

THE EFFECT OF LIQUID PHASE PROPERTIES ON GAS HOLDUP IN BUBBLE COLUMN REACTORS

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The effect of liquid phase properties on gas holdup in bubble column reactors was investigated within a large set of gas-liquid systems. Air was used as a gaseous phase in all experiments, liquid phases included distilled water and aqueous solutions of alcohols and electrolytes. Gas holdup values were determined in a sieve tray bubble column 0.15 m i.d. under conditions of stable uniform gas distribution and an attempt was made to relate these data with values of bubble coalescence ratio determined for respective gas-liquid systems in a coalescence cell. Experimental results proved strong influence of solute addition on bubble coalescence reduction and on the increase of gas holdup values in aqueous solutions of both alcohols and electrolytes. An unambiguous dependence was observed between gas holdup data and values of bubble coalescence ratio in alcohol solutions, the effect of coalescence suppression on gas holdup enhancement increased markedly with increasing gas flow rates. An empirical equation was proposed for estimation of lower and upper gas holdup limits in electrolyte solutions within the coalescence suppression region, *i.e.* at solute concentrations above coalescence transition value.

With the exception of concentrated glycerol solutions, homogeneous bubble beds were generated in all gas-liquid systems using the appropriate gas distributing plate. The positive effect of coalescence restraining on gas holdup values was even more significant in homogeneous bubble beds than under conditions of turbulent bubbling regime.

One of the major obstacles to be encountered on the route towards the *a priori* design of bubble column reactors for gas-liquid systems has been the present inadequate knowledge of the effect of system properties on hydrodynamics and rate of interfacial mass transfer in bubble beds formed in such reactors. Numerous empirical relations have been reported in literature¹⁻⁶ describing dependence of decisive bubble bed parameters (gas holdup, specific interfacial area, $k_L a$) on physical properties of both gaseous and liquid phases. Such correlations based upon more or less representative sets of experimental data give however inconsistent and often contradictory information regarding the effect of system properties on individual correlated parameters and neither of them can be fully recommended for a general use. It has been proved^{7,8} that the empirical correlations fail namely in cases when the liquid phase is not a pure component *i.e.* for both aqueous and non-aqueous solutions of organic and inorganic compounds. Whereas complete understanding of interfacial phenomena involved and subsequent theoretical description of gas-

-liquid systems behaviour seem still to be a task demanding long-term research, there is apparently an urgent need for operative correlations to be used in gas-liquid reactors design. It therefore seems to be worthy to look for proper representative factors characterizing gas-liquid systems behaviour on which such relations could be based. In doing so a diverse approach is apparently advisable to different groups of gas-liquid systems according to the nature of liquid phase used (pure liquids, aqueous or non-aqueous solutions of organic or inorganic substances, non-Newtonian fluids and their solutions) to account for strongly different behaviour of respective systems, observed experimentally.

An alternative approach to generalized treatment of gas-liquid systems could be possibly based upon the correspondence between liquid phase ability to promote or hinder gas bubbles coalescence and hydrodynamic and mass transfer characteristics of bubble beds for appropriate gas-liquid systems. It has been established⁹⁻¹³ that close links can be drawn between coalescence inhibition in mixed liquid phases and bubble bed characteristics (gas holdup, interfacial area) observed for respective gas-liquid systems. It can be therefore assumed that an appropriate coalescence characteristic could be used as a lumped parameter expressing the effect of system properties on hydrodynamics and mass transfer in bubble beds.

It was the aim of our work to determine gas holdup values in a sieve tray bubble column reactor for an extensive set of gas-liquid systems and to test the possibility of correlating these data within individual groups of liquid phases including pure organic liquids, their aqueous solutions and aqueous solutions of electrolytes. It was further our purpose to find out whether the bubble coalescence ratio (ratio of coalescing bubble pairs) can be used as a general characteristic of system coalescence behaviour and whether any direct relation can be obtained between this parameter and values of bubble bed gas holdup for individual gas-liquid systems. For all systems studied, experiments in the bubble column were performed under conditions of stable uniform gas distribution both at homogeneous (bubbly-flow) and heterogeneous (churn-turbulent) bubbling regime conditions in an attempt to determine also the possible effect of system properties on bubbling regime stability and on differences between gas holdup values corresponding to homogeneous and turbulent bubble beds.

EXPERIMENTAL

A single stage glass-wall column 0.15 m in diameter was used for experiments. Distributing plates were made of brass sheets of thickness 0.003 m, the holes were uniformly distributed on the plate area in the triangular pitch. Two distributing plates were used with identical free plate area, $\phi = 0.2\%$, hole diameters 1.6 mm (plate A) and 0.5 mm (plate B) were chosen on the basis of our former results⁸ to achieve both turbulent and homogeneous bubbling regime. Experiments were performed at zero liquid flow rate with constant liquid phase volume in the bed. Clear liquid height, H_0 , was 0.54 m, the ratio of clear liquid height to column diameter, H_0/D , thus being

equal to 3.5 in all experiments. Superficial gas velocities varied between 0.031 and 0.200 m s^{-1} , the lower velocity limit was chosen as to ensure stable uniform plate performance in the whole range of gas flow rates. Air was the gaseous phase in all experiments, liquid phases used and their physical properties are listed in Table I. Values of density, viscosity, and surface tension given

TABLE I

Liquid phases studied and their physical properties at 25°C.

Alcohols and their aqueous solutions

Liquids	ρ_L kg m^{-3}	$\mu_L \cdot 10^3$ Ns m^{-2}	$\sigma \cdot 10^3$ N m^{-1}
Distilled water	997	0.893	72.2
Ethanol	787	1.096	22.3
0.2 wt. %	996	0.886	71.9
0.5 wt. %	995	0.891	69.7
1.0 wt. %	993	0.903	67.2
Butanol	811	2.610	23.4
0.025 wt. %	997	0.880	72.1
0.05 wt. %	997	0.880	71.3
0.1 wt. %	997	0.892	69.8
1.0 wt. %	995	0.915	51.9
Glycerol	1 261	945	63.0
8 wt. %	1 018	1.10	72.1
39 wt. %	1 104	3.42	68.2
67 wt. %	1 173	14.0	64.1
84 wt. %	1 221	76	63.4

Aqueous solutions of electrolytes (0.5M)

Liquids	Ionic strength	ρ_L kg m^{-3}	$\mu_L \cdot 10^3$ Ns m^{-2}	$\sigma \cdot 10^3$ N m^{-1}	Molecular mass g mol^{-1}
NaCl	0.5	1 016	0.919	73.4	58.44
KCl	0.5	1 017	0.878	73.1	74.55
NaOH	0.5	1 017	0.971	73.9	40.00
CaCl ₂	1.5	1 036	1.005	73.8	110.99
Na ₂ SO ₄	1.5	1 057	1.025	73.6	142.04
MgSO ₄	2	1 054	0.900	73.3	120.36
K ₃ Fe(CN) ₆	3	1 084	0.978	74.2	329.10
K ₄ Fe(CN) ₆	5	1 112	1.109	74.2	368.22
Al ₂ (SO ₄) ₃	7.5	1 164	3.140	74.2	342.14

in the table were determined experimentally using standard physico-chemical methods¹⁴. The electrolytes were selected to include mono-, di-, and trivalent ions and to encompass large range of ionic strengths and molecular masses. All experiments were performed at 25°C and atmospheric pressure. Gas holdup values were determined by the bed expansion method, *i.e.* from the difference of clear liquid height and the overall height of aerated bed,

$$\varepsilon_G = (H - H_0)/H.$$

Bubble coalescence studies were carried out in the coalescence cell used firstly by Lessard and Zieminski¹⁵. Schematic chart of our equipment which was slightly modified in comparison with original Lessard's construction is shown in Fig. 1. The rate of bubble formation and the bubble coalescence ratio, ψ , defined as the ratio of coalescing bubble pairs to the overall number of pairs generated in a given time period, were determined visually for all gas-liquid systems studied. Experiments were performed at four gas feed rates, corresponding values of gas velocity related to the capillary orifice area, u_0 , ranged between 0.07 and 0.14 m s⁻¹. Distance of orifices was kept constant during all experiments and equaled to 2.5 mm.

RESULTS AND DISCUSSION

Aqueous Solutions of Alcohols

In Fig. 2, values of gas holdup determined under turbulent bubbling conditions in aqueous solutions of ethanol and butanol are plotted against superficial gas flow

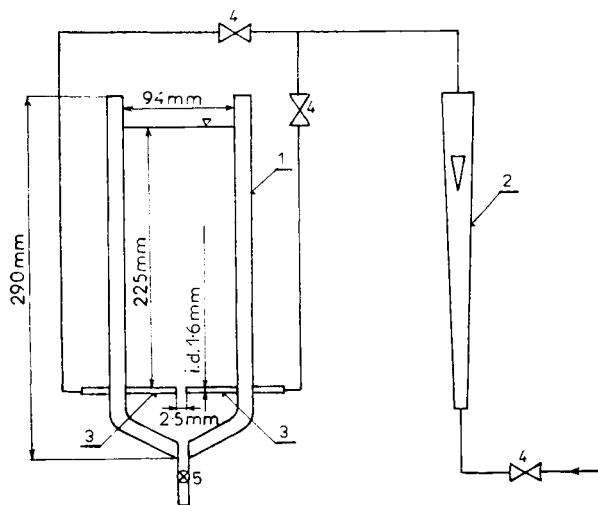


FIG. 1

Schematic chart of the equipment for coalescence studies; 1 vessel, 2 rotameters, 3 capillaries, 4 regulating valves, 5 discharge tap

rate, w_G . Experimental data clearly proved strong effect of both solutes on gas holdup already in the region of low alcohols concentrations ($c \leq 1$ wt.%). Apparently, the gas holdup increase due to solute addition as well as variations of bubble bed porosity with solute type and concentration cannot be satisfactorily explained by differences between characteristic physical properties of solutions (density, dynamic viscosity, surface tension) which were almost identical for the whole set of diluted ethanol and butanol solutions studied (see Table I). This observation agrees well both with our former data⁸ and with conclusions of Hammer and coworkers¹⁶ as well as with results of Charpentier's study¹⁷ on foaming of gas-liquid systems. Apparently, the significant effect of small amounts of polar organic solutes on gas holdup in their aqueous solutions can be qualitatively explained in terms of preferential solute concentration in an adsorption layer at gas-liquid interface^{18,19}. This phenomenon could be possibly quantitatively characterized by variables such as dynamic surface tension^{3,19} and/or surface viscosity²⁰, studies of such properties were however far beyond the scope and aims of our present work.

In Fig. 3 values of gas holdup obtained for ethanol and butanol solutions in the whole range of gas flow rates are plotted in semilogarithmic coordinates against bubble coalescence ratio, ψ . As can be seen from the figure, gas holdup data for the

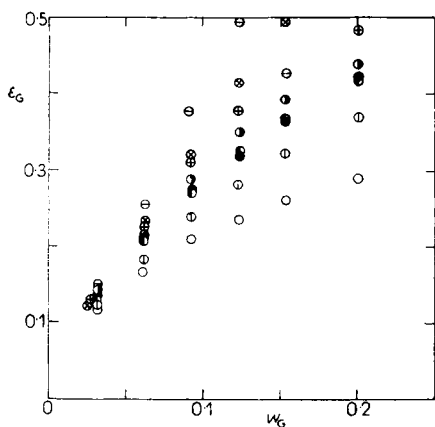


FIG. 2

Dependences of gas holdup on superficial gas velocity (w_G , m s^{-1}) for aqueous solutions of ethanol and butanol — turbulent bubbling regime (plate A); \circ distilled water; ethanol solutions, c (wt. %): \odot 0.2, \bullet 0.5, \bullet 1; butanol solutions, c (wt. %): \bullet 0.025, \oplus 0.05, \odot 0.1, \ominus 1

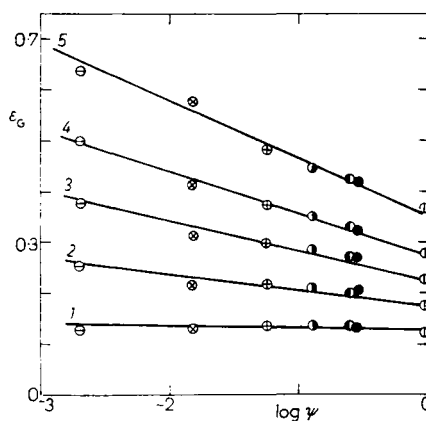


FIG. 3

Gas holdup as a function of bubble coalescence ratio — aqueous solutions of ethanol and butanol; w_G (m s^{-1}): 1 0.031; 2 0.061; 3 0.092; 4 0.123; 5 0.200. For symbol key refer to Fig. 2

two sets of solutions can be surprisingly well correlated as a function of $\log \psi$. It is further apparent from the graph that the effect of coalescence restraining on gas holdup in bubble bed decreased with decreasing gas flow rate and it was negligible at superficial velocities $w_G \leq 0.03 \text{ m s}^{-1}$. Due to limited number of solutes studied, no attempt was made to describe quantitatively the dependence of gas holdup on bubble coalescence ratio. Possible existence of a correlation function $\varepsilon_G = \varepsilon_G(\psi)$ as suggested by data in Fig. 3 seems however to be highly promising from the viewpoint of reactor design and modeling. An experimental study is therefore being prepared with a larger set of analogical gas-liquid systems aimed at the examination of the relation between the two variables.

Unlike ethanol and butanol, glycerol represents a non-polar solute with virtually negligible surface activity. Understandably thus, no effect of glycerol addition was observed in strongly diluted solutions ($c \leq 1 \text{ wt. } \%$) either on gas holdup or on bubble coalescence ratio. It is apparent from Fig. 4, in which gas holdup data for the experimental set of glycerol solutions ($c = 7-84 \text{ wt. } \%$) are plotted against superficial gas velocity, that maximum values of gas holdup were observed in solution 39 wt. % having dynamic viscosity $3.4 \cdot 10^{-3} \text{ N s m}^{-2}$. This is in good agreement with results reported by Eissa and Schügerl²¹ who observed for glycerol solutions maximum of the dependence ε_G vs μ_L at $\mu_L \approx 3 \cdot 10^{-3} \text{ N s m}^{-2}$ and explained qualitatively the existence and position of this maximum in terms of hindered bubble motion in viscous fluids. They suggested that in solutions with moderately raised viscosity upward bubble motion was hindered and consequently time of bubble residence in aerated bed increased while drag forces were still not sufficiently large to influence significantly bubble coalescence degree. Above a certain limiting value of viscosity however further drag forces increase promoted bubble coalescence enhancement and thus apparently caused monotonous decrease of gas holdup with increasing viscosity, observed experimentally²¹. Such an explanation seems to be supported even by results of our present coalescence measurements. Almost total coalescence ($\psi \rightarrow 1$) was observed in glycerol solutions 68 and 84 wt. % in comparison with low values of bubble coalescence ratio ($\psi \approx 0.1$) corresponding to solutions 8 and 39 wt. %.

Aqueous Solutions of Electrolytes

Experimental data of bubble coalescence ratio determined for the whole set of 0.5M electrolytes solutions studied in our work are summarized in Table II. As can be seen from the table, values ψ ranged between zero and 0.05 within the whole region of gas feed rates witnessing thus only minor differences of coalescence inhibition degree between individual solutions. Indeed such result is quite understandable in view of data published by Lessard and Zieminski¹⁵ who observed for majority of electrolytes used in our work (MgSO_4 , CaCl_2 , Na_2SO_4 , NaCl) values $\psi < 0.1$

TABLE II

Bubble coalescence ratios for aqueous solutions of electrolytes

Solute	u_0 m s^{-1}			
	0.14	0.12	0.09	0.07
NaCl	0.04	0.02	0.015	0.005
KCl	0.04	0.025	0.01	0.005
NaOH	0.015	0.005	0	0
CaCl ₂	0.05	0.025	0.01	0.005
Na ₂ SO ₄	0.035	0.025	0.01	0.005
MgSO ₄	0.015	0.005	0	0
K ₃ Fe(CN) ₆	0.03	0.015	0.005	0
K ₄ Fe(CN) ₆	0.025	0.015	0.005	0
Al ₂ (SO ₄) ₃	0.025	0.025	0.015	0.005

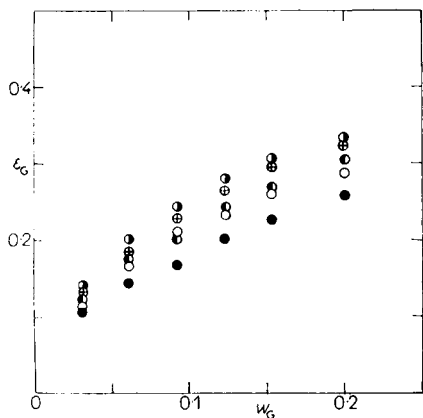


FIG. 4

Dependences of gas holdup on superficial gas velocity for aqueous glycerol solutions — plate A; ○ distilled water; glycerol solutions, c (wt. %): ⊕ 7, ● 39, ⊙ 67, ● 84

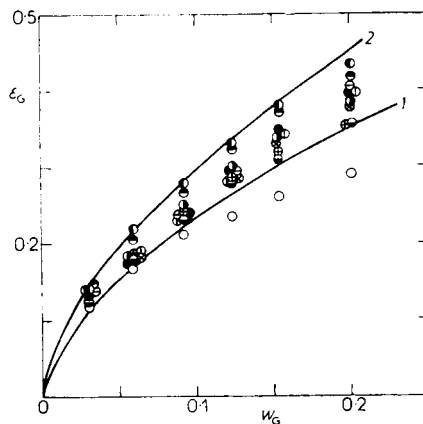


FIG. 5

Comparison of dependences ϵ_G vs w_G for aqueous solutions of electrolytes ($c = 0.5 \text{ mol l}^{-1}$); plate A; ○ distilled water; electrolytes: ● NaCl, ● KCl, ⊙ NaOH, ⊙ CaCl₂, ⊙ Na₂SO₄, ⊕ MgSO₄, ⊕ K₃Fe(CN)₆, ⊖ K₄Fe(CN)₆, ⊗ Al₂(SO₄)₃; — dependences calculated from Eq. (1) for $K_{\min} = 0.95$ (line 1) and $K_{\max} = 1.20$ (line 2)

already at solute concentrations lower than 0.3M. It has however to be pointed out that although the results of our coalescence measurements proved almost total coalescence suppression in all solutions of electrolytes investigated, significantly different values of bubble bed gas holdup were determined for individual solutions in bubble column reactor (see Fig. 5). As can be seen from Table I, physical properties of electrolytes solutions differed only slightly (with the single exception of relatively high viscosity of $\text{Al}_2(\text{SO}_4)_3$ solution), giving thus again no clue to explanation of gas holdup variations observed. Keitel and Onken^{12,13} proved in their recent studies devoted to coalescence in aqueous solutions that the Sauter mean diameter of bubbles in solutions of electrolytes could be well correlated by ionic strengths of these solutions. No such relation was however observed in our present study between ionic strength and gas holdup data even for the same electrolytes used by Keitel and Onken ($\text{Al}_2(\text{SO}_4)_3$, Na_2SO_4 , NaCl , NaOH). Lessard and Zieminski¹⁵ tried to find a relation between parameters characterizing ion-water interactions such as solution entropy or water self-diffusion, and coalescence transition concentration *i.e.* critical concentration of diluted electrolyte corresponding to the switch from complete coalescence ($\psi \rightarrow 1$) to significant coalescence inhibition ($\psi < 0.1$). Their experimental data proved that both solution entropy and water self-diffusion parameter could be successfully used for prediction of coalescence transition concentration in aqueous solutions of electrolytes. Analysis of gas holdup data obtained in our work for 0.5M solutions of CaCl_2 , NaCl , and KCl (*i.e.* at concentration well above the coalescence transition concentrations determined for these electrolytes by Lessard and Zieminski¹⁵) yielded however no relation between these data and parameters introduced by Lessard and Zieminski. Apparently thus, their approach cannot be applied for explanation of different behaviour of individual electrolyte solutions in the region of total coalescence restraining reflected by our gas holdup data.

As can be seen from Fig. 5, experimental gas holdup data for all electrolytes solutions studied in our work lied within the boundaries defined by exponential-type equation

$$\varepsilon_G = K_i w_G^{0.61} \quad (1)$$

with lower and upper limiting values of coefficient K_i , $K_{\min} = 0.93$ and $K_{\max} = 1.2$. Phulgaonkar, Kelkar, and Shah²² concluded from the vast experimental evidence^{4, 10, 15, 22} that above a certain critical value (corresponding obviously to coalescence transition concentration) electrolyte concentration has no influence on system coalescence behaviour and on gas holdup values. Considering this fact as well as a fairly representative set of electrolytes used in our work, empirical equation (1) with coefficients K_{\min} and K_{\max} can be recommended for a preliminary estimation of gas holdup in solutions of electrolytes at concentrations above the coalescence transition concentration, *i.e.* in the region of total coalescence suppression. Indeed,

possible effects of gas distributor type and geometry have to be considered cautiously prior to application of the equation (1) to another units.

Homogeneous Bubbling Regime

Gas holdup data obtained for individual gas-liquid systems studied in the column with distributing plate B, *i.e.* at conditions favourizing generation of homogeneous bubble bed, are presented in Figs 6–10. As can be seen from these figures, experimental dependences ε_G vs w_G exhibited for all solutions of alcohols and electrolytes with the exception of highly viscous concentrated glycerol solutions ($c = 67$ and 84 wt. %, $\mu_L = 14 \cdot 10^{-3}$ and $76 \cdot 10^{-3}$ Ns m $^{-2}$) clearly defined maxima corresponding to transition between homogeneous and turbulent bubbling regime^{8,23}. Experimental evidence also proved that values of gas holdup in homogeneous bubble beds were under comparable conditions significantly higher than in turbulent beds and that the differences between individual systems were in all cases more pronounced in the region of homogeneous bubbling regime. Apparently thus, the effect of system properties is even more important in homogeneous bubble beds than at turbulent bubbling conditions which has to be born in mind at bubble reactor design.

As can be seen in Figs 6 and 7, showing gas holdup data for ethanol and butanol*), values $w_{G_{max}}$ corresponding to maxima of dependences ε_G vs w_G were almost constant for respective sets of ethanol and butanol solutions ($w_{G_{max}} = 0.09$ and 0.12 m s $^{-1}$ for ethanol and butanol solutions respectively). Apparently this suggests that solute concentration has for systems of this type almost negligible effect on the region of homogeneous bubbling regime existence while influencing corresponding gas holdup values.

Data for glycerol solutions plotted in Fig. 8 proved that generation of homogeneous bubble bed was in highly viscous fluids prevented or at least significantly suppressed due to large drag forces promoting bubble coalescence. As a result, homogeneous bubbling regime was not observed in glycerol solution 84 wt. % and virtually identical values of gas holdup were obtained in this solution on both distributing plates used within the whole experimental range of superficial gas velocities (compare Figs 4 and 8). Only inexpressive maximum of dependence ε_G vs w_G was observed in glycerol solution 67 wt. % while fully developed homogeneous bubbling regime was achieved only at glycerol concentrations 7 and 39 wt. %. In the latter case however significantly lower values of gas holdup were obtained than in solution 7 wt. % in contrast to almost identical gas holdup values observed for the two solutions at turbulent bubbling conditions (see Fig. 4). Unfavourable effect of viscosity on homogeneous bubble bed formation which can be deduced

* No gas holdup data were obtained in butanol solutions 0.1 and 1.0 wt. % at gas flow rates higher than 0.077 m s $^{-1}$ due to massive overflow in the region of transition from homogeneous to turbulent bubbling regime.

from this experimental evidence has been clearly apparent even from Fig. 9 *i.e.* from comparison of the dependences ϵ_G vs w_G obtained on plates A and B for ethanol, butanol, and concentrated solution of glycerol ($c = 84$ wt. %) as liquid phases. Data for the three systems also convincingly confirm formerly⁸ observed independence of bubble bed gas holdup on distributing plate geometry at turbulent

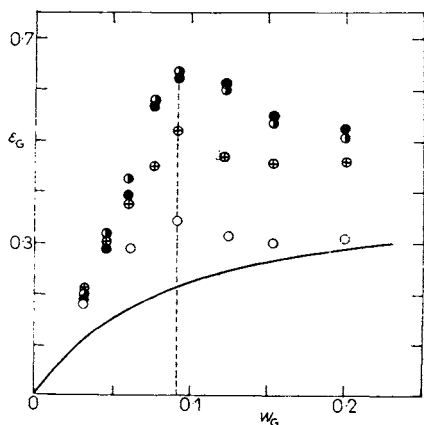


FIG. 6

Gas holdup in ethanol solutions as a function of superficial gas velocity — homogeneous bubbling regime (plate B); \circ distilled water; ethanol solutions, c (wt. %): \oplus 0.2; \bullet 0.5; \bullet 1. — dependence ϵ_G vs w_G for air-water system at turbulent bubbling conditions

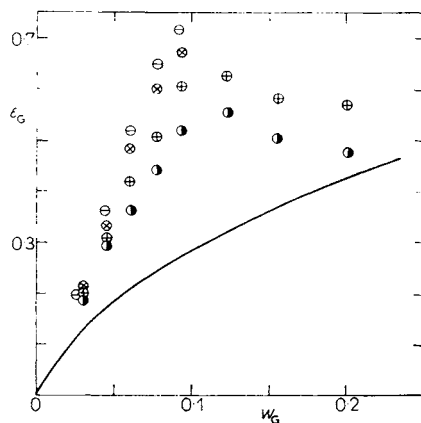


FIG. 7

Gas holdup in butanol solutions as a function of superficial gas velocity — homogeneous bubbling regime (plate B); c (wt. %): \bullet 0.025; \oplus 0.05; \otimes 0.1; \ominus 1; — data for turbulent bubbling regime, $c = 0.025$ wt. %

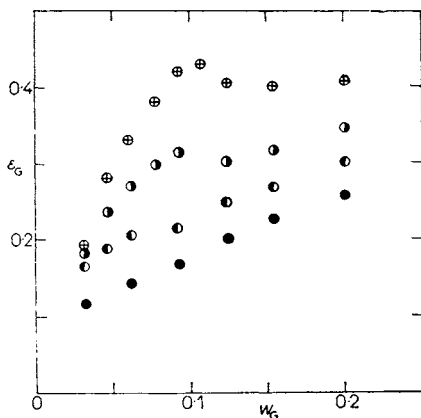


FIG. 8

The effect of glycerol concentration on bubbling regime — plate B. c (wt. %): \oplus 7; \bullet 39; \bullet 67; \bullet 84

bubbling conditions. Gas holdup data corresponding to turbulent bubbling regime were for all three systems correlated by the empirical exponential type relation²⁴

$$\varepsilon_G = a_i w_G^{b_i}, \quad (2)$$

values of coefficients a_i , b_i determined for respective liquid phases by the least

TABLE III

Coefficients of Eq. (2), $\varepsilon_G = a_i w_G^{b_i}$, for individual liquid phases

Liquid phase	a_i	b_i
Ethanol	1.19	0.63
Butanol	0.85	0.55
Glycerol (84 wt. %)	0.53	0.46

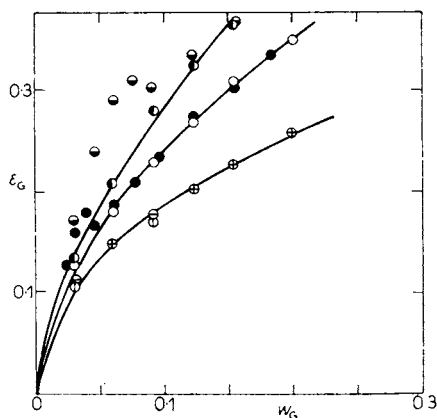


FIG. 9

The effect of viscosity on generation of homogeneous bubbling regime; ethanol ($\mu_L = 1.1 \cdot 10^{-3} \text{ N s m}^{-2}$): \circ plate A, \bullet plate B; butanol ($\mu_L = 2.6 \cdot 10^{-3} \text{ N s m}^{-2}$): \circ plate A, \bullet plate B; aqueous glycerol solution ($c = 84 \text{ wt. } \%$, $\mu_L = 76 \cdot 10^{-3} \text{ N s m}^{-2}$): \oplus plate A, \ominus plate B, \oplus identical values for both plates; — data calculated from Eq. (2) for coefficients a_i , b_i given in Table III

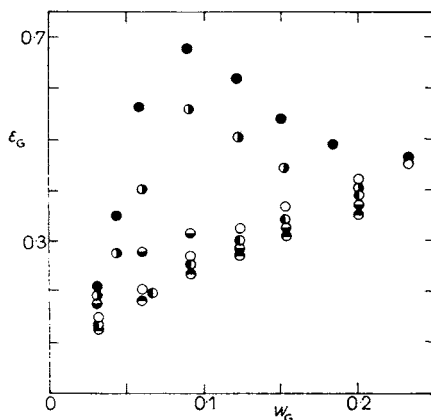


FIG. 10

The effect of bubbling regime on gas holdup in solutions of electrolytes, CaCl_2 : \circ turbulent, \bullet homogeneous; KCl : \circ turbulent, \bullet homogeneous; Na_2SO_4 : \circ turbulent, \bullet homogeneous

squares method are given in Table III. Fig. 9 proves good agreement of ε_G values calculated from Eq. (2) for these values of coefficients with experimental data obtained in the whole range of gas flow rates. Comparison of gas holdup data obtained for ethanol and butanol at both bubbling regimes further confirmed that gas holdup in systems with pure liquid phases has been strongly influenced by liquid phase viscosity. Surprisingly, this effect has been completely neglected in some commonly used correlations (see *e.g.* widely recommended Hughmark's relation²⁵). At the same time, no effect of viscosity on bubble coalescence was found within corresponding viscosity range ($\mu_{Et} = 1.1 \cdot 10^{-3} \text{ N s m}^{-2}$, $\mu_{Bu} = 2.6 \cdot 10^{-3} \text{ N s m}^{-2}$) and almost total coalescence was observed ($\psi \rightarrow 1$) for both alcohols in the whole experimental range of gas feed rates in the cell.

Comparison of dependences ε_G vs w_G obtained in solutions of electrolytes both at homogeneous and turbulent bubbling conditions has been demonstrated in Fig. 10 for three representative systems. As can be seen from the graphs, the differences between gas holdup data determined in individual solutions were in homogeneous bubble beds significantly larger than in turbulently bubbled beds. Values $w_{G_{\max}}$ corresponding to maxima of dependences ε_G vs w_G were, similarly as in the case of alcohols solutions, almost constant for all electrolytes ($w_{G_{\max}} \approx 0.09 \text{ m s}^{-1}$) independently of values $\varepsilon_{G_{\max}}$ achieved. Apparently such results suggest in agreement with our former data²⁶ that the region of homogeneous bubbling regime depends solely on the type and geometry of gas distributing device whereas system properties determine absolute values of gas holdup corresponding to conditions of fully developed homogeneous bubbling regime. It is apparent that if validity of this assumption would be confirmed by further experimental evidence it would be of considerable importance both for prediction of gas-liquid systems behaviour and for bubble reactors design.

LIST OF SYMBOLS

a_i, b_i	empirical coefficients in Eq. (2)
c	solute concentration
D	column diameter
d_0	plate hole diameter
H	height of aerated bed
H_0	clear liquid height in the bed
K_i	empirical coefficient in Eq. (1)
u_0	gas velocity in a capillary orifice
w_G	superficial gas velocity
ε_G	gas holdup ratio
φ	free plate area ratio
μ_L	dynamic viscosity of the liquid phase
ψ	coalescence ratio
ρ_L	liquid phase density
σ	surface tension

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