A STUDYOFSOLIDCONCENTRATIONONHOMOGENEOUS – HETEROGENEOUSFLOWREGIMEINBUBBLECOLUMNBYUSINGFOAMINGLIQUID.

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ABSTRACT

Experiments were conducted to study the homogenous – heterogeneous flow regime transition in a bubble column of 0.15m inside diameter for foaming liquid. Aqueous hexanol solution was used as a foaming liquid in the present study. The effects ofhexanol concentration “0.15, 0.25,0.3 wt. %”, solid loading “1, 3, 7,9,11 vol. %”and superficial gas velocity “0.03421 – 0.1226704 m/sec” have been studied in the present work. Alumina oxide was used as the solid phase. Drift flux was used to detect the transition point for homogenous - heterogeneous flow regime. The results show that the gas holdup increases with increasing superficial gas velocity, hexanol concentration and solid loading,while increasing hexanol concentration and solid loading result to delay the transition velocity from homogenous – heterogeneous flow regime.

Keywords: bubble column, slurry bubble column, homogenous – heterogeneous regime, foaming liquid.

NOMENCLATURE

UG superficial gas velocity.

C0 drift flux constant as defined by equation (3)

C1 drift flux constant as defined by equation (4)

H clear liquid height

HF created liquid height

GREEKSYMBOLS

εG Gas holdup

ρL Liquid density, (kg/m3)

μ Viscosity, (Pa.s)

M.wt. MolecularWight (kg/kmal)

D Diameter (mm)

εPorosity (-)

AsSurface area (kg/m3)

PbBulk density (kg/m3)

INTRODUCTION

Bubble columns are intensively used as multiphase contactors and reactor in chemical, biochemical and petrochemical industries (1).In bubble column reactors there are two principle flow regimes: homogeneous and heterogeneous flow regimes (2).

Homogeneous (bubbly) flow regime was characterized by bubbles of relatively uniform small size and rise velocities(3).Uniform bubble distribution and relatively gentle mixing are observed over the entire cross – sectional area of the column(4).

Heterogeneous (churn) flow regime was characterized by disturbed form of the homogeneous gas – liquid system due to enhanced turbulent motion of gas bubbles and liquid recirculation. As a result unsteady flow patterns and large bubbles with short residence time bare formed by coalescence due to high gas throughputs(3).

The homogeneous – heterogeneous flow regime transition is a gradual process of increasing the number of size of coherent structures (circulations) in the bubble bed. The transition is intermittent in the bubble column. The two flow regimes can be identified from the character of the experimental gas holdup(εG) verses gas flow rate (UG) graph of drift flux model.Bubble column reactors have different behaviour in the homogeneous and heterogeneous regimes, since the rate of transport processes depends on the hydrodynamics. Therefore, for rational reactor design and operation, it is of crucial important to know the range of parameters over which the respective regime prevails (5).

Different studies performed with different system and operating conditions provide different results in determination of boundaries regime transitions(4).Pino(6) proposed that

for superficial gas velocities lower then 5cm/sec, homogeneous flow regime prevails. Krishna(7)showed that the regime transition velocity increased with increasing gas velocity. Thorate(8) reported that the transition gas velocity depends on column dimensions, sparger design and physical properties of the system.

The presence of solids affects the gas – liquid mixture in many different ways: bubble formation (9), axial and radial gas holdup (10) mixing and dispersion (11), mass transfer (12) and flow regimes (13).

Most of the published work reported that the gas holdup generally decreased with increasing solid concentration,equivalently the mean bubble speed increases with solids (14).

Kelkarestimate the heterogeneous regime based on large values of distribution parameter in the drift flux(15).Clark, Krishna, Su used the drift flux model for determining the transition regime(16).

The purpose of the present work was to examine the effect of solid particles concentration on homogeneous – heterogeneous flow regime transition in bubble column in presence of surface active agents (0.15 vol. %, 0.25 vol. % and 0.3 vol. % hexanol) which cause foaming during the operation.

EXPERIMENTS ANDDATAEVALUATION

Experiments were carried out in a cylindrical (QVF) glass bubble column of 0.15m i.d and 1.6 height. The column was equipped with 3mm thick Plexiglas perforated plate sparger (104 hole and 1mm diameter) and relative free area 0.245%.This kind of plate produces the homogeneous, transition and heterogeneous bubbling regimes. Schematic diagram of experimental setup is shown in figure (1). Compressed air from laboratory lines was used as the gas phase. The gas flow rate was varied in the range of 0.033m/sec to 0.25m/sec to cover homogeneous and heterogeneous flow regimes. Aqueous solutions of (0.15 wt. %, 0.25 wt. % and 0.3 wt. %) hexanol was used as the liquid phase. Al2O3particles were used as the solid phase. Five values of solid loading were used (1, 3, 7, 9, 11 vol. %). The clear liquid height was 0.4m for all experiments (no liquid throughput).

Gas holdup was determined from bed expansion(17):

$$\varepsilon_G = \frac{H_F - H}{H_F} \dots\dots (1)$$

Each experimental run was repeated three times and the holdup values were averaged (relative error less than 6%)

HOMOGENEOUS – HETEROGENEOUS REGIME TRANSITION

A common procedure to locate the transition point homogeneous – heterogeneous regimes is to apply the drift flux analysis, which is based on mass conservation equations and relates velocities and concentration of the phases (18). The model looks at the relative motion of the two phases and is suggested for flows with flat radial profiles. The basic quantity is the drift flux, j which represents the gas flux through a surface moving at average velocity of the mixture and is given by Zuber and Findlay(19):

$$\frac{U_G}{\varepsilon_G} = C_0 U_G + C_1 \dots\dots (2)$$

The constants are given by the following equation:

$$C_0 = \frac{\langle \varepsilon_G U_G \rangle}{\langle \varepsilon_G \rangle \langle U_G \rangle} \dots\dots (3)$$

$$C_1 = \frac{\langle \varepsilon_G \varepsilon_L U_S \rangle}{\langle \varepsilon_G \rangle} \dots\dots (4)$$

The drift flux model is plotted verses the gas holdup, the change in the slope of the curve indicates the transition from homogeneous to heterogeneous regime (20). Also the transition point could be discriminated for each solid loading by gas hold up – gas flow rate graphs εG (UG).

RESULTS AND DISCUSSION

Effect of superficial gas velocity

Figure (2-4) shows the gas holdup as a function of superficial gas velocity and alcohol concentration at a given solid loading. It can be seen that, the gas holdup increases with increasing superficial gas velocity. This is attributed to the fact that the rate of breakup of bubbles increased.

In addition, increasing superficial gas velocity gives smaller bubbles. The smaller bubbles with lower rising velocity lead to form large residence time and consequently higher gas holdup. This increase in gas holdup has been found to be proportional in lower superficial gas velocity up to a point then it will become less pronounced in higher superficial gas velocity. This is attributed to the formation of large bubble which led to lower gas holdup. This indicates that in churn turbulent flow regime(21).

The churn – turbulent regime is characterized by the disturbed form of the homogeneous gas – liquid system bubbles of liquid recirculation. As a result unsteady flow patterns of large bubbles with short residence times are formed by coalescence due to high gas throughputs (3).

Effect of alcohol concentration

The liquid phase property has an impact on bubble formation and/or coalescing tendencies(1).

Figure (2-4) shown the effect of alcohol concentration on gas holdup and transition point at a given solid loading. It can be seen from these figures that an increase of alcohol concentration resulting in a higher gas holdup value. A very dense forming layer was observed at the top of dispersion for the aqueous solution of alcohol. As the concentration increases the gas-liquid mixture becomes milky white and frothy thereby increasing the gas holdup. It is known that the presence of small amount of aliphatic alcohol in water acts as a surfactant active agent and reduces the dynamic surface tension making liquid mixture non-coalescing. The average bubble size and bubble rise velocity decreases in non-coalescing liquid mixtures and as a consequence, the gas holdup increases(22).

The drift flux model is plotted against the gas holdup as shown in Figure (5-7); the change in the slope of the curve will indicate the transition from one regime to the other flow regime (20).

From Figures (2-7) it is clear that the addition of small amounts of alcohol increased the value of transition velocity (Utrens). This is attributed to the addition of alcohol which has the effect of stabilizing the homogeneous bubbly flow regime. This stabilization is caused by suppression of the coalescence tendency of small bubbles. The mechanism of the coalescence-preventing action of the alcohols was explained as follows: when alcohol dissolved in water, it strongly adsorbed at the interface. They behave as hydrophobic materials and that to be rejected from the bulk of the solution to the interface. They accumulate around the bubbles forming a “protective” monolayer and consequently the coalescence between the bubbles will be hindered. When a bubble moves through in a liquid adsorbed surface active material is pushed to the back of the bubble this causes a surface tension gradient which opposes the tangential shear stress. This phenomenon increases the drag on the bubble and consequently the rise velocity is reduced(23)

Effect of solid concentration

Figure (1-6) show the effect of solid loading on gas holdup and transition velocity as a function of superficial gas velocity at a given alcohol concentration. It can be seen from these figures that the gas holdup increases with increasing solid loading and lowering Utrems. This behaviour is attributed to accumulation of fine bubbles at high slurry concentration and the decrease in the rise velocity of small bubbles(1).

CONCLUSION

The main points concluded from the present study are summarized as follows:

1- The gas holdup increases with increasing superficial gas velocity, hexanol concentration and solid loading.

2- The transition velocity from homogenous – heterogeneous flow regime delay increasing hexanol concentration and solid loading.

EMPIRICAL CORRELATION OF RESULTS

The gas hold up is correlated in this work where the operating parameters (superficial gas velocity, solid concentration and alcohol concentration) are taken in to account, the relevant system properties (viscosity, density and surface tension) varied in the experiments due to variation in alcohol concentration and solid concentration as follows:

$$\varepsilon_G \alpha U_G, vol\%solid, wt\%\ alcohol \ldots\ldots (5)$$

Therefore the following correlation is proposed:

$$\varepsilon_G = aU_G^b C^c S^d \ldots\ldots (6)$$

The gas holdup data for this work was fitted to the form of Eq. (6) nonlinear least – square regression analysis using statistical software version 6 to estimate the coefficients a and exponent's b, c and d as:

$$\varepsilon_G = 1.569304 * \mathrm{U}_G^{0.411751} * C^{0.170897} * S^{0.094571}$$

Where R=0.910915

A comparison between the experimental results and the predicted values is shown in figure (8).

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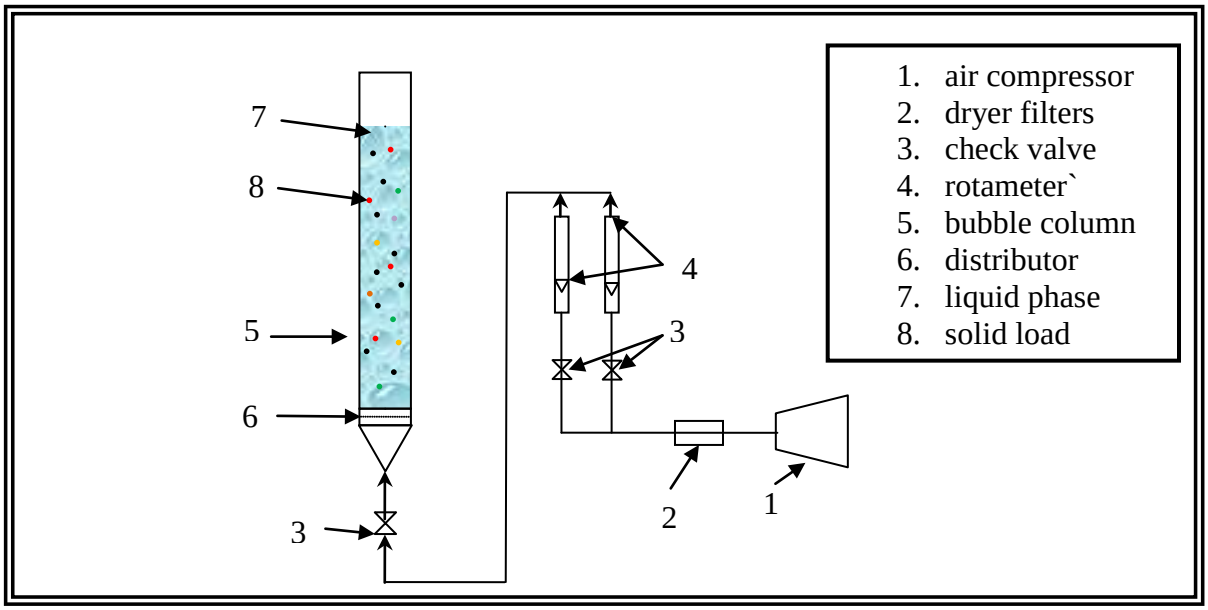

Figure (1): Experimental Apparatus

TABLE (1): PROPERTIES OF LIQUID AND SOLID PHASE:

Type of liquid	**Density $\rho(kg/m^3)$**	**Viscosity $\mu(Pa\ s) \times 10^3$**	**M.Wt (kg/kmol)**
Water (H_2O)	996.82	0.981	18
i-hexanol ($C_4H_{14}O$)	819	3.21	102

Type of solid	Diameter d (mm)	Porosity ε (-)	Bulk density $\rho_b(kg/m^3)$	Surface area $A_s(kg/m^3)$	shape
Al_2O_3	2.1	0.5	4000	320	Spherical

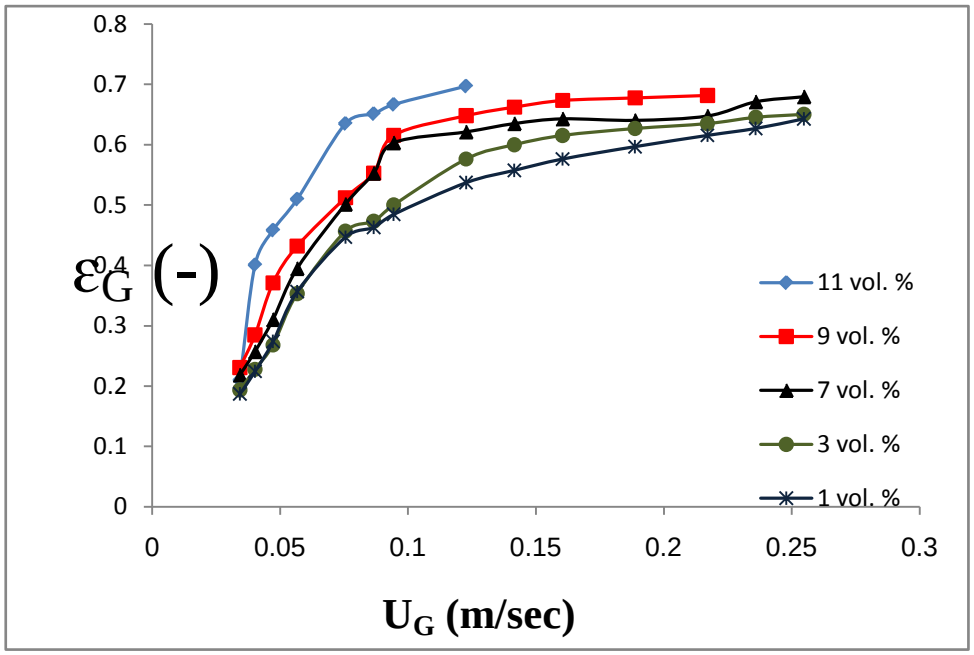

Figure (2): Superficial gas velocity VS. gas holdup as a function of solid loading (0.15 wt. %) hexanol concentration

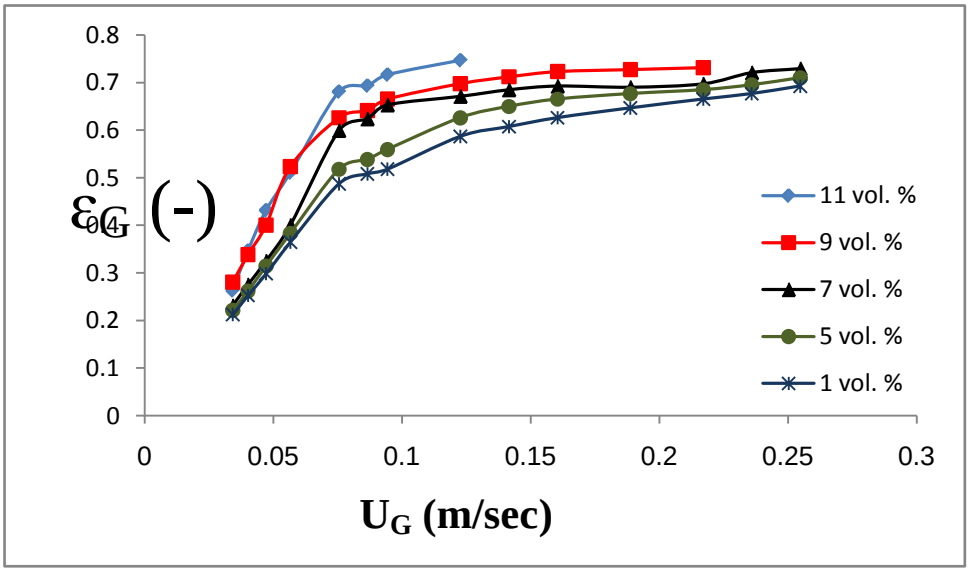

Figure (3): Superficial gas velocity VS. gas holdup as a function of solid loading (0.25 wt. %) hexanol concentration

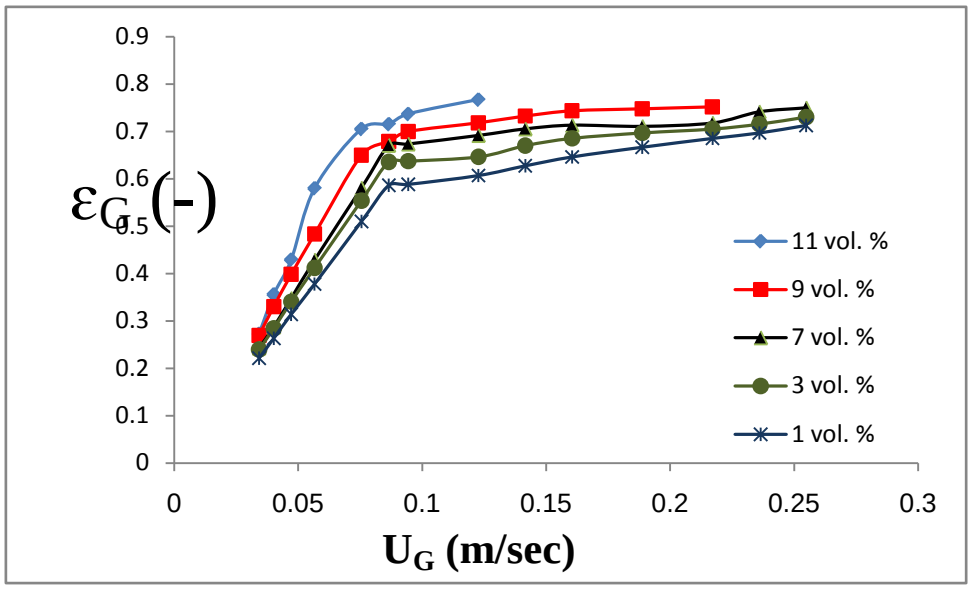

Figure (4): Superficial gas velocity VS. gas holdup as a function of solid loading (0.3 wt. %) hexanol concentration

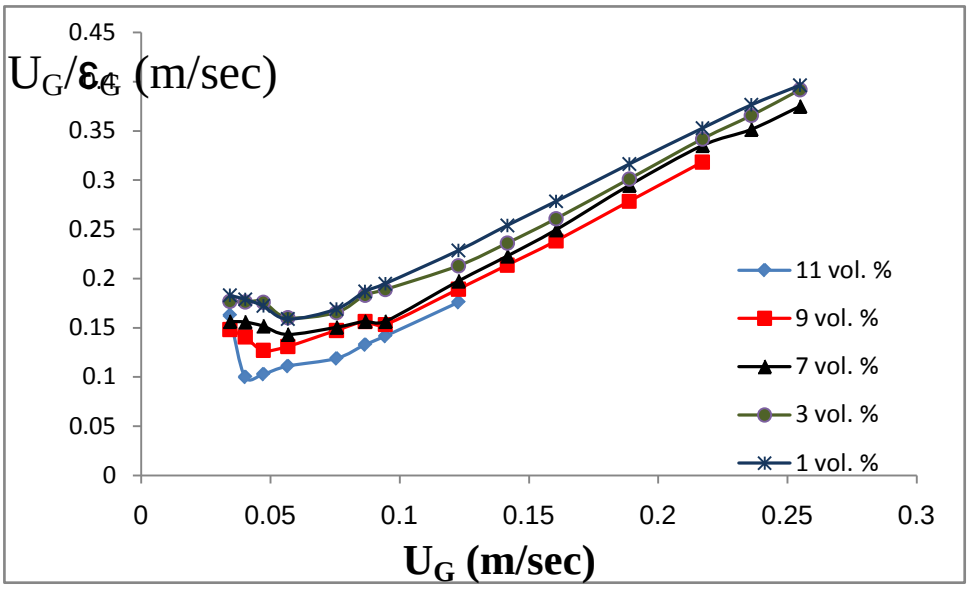

Figure (5): Superficial gas velocity VS. Drift flux as a function of solid loading (0.15 wt. %) hexanol concentration

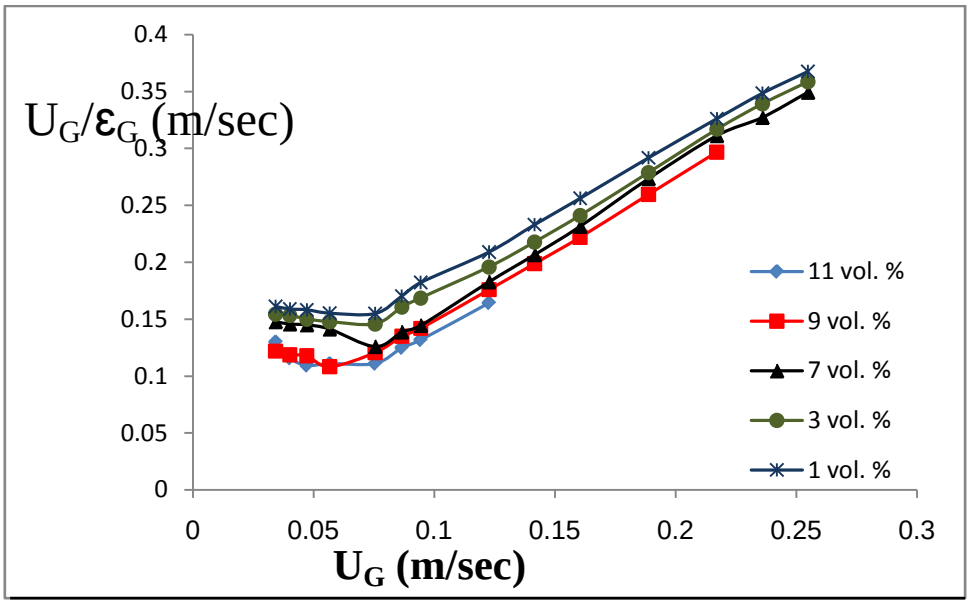

Figure (6): Superficial gas velocity VS. Drift flux as a function of solid loading (0.25 wt. %) hexanol concentration

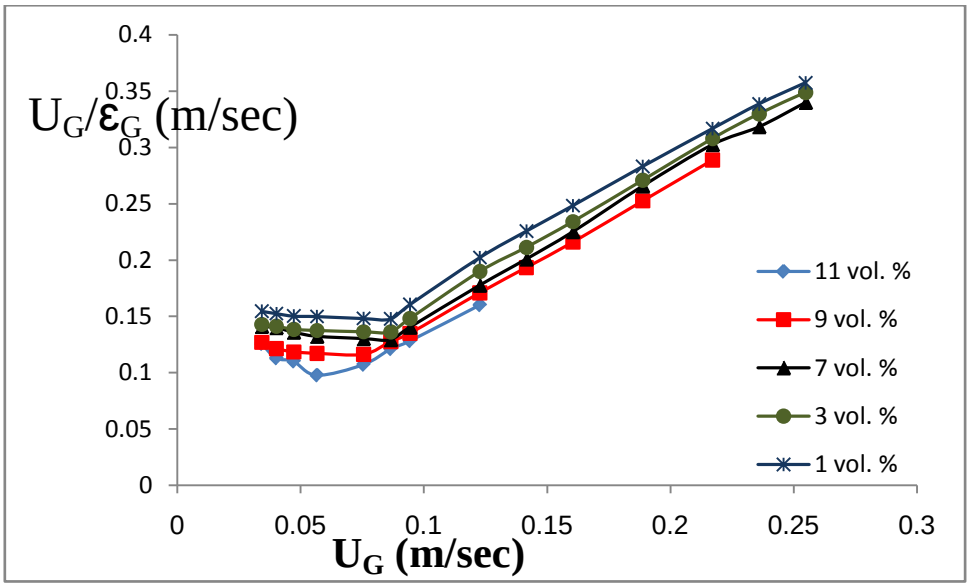

Figure (7): Superficial gas velocity VS. Drift flux as a function of solid loading (0.3 wt. %) hexanol concentration

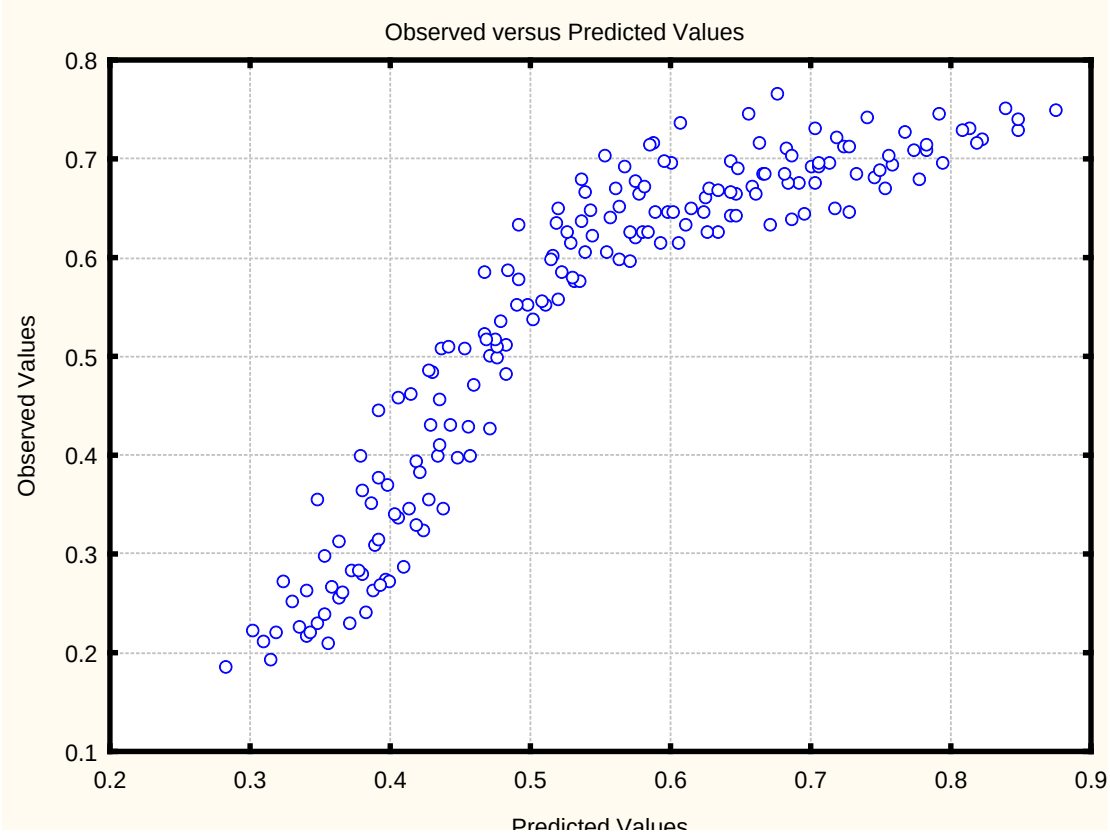
Observed versus Predicted Values
Observed Values
Predicted Values
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Figure (8)

TABLE (2) RESULTS OF SUPERFICIAL GAS VELOCITY AND GAS HOLDUP AT TRANSITION POINT

System	Solid loading									
	1%		3%		7%		9%		11%	
	U_G	ε_G	U_G	ε_G	U_G	ε_G	U_G	ε_G	U_G	ε_G
Air-water+0.15 wt% hexanol	0.056617	0.3565	0.056617	0.353333	0.056617	0.395065	0.047181	0.37112	0.04014	0.4011
Air-water+0.25 wt% hexanol	0.07549	0.48746	0.07549	0.518085	0.07549	0.59955	0.056617	0.523684	0.047181	0.43211
Air-water+0.3 wt% hexanol	0.086541	0.586396	0.086541	0.635844	0.086541	0.670355	0.07549	0.649476	0.056617	0.579804

دراسة تركيز الصلب للجريان المتجانس وغير المتجانس في الاعمده الفقاعيه باستخدام سوائل التوغيف

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الخلاصة

أجريت تجارب مختبرية لدراسة نظامتحول الجريان من متجانس الى غير متجانس في المحدد الفقاعي ذات قطري داخلي 0.15م لسائل رغوي. ثم استخدام محلول الهكسانول المائي كسائل رغوي في البحث الحالي ، وثم دراسة تأثيرات تركيز الهكسانول (0.15 و 0.25 و 0.3) والتركيز الصلب (1 و 3 و 7 و 9 و 11 كنسبة حجمية) وسرعة الغاز (0,03421 – 0,1226704 م/ثا) في البحث الحالي وقد تم أستخدام drift flux لتحسس نقطة التحول من نظام الجريان المتجانس الى غير المتجانس. وقد بينت النتائج ان gas holdup يزداد مع زيادة سرعة سرعة الغاز وتركيز الهيكسانول وتركيز المادة الصلبة بينما زيادة تركيز الهكسانول وتركيز المادة الصلبة تؤدي الى تأخر سرعة التجانس الى غير المتجانس.

الكلمات الداله: الابراج الفقاعيه، المناطق المتجانسه وغير المتجانسه، سوائل التوغيف.