flow. The main aim of this work is to provide insight into the effect of a draft tube on the air–water reactor mass transfer and hydrodynamics. A complex mathematical model was used to investigate the coalescence and breakup towards a more precise simulation of airlift reactors. The effect of the draft tube was considered in terms of coalescence and breakup to evaluate the reactor performance. The simulation results reveal that the presence of a draft tube in an airlift reactor results in a significant enhancement of the gas–liquid mass transfer rate, and a reduction in average liquid velocity and gas holdup. The coalescence and break-up affected the results significantly. The CFD predictions also confirmed that there was reasonable conformity between the predicted model values and the experimental data.

1. Introduction

In recent decades, with the technological progress of airlift reactors, increased attention has been given to computational fluid dynamics (CFD) modeling of gas–liquid two-phase flow [1–4]. Sokolichin et al. [5] reviewed many CFD simulations, which were used to achieve better control and system reliability. Blazej et al. [6] observed that in internal loop airlift reactors (ILARs), geometry affects the reactor performance significantly. They showed that an increase in ILAR geometry to an industrial size increases the riser gas holdup and overall liquid circulation velocity of the two-phase gas–liquid flow, especially in the heterogeneous regime. Kilonzo et al. [7] investigated the effects of baffle distances from the liquid free surface at the top and the distributor plate at the bottom of the reactor on ILAR hydrodynamics. They found that the liquid circulation velocity increases and remains unchanged as these clearances increase to some degree.

Many researchers have studied simultaneous hydrodynamics and mass transfer in bubble column and airlift reactors [8–12]. Nevertheless, a limited number of studies have focused on the optimization of reactor performance, its design or scale up. Bello et al. [13] as the pioneers in this case, studied the effects of geometry, such as the downcomer to riser

* Corresponding author. Tel./fax: +98 21 88261194.
E-mail address: abtin.ebadi.a@gmail.com (A. Ebadi Amooghin).

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Nomenclature

A_i	fluid particle surface area
a_i	interfacial area
C	distribution parameter dependent on the type of sparger
C_D	drag force coefficient
C_L	lift force coefficient
C_{TD}	turbulent dispersion coefficient
C_V	virtual mass force coefficient
D	diameter of the column
D	diffusion coefficient
D_b	bubble diameter
$D_{d,max}$	maximum distorted bubble limit
D_{crit}	volume-equivalent diameter of a bubble at boundary between groups 1 and 2
D_e	volume-equivalent diameter of a fluid particle
D_s	surface-equivalent diameter of a fluid particle
D_{sc}	critical bubble size for the group boundary with surface area and volume of A_{ic} and V_c
D_{sm}	Sauter mean diameter
d_B	bubble diameter
E_o	Eotvos number $\left(=\frac{g(\rho_L-\rho_G)d_B^2}{\sigma}\right)$
f	particle number density distribution function
g	gravitational constant
H	height
K_L	liquid side mass transfer coefficient
k	turbulent kinetic energy per unit mass
M_{ik}	generalized interfacial drag
n	fluid particle number per unit mixture volume
Re	Reynolds number
R_j	particle number source and sink rate due to j^{th}-particle interactions such as disintegration or coalescence
R_{ph}	particle source and sink rates per due to phase change
r	radius
r_d	average overall bubble radius
S_j	particle source and sink rates per unit mixture volume due to j^{th}-particle interactions such as disintegration or coalescence
S_{ph}	particle source and sink rates per unit mixture volume due to phase change
t	time
u	velocity vector
u_{slip}	axial slip velocity between gas and liquid
V	particle volume
$\dot{V}$	time derivative of volume V
V_c	critical bubble volume
v	particle velocity
v_b	terminal velocity of bubbles
v_g	average center-of-volume velocity of the dispersed (or gas) phase
v_i	interfacial velocity
v_{pm}	average local particle velocity weighted by particle number
$v_{S,G}$	superficial gas velocity in the riser
$v_{S,L}$	superficial liquid velocity in the riser
x	spatial coordinates

Greek symbols

α_d	average overall void fraction
α_g	void fraction of the dispersed (or gas) phase
ϕ	gas holdup
ε	turbulent energy dissipation rate per unit mass
Γ_g	mass generation for gas phase
η_{ph}	rate of volume generated by nucleation source per unit mixture volume
ρ_g	gas density
σ	surface tension
$\Delta\dot{m}_{12}$	inter-group mass transfer rates from group 1 to group 2