Gas Holdup and Backmixing in Bubble Column with Polymer Solutions

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INTRODUCTION

Many chemical industries, including biotechnology, food, and pharmaceutical processes, use viscous media in bubble column reactors. Many of the existing gas holdup correlations include an effect of viscosity (Shah et al., 1982), but they are based on the data in Newtonian media. Nishikawa et al. (1977), Nakanoh and Yoshia (1980), and Godbole et al. (1982) have reported holdup values in non-Newtonian media. They observed higher values of gas holdup than the ones predicted by Akita and Yoshida's (1973) correlation. Godbole et al. (1982) observed a strong effect of the column diameter on gas holdup and therefore proposed a gas holdup correlation incorporating the effect of column diameter.

The effect of liquid viscosity on the degree of liquid phase backmixing is not yet clearly understood. Cova (1974) and Aoyama et al. (1968) reported that the axial dispersion coefficient is independent of viscosity, while Pilhofer et al. (1978), Towell and Ackermann (1972), and Hikita and Kikukawa (1974) indicated that an increase in the liquid viscosity reduces the dispersion. The effect of non-Newtonian liquid medium was studied by Ulbrecht and Baykara (1980), but their analysis was restricted to very dilute polymer solutions and low gas velocities (<3 mm/s). This note extends this range of parameters and analyzes some gas holdup and axial dispersion coefficient data in CMC (carboxy methyl-cellulose) solutions.

EXPERIMENT

All the experiments were carried out in 0.154 m dia. and 3.35 m tall bubble column. The superficial gas velocity was varied from 0.03 m/s to 0.3 m/s, while the superficial liquid velocity was varied from 0.03 m/s to 0.1 m/s. All the gas holdup experiments were carried out at 25°C. Gas holdup was calculated using hydrostatic head technique, while the thermal dispersion coefficients were calculated by applying the axial dispersion model to the heat tracer experiments. The details of the experimental set up and the analysis of the raw data are given elsewhere (Kelkar et al., 1983).

Six CMC (7H4, Hercules, Inc.) solutions were used in the present study. The values of flow behavior index and consistency index were calculated using Fann viscometer and are presented in Table 1. Although viscosity is a temperature-sensitive parameter, while carrying out the dispersion measurements, the viscosity characteristics were assumed to be the same as the ones at the average temperature in the column. This assumption was justified since the total temperature difference between the bottom and the top of the column was approximately 10°C. The interfacial tension did not vary significantly (71 dyne/cm for low viscosity solution and 67 dyne/cm for high viscosity solution), and therefore is not incorporated in Table 1.

The apparent viscosity was calculated with the help of equation derived by Nishikawa et al. (1978), where the average shear rate in the bubble column was related to gas velocity by an equation

$$\dot{\gamma} = 5{,}000\, V_G \tag{1}$$

RESULTS AND DISCUSSION

The gas holdup showed an increase with gas velocity but remained essentially independent of the liquid velocity. When gas holdup is plotted as a function of apparent viscosity, as shown in Figure 1, the gas holdup shows a maximum with respect to the viscosity in the vicinity of 0.003 Pa·s. This value is close to the one observed by other investigators (Eissa and Schugerl, 1975; Bach and Pilhofer, 1978; Buchholz et al., 1978) for Newtonian liquids. This can be explained on the basis of hindered gas bubble motion in the viscous fluids, in which at relatively low viscosities drag forces are not large enough to cause bubble coalescence. These moderate forces contribute to more uniform distribution of bubbles and hence higher holdup. The similar observation is probably a result of Newtonian behavior of CMC solution at low concentrations. The gas holdup shows a decrease with an increase in the apparent viscosity, but the effect appears to flatten out above 0.2 Pa·s. The experimental values were compared with the correlation developed by Godbole et al. (1982) and were found to match within ± 8% error band.

In order to analyze the data further, a theory developed by Zuber

TABLE 1. RHEOLOGICAL PROPERTIES OF CMC SOLUTIONS

Concentration, ppm	Consistency Index, Pa·s^n	Flow Behavior Index
50	0.002	0.99
500	0.0045	0.98
1,000	0.05	0.76
1,200 @ 25°C	0.08	0.728
@ 35°C	0.07	0.735
1,800 @ 25°C	0.14	0.678
@ 35°C	0.125	0.682
2,300 @ 25°C	0.24	0.638
@ 35°C	0.165	0.66

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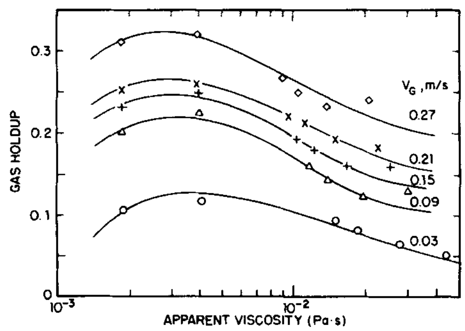

Figure 1. Effect of apparent viscosity on gas holdup for CMC solutions.

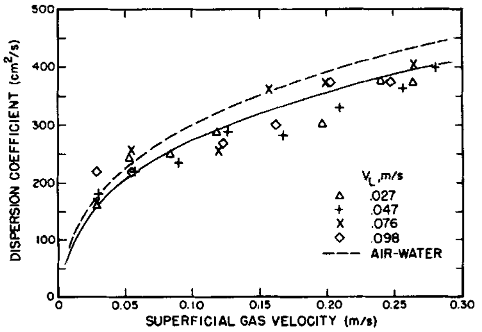

Figure 3. Effect of liquid velocity on axial dispersion coefficients for 1000 ppm CMC solution.

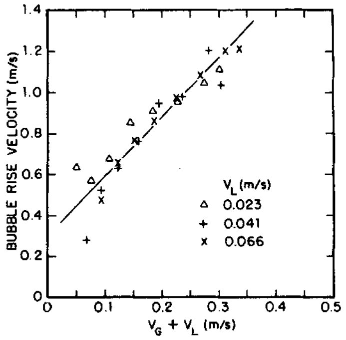

Figure 2. Bubble rise velocity as a function of ($V_G + V_L$) for 2300 ppm CMC solution.

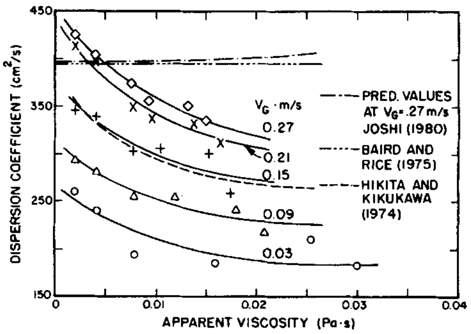

Figure 4. Effect of apparent viscosity on axial dispersion coefficients.

TABLE 2. ZUBER-FINDLEY COEFFICIENTS FOR CMC SOLUTIONS

Concentration, ppm	C_1, m/s	C_o
50	0.104	2.36
500	0.116	2.60
1,000	0.138	2.76
1,200	0.260	2.64
1,800	0.288	2.75
2,300	0.328	2.72

and Findley (1965) for churn turbulent flow regime was used. The final equation can be written as

$$\frac{V_G}{\epsilon_G} = C_o(V_G + V_L) + C_1 \quad (2)$$

where C_o is a distribution parameter that is a rough indication of non-uniform radial distribution of gas holdup and liquid phase velocity, which, in turn, depends on the effect of liquid circulation velocity on the terminal rise velocity of bubble. The second constant, C_1, indicates a qualitative estimate of single bubble rise velocity. Figure 2 shows the typical plot of bubble rise velocity vs. ($V_G + V_L$) for 2,300 ppm solution. The values of constants C_o and C_1 for all the solutions are presented in Table 2. It can be seen that the value of the distribution parameter C_o remains essentially independent of the concentration. However the value of C_1, which is an indication of bubble rise velocity, increases significantly with an increase in concentration. This indicates that the coalescence tendencies in the solution are enhanced with an increase in the viscosity, which results in larger bubble size and hence higher rise velocities. The continuous increase in C_1 and a constant value of C_o indicate that the increase in the bubble rise velocity is accompanied by a compensating increase in the liquid circulation velocity. It should be cautioned that the constants C_1 and C_o are very complexly interdependent, and the numerical values should be taken only in a qualitative sense to explain the physical phenomenon.

The axial dispersion coefficients increased with an increase in the gas velocity, but were independent of the liquid velocity, as shown in Figure 3. The apparent viscosity exerted a considerable effect on the dispersion coefficient values. Dispersion coefficients monotonically decreased with an increase in the viscosity, as illustrated in Figure 4. The data are compared with the existing correlations (Hikita and Kikukawa, 1974; Baird and Rice, 1975; Joshi, 1980) at one gas velocity, and it can be seen that none of the correlations predicts the data with consistency. Although the correlation by Hikita and Kikukawa (1974) predicts similar dependency on the viscosity, it consistently predicts lower values of the dispersion coefficient. It should also be noted that the data by these investigators were collected in Newtonian media. The present results clearly indicate that the dispersion coefficients decrease with an increase in the viscosity; however, the correlation for Newtonian solution is not applicable for non-Newtonian solutions. It is interesting to note that the correlation proposed by Joshi (1980) uses the concept of circulation velocity, where circulation velocity is defined as

$$V_c = 1.31[gd_c\{V_G - \epsilon_G u_{b\infty}\}]^{1/3} \quad (3)$$

In this expression, $u_{b\infty}$ is the single bubble rise velocity, and the author recommends the use of correlation by Clift et al. (1978) to calculate the value of $u_{b\infty}$. Instead of using this calculated value, if the value of C_1 is used in Eq. 3, this correlation seems to explain the variation in dispersion coefficient with respect to apparent viscosity in much more consistent fashion (within ± 20%). This suggests that the correlation by Joshi (1980) may be modified further to take into account the experimental value of bubble rise velocities, rather than the ones based on the literature correlations.

The decrease in the dispersion coefficient with respect to viscosity can be explained on the basis of an increase in the bubble size, which is indicated by the increase in the value of C_1 with viscosity. Thus the bubbles carry less amount of liquid in their wake at higher liquid viscosity, which leads to decreased backmixing.

OTHER POLYMER SOLUTIONS

In order to incorporate the effect of viscoelasticity on gas holdup and backmixing, experiments were performed with PAA (polyacryl amide) and PEO (polyethylene oxide) polymer solutions. Both solutions showed a consistent increase in gas holdup values with an increase in the concentration. The dispersion coefficients did not show any significant effect of concentration. However, both polymer solutions exhibited profuse foaming tendencies, and the foam was so stable that the experiments had to be abandoned because of the experimental difficulties. Thus the data were not very reliable and these systems are, therefore, not recommended for future studies.

ACKNOWLEDGMENT

The authors wish to thank Shirish Phulgaonkar for his help during the collection of data.

NOTATION

C_o = constant in eq. 2
C_1 = constant in eq. 2, m/s
d_c = diameter of column, m
g = gravitational constant, m/s^2
$u_{b\infty}$ = bubble rise velocity, m/s
V_c = liquid circulation velocity, m
V_G = superficial gas velocity, m/s
V_L = superficial liquid velocity, m/s
ϵ_G = gas holdup
$\dot{\gamma}$ = shear rate, s^{-1}

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Manuscript received July 26, 1983; revision received Dec. 15, 1983, and accepted Jan. 3, 1984.

Correction

In the Table of Contents for the January 1985 issue, an R&D note entitled "Effect of Pore Structure on Particle Ignition During Exothermic Gasification Reactions" by Jow-Lih Su and D. D. Perlmutter was not included.