Studies on Gas Hold-Up , Mass Transfer Coefficient, Mixing Time And Circulation Time In Bubble Columns With Draught Tube For Pseudo Plastic (Carboxymethyl) Cellulose And Glycerol Solutions

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Abstract

Bubble column reactors are widely used in chemical process industries for carrying out gas-liquid and gas-liquid-solid reactions such as absorption, biochemical process and coal liquefaction. To design such a column, four main parameters should by taken in consideration, the gas hold-up (e_g), liquid phase mass transfer coefficient (K_{La}), mixing time (t_m) and circulation time (t_c). The study includes the effect of gas velocity and liquid phase properties [Newtonian and non-Newtonian] on e_g, K_{La}, t_m and t_c in bubble column with draught tube when the ratio of the draught tube diameter to column diameter equal to 0.5 and the gas dispersed into the base of the draught tube by using [amultihole, 0.15mm equivalent diameter and 0.61% free sectional area] distributor.

Water and aqueous solutions of glycerol and CMC [Carboxymethyl Cellulose], were used as the liquid phase [Newtonian and non-Newtonian]. From experimental observations e_g, and K_{La} increased with increasing gas velocity and coalescence inhibition of liquid, while tm and tc decrease with increasing gas velocity.

It was found that increasing liquid viscosity and coalescence reduces e_g and K_{La} but increases t_m and t_c.

دراسةعلى زمن احتجاز الغازومعامل انتقال الكتلة وزمن الخلط وزمن الدوران في الاعمدة الفقاعية مع انبوب داخلي للمحاليل الاحادي مثيل سيليلوز وكليسيرول

الخلاصة

لقد شاع استخدام الاعمدة الفقاعية كمفاعلات ثنائية او ثلاثية الطـور فــي أغلــب العمليــات الكيميائية الصناعية مثال على ذلك الامتصاص والتفاعلات البايوكيميائية واسـالة الفحــم وغيرهـا. لتصميم هذه الاعمدة يجب الاخذ بنظر الاعتبار عدة عوامل مهمة مثل نسبة أحتجاز الغاز e_g ومعامل انتقال الكتلة(K_{La}) , زمن الخلط (tm) وزمن الدوران (tc) يتضمن البحث دراسة تــأثير كــلا مــن سرعة الغاز والخواص الفيزياوية للطور السائل (نيوتوني ام غير نيوتوني) على العوامل التالية :
أولا: - النسبة الحجمية للغاز Gas hold-up
ثانيا: -معامل انتقال الكتلة mass transfer coefficient
ثالثا: -وقت الخلط mixing time

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رابعا : -زمن الدوران circulation time

بأستخدام عمود فقاعي [Bubble column] من نوع [Draught tube] بطول 1.5متر ونسبة قطــر 0.5 (العمود الداخلي draught الى قطر العمود الخارجي).

استعمل موزع الغاز من نـوع [Multi Hole Tuyere] بقطــر مكـــافيء مقــداره 0.15 ملــم وبمساحة جريان متاحة 61% تمت دراسة تاثير تغير اللزوجــة والقـدرة علــى تجميـع الفقاعـات (Coalescence) للطور السائل النيوتوني وكذلك للطور السائل غير النيوتوني حيث استعمل الماء مع محلول الكليسيرول ومحلول كاربوكسيل مثيل سيليلوز (CMC) الغير نيوتوني، تمت مقارنة النتــائج في حالة استخدام الماء مع النتائج المستحصلة في حالة استخدام محلــول الكليــسيرول ذو اللزوجــة العالية اربعة عشر مرة ضعف الماء ويخضع لقانون نيوتن ، وكذلك أجريـت المقارنــة فــي حالــة استخدام محلول كاربوكسي مثيل سيليلوز (CMC) غير النيوتوني (لايخضـع لقانون نيوتن)

بالاضافة الى ذلك تمت دراسة تأثير تغير السرعة على العوامل اعلاه باستخدام سرع مختلفــة (0.01-0.1) متر /ثانية باستخدام نفس المحلولين اعلاه.لقد اظهرت النتائج بصورة عامة انــه بزيــادة سرعة الغاز تزداد قيم كلاً من(e_g)و(K_{La}) وتقل قيمة (t_m) و (t_c) اما في حالة زيـادة كـلاً مــن لزوجة السائل والقدرة على تجميع الفقاعات تؤدي الى نقصان قيم كلاً مــن(e_g) و(K_{La}) وزيــادة قيمة (t_m) و (t_c)

Introduction

The bubble column is widely used in industry as a simple and relatively inexpensive means of achieving intimate gas-liquid contact. Gas is bubble 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 and interfacial area and by 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 interrelated parameters; e.g. flow regime, gas hold-up, bubble size and bubble rise velocity in addition to physical properties of liquid.

The phenomena of liquid circulation is observed very often and mentioned by several authors.

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DeNevers (1968), supposed thatthe liquid circulation is caused by density differences between those parts which are either rich or poor with gas phase.

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 upward 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.

Gopal and sharma (1982) found that the values of liquid circulation velocity for a viscous solution (μ_L = 9.5 mpas) were seen to be lower than those for air-water system.

We can explain the dependence of the liquid circulation velocity in turbulent Flow upon the liquid viscosity by a manner analogous to flow in pipes.

Gas hold-up is one of the most important parameter characterizing the hydrodynamics of 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:

$$e_g \, \alpha \, V_g^{n}$$

The value of n depends on the flow regime (shah et al 1982) bubble flow 0.7 < n < 1.2 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:

$$\frac{\left(1-e_g\right)}{e_g}=0.4Fr^{-1/2}d_o/H_f \leq 3\times10^{-3}m$$

sveral 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 at al 1980; Mangart and Pilhofer, 1981; Koideet al 1984 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 $D_c \geq 1.0$ m.

In tall and small diameter bubble columns the determination of KLa 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, 1977, Schugert et al, 1974; Mangartz and Pilhofer 1981).

However, evaluation of the liquid phase concentration profiles can only be used in the presence of a large

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concentration difference a long 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, the Sparger design and are sensitive to the physico chemical properties, particularly, those which promote or prevent coalescence. In addition, the column diameter has some influence if it is small, say, $Dc \leq 0.15$ m. furthermore, the KLa values may vary spatially.

Deckwer et al, (1974) proposed an empirical correlation of type $K_{La} = b V_g^n$.

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

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

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

Purpose

This paper presents study of the effects of gas velocity, liquid phase properties on gas hold-up, liquid circulation velocity, mass transfer rate and mixing time, 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 and viscosity (Newtonian and non-Newtonian behaviour).

Experimental section

A schematic diagram of the experimental setup in this work isshown in Figures (1, 1.1,1.2).

Aplexiglass column of 0.15 m inside diameter and about 1.50 m total height with draught tube dimensions of 0.075 m inside diameter and 1.20 m total height 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 value to be opened or closed as required.

One of these lines is the air inlet flow. Air compressor supplied the line with the desired a mount of air needed, for the experiment, the amount of air was measured using a gas meter, and two calibrated rota- meters connected in parallel were used to measure the air flow rate.

The other line is the nitrogen gas inlet flow. The nitrogen gas 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

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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.

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 measured with a gas meter.

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 (pure water, water-glycerol, water-CMC (carboxy methyl cellulose)).

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

The distributor has equivalent pore diameter of 0.15 mm and free section of 0.61%. Visual monitoring of acid base reaction between HCl and NaOH was chosen to measure the mixing time.

Phenolphthalein was used as the indicator of the above reaction. The mixing time was taken as the time necessary to obtain complete color change from red to colorless; this technique is reliable (Drennan and Lehrer, 1976).

The method proposed by Guy et al. (1986) was used to determine the circulation time. The circulation time is the time between two successive crossing of tracer particle, in the same direction, through a chosen plane.

The reference plane was chosen to be the medium height plane and the particle was colored tracer of foam of a bout 5 mm diameter, which becomes totally impregnated when, immersed in the liquid and thus reaches the liquid density.

The tracer particle was clearly visible in liquids.

Results on Gas Hold-Up

The average gas hold-up e_g was calculated from 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.

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

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 thus 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 increases with increasing gas through-put, but interact mutually, depending on liquid phase properties.

The viscous solutions of glycerol and CMC show only slightly higher gas hold-up than water.

In spite of similar flow properties of the CMC and glycerol solutions, gas hold-up in the CMC solution is some

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what larger, due to accompanying coalescence inhibiting. In general, low viscosity liquid exhibits bubble disintegration behaviour, whereas, a trend towards bubble coalescing behaviour has been observed with increasing the viscosity of the liquid media, as shown by many investigators (e.g Caderbank 1976, Kara etal, 1982).

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 the different liquid phase systems used.

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

$$Log \frac{C_{sa} - C_i}{C_{sa} - C_o} = \frac{K_{La}}{2.303(1 - e_g)} \times t \quad ..2$$

The mass transfer coefficient in (water-glycerol) system reaches its maximum value at gas velocity of about 0.02 m/sec, owing to the strong coalescence promoting properties of highly viscous liquid, large bubbles are formed already at very small gas throughputs.

The reduction of bubble size with increasing gas velocity is a characteristic feature of pseudo-plastic (water-CMC) system (Haque and Nigam 1987), therefore the mass transfer coefficient are smaller than

that in water, and larger than in (water-glycerol) system.

Mixing Time and Circulation Time Results

It appears that liquid circulation and mixing time depends on many interacting (or interrelated) parameters, e.g, bubble size, bubble rise velocity and gas hold-up in addition to the physical properties of liquid.

The most reliable results for the influence of liquid properties on mixing time and circulation time are given in Fig (4) and (5).

These figures show the effect of gas velocity, for the different liquid phase systems on t_m and t_c.

The figures reveal the following:

1- The mixing time and circulation time for (water-CMC, Water-glycerol) decrease with increasing gas velocity because of increasing viscosity (water-glycerol) system, which has a viscosity 14 times that of pure water, tm and tc are larger than that in water. This is in agreement with literature (e.g. Franz et.al 1984).

2- At high values of gas velocity about 0.1 m/sec the tm and tc of different systems become equal because liquid velocities approach a constant value.

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, only for the case of (water-glycerol) system, the mass transfer coefficient reaches its maximum at gas velocity of 0.02 m/sec.

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2- The mixing time and circulation time decrease with increasing gas velocity for $V_g \leq 0.1$ m/sec.

3- Gas hold-up and mass transfer coefficient decrease with increasing liquid phase viscosity and liquid surface tension.

4- Mixing time and circulation time increase with increasing liquid phase viscosity and liquid surface tension.

Nomenclature

Ci concentration of dissolved oxygen at any time (ppm).

Co Initial concentration of dissolved oxygen (ppm).

Cs Saturated concentration of dissolved oxygen (ppm).

D Column diameter (m).

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

do Hole diameter of gas sparger (m).

Fr Orifice froude number V_{gc}^2 / gdo

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

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

e Hold-up (Fractional volume).

μ Dynamic viscosity (pa.s).

s Surface tension (N/m).

Subscripts

G gas.

L liquid.

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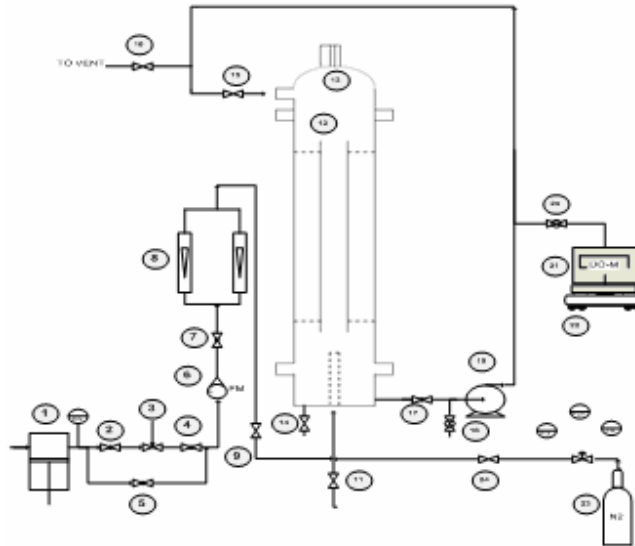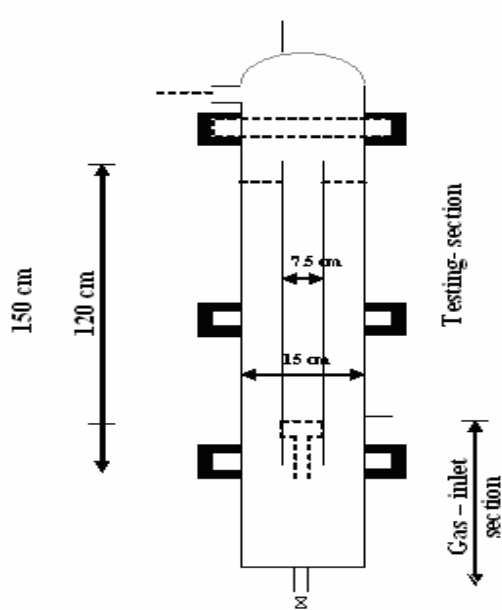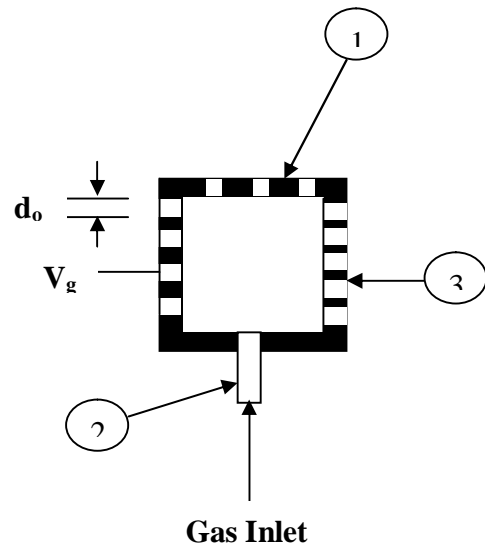Eng. & Tech. Journal, Vol.27, No.12, 2009

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Figure (1) Experimental-Apparatus

Figure (1.1) Column

1-Ceramic material, 2-Pipe, 3- Hole

Figure (1.2) Gas-distributor.

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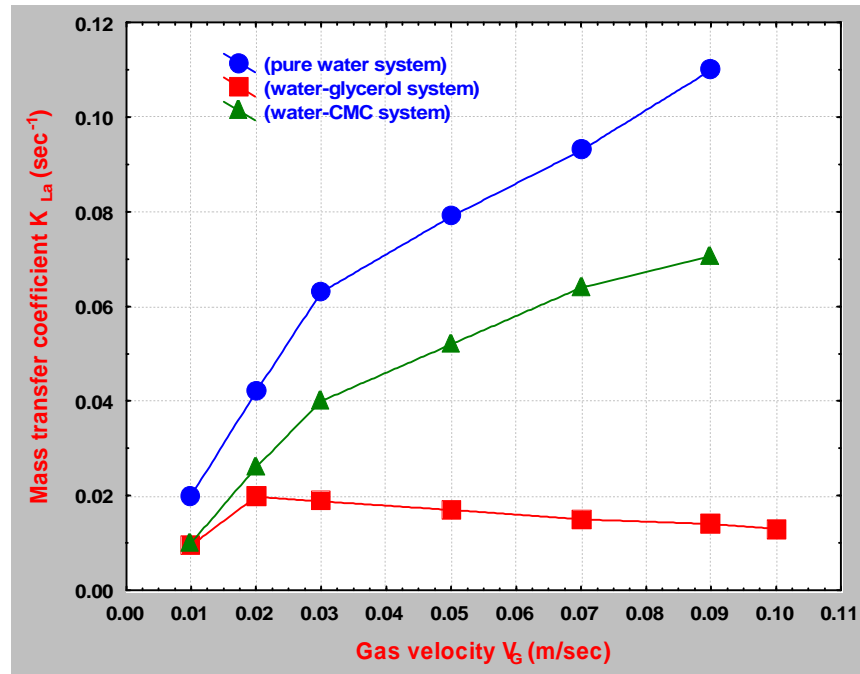Cellulose And Glycerol Solutions**

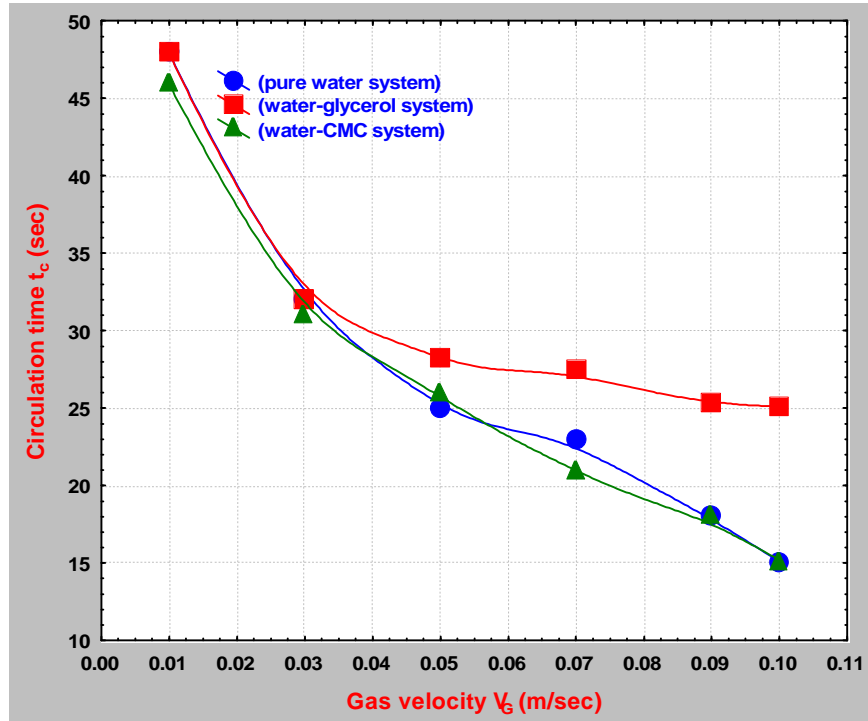**Figure (2) Gas hold-up vs. gas velocity for various systems**

Figure (3) Mass transfer coefficient vs. gas velocity for various systems

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

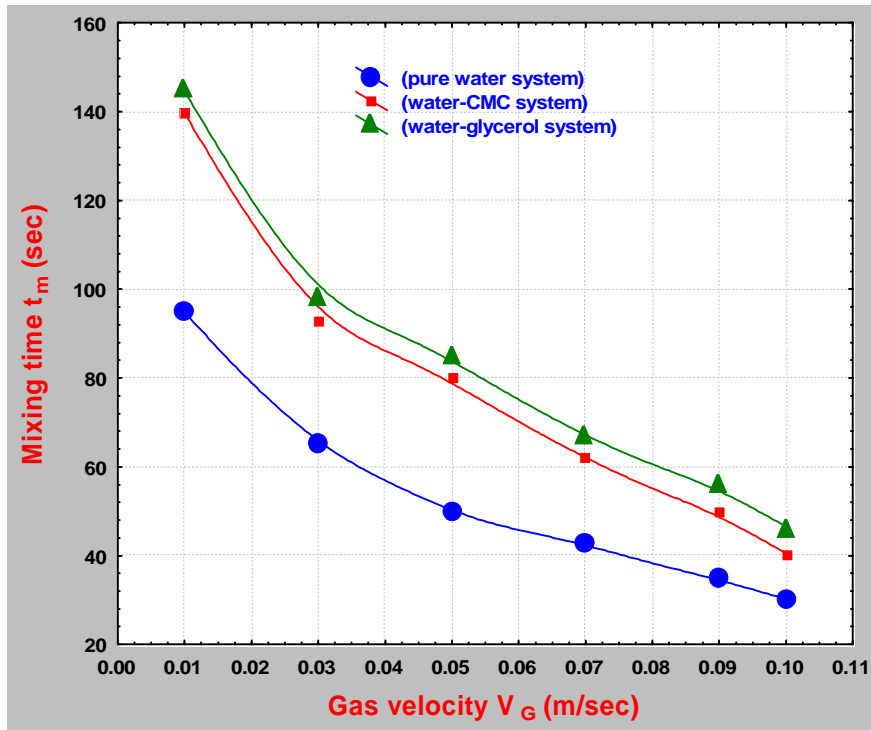**Figure (4) Circulation time vs. gas velocity for various
systems**

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Figure (5) Mixing time vs. gas velocity for various systems