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The Effect of Solid on the Homogenous- Heterogeneous Transition Region in Baffled and Unbaffled Bubble Column with Non-Newtonian Liquid

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Abstract

This research shows a comprehensive study on the effect of solid loading and non-Newtonian liquid on the hydrodynamic parameter of gas holdup as well as the critical values of gas holdup and gas velocity of transition zone from homogenous to heterogeneous region in both baffled and unbaffled babble column.

The experiments were carried out using column of 15cm inside diameter and 2m height with aspect ratio (L/D=4.5) using perforated plate gas sparger 54 holes with size equal to 1mm diameter and with free area of holes to cross sectional area of column 0.24.

The three phase system consists of air-non Newtonian liquid of polyacrilamined (PAA) –solid of alumina particles. The measured values of gas holdup and transition points of gas holdup and gas velocity were compared with different values of PAA concentration (0, 0.01, 0.05 and 0.1)wt% and four values of solid loading (0, 3, 5 and 11)wt% in baffled and unbaffled column.

The results show that the transition values of gas holdup and gas velocity decreased with increasing of PAA concentration under constant values of Newtonian liquid while they dis approved with non-Newtonian liquid.

The solid loading shows an unstable influence of decreasing and increasing of the critical values in all PAA concentration and in both baffled and unbaffled column. First, these values decreased when solid loading in the range (0-3)wt% then they increased with increasing of solid loading from 3wt% to 11wt%.

تأثير المادة الصلبة على منطقة انتقال الجريان من المنطقة المتجانسة الى المنطقة الغير متجانسة في عمود التفقيع الخالي والحاوي على العوائق باستخدام سوائل غير نيوتونية

الخلاصة

هذا البحث يضهر دراسة شاملة عن تأثير الطور الصلب والسوائل الغير نيوتونية على الخواص الهيدروديناميكية من محتوى الغاز والنقاط الحرجة من محتوى الغاز وسرعته على منطقة الانتقال من المنطقة المتجانسة الى المنطقة الغير متجانسة في عمود التفقيع الخالي والحاوي على العوائق.

تم اجراء التجارب في عمود تفقيع بقطر 15سم وارتفاع 2م بنسبة ارتفاع الى قطر (4.5) باستخدام موزع هواء مثقب يحوي على 56 ثقب بقطر 1ملم وبمساحة ثقوب الى مساحة مقطعية للعمود مقدارها 24و0 .الاطوار الثلاثة هي الطور الغازي وهو الهواء وطور السائل وهو سائل غير نيوتوني وطور صلب من الاومينا.

القيم المقاسة من محتوى الغاز ونقاط التحول تم مقارنتها بتراكيز مختلفة من البولي اكرا امايند (0, 0.01, 0.05, 0.1) نسبة وزنية وقيم مختلفة من تركيز المادة الصلبة (0, 3, 7 , 11) نسبة وزنية في عمود تفقيع خالي وحاوي على العوائق.

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اظهرت النتائج ان نقاط التحول من محتوى الغاز ومن سرعة الغاز تقل مع زيادة تركيز البولي اكرللكايد تحت قيم ثابتة من محتوى المادة الصلبة وهذه القيم تتحسن في عمود التفقيع الحـــاوي على عوائق بوجود سائل غير نيوتوني.
ان وجود المادة الصلبة اظهر تأثير غير مستقر من نقصان وزيادة في القيم الحرجة لكل تراكيز السائل الغير نيوتوني في عمود التفقيع الحاوي والخالي من العوائق. اولا هذه القيم تقل عنـــدما يكون تركيز المادة الصلبة من 0 الى 3% نسبة وزنية ثم يزداد بزيادة محتوى المادة الصلبة من 3% الى 11% نسبة وزنية.

Keywords: Three phase, non-Newtonian liquid, baffles, homogenous and heterogeneous region

Nomenclature

j_{GL}	**Drift flux , m/s**
U_G	**Superficial gas velocity**
U	**Mean slip bubble velocity, m/s**
u_0	**Bubble terminal velocity**
A	**Bubble drift coefficient (drift volume/bubble velocity), dimensionless**
F	**Solid content = solid loading/100, dimensionless**
N	**Flow behavior index**
M	**Consistency index, $Pa.s^n$**

Greek symbols

ε_G	**Gas holdup**
ρ_{mix}	**Density of mixture, Kg/m^3**
ρ_L	**Liquid density, Kg/m^3**
Pp	**Particle density, Kg/m^3**
Σ	**Surface tension, N/m**
Γ	**Shear rate**
T	**Shear stress**
μ_{app}	**Apparent viscosity, mP.s**
µ	**Viscosity, mP.s**

Introduction

Slurry bubble columns are intensively used as multiphase contactors and reactors in chemical, biochemical and petrochemical industries. They provide several advantages during operation and maintenance such as high heat and mass transfer rates, compactness and low operating and maintenance costs. Three-phase bubble column reactors are widely employed in reaction engineering, i.e. in the presence of a catalyst and in biochemical applications where microorganisms are utilized as solid suspensions in order to manufacture industrially valuable bio-products [1]. In order to improve the efficiency of the bubble columns, baffle plates, draft tubes and mesh wires have been used in bubble columns [2].

The fluid dynamic characterization of bubble column reactors has a significant effect on the operation and performance of bubble columns. The flow regimes in bubble columns are classified and maintained according to the superficial gas velocity employed in the column. Three types of flow regimes are commonly observed in bubble columns which are the homogeneous (bubbly flow) regime; the heterogeneous (churn-turbulent) regime and slug flow regime[3]. The detection of regime transition from homogeneous to churn-turbulent flow and the investigation of the transition regime are quite important. As the transition takes place, significant changes are observed in the hydrodynamic behavior of the system. There exists an onset of upward liquid circulation in the column centre and downward liquid circulation near the column wall. As a result more gas entry takes place in the centre, leading to build-up of transverse holdup-profile that enhances liquid circulation. [1].

Different studies performed with different systems and operating conditions provide different results in determination of regime boundaries and regime transitions. For instance [3] proposed that below 4 cm/s superficial velocity a bubbly flow regime prevails. [4] also reported approximately the same velocity for a bubbly flow regime. [5] proposed that for superficial velocities lower than 5 cm/ s, homogeneous (bubbly) flow prevails. [6] observed the churn-turbulent flow regime for gas superficial velocities between 2 and 5 cm/s.

The effect of solid concentration and particle size on gas holdup has been investigated by a number of researchers. Several researchers concluded that an increase in solids concentration generally reduced the gas holdup [7, 8 , 9 , 10, 11, 1, 12, l3].[1l] also reported that for low solids loading (<5 vol.%), the behavior of the slurry bubble column is close to that of a solid-free bubble column. Contrarily, [9] found a strong dependence of gas holdup on solids concentration at low solids concentrations. [7] reported that the effect of solid concentration on gas holdup becomes significant at high gas velocities (>10–20 cm/s).

The aim of the present work is to study the effect of solid loading on the homogenous –heterogeneous flow regime with and without baffle plate for non-Newtonian fluid.

Experimental Work

The experiments were carried out in a QVF cylindrical column (Figure 1)15cm inside diameter and 2m height with static liquid height to column diameter 4.3. The system is operated in a semi-batch mode with stagnant liquid and continuous gas flow.

A compressed air was dispersed from the bottom of the column through perforated plate consisted of

54 hole and 1mm diameter and free surface area to cross sectional diameter 0.24.

Water and non-Newtonian liquid of polyacryamide solution in different concentrations of (0.01, 0.05, and 0.1) wt% were used as a liquid phase. Polyacrylamide solution is considered as a time independent fluid of pseudoplastic type that is characterized by power law model. Its rhelogical properties of flow index (n) and consistency index (m) were calculated using Fann Viscometer (model 35A) [14]. Other physical properties such as density, viscosity and surface tension were measured by means of pycnometer , Brookfield viscometer (Brookfield Eng.lab.Inc., USA).and two capillary tubes having diameters of (1 and 2) mm respectively. These properties are tabulated in Table (1)

The flow behavior of psudoplastic PPA solution is characterized by the power law model of Ostwld-de-Waele as

$$\tau yx=m(\gamma yx)^{n} \qquad (1)$$

$$\mu app=m(\gamma yx)^{n-} \qquad (2)$$

Where τ is the shear stress, m is the consistency index, γ is the share rate, n is the power low index. In order to calculate the apparent viscosity prevailing in the bubble column, the effective shear rate was calculated using a relation proposed by [15] . [15]:

$$\gamma=2800UG \qquad (3)$$

The solid phase is alumina particle with 2mm size and with density of 4000kg/m^3.

Ten aluminum baffles cited, from the top, inside the column as shown in Figure (1), each plate had 8cm width and 1cm height. The distance between each two plates was 13cm.

Experiments were conducted at steady state with gas flow rate varying from 0-0.2m/s. The gas flow rate was read from rotameter and the gas holdup was determined from bed expansion with ±3% error.

Results and Discussion

In this study the effect of different variables like; the existing of baffles, solid loading and PAA concentration on gas holdup and critical values of critical gas velocity and gas holdup of transition from homogeneous region to heterogeneous one was examined as follows:

Effect of baffles

Gas holdup considered as one of the most important hydrodynamic parameter in reactor design, the effect of baffles on their values is shown in figures (2-13)

From these figures we can see that gas holdup is higher in baffled column than unbaffled one in Newtonian liquid and different solid loading, figures(2- 4). Opposite results can be noticed for non-Newtoinan liquid figures(5- 13) with different solid loading.

In order to calculate the critical gas holdup and critical velocity of transition a drift flux model was used. In this model, the experimental volumetric flux equation (4) is plotted with the theoretical one equation (5) against gas holdup, figures(14-21)

$J_{exp} = U_G(1-\varepsilon_G)$ (4)

$J_{theo} = \varepsilon_G\, u(1-\varepsilon_G)$ (5)

At homogeneous region $J_{exp}=J_{theo}$, the point of deviation is considered as the critical point. Many experimental correlations were cited in literature defining the mean slip velocity of bubble, like that made by Rishman-Zaki. In this work we will use the correlation made by (19), as shown below:

$u=uo(1-a\varepsilon G/(1-\varepsilon G))$ (6)

The critical values of gas holdup and gas velocity calculated from these figures, show similar behavior under the action of baffles with changing solid loading and PAA concentration as mentioned above. i.e. the gas holdup decreased with the presence of baffles in non-Newtonian liquid.

This behavior can be explained if we remember that high viscosity of non-Newtonian liquid gives a resistance to the motion of bubbles making them easy to be trapped under the baffle plate causing an uniformity of bubble distribution in bubble column. In Newtonian liquid the chance of bubble to run away from the baffle plate will be much easily since the liquid circulation will increase making an increase in the values of gas holdup.

Effect of solid loading

As mentioned in the literature, most of the chemical reactors include three phase gas-liquid and solid. The existing of solid phase caused a significant effect on the hydrodynamic properties like gas holdup, this effect can be shown in figures (2-13).

In all baffled column with Newtonian and non-Newtonian liquid the values of gas holdup decreased with the presence of solid up to 3 wt% loading, then these values increase with the increasing of loading from 3wt% to 11wt%, the same behavior is shown in unbaffled column Newtonian and non-Newtonian system.

Similar criteria noticed for the values of critical gas holdup and gas velocity , i.e they decreased with solid loading up to 3wt% then increased with slid loading up to 11wt%, as shown in figures (22-25).

This dual effect of increasing and decreasing is very interesting and important and can be explained if we make an attention that the presence of solid particles means the presence of other phase that occupied certain space of the column. Consequently the bubble concentration is different weather based on gas-liquid or gas-liquid-solid system.

Indeed all the empirical equations used for calculation of critical values were based on two phase system (gas-liquid). Hence, the existence of solid particles makes some unstable criteria. We suggest that this unstable behavior of increasing and decreasing is attributed to the effect of solid phase on some physical properties like density and viscosity.

The influence of solid phase on density is estimated in terms of effective density (mixture density), $\rho_{mix} = (1-f)\,\rho_{liq} + f\,\rho_p$

In our study, the particle density is 4000kg/m^3 which is much higher than that of liquid density (1000-1003)kg/m^3. Hence the presence of solid caused a significant change on the effective density i.e bouncy force and settling velocity of particles.

[16] concluded that the bubble size generally increased due to the downward force exerted by settling solids on growing bubbles. So, according to mixture density equation, increasing of solid loading caused an increase in magnitude values of particle density that inhibits the boring and growing of bubbles.

It is well known that viscosity has a dual effect on gas holdup, first it inhibits the bubble rise velocity due to the higher tendency of energy absorption of body motion (bubbles), this inhibition caused an increase in gas holdup. Second, the high viscosity of medium promotes the coalescence of bubbles than bubble break-up leading to a decrease in gas holdup.

This dual effect is responsible on increasing and decreasing of gas holdup when solid loading increase.

A reverse criteria was found by [17] results in which gas holdup first increased with solid loading (0-5)wt% then it decreased at high solid loading > 5wt%. This reverse behavior can be caused due to the non-Newtonian liquid used in this work.

Effect of PAA concentration

Figures (2-13) shows the effect of PAA concentration on gas holdup with different solid loading and in both baffled and unbaffled column.

It can be clearly shown from these figures that the gas holdup values for non-Newtonian liquid is lower than that for Newtonian liquid and this decreasing accelerates with the increasing of PAA concentration.

Also the same phenomena can be noticed for critical gas holdup and gas velocity ,figures (22-25). This result reconciles the contradiction that is reported in literature like [18] , [19] , [20] and [21].

The discussion of this behavior is mentioned in the last section, i.e the accelerating of liquid viscosity promotes bubble coalescence that inhibits gas holdup and gas velocity of transition from homogeneous to heterogeneous region.

Conclusions

The effect of non-Newtonian liquid, baffle presence and solid loading on the gas holdup-superficial gas velocity graph and critical values of gas holdup and gas velocity was experimentally examined. The results show:

1- Overall gas holdup as well as critical values inhibited with the presence of baffles in non-Newtonian liquid while they are promoted in unbaffled column.

2- In both baffled and unbaffled column the presence of solid has a dramatic effect on the critical values. This effect is changed when the solid loading less than 3wt% than that for more than 3wt%.

3- The non-Newtonian solution plays an effective rule in decreasing the overall gas holdup and the critical values.

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the Journal of Engineering and Technology.

Table (1): Physical Properties of Liquids

Liquid Concentration of PAA wt%	Flow Behavi index, N	Consistency Index, m , $Pa.s^n$	Density at 303K ρ_L, Kg/m	Surface Tension, σ, N/m	Viscosity, μ, mPa.s
0	1	0.001	1000		1
0.01	0.9	0.0011	1000.2	0.0208	1.01
0.05	0.851	0.0015	1001.7	0.0232	1.10
0.1	0.81	0.002	1003.01	0.0245	2.5

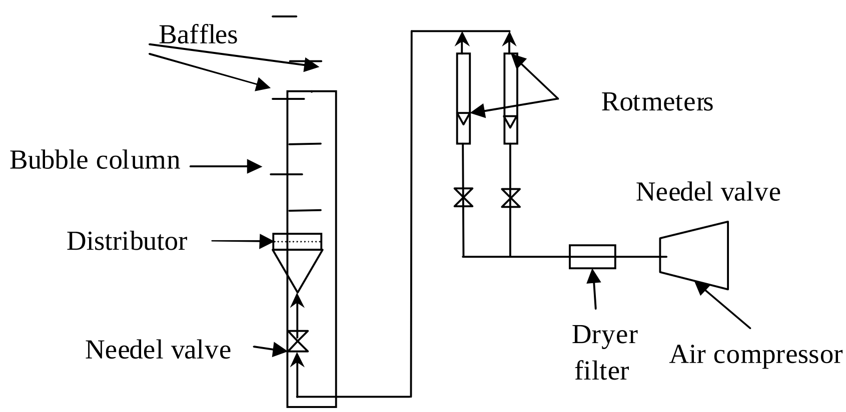

Figure (1) :Schematic Diagram of the Apparatus

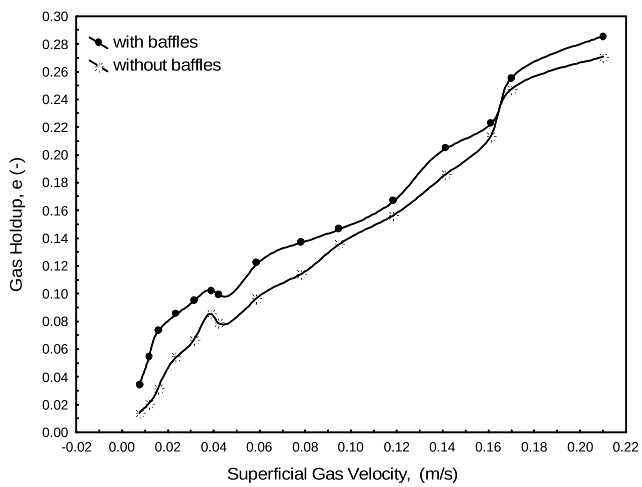

Figure (2): The effect of baffles on gas holdup in water system and 3wt% solid loading

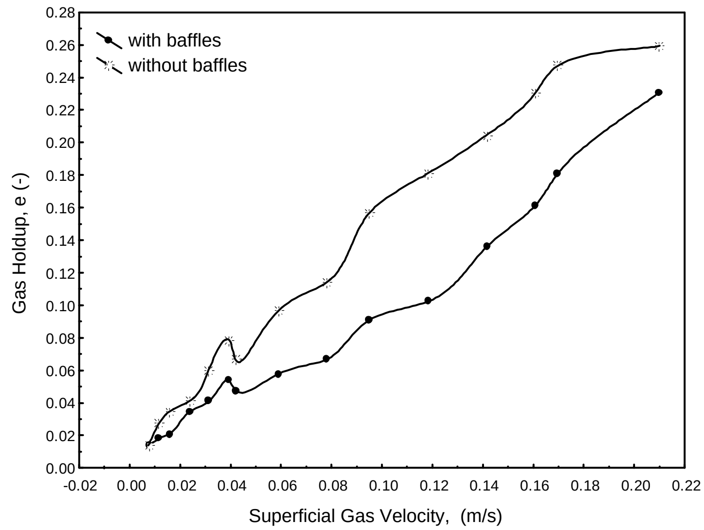

Figure (3): The effect of baffles on gas holdup in 0.01wt% of PAA system and 3wt% solid loading

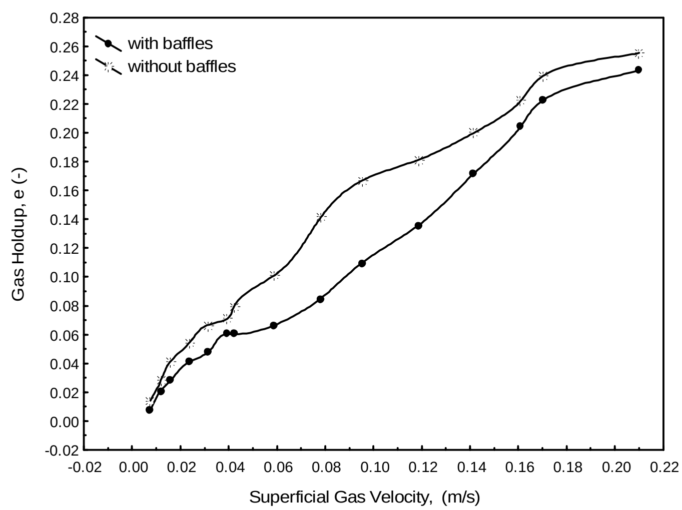

Figure (4): The effect of baffles on gas holdup in 0.05wt% of PAA system and 3wt% solid loading

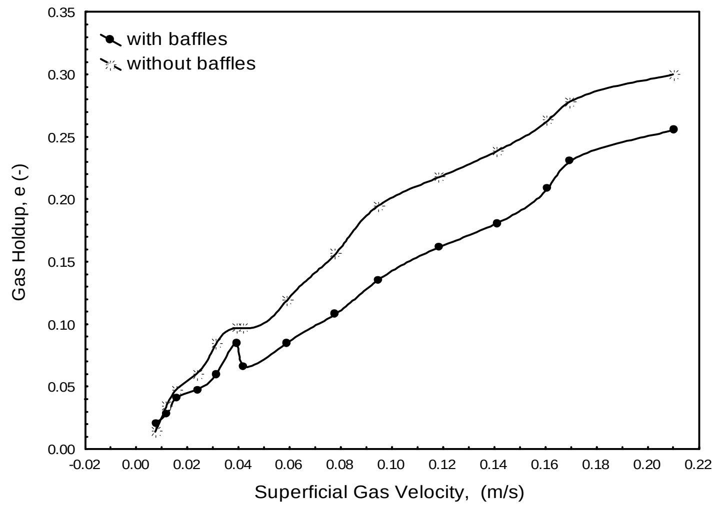

Figure (5): The effect of baffles on gas holdup in 0.1wt% of PAA system and 3wt% solid loading

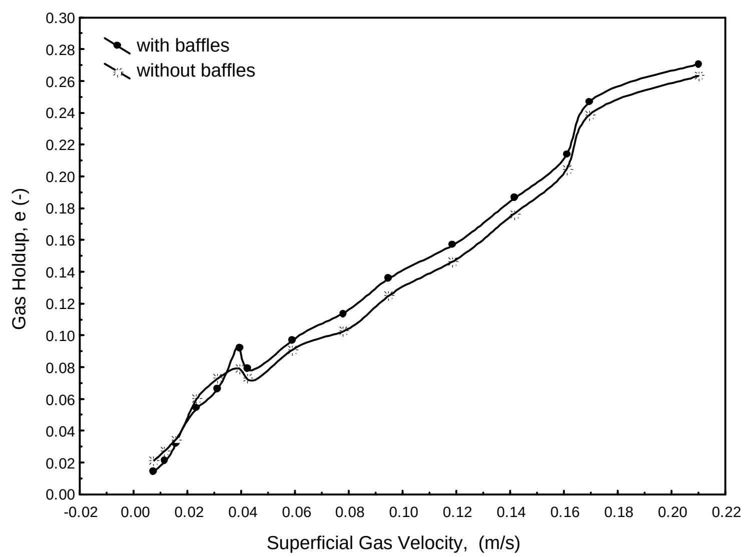

Figure (6): The effect of baffles on gas holdup in water system and 7wt% solid loading

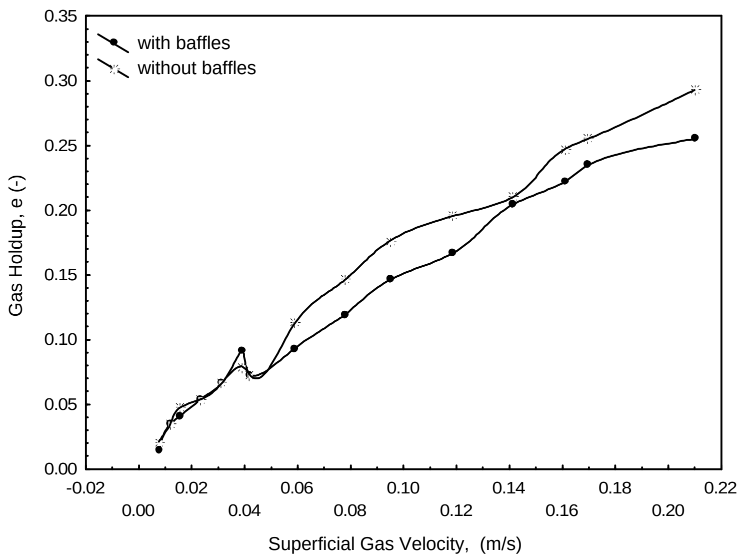

Figure (7): The effect of baffles on gas holdup in 0.01wt% of PAA system and 7wt% solid loading

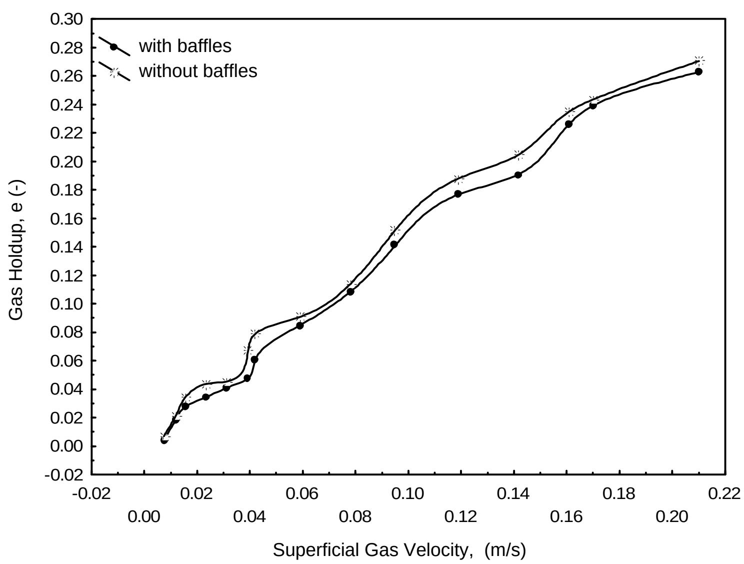

Figure (8): The effect of baffles on gas holdup in 0.05wt% of PAA system and 7wt% solid loading

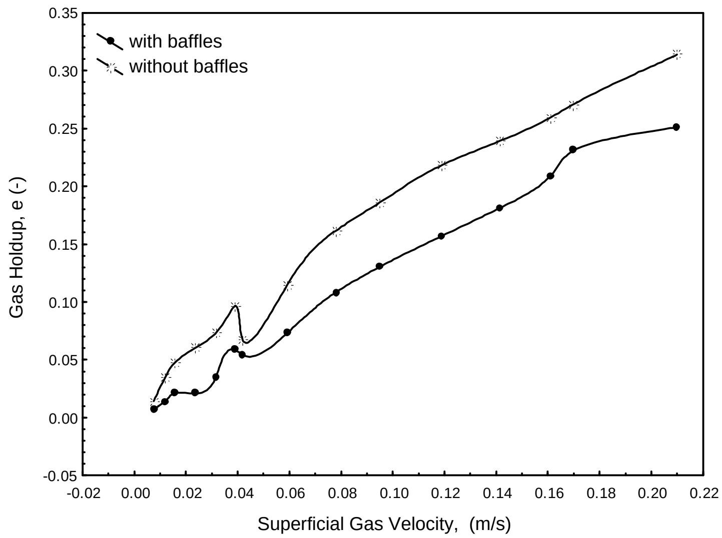

Figure (9): The effect of baffles on gas holdup in 0.1wt% of PAA system and 7wt% solid loading

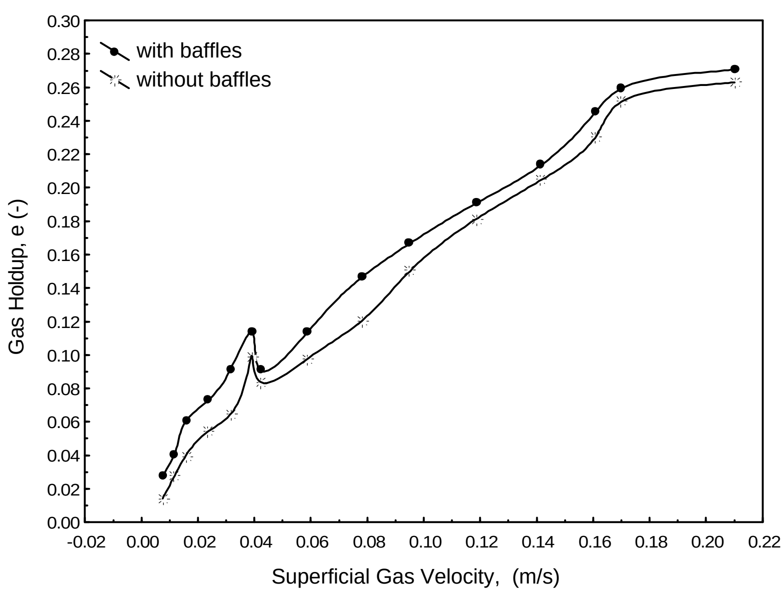

Figure (10): The effect of baffles on gas holdup in water system and 11wt% solid loading

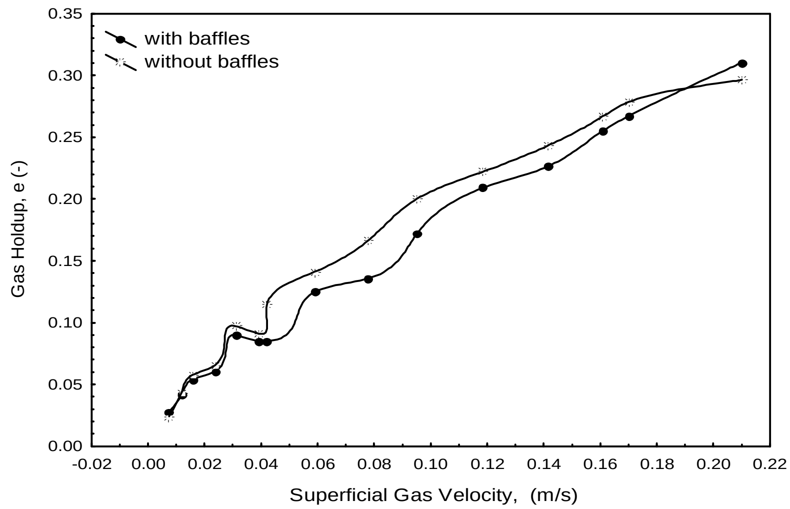

Figure (11): The effect of baffles on gas holdup in 0.01wt%of PAA system and 11wt% solid loading

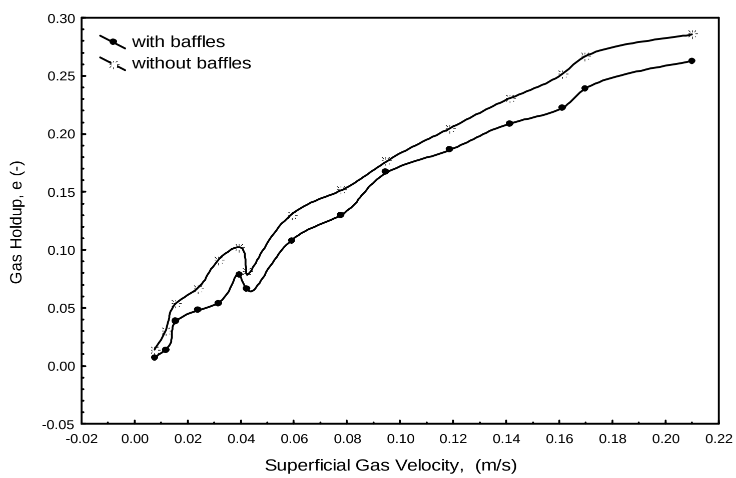

Figure.(12)

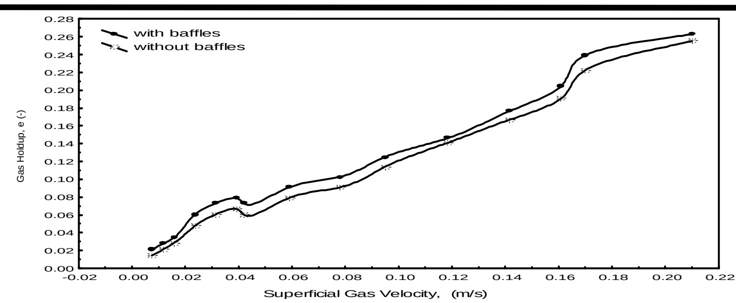

Figure (13): The effect of baffles on gas holdup in 0.1wt% of PAA system and 11wt% solid loading

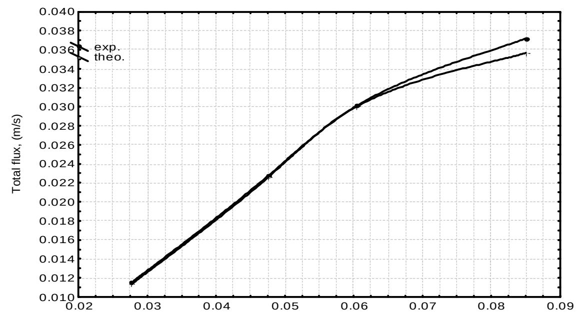

Figure (14): Drift flux versus gas holdup in 0.01wt% of PAA solution and 3wt% of solid in baffled column (e_c=0.062 and U_c=0.03)

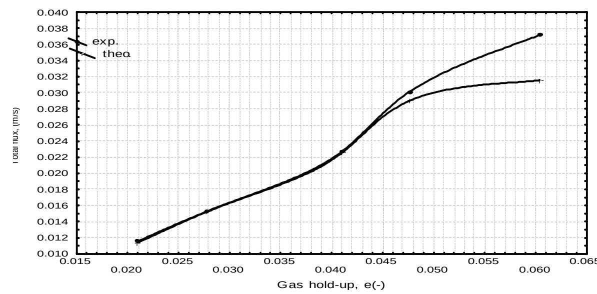

Figure (15): Drift flux versus gas holdup in 0.05wt% of PAA solution and 3wt% of solid in baffled column (e_c=0.045 and U_c=0.026)

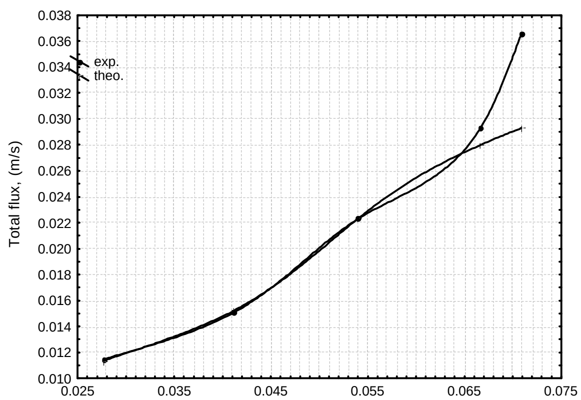

Figure (16): Drift flux versus gas holdup in 0.05wt% of PAA solution and 3wt% of solid in unbaffled column (e_c=0.065 and U_c=0.027)

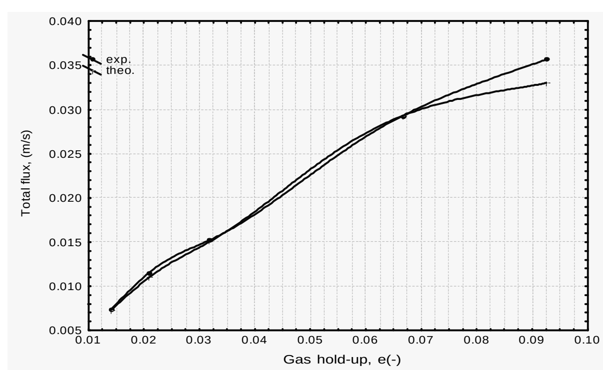

Figure (17): Drift flux versus gas holdup in 0.01wt% of PAA solution and 7wt% of solid in baffled column (e_c=0.068 and U_c=0.03)

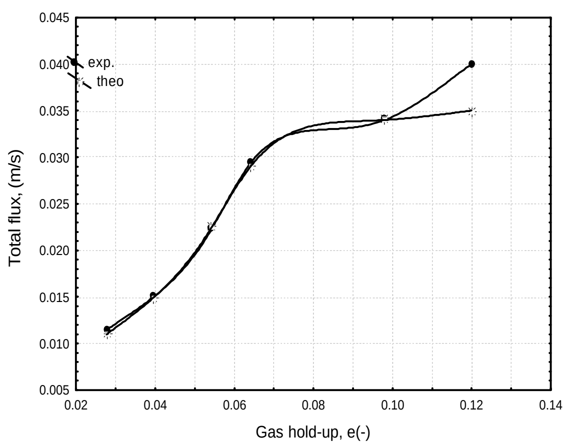

Figure (18): Drift flux versus gas holdup in water and 11wt% of solid in unbaffled column (e_c=0.098 and U_c=0.034)

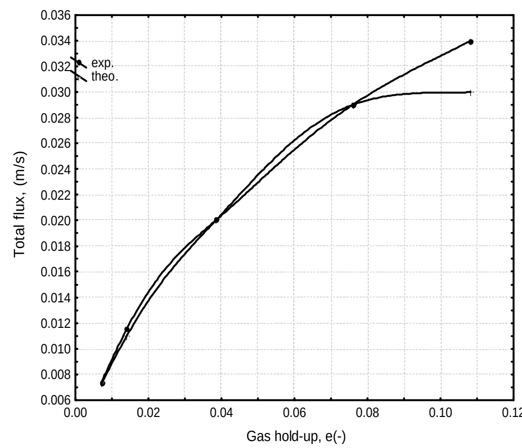

Figure (19): Drift flux versus gas holdup in 0.05wt%of PAA solution and 11wt% of solid in baffled column (e_c=0.075 and U_c=0.029)

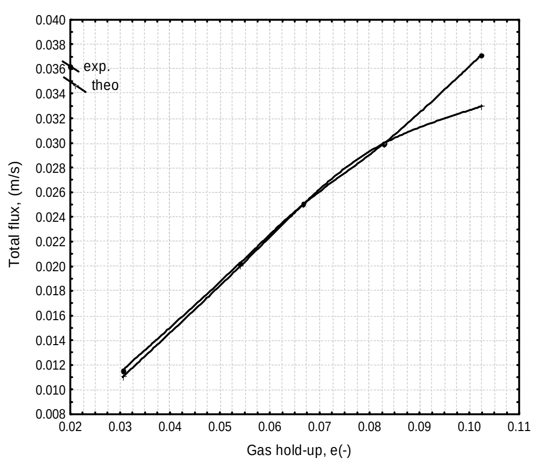

Figure (20): Drift flux versus gas holdup in 0.05wt%of PAA solution and 11wt% of solid in unbaffled column (e_c=0.083 and U_c=0.03)

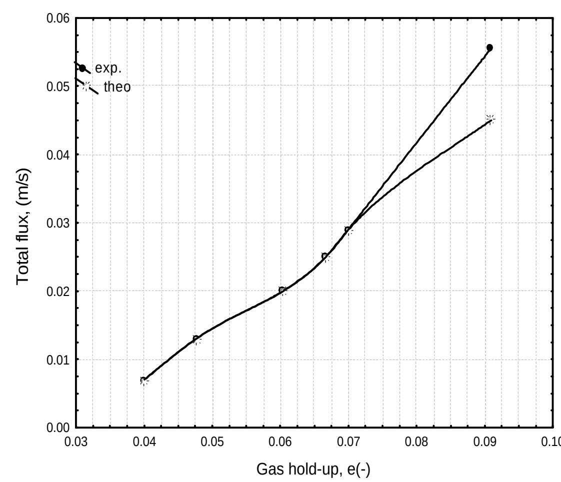

Figure (21): Drift flux versus gas holdup in 0.1wt%of PAA solution and 11wt% of solid in unbaffled column (e_c=0.07 and U_c=0.027)

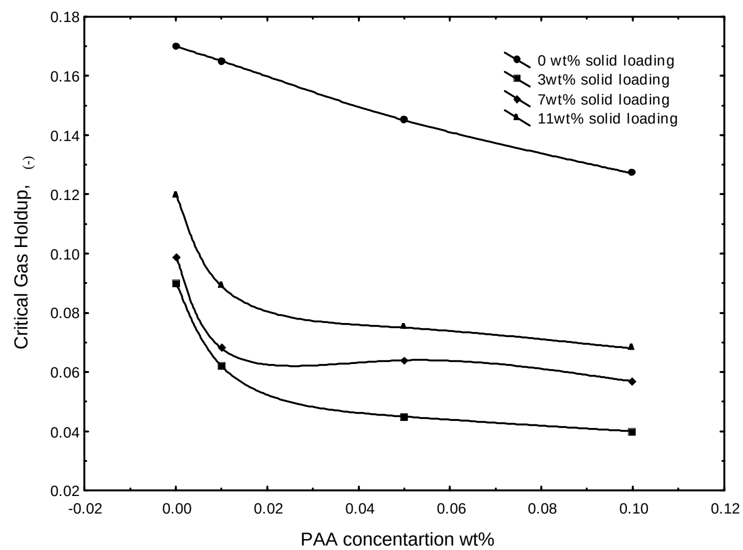

Figure (22): Critical gas holdup versus PAA concentration in baffled column with different solid loading

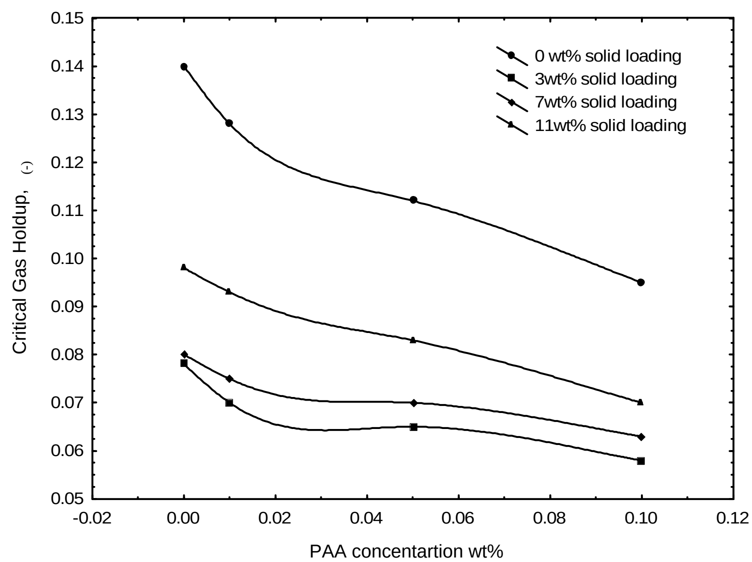

Figure (23): Critical gas holdup versus PAA concentration in unbaffled column with different solid loading

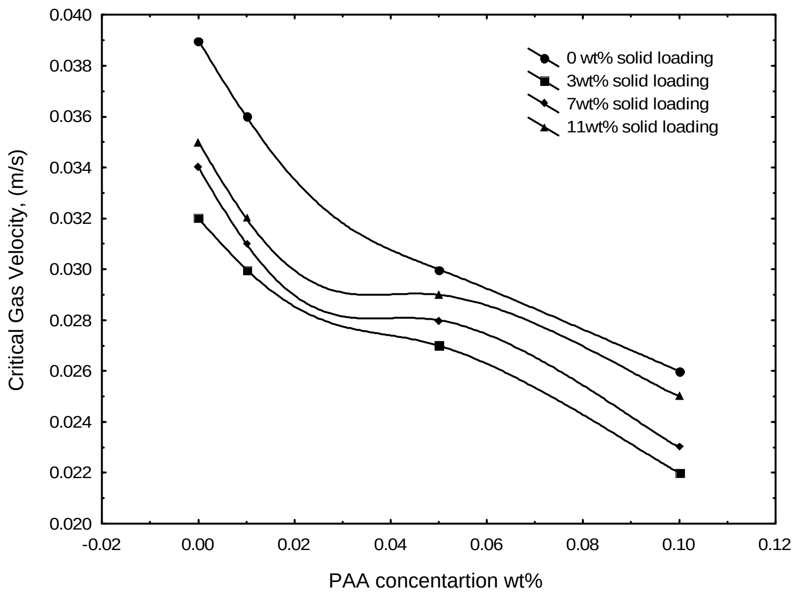

Figure (24): Critical gas velocity versus PAA concentration in baffled column with different solid loading

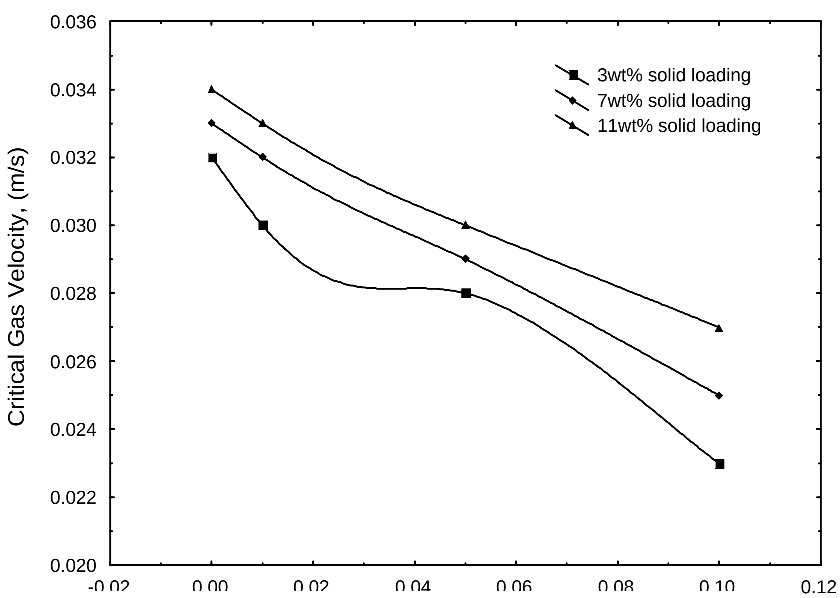

Figure (25): Critical gas velocity versus PAA concentration in unbaffled column with different solid loading