TRANSPORT CHARACTERISTICS OF A MECHANICALLY AGITATED AERATED VESSEL

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The gas holdup and impeller power input in a mechanically agitated aerated vessel were measured for aqueous solutions of ten inorganic salts as functions of the type and concentration of the electrolyte present, the impeller speed, and the gas flow rate. The dependence of the holdup on the physical properties of batch is best described by relations including the quantity $X = c(\mathrm{d}\sigma/\mathrm{d}c)^2 F$, where $F = (1 + \mathrm{d}\ln f/\mathrm{d}\ln c)^{-1}$. The best fit to experimental holdup data is given by the empirical equation $Z = 5{\cdot}0 \,.\, 10^{-4}\ \mathrm{Re}^{-0.226}\ \mathrm{Kp}^{0.25}\ \mathrm{We}^{1.09}\ Y^{1.16}$, where $\mathrm{Kp} = \dot{V}_g/nd^3$, $Y = 2 - \exp(-X^+)$, $X^+ = X/X_{\mathrm{crit}}$, $X_{\mathrm{crit}} = 3.\ 10^{-6}$ k mol^{-1} kg^2 m^3 s^{-4}, with mean and maximum deviations between calculated and experimental values of 12% and 20%, respectively. Incorporation of quantities that improve the ability of holdup correlations to account for the dependence of gas holdup on the physical properties of electrolyte solutions fails to produce the same effect in correlations for impeller power input to aerated batch. The best estimate of the power input (within 20%) is obtained by using the equation $P_a P_0 = 0{\cdot}226\ \mathrm{We}^{-0.0081}\ \mathrm{Kp}^{-0.294}$.

In designing mechanically agitated bubble reactors one needs to know how transport characteristics (volumetric mass transfer coefficient, gas holdup, and impeller power input) depend on the impeller speed, aeration intensity, and batch properties. Transport characteristics of aerated stirred tanks have been studied extensively, but mostly as functions of the intensities of agitation and aeration for a particular type of batch, while the effect of the physical properties of batch has been investigated to a much smaller extent and frequently for electrolyte-free batches. Of the ordinary components of industrial batches, it is, however, just electrolytes, their type and concentration, that have considerable influence on the properties of gas bubble dispersion and hence on all transport characteristics[1-4]. Some correlations have been proposed to describe the effects of electrolytes on some of the transport characteristics. However, experimental data have so far been insufficient for the applicability of these correlations to be judged with reasonable certainty.

Therefore, a series of experiments were performed to investigate variations in transport characteristics of an aerated stirred vessel with aeration intensity, impeller speed and electrolyte concentration for binary aqueous systems of ten inorganic salts. Equations proposed in the literature were tested to select those which best

correlate the experimental results. This paper gives results for gas holdup and impeller power input. Correlations for the volumetric mass transfer coefficient in aerated batches of aqueous electrolyte solutions will be discussed in a second part of this paper.

Gas Holdup Correlations

The properties of gas bubble dispersions in aerated liquid batches have been studied by several authors[5-8], mostly for electrolyte-free systems. In such cases, the dependence of the holdup on the experimental conditions in a vessel baffled in the turbulent region may be described by equations of the type

$$Z = f(\mathrm{Re}, \mathrm{Kp}, \mathrm{We}) \tag{1}$$

obtained for a given geometry for example by dimensional analysis if impeller diameter, impeller speed, gas flow rate, viscosity, density and surface tension are regarded as the decisive quantities. Experiments with solutions containing strongly dissociated inorganic salts[1-4] have shown that relations of the type of Eq. (*1*) give a good representation of data for the holdup as a function of impeller speed and gas flow rate, but fail to describe the dependence on the type and concentration of electrolyte present. This indicates that viscosity, density, and surface tension are not sufficient to characterize physical properties of aerated electrolyte solutions and that an additional characteristic quantity must be included. This view receives support from results of Marruci and Nicodemo[3], who studied gas bubble coalescence in bubble columns with electrolyte solutions. They found that a change in viscosity, density and surface tension by a maximum of 8% with change in the type and concentration of salt resulted in as much as an eightfold change in the mean gas bubble diameter. They also found that if the salt concentration exceeded a certain critical value (generally different for different salts), increasing the concentration had no longer an effect on the magnitude of mean bubble diameter. They advanced the view that the bubble coalescence was prevented by an electrical force of repulsion arising as a result of a difference in the salt concentration at the surface and in the bulk of the liquid, and showed that the force should be proportional to the quantity

$$E = \frac{1}{2} kc \frac{\mathrm{d}\sigma}{\mathrm{d}c} F \tag{2}$$

(this relation applies only to salts that split into two ions). The quantity F is defined by

$$F = \left(1 + \frac{\mathrm{d} \ln f}{\mathrm{d} \ln c}\right)^{-1} . \tag{3}$$

Indeed, they found[3] the mean bubble size to decrease with increasing E under otherwise the same conditions.

Machoň and Linek[9] assume that the stability of the liquid film of electrolyte solution in a mechanically agitated vessel may be characterized by the ratio of inertial forces to the difference, ΔP, in osmotic pressure between the surface and the bulk of the liquid phase. They have shown that this quantity may be estimated from the relation

$$\Delta P = E/b , \tag{4}$$

where b is the thickness of the film separating the bubbles at the moment of their contact. As the

value of b is difficult to determine independently, and moreover depends on the same properties of solution as does the quantity E, Machoň and Linek characterized the ratio of inertial forces to osmotic pressure differencence by the dimensional quantity

$$W = \frac{n^2 d^2 \varrho}{E} . \tag{5}$$

Incorporation of W into an empirical correlation for the volumetric mass transfer coefficient improved the fit to data for $k_L a$ as a function of the type and concentration of electrolyte in solution.[9] It may be expected that inclusion of this quantity will also be successful in handling the effect of batch properties on the gas holdup, since the latter is likewise determined by the stability of the liquid film surrounding the bubbles.

Lee and Meyrick[10] assume that the gas bubble coalescence is hindered by an increase in the surface tension as the film separating the bubbles in contact with each other thins down. Hence they deduce that the effect of the physical properties of batch on the holdup should be characterized by a parameter X of the form

$$X = c \left(\frac{\mathrm{d}\sigma}{\mathrm{d}c} \right)^2 F . \tag{6}$$

A correlation including this parameter showed good agreement with data for gas holdup as a function of the type and concentration of electrolyte[10]. The authors also stated that use of the parameter X instead of E in correlating the original data of Marrucci and Nicodemo[3] reduced the scatter of data about the theoretical curve.

Machoň and coworkers[11] have studied the behaviour of the gas holdup in an aerated vessel equipped with a six-blade turbine impeller over a wide range of the parameter X and found, for the salts used in their study, that if $X > X_{\mathrm{crit}} = 3 \cdot 10^{-6}$ kmol^{-1} kg^2 m^3 s^{-4}, the magnitude of gas holdup is no longer affected by either concentration or type of salt. From the trend in the variation of gas holdup with X they conclude that the holdup may be correlated by an equation of the type

$$Z = A \mathrm{Kp}^{a2} \mathrm{We}^{a3} Y^{a5} , \tag{7}$$

where

$$Y = 2 - \exp\left(-X^+\right) \tag{8}$$

and

$$X^+ = X / X_{\mathrm{crit}} . \tag{9}$$

Machoň and coworkers[11] have tested Eq. (7) against their experimental data as well as data of other authors. Their own data give $A = 1{\cdot}3 \cdot 10^{-4}$; $a2 = 0{\cdot}36$; $a3 = 1{\cdot}00$; $a5 = 0{\cdot}56$. Eq. (7) applies very well to results obtained on the same apparatus, but the parameters are sensitive to even a very small change in geometry: the parameter A, for instance, changes by 40% on going from an impeller diameter of 75 mm to 100 mm on otherwise the same apparatus.

The gas holdup is often estimated from an equation proposed by Hassan and coworkers[6].

$$Z = p \left(\frac{\dot{V}_g n^2}{\sigma} \right)^q , \tag{10}$$

where p and q are constants dependent on the geometry of the system and on the kind of solute. It is clear that Eq. (*10*) must suffer from the same disadvantages as Eq. (*1*).

The conclusions to be drawn from the foregoing discussion are as follows:

Expressions of the type of Eq. (*1*) give a good description of the variation in holdup as a function of impeller speed and gas flow rate, confirming that the set of independent dimensionless variables Re, Kp, and We have been properly chosen.

Thus, in searching for an adequate form of the correlation for gas holdup as a function of physical properties of electrolyte solutions, the three independent variables should be retained and the problem should be solved by adding another variable specific for the behaviour of electrolyte solutions. So far, the quantities E, W, X, and Y have been proposed for this purpose. The quantities E and X may be regarded as tantamount to W and Y, respectively, so that only W and Y will be considered in the following discussion. The correlating equation for gas holdup in electrolyte solutions aerated in a baffled stirred vessel may be of the general form

$$Z = A\mathrm{Re}^{a1}\mathrm{Kp}^{a2}\mathrm{We}^{a3}W^{a4} \qquad (11a)$$

or

$$Z = A\mathrm{Re}^{a1}\mathrm{Kp}^{a2}\mathrm{We}^{a3}Y^{a5}\,. \qquad (11b)$$

Power Input Correlations

A considerable amount of work has been done concerning the power input to an impeller in an aerated liquid. A number of older papers have been reviewed by Strenk[12]. The results are most frequently expressed in terms of the ratio P_a/P_0, where P_a is the power input to aerated liquid and P_0 the power input to non-aerated liquid under otherwise the same conditions. The available data indicate that the ratio P_a/P_0 largely depends on the magnitude of gas holdup.

Recent results have shown that the gas holdup alone is not sufficient to characterize the dependence of the ratio P_a/P_0 on the experimental conditions. Hassan and Robinson[6] measured the variation in P_a/P_0 with gas flow rate and impeller speed for aqueous solutions of organic substances and for 0·4M-Na_2SO_4, using systems of different geometries. They correlated their results by an equation of the form

$$P_a/P_0 = B\mathrm{Kp}^{b2}\mathrm{We}^{b3}(\varrho/\varrho_d)\,, \qquad (12)$$

where ϱ_d is the density of gas bubble dispersion in liquid, given by

$$\varrho/\varrho_d = 1 + Z\,. \qquad (13)$$

If the gas holdup had been a major factor governing the magnitude of the ratio P_a/P_0, the constants in Eq. (*12*) should have been independent of the physical properties of batch. Measurements showed, however, that only $b3$ remained unchanged ($b3 = -0{\cdot}38$) over the whole range of experiments; $b2$ varied from $-0{\cdot}22$ to $-0{\cdot}25$, depending on the impeller type; and the constant B for the Na_2SO_4 solution stirred with a six-blade turbine impeller was 24% lower than that found for the other batches. This implies that the correlation for the power input ratio should involve

a parameter other than, or one in addition to, ϱ/ϱ_d to provide a better representation of P_a/P_0 as a function of the properties of batch.

Hassan and Robinson[6] also studied the dependence of the power input P_a on the impeller speed with other conditions kept unchanged. They found that in the turbulent region of a baffled vessel, $P_a \sim n^3$. As the same is known to apply to P_0, the ratio P_a/P_0 should be independent of the impeller speed.

Michel and Miller[13] found their data to be represented by the equation

$$P_a = C_1 \left(\frac{P_0^2 n d^3}{\dot{V}_g^{0.56}} \right)^{C_2}, \qquad (14)$$

where C_1 and C_2 are constants. The influence of the physical properties of batch is incorporated in the value of the constant C_1, and so this equation is not sufficiently universal. The authors followed the variation in P_a with $\dot{V}_g$ over a wide range of gas flow rates and found that the proposed equation gave a better representation of the data than did the normally used dimensionless quantity Kp. The value of 0·43 to 0·45 given by the authors for the constant C_2 satisfies the requirement of the independence of the ratio P_a/P_0 on the impeller speed ($P_a/P_0 \sim n^{0,01}$).

EXPERIMENTAL

A cylindrical vessel (of polymethyl methacrylate) with 290 mm inner diameter was used, equipped with a stainless steel six-blade turbine impeller. The vessel was provided with four baffles and a glass coil fed with water from a thermostat. To prevent entrainment of liquid in aeration, the vessel was covered with a lid. Gas exited the vessel through a free opening surrounding the impeller shaft where the entrainment was minimal. Schematic drawings of the vessel and the impeller are given in Fig. 1. The liquid volume V_1^0 was $1{\cdot}82 \cdot 10^{-2}$ m^3 for all measurements.

The gas holdup is the relative increase in batch volume due to aeration, $Z = (V_1^a - V_1^0)/V_1^a$. The volume of aerated batch V_1^a was determined by numerical integration using time-averaged heights of the irregularly rippled surface of aerated and agitated liquid measured at several places in the vessel by the method of electrically conducting contact tip proposed by Vlček and coworkers[14]. A detailed analysis of the theoretical foundations of the method has been given previously[14]. The principle of the measurement is that a conducting tip located at a precisely adjusted height above a given point of the vessel bottom is connected to an electrical circuit which records the sum of time periods, s, during which the tip is in contact with the conducting batch. The mean height of the rippled liquid surface at the given point is indicated by the vertical position of the tip at which s is equal to half the time period of experiment (*c.* 5 min in our case). Vlček and coworkers[14] have shown that for vessels similar in geometry to those used in the present work, measurements of the mean height of liquid at five places suitably chosen on the symmetry axis between two arbitrary baffles are sufficient for the batch volume to be determined with reasonable accuracy.

The apparatus and the procedure used to measure the holdup were essentially the same as those described by Vlček and coworkers,[14] but some technical improvements had been incorporated. The original apparatus[14] had one conducting tip probe which had to be moved horizontally five times after each holdup measurement. The apparatus used in the present work had five tip probes on a horizontal beam placed in the plane halving the angle between two baffles. The probes were 25 mm apart. The height of the probe tip above the vessel bottom could be adjusted by means of a micrometer screw within 0·15 m with an accuracy of 0·01 mm. These alterations reduced the time of experiments by 85% compared with the original arrangement. By thorough

testing of the apparatus, Hovorka[15] established that the error in measurement of the height of rippled unaerated liquid level was 0·01 mm, equal to the precision of mechanical adjustment of the tips. The reproducibility of holdup measurements was checked by measuring air holdup in a $2{\cdot}5 \cdot 10^{-3}$M-NaCl solution over the whole ranges of impeller speeds and aeration intensities. The maximum deviation of holdups from repeated experiments was found to be 4% of the average value, the mean spread being 2%. As the magnitude of the deviation is independent of both the impeller speed and the air flow rate, the latter figure may be considered as a representative estimate of random error in holdup measurement.

The power input was measured tensometrically. A steel strip built in the impeller shaft experienced a distortion by the transmitted torque. An AP-15-6-20 wire tensometer epoxy-glued to the strip was connected to an a.c. Wheatstone bridge. The strip was chosen such that the out-of-balance voltage signal due to a change in the tensometer resistance varied linearly with the transmitted torque. The voltage signal was first fed to an amplifier rotating along with the shaft,

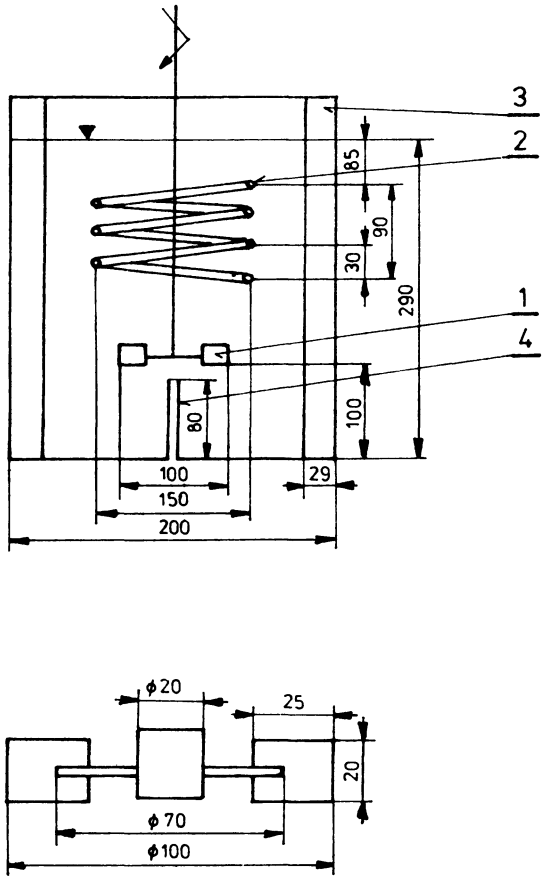

FIG. 1

Schematic diagrams of vessel and impeller. 1 impeller, 2 thermostatting coil, 3 baffle, 4 gas inlet

and the amplified signal was collected from a pair of brass rings by silver-graphite brushes and fed to a data logging system. Before each measurement, the instrument was calibrated by a torque produced by a weight of known mass. Extensive tests, described in detail by Hovorka[15], had shown that the relative error of power input measurement by this instrument was 2%.

The solutions used were made up from salts of analytical grade and distilled water. The air for aeration was fed from a piston compressor through layers of activated carbon and basalt wool. Before entry into the apparatus, the air was saturated with water at the temperature of the experiment. Prior to each change of solution, the glass walls of the apparatus were washed with a potassium dichromate–sulphuric acid mixture, the rest with a warm soda solution, and the whole apparatus was then flushed with distilled water. A survey of the solutions and of other experimental conditions is given in Table I.

RESULTS AND DISCUSSION

Parameters of regression equations were calculated by searching for such a vector of parameters, $\mathbf{S}\{S_1, S_2, \ldots, S_p\}$, for which a minimum was found in the mean sum of squares of deviations

$$s^2 = \frac{1}{n - p} \sum_{i=1}^{n} [Z_i - f(\boldsymbol{x}_i, \mathbf{S})]^2 ,$$

where n is the number of experimental points, p is the number of the parameters S_1 to S_p, $\boldsymbol{x}_i$ is the value of the vector of independent variables for i-th experimental

TABLE I

Experimental conditions. $\dot{V}_g \cdot 10^4$, $m^3 s^{-1}$: 1·4; 2·8. n, s^{-1}: 4·167; 5·833; 7·500; 9·167; 10·833. $t = 20°C$

Salt	Concentration, kmol m^{-3}			
NaCl[a]	0·175	0·325	0·500	1·000
KCl[a]	0·100	0·250	0·500	1·000
KNO_3	0·150	0·300	0·600	1·000
KI	0·250	0·600	1·000	2·000
NaSCN	0·200	0·500	1·000	3·000
$MgCl_2$[a]	0·150	0·350	0·500	1·000
Na_2SO_4[a]	0·050	0·200	0·500	1·000
K_2SO_4	0·050	0·100	0·200	0·500
$MgSO_4$	0·100	0·200	0·500	1·000
$Al_2(SO_4)_3$	0·050	0·100	0·200	0·500
H_2O[a]	—	—	—	—

[a] Both power input and gas holdup were measured; in the remaining cases, only holdup was measured.

TABLE II

Comparison of results from fitting various equations to data for gas holdup in a mechanically agitated aerated vessel; $Z = 0{\cdot}0229\ Re^{-0.666}\ Kp^{0.263}\ We^{1.3}$ (*15*), $Z = 0{\cdot}0018\ Re^{-0.25}\ Kp^{0.247}\ We^{1.223}\ W^{-0.13}$ (*16*), $Z = 8{\cdot}09 \cdot 10^{-5}\ Kp^{0.252}\ We^{0.979}\ Y^{0.892}$ (*17*), $Z = 5{\cdot}0 \cdot 10^{-4}\ Re^{-0.226}\ Kp^{0.25}\ We^{1.09}\ Y^{0.16}$ (*18*), $Z = 0{\cdot}105\ (\dot{V}_g n^2/\sigma)^{0.637}$ (*19*)

Number of equation	$s^2 \cdot 10^5$ overall	$s^2 \cdot 10^5$ for individual salts										
		H_2O	KI	NaCl	Na_2SO_4	$MgCl_2$	KNO_3	KCl	NaSCN	K_2SO_4	$MgSO_4$	$Al_2(SO_4)_3$
(*15*)	4·90	4·45	4·82	2·59	8·72	4·57	5·75	4·60	4·63	9·07	5·23	5·48
(*16*)	2·91		7·43	1·70	2·75	3·32	2·78	2·20	2·31	4·24	4·31	1·80
(*17*)	2·56		6·31	1·40	1·81	2·17	2·21	1·98	1·69	2·61	2·95	5·00
(*18*)	2·32		4·78	1·51	2·02	2·47	2·29	2·30	1·46	5·25	4·03	2·16
(*19*)	11·32	17·0	6·78	6·61	20·00	10·20	7·39	6·72	6·01	1·34	13·40	27·40

point, and $f(\mathbf{x}_i, \mathbf{S})$ and Z_i are, respectively, the calculated and measured values of holdup. The resulting equations are given in Table II, together with the overall values of s^2 and with sums of squares of deviations for the individual batches. Graphical comparisons of calculated and measured values are shown in Figs 2–6. Values of physical properties of solutions required for the calculations were taken from a data bank based on literature data cited elsewhere[15].

Gas Holdup Correlations

The poorest fit of experimental results is given by Eq. (*19*) proposed by Hassen and Robinson[6], where surface tension is the only quantity characterizing the physical properties of batch. Here, the maximum deviation between calculated and experimental holdup values reaches as much as 100%. Eq. (*15*), which has the same form as Eq. (*1*) used for nonelectrolyte batches, is apparently also inadequate. Inclusion of the quantity W in Eq. (*16*) substantially reduces the scatter of points about the fitted line, but this equation still tends to underpredict the holdup by as much as 30%. It may be stated that the quantity W does not satisfactorily allow for the dependence of holdup on the physical properties of batch. Among the relations so far proposed, Eq. (*17*), of the same form as the relation published by Machoň and coworkers,[11] produces the best agreement with the data, but at high impeller speeds the maximum deviation is again about 30%. Machoň and coworkers quote 32% as maximum deviation for their data. The mean and maximum deviations are least (12% and 20%, respectively) with Eq. (*18*), which contains the Reynolds number in addition to quantities appearing in Eq. (*17*). The reason why Eq. (*18*) gives the best agreement may be seen with reference to Table III which gives exponents q1 and q2 of expressions of the form $Z \sim n^{q1} \dot{V}_g^{q2}$ derived from Eqs (*15*) to (*19*) and two other equations by expressing the holdup as a function of impeller speed and gas flow rate only. Eqs (*15*) to (*18*) give the same dependence of holdup on n and $\dot{V}_g$ and hence the reason for their different fits to experimental data must lie in their different capabilities to account for the dependence of holdup on physical properties of batch. Since extension of Eq. (*17*) to include the Re criterion has no effect on the exponent of the function $Z = Z(n)$, it may be concluded that the improvement of fit is due to allowance which has been made for viscosity. The expression proposed by Hassan and Robinson[6] (Eq. *19*) contains an unjustified requirement for the exponent of the dependence on impeller speed to be exactly twice that of the dependence on flow rate. Table IV gives a comparison of numerical values of constants in Eq. (*7*) obtained by various authors. The values of Dolejš[16] were obtained with an apparatus of the same geometry as used in the present work, but with a smaller number of batches (water, four concentrations of K_2CO_3). The data of Machoň and coworkers[11] were measured on an apparatus which differed from the above two only in that the impeller diameter was 100 mm instead of 75 mm. Moreover, about 50% of their

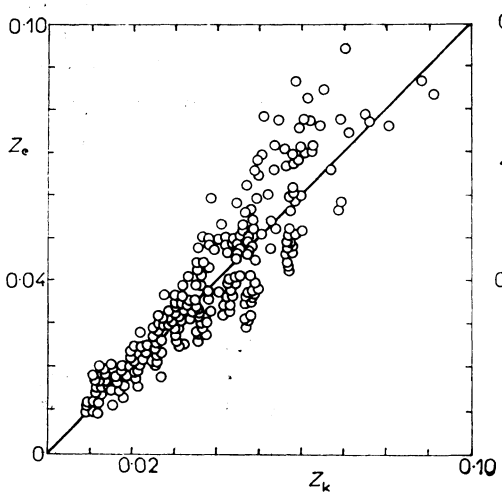

FIG. 2

Comparison of experimental holdup values, Z_e, with those calculated from Eq. (*15*), Z_k

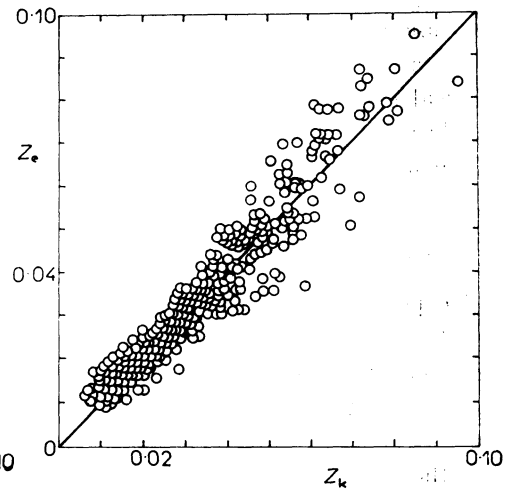

FIG. 3

Comparison of experimental holdup values, Z_e, with those calculated from Eq. (*16*), Z_k

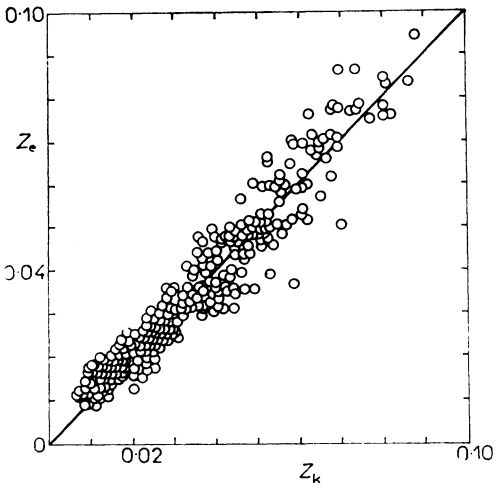

FIG. 4

Comparison of experimental holdup values, Z_e, with those calculated from Eq. (*17*), Z_k

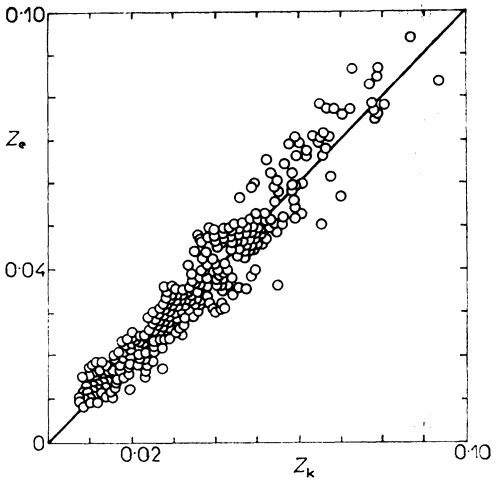

FIG. 5

Comparison of experimental holdup values, Z_e, with those calculated from Eq. (*18*), Z_k

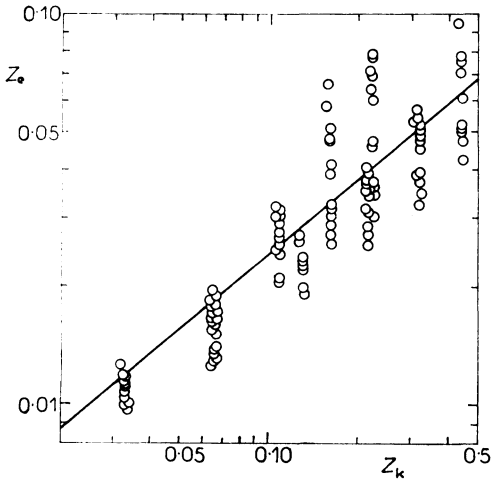

FIG. 6

Comparison of experimental holdup values, Z_e, with those calculated from Eq. (*19*), Z_k

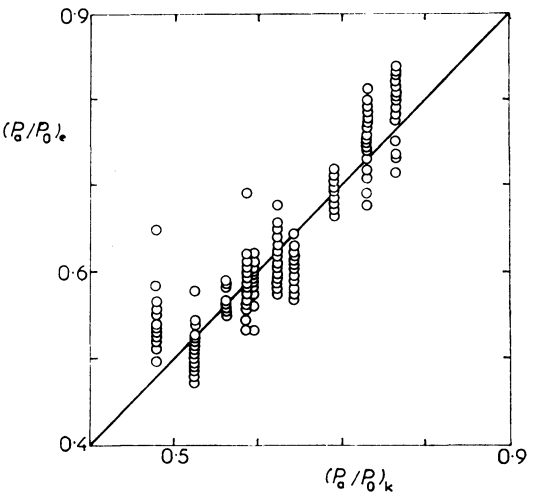

FIG. 7

Comparison of experimental values of power input ratio, $(P_a/P_0)_e$, with those calculated from Eq. (*20*), $(P_a/P_0)_k$

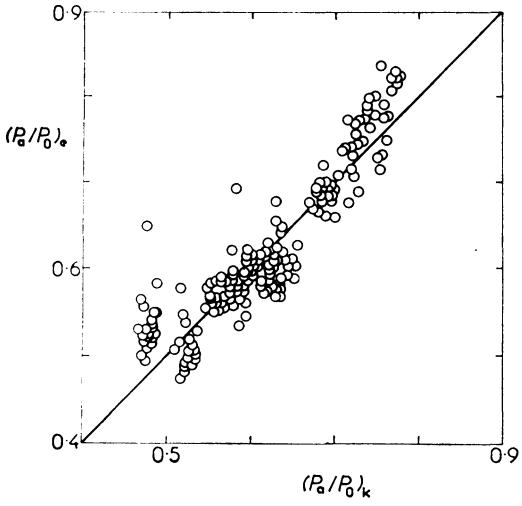

FIG. 8

Comparison of experimental values of power input ratio, $(P_a/P_0)_e$, with those calculated from Eq. (*21*), $(P_a/P_0)_k$

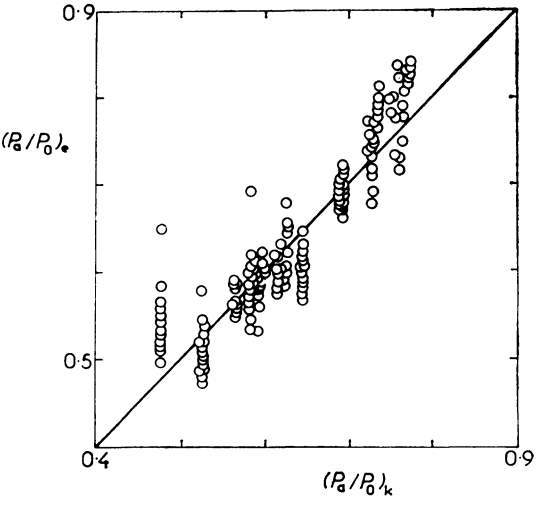

FIG. 9

Comparison of experimental values of power input ratio, $(P_a/P_0)_e$, with those calculated from Eq. (*22*), $(P_a/P_0)_k$

TABLE III

Dependence of holdup on impeller speed and gas flow rate

Equation	$q1$	$q2$
(*15*)	1·67	0·26
(*16*)	1·67	0·25
(*17*)	1·71	0·25
(*18*)	1·70	0·25
(*19*)	1·27	0·64
Machoň and coworkers[11]	1·64	0·36
Hassan and Robinson[6]	0·88	0·44

TABLE IV

Comparison of constants in Eq. (*7*) obtained by various authors

	$A \cdot 10^4$	$a2$	$a3$	$a5$
This work	0·809	0·252	0·979	0·892
Machoň and coworkers[11]	1·3	0·36	1·00	0·56
Dolejš[16]	0·9	0·36	0·73	0·34

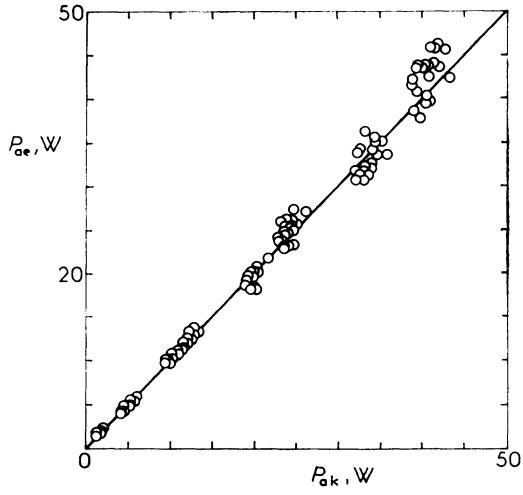

FIG. 10

Comparison of experimental values of power input to aerated vessel, P_{ae}, with those calculated from Eq. (*23*), P_{ak}

TABLE V

Comparison of results from fitting various equations to data for power input to a mechanically agitated aerated vessel

Equation	Eq. No	$s^2 \cdot 10^2$ overall	$s^2 \cdot 10^2$ for individual salts					
			H_2O	NaCl	KCl	Na_2SO_4	$MgCl_2$	K_2SO_4
$P_a/P_0 = 0{\cdot}226\ We^{-0.0081}\ Kp^{-0.294}$	(*20*)	0·14	0·31	0·14	0·12	0·22	0·17	0·07
$P_a/P_0 = 0{\cdot}210\ We^{0.021}\ Kp^{-0.291}\ W^{0.013}$	(*21*)	0·13		0·14	0·11	0·24	0·14	0·08
$P_a/P_0 = 0{\cdot}209\ We^{0.0096}\ Kp^{-0.288}(\varrho_d/\varrho_l)^{-0.565}$	(*22*)	0·14	0·33	0·15	0·12	0·23	0·17	0·08
$P_a/P_0^{0.468} = 0{\cdot}686(P_0 nd^3/\dot{V}_g^{0.6})^{0.468}$	(*23*)	4·21	12·73	5·64	4·57	4·30	3·98	2·76

data were obtained in the region where $X > X_{crit}$ (in this work, 20% of data relate to this region). Apparently, the value of the constant A strongly depends on geometrical parameters: a 25% decrease in impeller diameter results in 40–50% increase in A. The relatively small value of the constant a5 given by Machoň and coworkers,[11] who measured half of their data in the region $X > X_{crit}$, suggests that it would be appropriate to use different relations for supercritical and subcritical values of X; however, there is not yet enough data to verify this proposition.

Power Input Correlations

Coefficients of regression equations for the ratio P_a/P_0 (Table V) were obtained in the same way as with the holdup. The calculated values are compared with experimental data in Figs 7–10. The poorest fit is given by Eq. (*23*) proposed by Michel and Miller[13]. Apparently, this relation is applicable only to data obtained for a single kind of batch in systems of similar geometries. Eqs (*20*), (*21*) and (*22*) produce essentially the same agreement with the data, indicating that neither the introduction of W nor the modification proposed by Hassan and Robinson[6] improves the ability of the correlations to account for the dependence of the ratio P_a/P_0 on the physical properties of batch. Maximum deviations between measured values and those calculated from Eqs (*20*)–(*22*) are about 20% for $0{\cdot}4 < P_a/P_0 < 0{\cdot}5$, and about 14% for $0{\cdot}5 < P_a/P_0 < 0{\cdot}7$. For the time being, the simplest Eq. (*20*) may be recommended for practical use.

CONCLUSION

Among the correlations so far proposed for calculating gas holdup in aqueous solutions of electrolytes in mechanically agitated aerated vessels, Eq. (*18*), based on 410 experimental points, is the most suitable, giving the least mean (12%) and maximum (20%) deviations between calculated and measured values.

The present treatment involving 210 experimental points has failed to identify a relation for the ratio of the impeller power inputs to aerated and unaerated batch which would give better results than the simple Eq. (*20*) (maximum error, 20%). Additional independent variables so far proposed in the literature do not improve the fit of this equation to the data for the ratio P_a/P_0 as a function of the properties of batch.

LIST OF SYMBOLS

a	interfacial area per unit of liquid phase volume
ai; $i = 1-5$	exponents on Re, Kp, We, W, and Y, respectively, in correlations for holdup
A	multiplication constant in correlations for gas holdup

b	thickness of film layer between two gas bubbles in contact with each other
$b1$, $b2$, $b3$	exponents on Kp, We, and W, respectively, in correlations for impeller power input to aerated batch
B	multiplication constant in correlations for impeller power input to aerated batch
c	concentration
C_1, C_2	constants in Eq. (*14*)
d	impeller diameter
E	quantity defined by Eq. (*2*)
f	activity coefficient
F	quantity defined by Eq. (*3*)
h	height of sensor tip above the vessel bottom
k	overall number of ions produced on splitting of salt molecule in aqueous solution
k_La	volumetric mass transfer coefficient
Kp	$= \dot{V}_g/(nd^3)$
n	impeller speed
p	constant in Eq. (*10*)
P	probability
P_0	impeller power input to unaerated batch
P_a	impeller power input to aerated batch
q	constant in Eq. (*10*)
Re	$= (nd^2\varrho)/\eta$
s	overall time period of contact between point probe and batch
s^2	sample variance
V_l^0	volume of liquid in batch
V_l^a	volume of aerated batch
$\dot{V}_g$	gas flow rate
W	quantity defined by Eq. (*5*)
We	$= (nd^3\varrho)/\sigma$
X	quantity defined by Eq. (*6*)
X^+	quantity defined by Eq. (*9*)
Y	quantity defined by Eq. (*8*)
z	variable height of liquid surface
$\bar{z}$	mean height of liquid surface (time average)
Z	gas holdup in batch
η	dynamic viscosity of liquid
ϱ	density of liquid
ϱ_d	mean density of bubble dispersion in liquid
σ	surface tension

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