Eng. & Technology, Vol.25, Suppl. of No.2, 2007

Characteristics of Bubbles and Gas Holdup In A Two-Phase Column For Different Liquid Phases

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Received on: 31/5/2005
Accepted on: 21/11/2005

Abstract

Experimental study of gas holdup (E_g), bubble diameter (d_{vs}) interfacial area (a) m^{-1}, small bubble rise velocity (U_{bs}), and bubble rise velocity (U_{br}) in (0.1m i.d) and (1.5m) high column operated at ambient temperature and pressure conditions. The superficial gas velocity (U_g) was varied in the range of (0-0.3) m/s, spanning both the homogenous and heterogeneous flow regimes. Air was used as the gas phase.

Different liquids were used as liquid phase (Water, Ethanol, Butanol, paraffin oil solutions).

Experimental results shows that the influence of liquid properties on (E_g) is considerable, where the lower surface tension (s) gives a lower (U_{br}) and therefore a higher (E_g). High viscosity (m_L) leads to large bubbles and therefore a low (E_g) and (a) , for coalescence liquids bubble diameter increases with increasing gas velocity.

A correlation based on dimensionless groups for the predicition of (E_g) liquid properties is proposed, and found to be in good agreement with the experimental data.

Keywords :- Holdup, Bubble column, Coalescence, Bubble size

الخلاصة

تمت دراسة قيمة احتجاز الغاز وسرعة ارتفاع الفقاعة وسرعة ارتفاع الفقاعة الصغيرة، بالإضافة إلى (a) في عمود بأبعاد (١,٠ متر) وارتفاع (١,٥ متر) تحت ظروف اعتيادية. سرعة الغاز (٠ - ٠,٣٠) متر/ساعة. استخدمت عدة مكونات للطور السائل (ماء، ايثانول ١% وزناً، بيوتانول ١,٥% وزناً، بالإضافة إلى البرافين ٥٠% وزناً).

التجارب أثبتت أن لزوجة السائل والشد السطحي للسائل لها تأثير كبير على (E_g) و(a)، (U_{br})، (U_{bs})، (d_{vs})، حيث أنه بتقليل الشد السطحي فإن (U_{br}) تزداد ويقل (E_g). زيادة اللزوجة ستؤدي إلى تكوين فقاعات كبيرة وبالتالي يقل (E_g) وكذلك (a) ولكن تزيد من (d_{vs}).تم إيجاد معادلة رياضية لتأثير خواص السائل على (Eg) باستخدام طريقة التحليل.

Introduction

Bubble columns are widely used in chemical process industries, for their simple construction without moving parts, and high-energy efficiency for mass transfer.

Bubble formation are largely dependent on the sparger type. The oriental bubble diameter with the superficial velocity and liquid properties determine the bubble diameter, holdup and circulation patterns (1).

Vandu and R.Krishna (2) studied bubble size and rise velocity in a rectangular slurry bubble column

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https://doi.org/10.30684/etj.25.2.16
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using a porous catalyst. They found that increasing slurry concentration E_g is significantly reduced small bubbles therfore reduced in number.

Mouza, Dalakoglon [(3)], studied the effect of liquid properties on E_g using fast-video technique. A correlation based on dimensionless group for E_g in homogenous regime is proposed.

Vandu, Koops [(4),] studied the volumetric mass transfer coefficient (K_{La}) in a slurry bubble column using paraffin oil. For superficial (gas velocity > 0.1 m/sec), (K_{La}/E_g) was found to be independent of (U_g).

Tsyge, Terasaka [(5),] found a dimensionless equation for the volume of bubble (Vb) formed in highly viscous-Newtonian liquids.

Experimental apparatus and procedure:

The experimental apparatus as shown in fig. (1), consists of a vertical plexiglas column (1.5 m) height, and (0.1 m i.d). The column is equipped with an appropriate rotameter for gas flow measurement and control. For uniform distribution of the gas phase, a gas distributor with a single hole in the middle (2 cm diameter) was placed at the bottom of the column.

Several liquids, whose physical properties are presented in table (1), were employed as the liquid phase.

Liquid phase	Viscosity μ_L (Kg/m.s)	Density r_L (Kg/m^3)	Surface tension σ (N/m)
Water	1.002	998	0.0728
Butanol 1.%wt	0.9	991	0.048
Ethanol 1%wt	1.07	798	0.028
C_9-C_{11} paraffin-oil	0.85	726	0.023.2

Table (1) [(3, 4)] physical properties of the liquid-phase at 25°C

Measurements:

1- Gas holdup (E_g) was estimated by bed expansion (Shah, et al., 1984) [(6).]

$$E_g = \frac{H - H_o}{H} \quad \text{..........(1)}$$

2- Gas superficial velocity (U_g)

$$U_g = \frac{Q}{A} \qquad \text{............(2)}$$

3- Two different correlation were used to estimate the interfacial area (a). (a_{theo}.) was estimated using (Akita & Yoshida) (1974) correlation [(7).]

$$a_1 = \frac{1}{3} D_C \left(\frac{g \cdot D_C^2 \cdot r_L}{s} \right)^{0.5} \left(\frac{g \cdot D_C^3}{u_L^2} \right)^{0.1} E_g^{1.13} \quad \text{...............(3)}$$

(a_{exp}) was estimated using (Shah, et al., 1982) [(8)]

$$a_2 = \frac{6 E_g}{d_{vs}} \qquad \text{...............(4)}$$

$$d_{vs} = 26 D_c \left(\frac{D_c^2 . g . r_L}{s} \right)^{-0.5} \left(\frac{g . D_c^3}{u_L^2} \right)^{-0.12} \left(\frac{U_g}{\sqrt{g . D_c}} \right)^{-0.12} \quad \text{........................(5)}$$

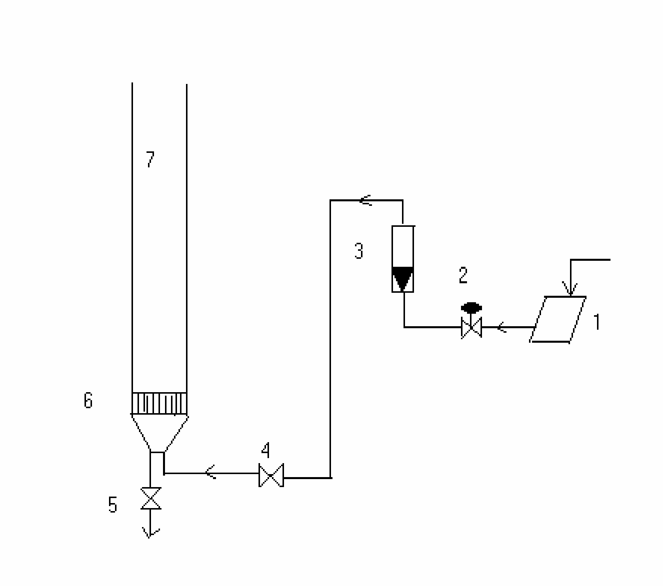
4- Bubble rise velocity (U_{br}), was found using drift flux model of Zuber and Findley (1965) (9)

$$\frac{U_g}{E_g} = C_o + U_g + U_{br}$$

A plot of (U_g/E_g) us (U_g), (U_{br}) can be found from the intersection of (U_g/E_g) axis's.

5- Small bubble rise velocity (U_{bs}), was estimated using (J.C. Schouten) correlation (2003) (10).

$$U_{bs} = \frac{U_g}{E_g(1 - E_g)} \quad ......(6) \quad \text{for } U_g < U_{tran.}$$



1- Compressor
2- Needle valve
3- Rotameter
4,5- Valves
6- Gas distributor
7- Column

Fig. (1) Experimental-Apparatus

Experimental results and discussion

1) **Gas holdup**

In fig. (2), the data are plotted in terms of gas holdup vs gas superficial velocity for different liquid phases.

The first part of the curve corresponds to the homogenous regime, where the gas holdup increases with the gas velocity. A transition regime follows where a slight decrease in gas holdup is observed. Finally, at the heterogeneous regime the gas holdup continues to increase but with a lower slope than the homogenous regime. In the homogenous regime, as the gas holdup increases the hindrance progressively reduces the bubble velocity leading to further increases in the gas holdup.

The opposite holds true for the heterogeneous regime, where the bubble velocity increases in the central core of the column and this lead to the large-scale circulation patterns of liquid and gas resulting in a decrease in the gas holdup with (U_g) due to very large bubbles existing as a result of coalescence.The results agreed with results pointed by Ruzicka, et al., (2003). (12)

2) Gas liquid interfacial area

The optimum operating conditions of bubble column would be the ones that enhance mass transfer and this is accomplished by maximizing the gas/liquid interfacial area.

As in fig. (3), the homogenous-bubbly flow regime encountered at the lower gas flow rates is most desirable for mass transfer operations, since by exhibiting a large gas holdup valve accompanied by relatively small bubble size, provides a greater interfacial area. Variation between a_1 and a_2 due to physical properties of liquid phase in the formation of the correlation. It can be seen that increasing viscosity will decrease (a) due to reducing (E_g).

3) **Liquid properties**

3-1) **Viscosity of the liquid**

Gas holdup is very dependant on the viscosity of the liquid, where a high viscosity leads to large bubbles and therefore to low gas holdup, a_1 shown in fig. (2). An increase in viscosity hinders film drainage during the thinning process and thus inhibits coalescence. However a further increase of liquid viscosity leads to decrease of turbulence in the liquid phase favoring large bubble formation by coalescence, which leads to an increase of the larger bubble number at expense of the smaller ones. From fig.(3),it can be seen that increasing viscosity will decrease (a) due to reducing (E_g) .

3-2) **Surface tension**

The effect of surface tension on gas holdup can be qualitatively described in that a lower surface tension gives a lower bubble rise velocity and therefore a higher holdup, as shown in figs (2, 4, 5), besides an increase in liquid phase viscosity shifts the transition point to slightly higher velocities.

The only exception is water whose transition velocity is lower than that of Butanol solution despite its slightly higher viscosity, this behavior can be attributed to the simultaneous effects of both relatively low viscosity and high surface tension, as shown in table (2) .

The results are in a good agreement with results reported by (Mouza & Dalakoglou) (2005) (3).

4) **Small Bubble diameter**

Mean bubble size depends on the liquid properties which may either promote or inhibit coalescence of the primary bubbles formed . Generally bubbles coalescence occurs by collision , liquid film drainage(controlling step) and rupture (almost instantaneous). Bubble coalescence is a function of contact time between bubbles and U_{br}. As shown in Fig.(6), (d_{vs}) increases as U_g increases, this is because of higher U_{br} and lower E_g , therefore bubble diameter increase. Results agreed in behavior with results reported by J. Zahraduik (1997)(13) , who studied the effect of liquid properties on flow regime in bubble column as a function of d_{vs} , U_{br} , E_g and U_g .

5) **Small bubble rise velocity**

Figure (5) shows the relation between gas velocity and bubble rise velocity. In a homogenous regime due to formation of almost small bubbles, the bubble rise velocity is large. In heterogenous regimes, bubbles will grow larger due to coalescence, this will reduce the increase in the bubble velocity less than in a homogenous regime.

6) <u>Correlation obtained using dimensionless analysis</u>

In order to formulate a generalized correlation that would incorporate the relative effects of all the above factors, dimensionless analysis was used.

Gas holdup (E_g)

$$E_g = f(U_g, s, m, r_L, g, D_C)$$

$$E_g = C_O \cdot F_r \cdot E_O \cdot A_r \left(\frac{d_O}{D_C} \right)^f$$

$$E_g = 0.0012 \ F_r^{0.38} \ A_r^{0.062} \ E_o^{1.5} \ (d_o / D_c)^{0.55}$$

The Proposed correlation have been achieved by using statistical analysis software and found a good agreement with available data for the homogenous regime.From the correlation obtained it can be seen that the E_o and F_r are more effect than A_r , which mean that the effect of surface tention and superfacial gas vcelocity are more effective than liquid density and viscosity on gas holdup.

Conclusions

In a bubbles column, the homogenous flow regime is usually the most desirable, because it enhances the efficiency of equipment by providing a great gas liquid interfacial area. It was found that an increase in gas flow rate increases bubble collision probability resulting in greater bubble size.

An increase in liquid viscosity favors larger bubble formation by decreasing turbulence, a fact that both promotes bubble coalescence and hinders breakage.

Increasing surface tension favors small bubble formation by promoting breakage and demoting coalescence.

Correlation for E_g was proposed, combinning the effect of liquid properties on E_g.

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Nomenclature

A	Cross-sectional Area	m^2
Ar	Archimedes number	$D_C^3\rho_L^2 g/\ \mu_L^2$ (-)
a_1 and a_2	Interfacial area	m^{-1}
C_o	Distribution coefficient	(-)
D_C	Column diameter	m
do	Hole diameter of distributor	m
d_{vs}	Sauter mean bubble diameter	m
E_g	Gas holdup	(-)
E_0	Eotovs number $D_C^2\rho_L g/\sigma_L$	(-)
Fr	Froude number $\frac{U_G}{\sqrt{gD_C}}$	(-)
g	Acceleration of gravity	m/s^2
H	Dispersion height due to the presence of bubbles	m
H_o	Ungassed column height	m
Q	Gas-flow rate	m^3/s
U_g	Superfacial gas velocity	m/s
U_{br}	Bubble rise velocity	m/s
U_{bs}	Small bubble rise velocity	m/s

Greek Letters

m_L	Liquid viscosity	Pa.s
r_L	Liquid density	Kg/m^3
s	Surface tension	N/m

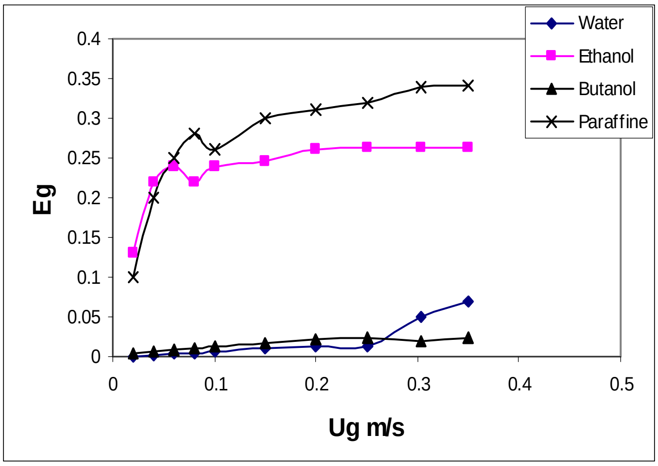

Figure (2) Gas holdup vs gas velocity for different liquid-phase

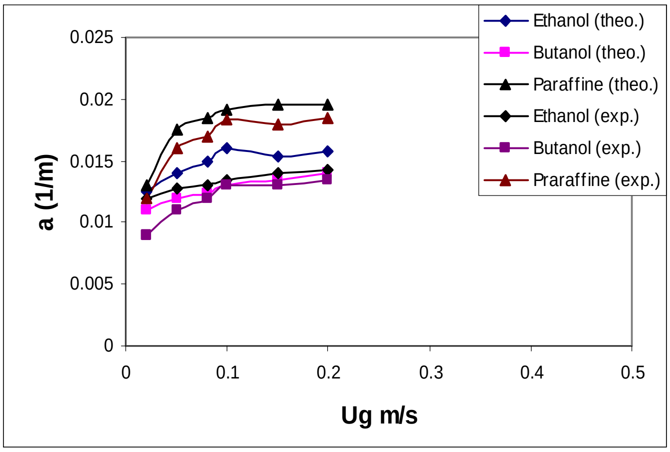

Figure (3) Gas velocity vs interfacial area (theo. and exp.) for different liquid-phase

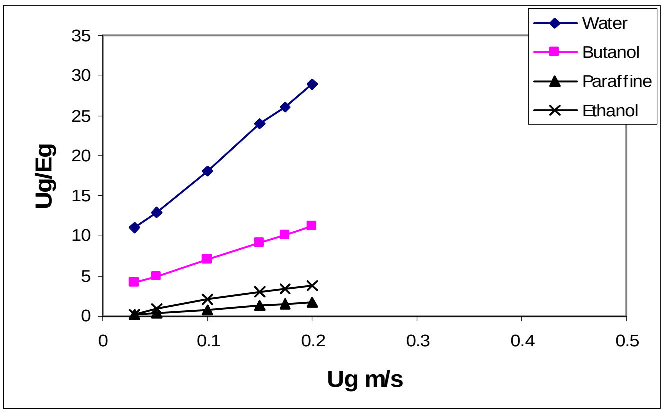

Figure (4) Gas velocity vs (Ug/Eg) for different liquid-phase

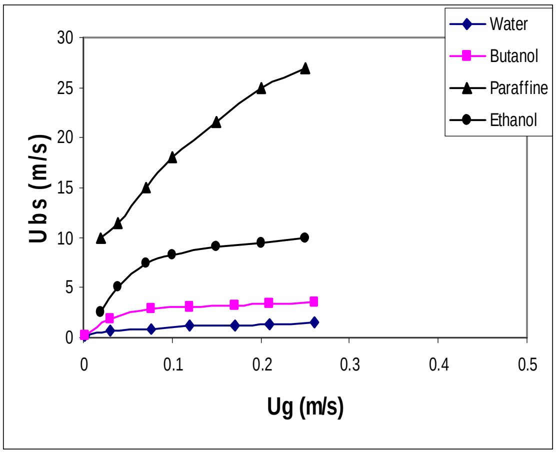

Figure (5) Small Bubble rise velocity vs gas velocity for different liquid-phase

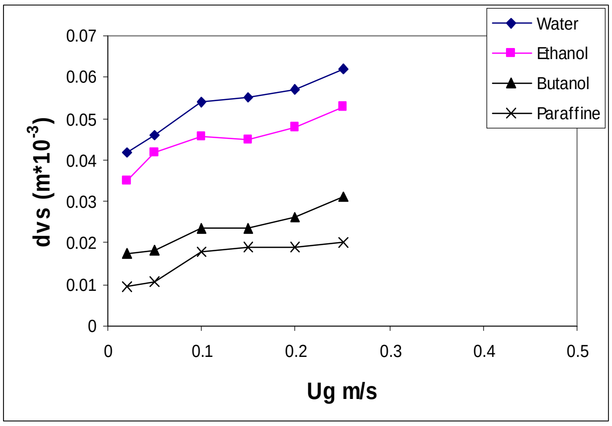

Figure (6) Small Bubble diameter vs gas velocity for different liquid-phase

Liquid Phase	**Ug (m/s)**	Eg
Water	**0.2**	0.014
Butanol	**0.25**	0.022
Ethanol	**0.05**	0.24
Paraffin – Oil	**0.075**	**0.27**

Table (2) Transition Points for Different Liquid Phases .