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Short Communication

Effect of gas sparger design on bubble column hydrodynamics using pure and binary liquid phases

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HIGHLIGHTS

- The effect of viscosity on gas holdup and regime transition was studied.
- The effect of the gas sparger design was studied.
- Highly viscous liquid phases produce gas holdup curve similar to the one obtained with “coarse” spargers.
- The shape of the needle sparger was discussed based on the Ledinegg instability.
- The flow-regime transition-points were compared with correlations reported in the literature.

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ABSTRACT

It is known that the fluid dynamics and transport phenomena in bubble columns depend mainly on the bubble column design (i.e., the column diameter, aspect ratio, and gas sparger openings) and the liquid phase properties. In this communication, we contribute to present-day discussion through an experimental study concerning the combined effects of the gas sparger design and liquid phase properties on both the gas holdup and the main flow regime transition. The experimental study concerning gas holdup measurements was conducted in a large-diameter and large-scale bubble column (with a height of 5.3 m and inner diameter of 0.24 m) operated in the batch mode. Air was used as the dispersed phase (using gas superficial velocities in the range 0.004–0.20 m/s), and various water–monoethylene glycol (MEG) solutions were employed as binary liquid phases. The water–MEG solutions tested have viscosities between 0.9 mPa·s and 7.97 mPa·s, densities between 997.086 kg/m^3 and 1094.801 kg/m^3, and surface tension between 0.0715 N/m and 0.0502 N/m. Two gas spargers were tested: (a) a spider sparger (“*coarse gas sparger*”) and (b) a needle sparger (“*fine gas sparger*”). The former produced a poly-dispersed homogeneous flow regime resulting in a concave gas holdup curve, whereas the latter produced a mono-dispersed homogeneous flow regime resulting in an *S-shaped* gas holdup curve. It was observed that the mono-dispersed bubble size distribution stabilized the homogeneous flow regime. The addition of MEG produced different effects depending on the gas sparger design. The addition of MEG in the “*coarse gas sparger*” configuration produced what is usually referred to as “*dual effect of viscosity*”: depending on the MEG concentration, the homogeneous flow regime was stabilized/destabilized, and thus, the gas holdup increased/decreased. Conversely, the addition of MEG in the “*fine gas sparger*” changed the shape of the gas holdup curve from an *S-shape* to concave, thus rendering it similar to the ones produced by “*coarse gas sparger*”. We speculate that viscous solutions reduce the influence of the inlet conditions in large-diameter and large-scale bubble columns; this is a matter of future research.

1. Introduction

Two-phase bubble columns are multiphase reactors/contacting devices, wherein a gas phase is dispersed into a continuous phase (i.e., a liquid phase—the subject of this study—or a suspension) in the form of “*non-coalescence-induced*” bubbles or of “*coalescence-induced*” bubbles. Two-phase bubble columns are widely used in chemical, petrochemical, and biochemical industries because of a number of advantages that they provide in both design and operation: simplicity of construction, lack of mechanically operated parts, low energy input requirements, reasonable price, and high

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Nomenclature

Non-dimensional numbers

$AR = \frac{H_D}{d_c}$	aspect ratio of column
$Bo = \frac{g d_{c,eq}^2 \rho_L}{\sigma}$	bond number
$Fr_{trans} = \frac{U_{G,trans}}{\sqrt{g d_{c,eq}}}$	Froude number in the transition point
$Mo = \frac{g \mu_L^4 (\rho_L - \rho_G)}{\rho_L^2 \sigma^3}$	Morton number
$Re_{ref} = \frac{U_{ref} d_{c,eq} (\rho_L - \rho_G)}{\mu_L}$	Reynolds number at reference conditions
$We_{trans} = \frac{U_{G,trans}^2 d_{c,eq} (\rho_L - \rho_G)}{\sigma}$	Weber number in the transition point

Acronyms and Abbreviations

BSD	bubble-size distribution
Exp	experimental value
MEG	monoethylene glycol
NS	needle gas sparger
SP	spider gas sparger

Symbols

B	parameter in Reilly et al. (1994) correlation (Eq. (13))[−]
a_i (i = 1,2,3)	parameters in Ribeiro (2008) correlation (Eq. (18)) [−]
b_i (I = 1,2,3)	parameters in Ribeiro (2008) correlation (Eq. (19)) [−]
c_i (i = 1,2,3,4,5)	parameters in Ribeiro (2008)) correlation (Eq. (24))[−]
c_{MEG}	mass concentration of MEG [%]
d_o	gas sparger holes diameter [mm]
d_c	diameter of the column [m]
$d_{c,eq}$	equivalent diameter of bubble column (Eq. (23)) [m]
e_i (i = 1,2,3,4,5)	parameters in Ribeiro (2008) correlation (Eq. (24))[−]
f_i (i = 1,2)	functions used the Ribeiro (2008) correlation (Eq. (17)) [−]
g	acceleration due to gravity [m/s^2]
h	height along column [m]
H_c	height of column [m]
H_D	height of free-surface after aeration [m]
H_0	height of free-surface before aeration [m]
M	gas momentum per unit mass [m/s/kg]
n	exponent in Eqs. (11) and (12)[−]
n_0	number of holes in sparger[−]
J	drift-flux [m/s]
S_i (i = 1,2,3)	parameters in swarm velocity method (Eq. (6))[−]
U_b	parameter in drift-flux method [m/s]
u_∞	terminal velocity of an isolated bubble [m/s]
U	superficial velocity [m/s]
u	mean rise-velocity [m/s]
V	volume [m^3]

Greek symbols

ε	holdup [−]
ρ	density [kg/m^3]
σ	surface tension [N/m]

Subscripts

L	liquid phase
G	gas phase
ref	reference value
T, E	subscripts in drift-flux formulation
trans	transition point
transition	transition flow regime
swarm	swarm velocity
Wallis	Wallis plot method
wt	weight

performance (i.e., a large contact area between the liquid and gas phase and reasonable mixing within the liquid phase throughout the column). Notwithstanding the straightforward bubble column arrangement (a vertical cylinder with no internals, in which the gas enters through a gas sparger located at the bottom) bubble columns are characterized by remarkably complex interactions at the "*bubble-scale*", which physically manifest at the "*reactor-scale*" in the different flow regimes. When the gas superficial velocity (in a large-diameter and large-scale bubble column[1] with non-foaming liquids) is increased, the homogeneous flow regime, transition flow regime, and heterogeneous flow regime are progressively observed (see also the flow maps of Shah et al. (1982)). The homogeneous flow regime is defined as the flow regime where only "*non-coalescence-induced*" bubbles exist (e.g., as defined in Ref. (Besagni and Inzoli, 2016) by the gas disengagement approach). The homogeneous flow regime can be further classified into (a) the "*mono-dispersed homogeneous*" flow regime and (b) the "*pseudo-homogeneous*" flow regime, depending on the prevailing bubble size distribution (BSD) in the systems (i.e., in the developed region of the two-phase flow). In this respect, it is established that the prevailing BSD in the systems is mainly imposed by the gas sparger openings. The transition flow regime is identified by the appearance of "*coalescence-induced*" bubbles, and it is characterized by large flow macro-structures and a widened BSD due to the onset of the coalescence phenomena. The heterogeneous flow regime is dominated by "*coalescence-induced*" bubbles, which rise in the column, causing high coalescence and breakage rates. For a more complete discussion concerning the flow regimes, please refer to Refs. (Besagni and Inzoli, 2017). Please note that the definition, classification, and modeling of the flow regimes in bubble columns is a matter of ongoing investigation.

The complete and precise description of the fluid dynamics of the different flow regimes at the different scales (from the "*bubble-scale*" to the "*reactor-scale*") is not feasible with the present body of knowledge. Thus, the fluid dynamic interactions are summarized as local (i.e., the BSDs and bubble shapes) and global (i.e., the gas holdup—a dimensionless parameter defined as the volume of the dispersed phase divided by the total volume) fluid dynamic properties. In particular, the gas holdup determines the mean residence time of the gas phase and, in combination with the size distribution of the dispersed phase, the interfacial area, which is related to the heat and mass transfer phenomena. In addition, the shape of the gas holdup curve (the analytical relationship between the gas holdup and gas superficial velocity) and thus, the fluid dynamics and transport phenomena in bubble columns, relies on the bubble column design (i.e., bubble column diameter, aspect ratio, and gas sparger openings) and the liquid phase properties. With regard to large-diameter and large-scale bubble columns, the shape of the gas holdup curve mainly depends on the gas sparger openings: (a) "*coarse gas spargers*" produce the "*pseudo-homogeneous*" flow regimes, resulting in monotonic gas holdup curves that are concave in shape; (b) meanwhile, "*fine gas spargers*"

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[1] For the discussion concerning the definition of large-diameter and large-scale bubble columns, the reader may refer to the discussion concerning the scaling up of bubble column proposed in the introduction of Ref. (Besagni et al., 2017a).