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Effect of Baffles on Homogenous-Heterogeneous Regime in Two Phase Bubble Column With Non-Newtonian Liquid

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Abstract

This work presents a comparison of the flow region in baffled and unbaffled bubble columns with Newtonian and non-Newtonian liquids. The experiments were carried out in column of 15 cm inside diameter and 2m height with aspect ratio (L/D=4.5), using perforated plate gas sparger, 54 holes of 1mm diameter, and with free area of holes to cross sectional diameter of vessel 0.24. The two phase system consists of air and non Newtonian liquid of polyacrylamide (PAA).

The gas holdup was measured and the transition point from homogenous to heterogeneous region was calculated under different concentrations of PAA (0, 0.01, 0.05, and 0.1)wt% in baffled and unbaffled columns. The results show that the measured values of gas holdup are increased in the presences of baffles in homogenous region, while, they decrease in heterogeneous region.

The transition points of gas holdup and superficial gas velocity were estimated from drift flux plot. It was concluded that they were decreased with increasing viscosity and increased in the presence of baffles.

Keywords: Non-Newtonian liquid, baffled bubble column, homogenous and heterogeneous flow.

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

الخلاصة

هذا البحث يقدم مقارنة لمناطق الجريان في عمود التفقيع الحاوي على عوائق والخالي من العوائق باستخدام سوائل نيوتونية وسوائل غير نيوتونية. 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 تقوب الى مساحة مقطعية للعمود مقدارها 24و0 .الطور الثنائي المستخدم هو الهواء وسوائل نيوتونية (الماء) وسوائل غير نيوتونية .

تم قياس محتوى الغاز وحساب نقطة التحول من الجريان المتجانس الى الجريان المتغير الخواص تحت (0, 0.01, 0.05, 0.1) في عمود خالي و حاوي على عوائق.PAAتراكيز مختلفة من

اظهرت النتائج ان القيم المقاسة من محتوى الغاز تزداد بوجود العوائق في منطقة الجريان المتجانس بينما تقل في منطقة الجريان المتغاير الخواص.

تم حساب نقاط التحول لمحتوى الغاز و سرعة الغاز باستخدام رسم التدفق الكتلي . وتم الاستنتاج ان هذه القيم تقل بزيادة اللزوجة وتقل بوجود العوائق

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Nomenclature

jGL	Drift flux , m/s
UG	Superficial gas velocity
UL	Superficial liquid velocity
u	Mean slip bubble velocity, m/s
u0	Bubble terminal velocity
a	Bubble drift coefficient (drift volume/bubble velocity), dimensionless
v	Rise velocity of single bubble, m/s
Vb, large	Rise velocity of swarm of large bubbles, m/s
B	Constant in equation 9
c	Constant in equation 10
w	Constant in equation 10
n	Flow behavior index
m	Consistency index, Pa.sn

Greek symbols

εG	Gas holdup
εL	Liquid holdup
ρL	Liquid density, Kg/m3
σ	Surface tension, N/m
γ	Shear rate
τ	Shear stress
μapp	Apparent viscosity, mP.s
μ	Viscosity, mP.s

Introduction

Bubble columns are multiphase contactors and they widely used in chemical, petrochemical, biochemical, and pharmaceutical industries for various processes such as: partial oxidation of ethylene to acetaldehyde, wet-air oxidation, liquid phase methanol synthesis, Fisher Tropsch synthesis [1],[2] and [3].Bubble columns can be operated in different flow regimes depending on the gas flow rate, column dimensions, the physicochemical properties of the two-phase mixture, and the operating conditions. Three operating flow regimes are: homogeneous, transitional and heterogeneous. These regimes differ from one another in hydrodynamic and transport characteristics, as well as in their suitability for a particular technology process [3].

The homogenous bubbly flow regime is characterized by uniform bubbles with small size distribution ≤ 7 mm. It is produced by plates with small and closely spaced orifices at low gas flow rates, these bubbles are small, spherical, monodispersed , and rise vertically with small vertical and horizontal fluctuations. The heterogeneous flow region is characterized by the formation of non-uniform and large bubbles in the size of 20-70mm. It is produced either by plates with small and closely spaced orifices at high gas flow rates. The homogenous-heterogeneous transition regime is a gradual process of increasing the number and size of coherent structures in the bubble bed. It is characterized by beginning of coalescence and formation of larger bubbles [4] and [5]

The interest in the type of operating flow regime, from industrial point of view, varies between the bubbly and heterogeneous flow regimes depending on the mass transfer and reactions rates of the process involved [6].

The flow pattern in a bubble column is also affected by the rheological properties of the liquid, especially when using highly viscous non-Newtonian fluids.

There are numerous results scattered in literature about the effect of the liquid viscosity on the gas holdup in the heterogeneous regime. Generally, it is reported that the holdup decreases with increasing viscosity. This is attributed to the presence of large population of big and fast bubbles with short retention time in the bed [7], [8] and [9]. Not only the viscous media are favourable for formation of big bubbles directly at the gas distributor [10], but also they promote bubble coalescence and suppress bubble breakup in the bed [6], [11], [12] and [13].

In order to improve the efficiency of the bubble columns several variations of the basic bubble column have been investigated such as using baffle plates, drift tubes and mesh wiers. The literature cited on the use of bubble plate is very limited [14], [15] and [16]. Therefore, the aim of this work is to compare flow regions and gas holdup obtained with Newtonian and non-Newtonian liquids in the presence and absence of baffles, as well as getting empirical correlation of gas hold up and critical gas velocity with the variables.

The aim of the present work is to study the effect of the presence of baffle plates on the homogenous –heterogeneous flow regime for non-Newtonian fluid.

Theory

The homogenous-transition-heterogeneous regime can be distinguished by gas holdup and gas flow rate (e-q) graph. In this graph the gas holdup increases linearly and progressively with gas flow rate (homogenous regime) up to maximum value then the increase follows a rational function (heterogeneous regime). The maximum point indicates the transition point.

However, sometimes it's difficult to find the transition point from this graph especially when the graph doesn't show a maximum in gas holdup or when the change in slope is gradual. Therefore several models have been suggested for the transition zone and among the most famous ones is Wallis model [17]. In this model the drift flux (the volumetric flux of either plot relative to a surface moving at volumetric average velocity) is plotted against the gas holdup.

$$J_{GL}= U_G(1-\varepsilon_G) \pm U_L\varepsilon_L \qquad 1$$

$\pm$ represents the counter current or co-counter current flow of liquid. For batch reactor U_L is zero therefore equation (1) will be:

$$J_{GL}= U_G(1-\varepsilon_G) \qquad 2$$

The change in slope of the curve represents the transition from homogenous to heterogeneous flow. Also, the transition point can also be found by plotting the experimental drift flux cited in equation (2) and the theoretical flux, equation(3), with the gas holdup in the same graph.

$$J_{theo}= \varepsilon_G\, u(1- \varepsilon_G) \qquad 3$$

in which u represents the mean slip bubble velocity

At homogeneous regime $J_{exp} = J_{theo}$, the point of deviation is considered as the critical point.

The mean slip velocity of bubble (u) was calculated by many empirical correlations like that made by Richardson-Zaki or the one made by Ruzika [18].

$$u = u_o\,(1- a\,\varepsilon_G/(1- \varepsilon_G)) \qquad 4$$

The relation of gas holdup and gas flow has been cited in several models like that made by Krishna, et al [19] who proposed a relation of gas hold up and gas flow depending on the size of bubbles, in his model if $U_G \le U_{trans}$ then the gas holdup in the homogenous flow regime is given by:

$$\varepsilon_G = U_G /u \qquad 5$$

in which

$$u = v(1- \varepsilon_G) \qquad 6$$

And if $U_G \ge U_{tran}$ then the total gas holdup in the heterogeneous regime is :

$$\varepsilon_G = \varepsilon_{b,large}+ \varepsilon_{trans}(1- \varepsilon_{b,large}) \qquad 7$$

$$\varepsilon_{b,large}=(U-U_{trans})/V_{b,large} \qquad 8$$

Ruzika, et al [19] cited another model for gas hold up and gas flow (e-q) for homogenous, transition, and heterogeneous regimes. For homogenous regime the gas holdup is

$$\varepsilon_G = \frac{U_G + u_o - \sqrt{B}}{2(1-a)w} \qquad 9$$

and for heterogeneous regime:

$$\varepsilon_G = \frac{U_G}{w + cU_G} \qquad 10$$

Experimental Work

The experiments were carried out in a QVF cylindrical column (Figure1)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.

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) . 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)

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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. these plates were connected with two aluminum rods settled on the internal sides of the bubble column.

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.

Results and Discussion

Gas Holdup

Effect of Baffles

The effect of baffles on gas holdup for different concentrations of PAA is displayed in Figures (2-5). These figures show that, at comparable operating conditions, the gas holdup was larger in baffled column than unbaffled one,. This is caused by the trapping of gas bubbles under the baffle plates. Similar behavior is shown by O'Dowd, et al. [14], and Yamashita [16] while it differs from that of Shah et al. [21] who reported that the gas holdup is unaffected with the presence of baffles in bubble column, this difference may be caused by the difference in column diameter or the difference in the number of baffles and their arrangement.

When the superficial gas velocity to heterogeneous regime is increased, the gas holdup in baffled column will be less than that in unbaffled one. This behavior is due to the existence of high liquid circulation making it easier for gas bubbles to run away from the baffle plate.

Effect of Viscosity

We can notice from Figures (6-7) the values of gas holdup in Newtonian solution (0% PAA) are more than that in non-Newtonian solution in both baffled and unbuffled column. Also, the gas holdup decreases, in non-Newtonian solution, with the increasing of PAA concentration from 0.01 to 0.1%. This result is confirmed by other workers like Wikinson, et al.[22], Ruzicka, et al.[6] and Fransolate, et al.[13]. The explanation of this behavior lines in the trend to decreasing of bubble breakup and increasing of bubble coalescence rates with the increasing of liquid viscosity. Furthermore, this trend results in existence of many large bubbles with high rise velocity which leads to decrease in gas holdup.

The effect of apparent viscosity and superficial gas velocity on gas holdup can be related by the following power law function which was already proposed by other workers: Eickenbusch et al., [20] and Fransolate, et al.[13].

$$\varepsilon_G = aU_G^{\,b}\,\mu_{app}^{\,-c} \qquad 14$$

the apparent viscosity is already related to superficial gas velocity by means of equations (12) and (13).

A least square method was used to fit equation (14) with the experimental data. Parameters estimated are (a= 0.28, b= 0.4, c=0.1), with variance of 0.98. These parameter are nearly similar to those reported by Fransolet et al.(2005) (a=o.26, b=0.54 and c=0.14).

Effect of Superficial Gas Velocity

In all figures cited above, it is clearly shown that gas holdup increases with increasing gas velocity. This trend is the same as that observed by many workers e.g, Joshi et al.[23], Kara et al.[24], Kemoun et al.[25], Pandit and Joshi [26].

The dependence of gas holdup on superficial gas velocity of unbaffled column (Figure 6) changes smoothly from the typical transition curve with expressive maxima to monotonous line of the heterogeneous regime with increasing viscosity from 1mP to 2.2mP. This behavior is similar to that proposed by Zahradnik et al.[7] and Ruzicka et al.[6] (pirical rule) who said that the homogenous region cannot exist at high liquid viscosity ,say > 8mP cited by Zahradnik et al.[7] and >3mP in the work of Ruzicka et al.[6], in our results it is 2.2.

On the other hand in baffled column (Figure 7) the typical transition curve with expressive maxima is still present even at high liquid viscosity, this can be attributed to the presence of baffles.

Critical Values

The critical values of gas holdup and superficial gas velocity were found by plotting the theoretical and experimental drift flux with gas holdup Figures (8-15). The point of deviation of the data represents the critical value.

Effect of Baffles

The influence of baffles existence on the values of transition parameter of gas holup and gas velocity is represented in figures (16-17). It is clearly shown that these parameters increase with the existence of baffles, this is a normal case as we mentioned in previous section that the gas holdup in homogenous regime increases with baffles existence.

Effect of Viscosity

Figures (16-17) show a general decrease in the critical values with increasing viscosity from (1 to 2.5)mPa.s in both baffled and unbaffled columns. This is natural since increasing viscosity causes a decrease in gas holdup.

The critical data can be fitted with the following empirical power law equation:

$e_c = a\,\mu^b$ 15

$U_c = c\,\mu^d$ 16

A least square method was used to estimate the constants in the above equations and they were :(a=0.165 , b=-0.369 , c=0.033 , and d=-0.33) for baffled column and (a=0.132, b=-0.459, c=0.024 and d=-1.33) for unbaffled column. These parameters are differ from that estimated by Ruzick, et al.[6] which are :(a=0.28 , b=-0.37 , c=0.048 , and d=-0.24).

Gas holdup – superficial gas velocity plot

The experimental data can be fitted with the model obtained by Krishna et al.[19] or that by Ruzicka et al. [18] as represented in figure (18). It is clearly observed from this figure that the model made by Ruzicka et al. is more in agreement with our experimental data than that of Krishna.

Conclusions

In the present work it can be concluded:

1- The gas holdup decreases with increasing viscosity

2- In homogenous region the values of gas holdup are less in the presence of baffles while in heterogeneous region the case is the opposite.

3- The gas holdup-gas flow plot shows a maximum point in both baffled and unbaffled column.

4- The transition points decrease with increasing viscosity.

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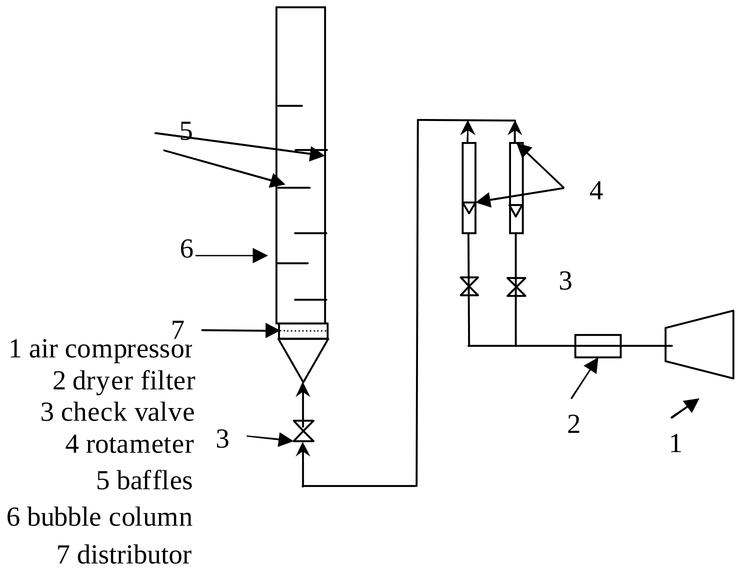
Table (1) : Physical Properties of Water and PAA Solution

Liquid Concentration of PAA wt%	ow Behavior index, N	Consistency Index, m , Pa.s^n	Density at 303K ρ_L, Kg/m^3	Surface Tension, σ, N/m	Apparent Viscosity, μ, mPa.s
0(water)	1	0.001	1000	0.07	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) : Experimental Apparatus



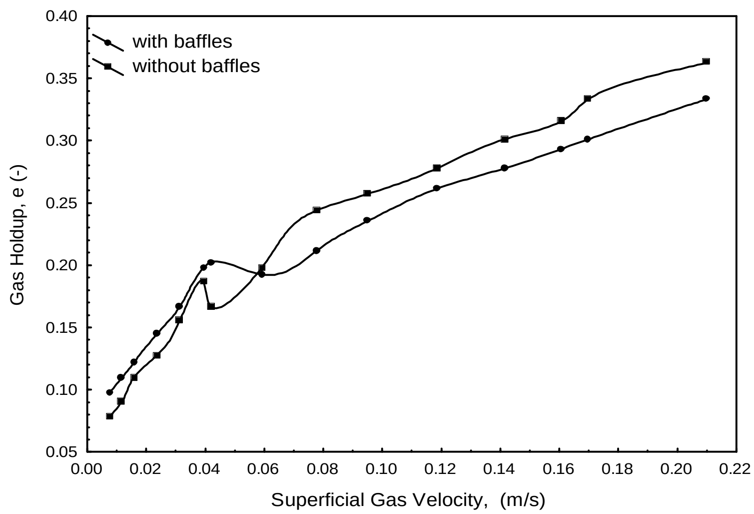


Figure (2)

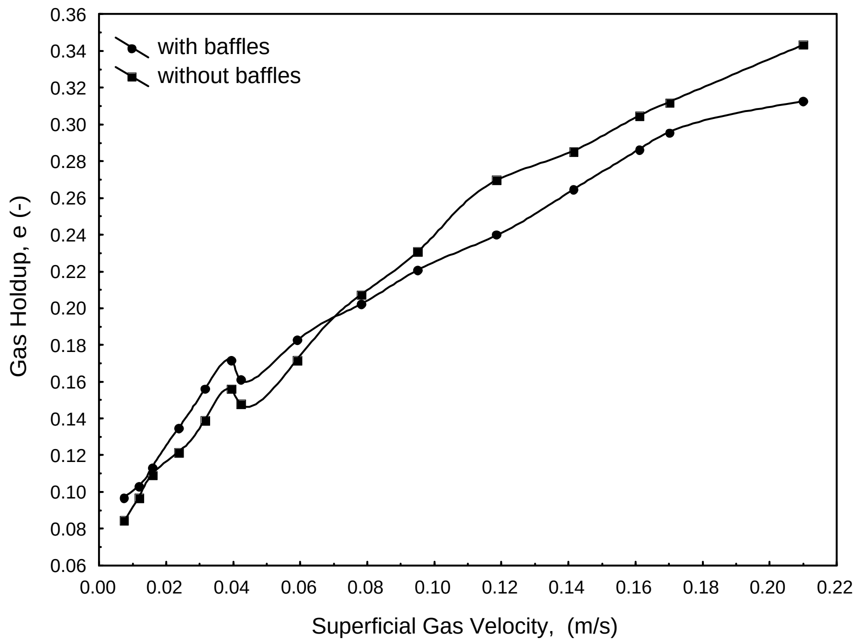


Figure (3): The effect of baffles on gas holdup in 0.01wt% of PAA solution

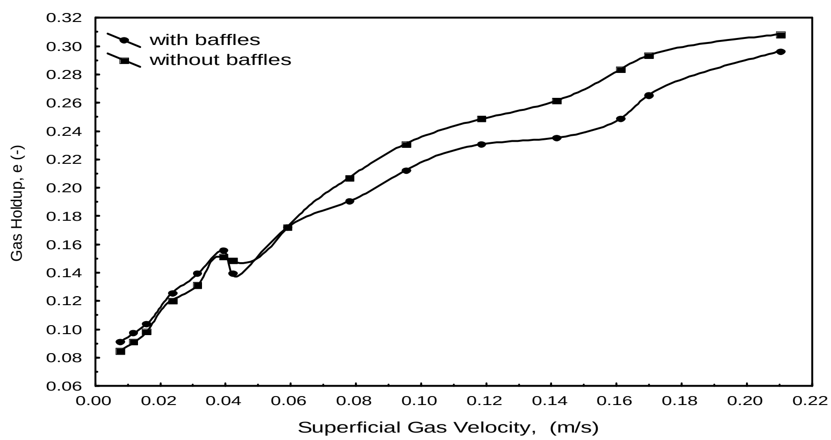


Figure (4)

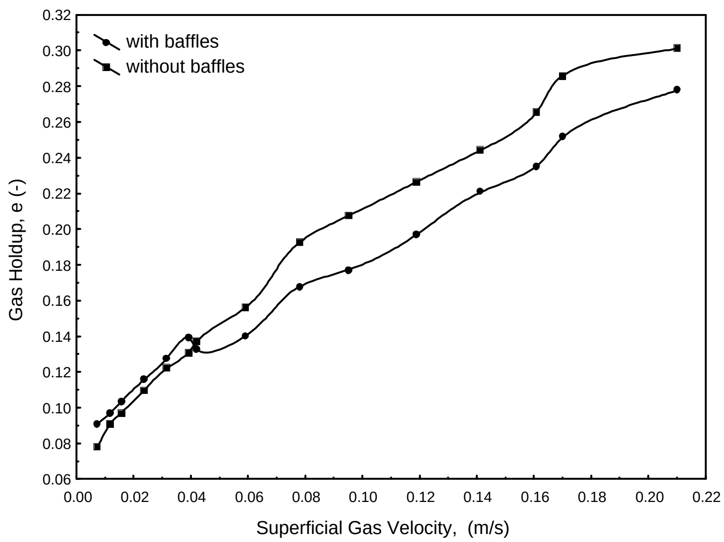


Figure (5): The effect of baffles on gas holdup in 0.1wt% of PAA solution

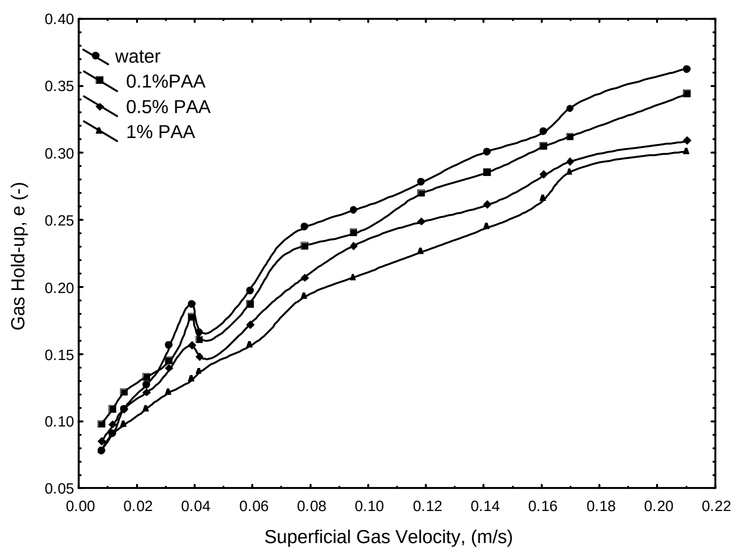


Figure (6): Gas holdup versus superficial gas velocity in different concentrations of PAA solution in unbaffled column

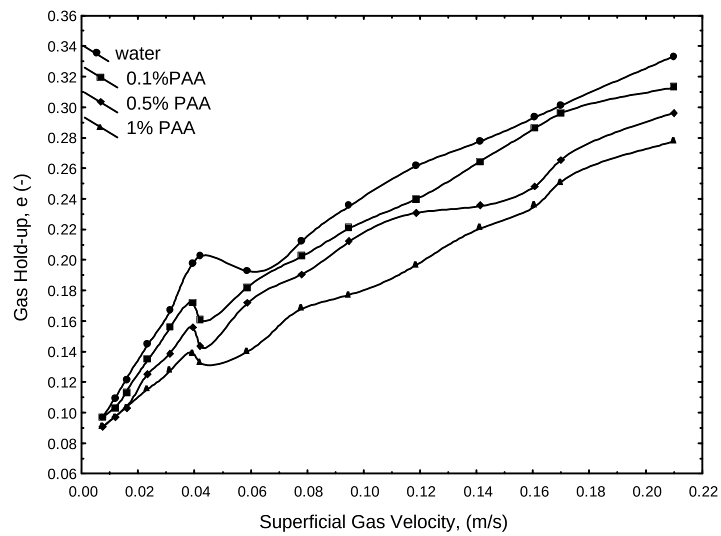


Figure (7): Gas holdup versus superficial gas velocity in different concentrations of PAA solution in baffled column

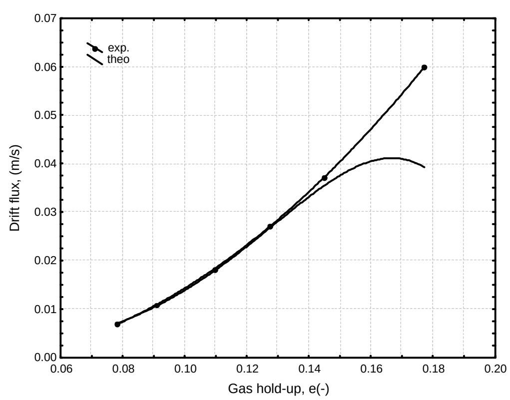


Figure (8): Drift flux versus gas holdup in water in unbaffled column (e_c=0.14 and U_c=0.033)

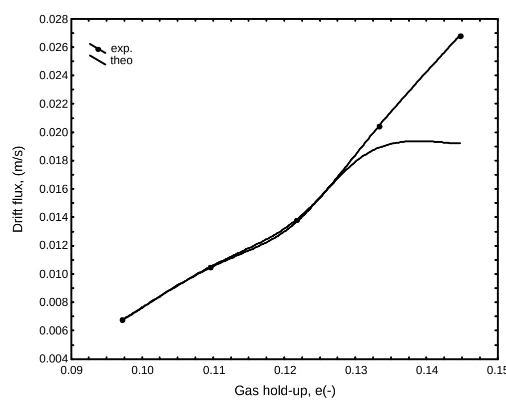


Figure (9): Drift flux versus gas holdup in 0.01wt% of PAA solution in unbaffled column (e_c=0.128 and U_c=0.017)

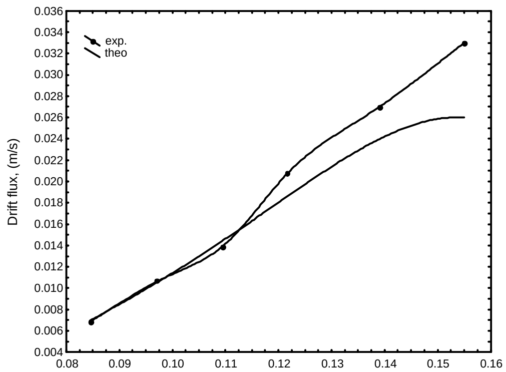


Figure (10): Drift flux versus gas holdup in 0.05wt% of PAA solution in unbaffled column (e_c=0.112 and U_c=0.015)

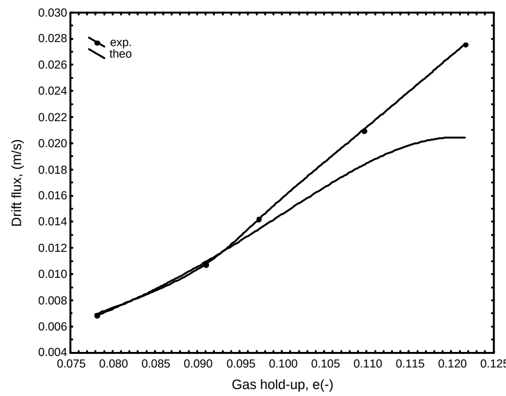


Figure (11): Drift flux versus gas holdup in 0.1wt% of PAA solution in unbaffled column (e_c=0.095 and U_c=0.012)

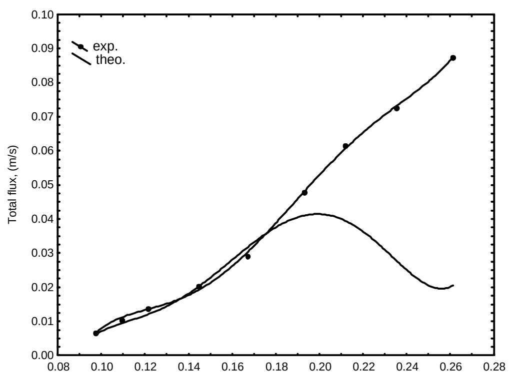


Figure (12): Drift flux versus gas holdup in water in baffled column (e_c=0.17 and U_c=0.039)

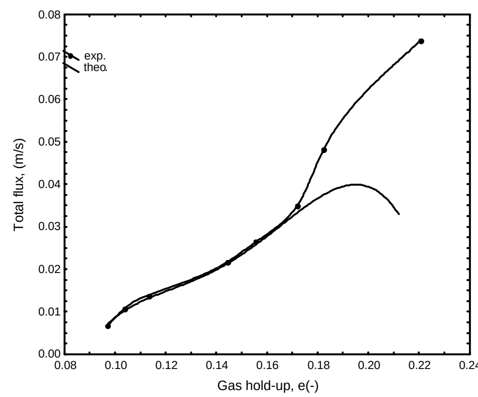


Figure (13): Drift flux versus gas holdup in 0.01wt% of PAA solution in baffled column (e_c=0.165 and U_c=0.03)

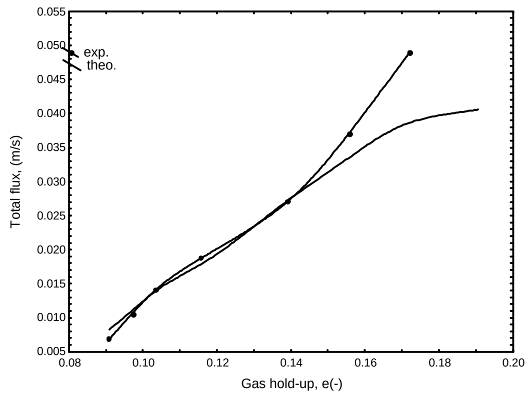


Figure (14): Drift flux versus gas holdup in 0.05wt%of PAA solution in baffled column (e_c=0.145 and U_c=0.028)

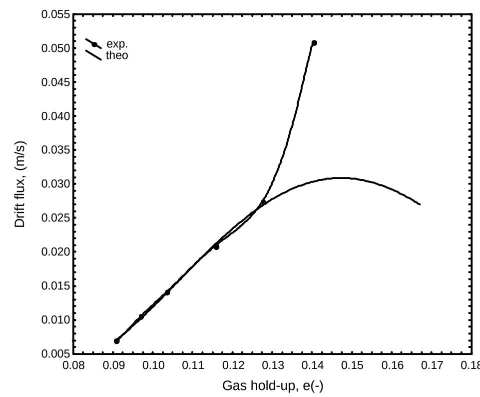


Figure (15): Drift flux versus gas holdup in 0.05wt%of PAA solution in baffled column (e_c=0.127 and U_c=0.026)

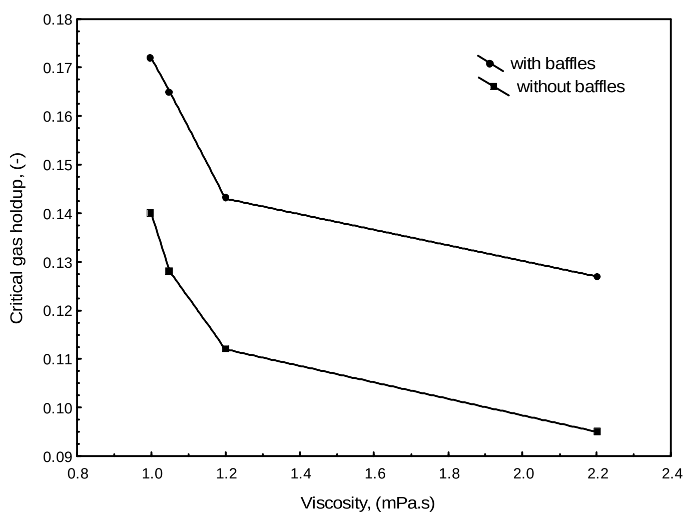


Figure (16): Critical gas holdup versus viscosity in baffled and unbaffles column

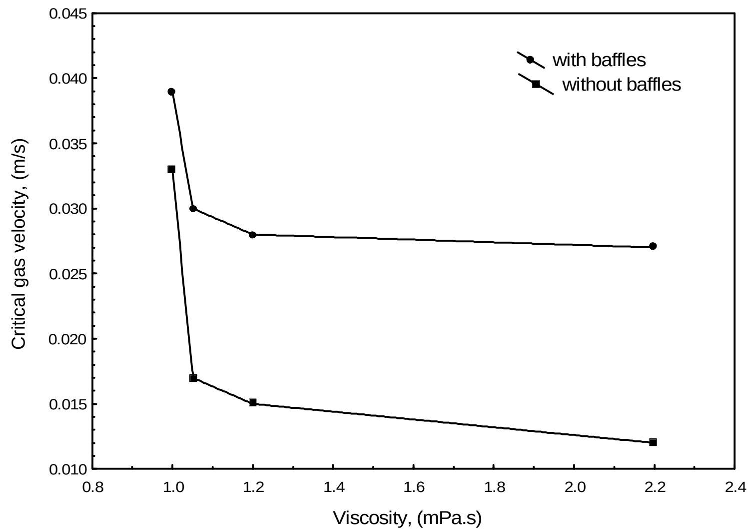


Figure (17): Critical gas velocity versus viscosity in baffled and unbaffles column

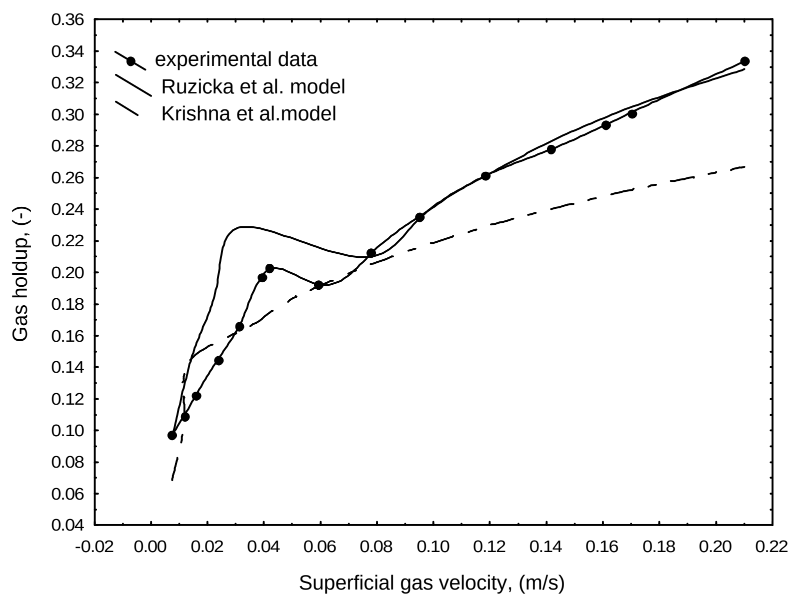


Figure (18): Comparison of experimental data with Krishna and Ruzicka models for water system and unbaffled column