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Effect of Adding Alcohols and Gas Velocity on Gas Hold up and Mass Transfer Coefficient in Bubble Columns with Draught Tube

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Abstract

The bubble columns are widely used as a two or three phase reactor in industrial chemical process such as absorption, biochemical reactions, coal liquefaction, etc. To design such a column, two main parameters should be taken in consideration, the gas hold-up (ε_g), and the liquid phase mass transfer coefficient K_{La}. The study includes the effect of gas velocity and the addition of alcohols on gas hold-up and mass transfer coefficient in bubble column with draught tube when the length of the column is 1.5m and the ratio of the draught tube diameter to the column diameter equals 0.5 and the air dispersion into the base of the draught tube using a multi hole tuyere is equivalent to a diameter of 0.15 mm and has a free sectional distributor area of 61%.

Water and three aqueous solutions of 10% concentration methanol, ethanol and isopropanol, were used as the liquid phase. The various gas velocity (0.01-0.1) meter/sec are used and the results were compared in case of using water only without the addition of alcohols. From experimental observations, ε_g and K_{La} increase with increasing gas velocity and with the coalescence inhibition of liquid.

Keyword: *Alcohols, Gas velocity, Gas hold up, Mass transfer, Bubble column*

1. Introduction

The bubble column is widely used in industry as a simple and relatively inexpensive means of achieving intimate gas-liquid contact. Gas is bubbled into a deep pool of liquid in cocurrent or countercurrent flow and is dispersed as a bubble swarm of high interfacial area. The absorption may be accompanied by a chemical reaction.

The output from such a reactor is obviously influenced by gas hold-up, by interfacial area and by the internal circulation of liquid induced by the bubbles.

In bubble columns the hydrodynamics transport and mixing properties depends strongly on the prevailing flow regime.

Many investigators have proposed different criteria to differentiate flow regime (Shah et al 1982). Hyndman (1997) has characterized the upward movement of the bubble swarms into three separate flow regimes.

The type of gas distributor physicochemical properties of the liquid can affect the transition between the flow regimes (Thorat et al 2004).

In past decades, a number of attempts were made to describe the flow pattern in the liquid phase of a bubble column. However, liquid circulation velocity depends upon many flows interrelated parameters, e.g flow regime, gas hold-up, bubble size and bubble rise velocity in addition to physical properties of liquid.

The liquid phase flow pattern in bubble column was qualitatively described by Kawagoe K, (1976) and by Schumpe A, and Grund, G.R. (1986), who identified the existence of two streams in the column: one heading upwards driven by the buoyancy of gas bubbles and the other carrying the liquid down. Normally, the rising stream would be centrally located, but instabilities are likely to occur.

Gas hold-up is one of the most important parameter characterizing the hydrodynamics of the gas bubble columns.

It can be defined as the fraction by volume of the gas phase in two and three phase mixtures in the column.

A large number of correlations for gas hold-up have been proposed in the literature (see for example shah et al 1982 and Pandit and Joshi 1984).

The simple relationship between the gas hold-up and gas superficial velocity for limited range of operating conditions, is given by:

$$\varepsilon_g \ \alpha \ V_g^n$$

The value of n depends on flow regime (shah et al 1982) bubble flow 0.7 < n < 1.2 and churn turbulent 0.4 < n < 0.7.

The gas hold-up profile is parabolic with a maximum at the center (pandit and Joshi 1984, Wu,y. 2001).

A number of investigators also reported a decrease in the gas hold-up with an increase in liquid viscosity.

Godbole et al (1984) proposed a correlation for churn turbulent regime.

Miyahara et al (1986) have given the gas hold-up in draught tube using a sieve plate without liquid flow as follows:

$$\frac{(1-\varepsilon_g)}{\varepsilon_g} = 0.4Fr^{-1/2} d_o / H_F \le 3\times10^{-3} m$$

Several studies (Mashelkar, 1970, Deckwer et al. 1974; Urza and Jackson, 1975; Burckart and Deckwer 1976; Maclean et al. 1977; Schugerl et al. 1977; Shiaya and Dunn 1978; Alvarez Cuenca et al. 1980; Mangart and Pilhofer, 1981; Koide et al 1984 and Haque et al. 1987) indicate that the knowledge of the residence time distribution of the phases is necessary to determine the volumetric mass transfer coefficient, K_{La}.

The assumption of complete mixing is only justified in large diameter columns, say $D_c \geq 0.1$m.

In tall and small diameter bubble columns the determination of K_{La} should be based on the concentration profile measured at cocurrent or counter-current flow along the column and evaluated by means of the axial dispersion model (Deckwer et al. 1974, Schugerl et al. 1977 and Mangartz and Pilhofer 1981).

However, evaluation of the liquid phase concentration profiles can only be used in the presence of a large concentration difference along the column. This can be achieved by moderate gas velocities (usually $V_g < 0.1$ m/sec) or high liquid flow rates.

Volumetric mass transfer coefficients depend on the gas velocity, and the sparger design and are sensitive to the physicochemical properties, particularly, those which promote or prevent coalescence. In addition, the column diameter has some influence if it is small say, $D_c \leq 0.15$ m. Furthermore, the KLa values may vary spatially. Deckwer et al (1974) proposed an empirical correlation of type

$$K_{La} = bV_g^n$$

This equation can be recommended with n = 0.8, but the constant b depends sensitively on the type of sparger and liquid media.

Deckwer et al (1981) proposed an empirical correlation for oxygen mass transfer in highly viscous Newtonian and non-Newtonian liquids in bubble columns;

$$K_{La} = 0.00315 V_g^{0.59} \mu_{eff}^{-0.84}$$

2. Purpose

This paper presents a study of the effects of gas velocity and the addition of alcohols to liquid phase on gas hold-up and mass transfer rate for the case that the ratio of draught tube diameter to column diameter is equal to 0.5 and the air is sparged into the base of the draught tube using aqueous solutions differing in coalescence behaviour.

3. Experimental Section

A schematic diagram of the experimental set-up used in this work is shown in Figures (1, 1.1, and 1.3).

Aplexiglass column of an inside diameter of 0.15 m and about a total height of 1.50 m with draught tube dimensions inside diameter of 0.075 m and a total height 1.20 m was used.

The draught tube was fitted with three support legs at the upper and the lower end of the column so as to locate it in central position at any distance above the base.

The column consists of two main sections, namely: the gas inlet section and the liquid recycling testing section. The gas inlet section consists of a gas distributor.

At the bottom of this section, two lines are connected together before entering the distributor section each line has a valve to be opened or closed as required.

One of these lines is the air inlet flow.

Air compressor supplied the line with the desired amount of air needed; for the experiment, the amount of air was measured using a gas meter, and two calibrated rotamaters connected in parallel were used to measure the air flow rate.

The other line is the nitrogen gas inlet flow. The nitrogen was supplied from a cylinder.

A gate valve was used in the nitrogen flow, which must be shut off when air was sparged to the column, and must be opened during desorption process.

The liquid testing section contains two openings, one for liquid out-flow and the other for liquid in flow.

The circulation of liquid in the column was achieved using a centrifugal pump placed in the recycling line. A ball valve placed in the middle of the recycling line was used to take various samples at various times to measure the concentration of the dissolved oxygen during the operation.

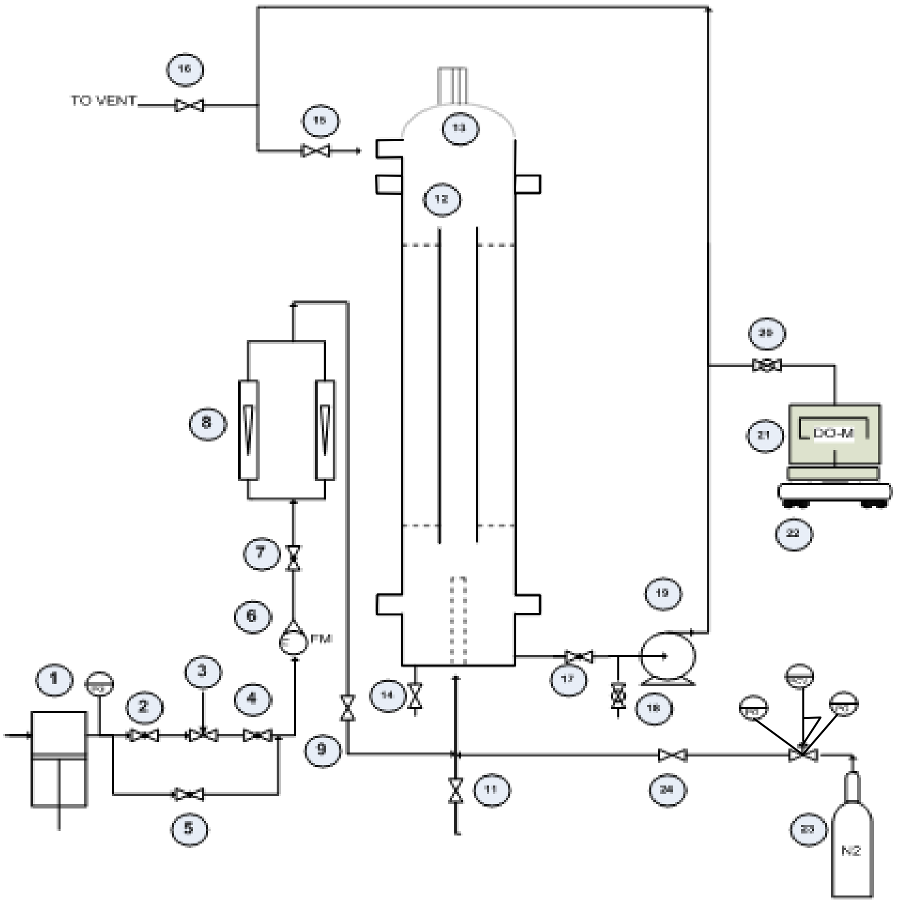

Fig. 1. Experimental-Apparatus, **1: Air compressor, 2, 4, 5, 7, 17: Globe valves, 3: Needle valve, 6: Gas meter, 8: Gas rotameter, 9: Two-way valve, 10: Gas distributor, 11, 14, 15, 16 ,24: Gate valves, 12: Draught tube, 13: Column, 18, 20: Ball valves, 19: Centrifugal pump, 21: Dissolved oxygen meter (Do-m), 22: Move table, 23: Nitrogen cylinder, PG, PCV: Pressure control valve pressure Gauge**

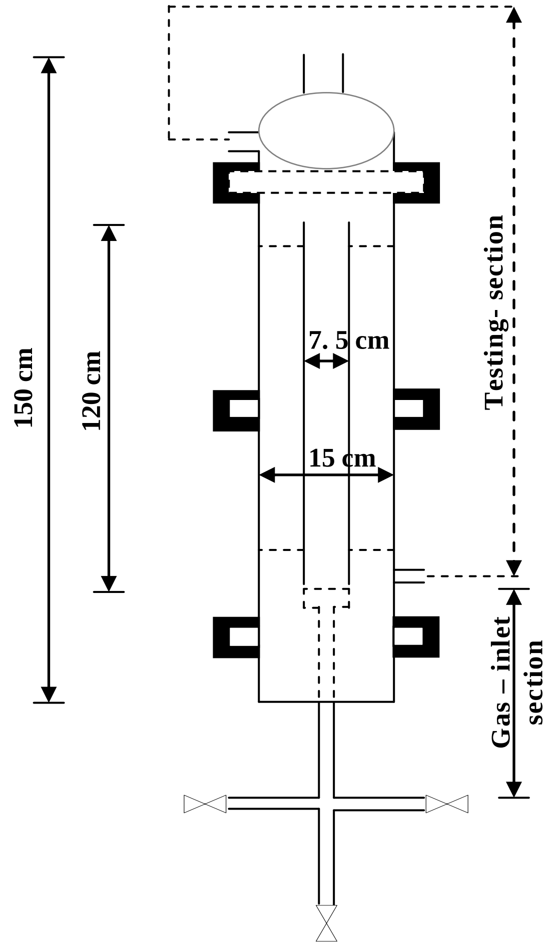

Fig. 1.1. Column

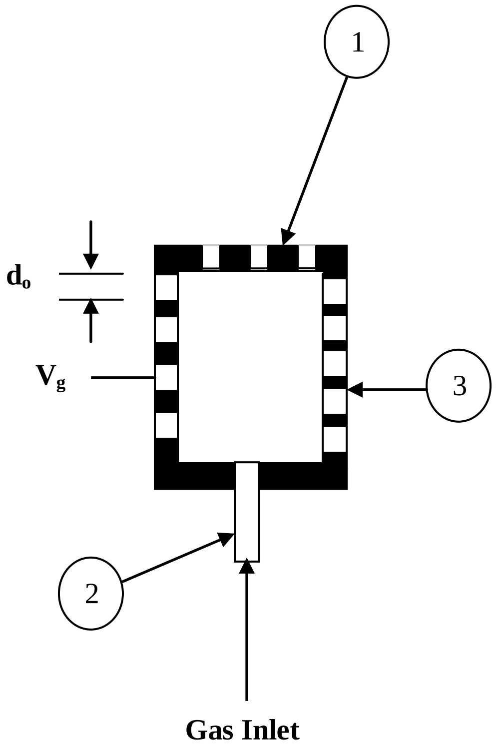

Fig. 1.2. Gas-distributor,
1: Ceramic material, 2: Pipe, 3: Hole.

The water is fed to the top of the column and discharged from the bottom of the column using a centrifugal pump. Compressed air at (100-150) psig was supplied using a reciprocating compressor.

The desired air flow rate was set-up using needle valve and the amount was measured with a gas meter.

Table 1,
Physical Properties for Pure Liquids at T=25°C

Liquid phase	ρ kg/m^3×10^3	μ pa.s×10^{-3}	σ N/m	ν_l cm^2/sec
water	0.998	0.997	0.072	0.8986
methanol	0.791	0.83	0.070	0.566
ethanol	0.789	1.003	0.068	0.9085
Iso-propanol	0.785	0.85	0.066	0.9792

The dissolved oxygen concentration in the liquid phase was measured using oxygen meter, which consists of a gold metal electrode. The liquid phase (batch) consists of the following systems (only water, water-methanol, water-ethanol, water-iso propanol).

The gas distributor in Fig (1.2) was constructed from a ceramic material and the type is a multi hole tuyere.

The distributor has equivalent pore diameter of 0.15 mm and a free section of 0.61%.

Table 2,
Physical Properties for Mixtures Used With Various Concentrations at T=25°C

Liquid phase	ρ kg/m^3×10^3	μ pa.s×10^{-3}	σ N/m	ν_l cm^2/sec
Water-methanol 10%	0.9815	0.795	0.067	0.8226
Water-ethanol 10%	0.9817	0.910	0.065	0.9400
Water-iso-prpanol 10%	0.982	0.972	0.062	0.8932

Fig. 1.3 Column

4. Results on gas hold-up

The average gas hold-up ε_g was calculated in equation (1) using the data of clear-liquid height H_L and the height of the aerated liquid H_f which were determined by visual observation.

$$\varepsilon_g = \frac{H_f - H_L}{H_f} \qquad \text{... (1)}$$

The experimental gas hold-up was found by measuring the difference between initial liquid height and final liquid height.

Since it was rather difficult to read directly the level of the aerated liquid, the values of gas hold-up obtained probably involves an error of about 5%, established via repeated measurements.

Fig (2) shows the influence of gas velocity for the different liquid phase systems used.

The gas hold-up was found to increase with increasing gas through, but interact mutually, depending on the liquid phase properties.

The gas hold-up of isopropanol solution is roughly twice as that of pure water for aqueous solutions of aliphatic alcohols; a considerable increase in the gas hold-up with alcohol chain length was observed.

The gas hold-up decreased in the following order iso propanol> ethanol > methanol. The decrease in surface tension in the presence of alcohols were not sufficient to explain this phenomenon.

Bubble dynamics and bubble swarm structure in the presence of surfactant solutions can explain this behaviour qualitatively.

In the presence of alcohols, the bubbles become rigid and hence have low rise velocities resulting in a bubbly flow regime up to surprisingly high gas velocities (0.08-0.1 m/sec).

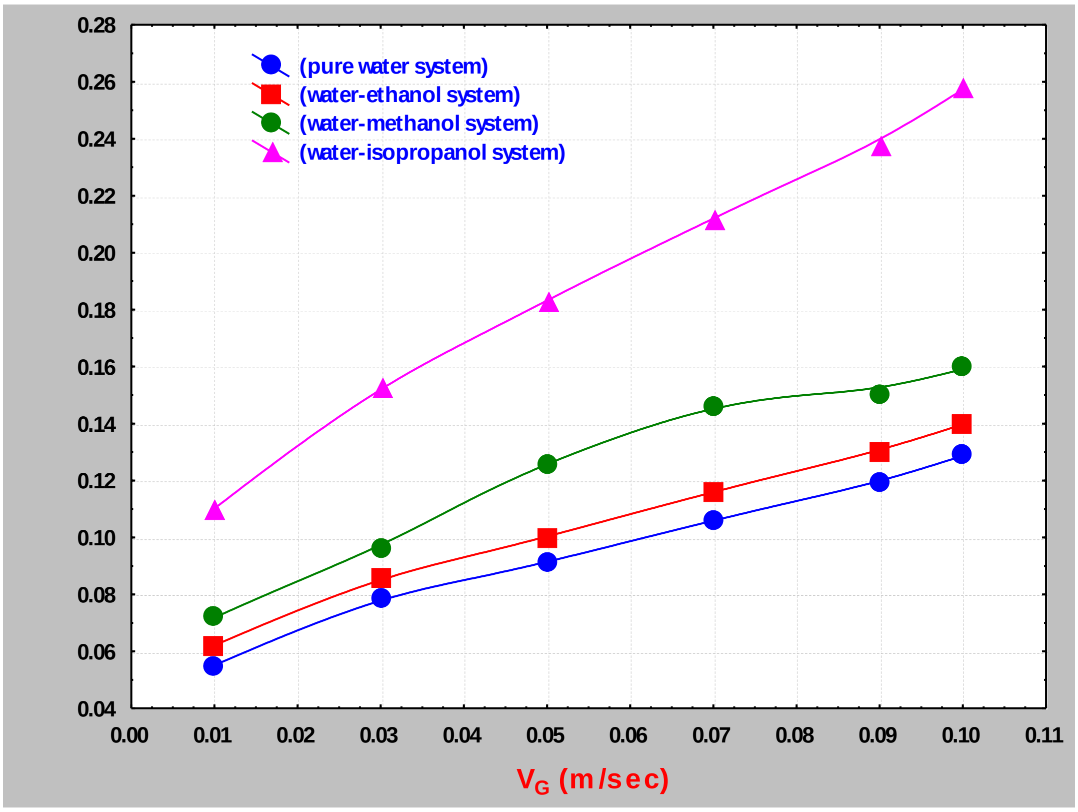

Fig. 2. Gas Hold-up vs. Gas Velocity for Various Systems

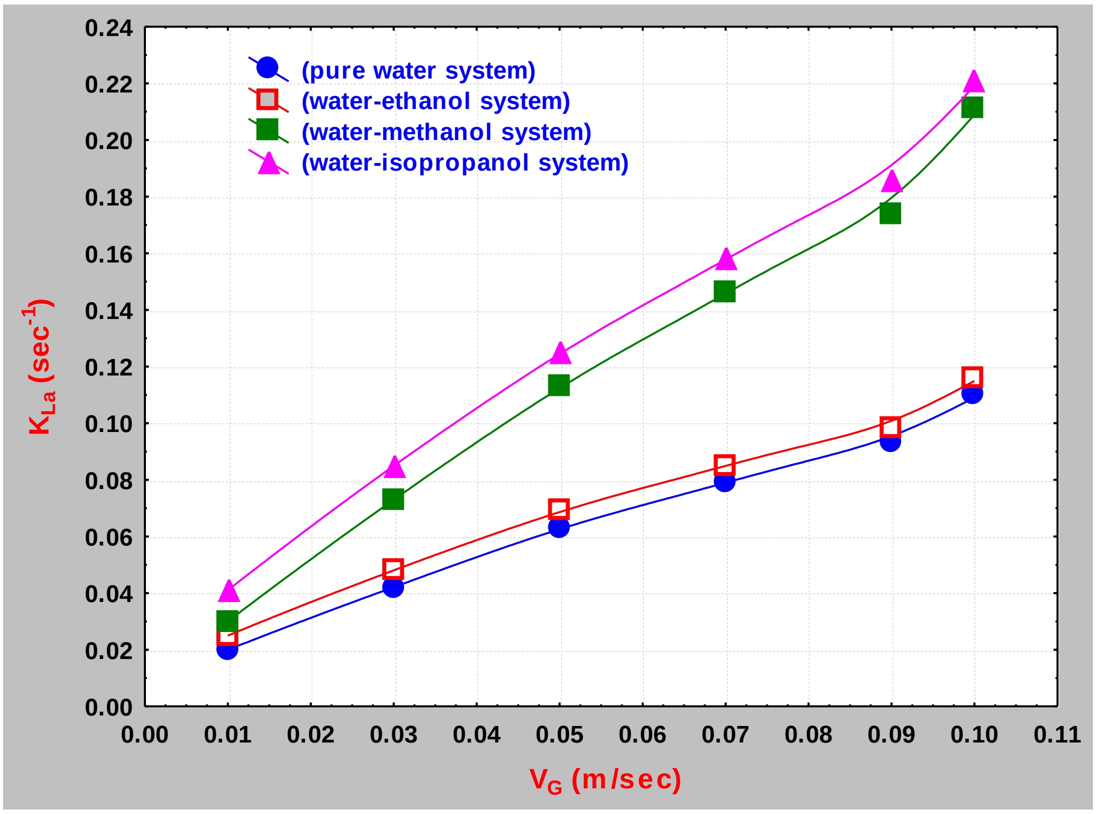

Fig. 3. Mass Transfer Coefficient vs. Gas Velocity for Various Systems

5. Mass transfer coefficient results

The physical absorption of oxygen in the air by liquid was employed to determine the mass transfer coefficient.

The mass transfer coefficient K_{La} was calculated using equation (2).

The results will be expressed as (K_{La}) exp.

The volumetric mass transfer coefficient K_{La} is a function of gas hold-up and mean bubble size.

Fig (3) shows the influence of gas velocity, for different liquid phase systems used.

The K_{La} values for water increases with increasing gas velocity because of the increase of the axial dispersion coefficient D_L.

$$Log\frac{C_{Sa}-C_i}{C_{Sa}-C_o}=\frac{K_{La}}{2.303(1-\varepsilon_g)}\times t \qquad \dots (2)$$

A similar dependence of KLa on gas velocity was observed for all other liquid phase systems.

On account of the strong coalescence inhibition the volumetric mass transfer in (water-isopropanol) system reaches twice the values of pure water.

For aqueous solutions of aliphatic alcohols, (Ethanol Methanol), the bubbles become more rigid and hence low rise velocities and bubbles coalescence were obtained so that the mass transfer coefficients were larger in water.

6. Conclusions

From the present study the following conclusions were made:

1- The gas hold-up and mass transfer coefficient increase with increasing gas velocity for $V_g \leq$ 0.1 m/sec.
2- Gas hold-up and mass transfer coefficient decrease with increasing liquid surface tension.

Nomenclature

C_i = Concentration of dissolved oxygen at any time (ppm).

C_o = Initial concentration of dissolved oxygen (ppm).

C_{sa} = Saturated concentration of dissolved oxygen (ppm).

D = Column diameter (m).

d_o = Hole diameter of gas sparger (m).

D_L = Liquid phase axial dispersion coefficient (m^2 /sec).

Fr = Orifice froud number $\frac{V_g^2}{g.d_o}$.

g = Acceleration due to gravity (m/sec^2).

H_f = Level of aerated liquid during operation (m).

H_L = Clear-liquid height (m).

K_{La} = Over all mass transfer coefficient (sec^{-1}).

t = Time (min).

V_G or Vg = Superficial gas velocity (m/sec).

Greek latters

ε = Hold-up (fractional volume).

μ = Dynamic viscosity (pa.s)

ν_l = kinematic viscosity (cm^2/sec)

σ = Surface tension (N/m).

Subscripts

G = Gas.

L = Liquid.

7. References

[1] Akita, K. and F.Yoshida: Ind. Eng. Chem., Process Des. Develop., 16, 76 (1984).

[2] Alvarez-cunca, M., and M. A. Nerenbreg, “Oxygen Mass Transfer in Bubble Columns Working at an Liquid Flow Rates”, AICHEJ., 27, 66 (1980).

[3] Brennan, R., D., Cosserat and J. C. Carpentier, “Influence of column diameters of high gas through puts on the operation of a bubble column”, the chemical engineering journal, 16, 115 (1978).

[4] Burekhart, R., and W. D. Deckwer, “Bubble size distribution and interfacial areas of electrolyte solutions in bubble columns” chem.. eng. sci, 30, 351 (1976).

[5] Calderbank, P. H., chemical engineer, 45, 225 (1976) (Kara et al 1982).

[6] Deckwer, W. D., Burckhart, R. and zoll, G., “mixing and mass transfer in tall bubble columns” chem.. eng. sci. 29, 2177-2188 (1974).

[7] Franz , K., Borner, T., Kantorek, H. J. and Buchholz, R., “flow structures in bubble columns”, Ger. chem. eng., 365-374 (1984).

[8] Godbole, S. P., Schumpe, A., Shah, Y.T. and carr, N.L., “Hyrodynamics and mass transfer in non-newtonian solutions in a bubble column”, AICHE J., 30 (20) 213-220 (1984).

[9] Guy C., Carreau, P. J. and paris, J., “Mixing characteristics and gas hold-up of bubble column” can.S. chem..eng. 64(2), 23-35 (1986).

[10] Hyndman, C.L., Larachi F, Gay C. “Understanding gas-phase hydrodynamics in bubble columns”, chem.. eng. sci 52, 63-77 (1997).

[11] Kawagoe, K., Inoue, T., Nakao. “Flow-Pattern and gas hold-up conditions in gas-sparged contactors” int. J. Chem. eng. 16, (176-183) (1976).

[12] Koide, K., Takazawa, A., Komura, M. and Matsunage, H. “Gas hold-up of volumetric liquid phase mass transfer in solid suspended bubble columns”, J. Chem. Eng. Japan, 17 (5) 459- 466 (1984).

[13] Maclean, G.F., L. E. Erickson, K. H. Hsu, and L. T. Fan, “oxygen transfer and axial desperation in an aeration tower containing Static mixers”, Biotechn. Bioengng. 19, 493 (1977).

[14] Mangertz, K. H., and Pilhofer, “Interpretation of mass transfer measurements in bubble columns

considering desperation of both phases", chem.. eng. sci., 36, 1069 (1981).

[15] Mashelkar, R.A., and M.M. Sharma, "Mass transfer in bubble columns", trans. inst. chem. eng., 48, T162 (1970).

[16] Pandit, A.B. and Joshi, J.B., "Mixing in mechanically agitated gas liquid contactors, bubble columns and modified bubble columns", chem. eng. sci., 8, 1189-1215 (1982).

[17] Pandit, A.B. and Joshi, J.B., "Three phase sparged reactions, some design aspects", Rev. chem. eng., 2, 1-84 (1984).

[18] Schumpe, A., Grund, G. "The gas disengagement technique for studying gas hold-up structure in bubble column", can. J. Chem. Eng. 64, (891-896) (1986).

[19] Schugerl, K., J. Lucke, and U. Oels, "bubble column bioreactions", Adv. Biochem. eng., ed., T. K. Ghose, A. Fiechter, and N. Blakeborogh, 7, 1 (1977).

[20] Shah, Y. T., Kelkar, B. G., Godbole, S. P. and Deckwer, W. D., "Design parameters estimation for bubble column reactors", AICHE, J., 28 (3), 353-379(1982).

[21] Shiaya, S., and I. J. Duna, "Dynamic oxygen mass transfer coefficient measurement method for column reactors", chem.. eng. sci., 33, 1529 (1978).

[22] Thorat, B. N., Joshi, J. B., "Regime transition in bubble columns", sci 28, 423-430 (2004).

[23] Urza, I. J., and Jackson, "pressure aeration in a 55-ft bubble column", ind. eng. chem. process des. dev., 14, 106 (1975).

[24] Wu, Y., Ong, B. J., AL-Dahhan, M. H. "Prediction of gas hold-up profiles in bubble column reactors", chem. eng. sci., 30, 1207-1210 (2001).

تأثير اضافة الكحولات وسرعة الغاز على زمن احتجاز الغاز ومعامل انتقال الكتلة في العمود الفقاعي ذو الانبوب الداخلي

علي عبد الرحمن نجم
قسم الهندسة الكيمياوي / الجامعة التكنولوجية

الخلاصة

لقد شاع أسنخدام الاعمدة الفقاعية كمفاعلات ثنائية او ثلاثية الطور في أغلب العمليات الكيميائية الصناعية مثال على ذلك عمليات الامتصاص والتفاعلات البايوكيميائية واسالة الفحم وغيرها. في مثل هذه الاعمدة يحب الاخذبنظر الاعتبار عاملين مهمين هما نسبة احتجاز الغاز (ε_g) ومعامل أنتقال الكتلة (K_{La}).

يتضمن البحث دراسة تأثير أضافة الكحولات وتغير سرعة الغاز على نسبة احتجاز الغاز (ε_g) ومعامل انتقال الكتلة (K_{La}) باستخدام عمود فقاعي (Bubble Column) من نوع (Draught Tube) بطول 1.5 متر ونسبة قطر 0.5 (العمود الداخلي(Draught) الى قطر العمود الخارجي).

استعمل موزع الغاز من نوع (Multi Hole Tuyere) بقطر مكافئ مقداره 0.15 ملم وبمساحة جريان متاحة 61% تم استعمال ثلاثة محاليل للكحولات بتركيز 10% (الميثانول – الايثانول – الايزوبروبانول) حيث استخدمت سرع متعددة للغاز (0.1-0.01) متر/ ثانية وتمت مقارنة النتائج في حالة استخدام الماء فقط دون أضافة الكحولات . اظهرت التجارب العملية انه بزيادة سرعة الهواء والقدرة على منع تجمع الفقاعات يؤدي الى زيادة نسبة احتجاز الغاز (ε_g) ومعامل انتقال الكتلة (K_{La}).
