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INTEROFFICE MEMORANDUM

Subject Entrance Effect on Gas Holdup (87-0-8884)

To R. F. Weimer (Location, Organization, or Department)

From D. H. S. Ying (Location, Organization, or Department)

cc: E. N. Givens
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Summary

Entrance effect was the key to explain the unusually high gas holdup results in Deckwer's work as indicated by the recent results using gas sparger (porous plate) in the 5-inch diameter column. Substantially higher gas holdup was measured in both kerosene/nitrogen and water/air systems when a sparger was inserted into the column. The average pore opening of the sparger strongly influenced the gas holdup; gas holdup decreased with increasing pore size. Foam was readily formed in kerosene with and without the sparger. Gas holdup would be 50% higher if foam was considered as part of the system. Foam formation would definitely limit the applicability of Deckwer's method of measuring gas holdup. The correlation of Yoshida and Akita failed to describe the gas holdup data of kerosene/nitrogen system, indicating its application for hydrocarbon system to be questionable. Furthermore, the presence of solid particles reduced gas holdup when a porous plate was used. The behavior of solid phase, be it in suspension or settled mode, made a substantial difference in the degree of reduction.

Introduction

In an APCI technical seminar (December 5, 1979), Deckwer et al presented gas holdup data for the Fischer-Tropsch synthesis in slurry reactor. Their work showed that the gas holdup in molten paraffin with melting point between 80°C and 110°C was much higher than the prediction from the correlation of Yoshida and Akita which was the best one to describe our gas holdup data obtained from aqueous system. It was suspected that entrance effect was an important factor to determine gas holdup (memorandum from D. H. S. Ying to E. N. Givens on December 6, 1979) since Deckwer et al used gas sparger versus single orifice as in our column. The purposes of the present work were to investigate the effect of gas sparger on gas holdup and to test the applicability of Yoshida and Akita's correlation for hydrocarbon system. Both kerosene and water were used in this work. Effects of solids (coal and sand) were also investigated.

Experimental Method

Two methods were used to measure gas holdup in a 5-inch diameter column. One method, which was used in our past studies, was to flow gas up through the column which was completely filled with liquid. Allowing the displaced liquid to leave the column, we could calculate gas holdup from the difference between the initial liquid level and the final liquid level after the gas flow was stopped. The other method was to partially fill the column and measure the expanded level. The difference between the expanded level and initial level represented the gas holdup in the system. The former one was called displacement method and the latter one was named expansion method. The expansion method had the advantage of accurately measuring the foam and also cross-checked the displacement method.

The gas sparger was a 3/16 inch thick metal porous plate. Three different plates were used; their average pore openings were 40, 60, and 100 microns.

Gas Sparger Versus Single Opening Inlet

The gas holdup results for kerosene/nitrogen system in the absence of a sparger were summarized in Figure (1). Foam was readily observed at all gas velocities; the amount of foam increased with increasing gas velocities. The displacement method would result with gas void fraction higher than actual value because foam could exit the column as it was formed. In opposition, gas holdup data (triangle data in Figure (1)) from the expansion method would be under-estimated if foam was excluded in the calculation since foam was formed at the expense of the liquid. Hence these two sets of results (circle and triangle data in Figure (1)) should bracket the true holdup value. However, the width of this bracket increased with increasing gas velocities due to more severe foamation problem. Therefore, the data at low gas velocities (less than 0.10 ft/sec) were more informative. Furthermore, if the foam was considered as part of the system, the gas holdup would be incorrectly over-estimated by as high as 50% of the true value.

Gas holdup in kerosene/nitrogen system in the presence of a porous plate with an average opening of 40 microns was also shown in Figure (1). The scattered data were due to foam formation, and the results from displacement method and expansion method (excluding foam) again bracketed the true holdup value similar to the discussion in the case of no sparger. Gas void fraction and amount of foam were several factors higher with sparger than without. This dramatic gas holdup difference was due to the extremely fine gas bubbles generated by the porous plate. Exact measurement of bubble dimension was not available, but visual observation indicated bubble diameter less than 1/32 inch. The gas holdup difference between single opening inlet and porous plate undoubtedly showed the importance of entrance effect and explained the unusual high holdup values measured in Deckwer et al's work. Furthermore, if foam existed in their molten paraffin system, the gas holdup results determined by their method would be questionable.

Gas holdup in water/air system showed qualitatively similar difference between single opening inlet and porous plate as shown in Figure (2). A porous plate with an average 100-micron opening was used in this study. With the porous plate, higher holdup was measured accompanying the smaller bubbles observed. Because of the absence of foam in water/air system, good agreement between displacement method and expansion method was obtained for the entire velocity range. This gas holdup difference in the non-foaming water/air system further leaned support to the entrance effect.

Correlation of Yoshida and Akita

The correlation of Yoshida and Akita, which was proven the best to describe the gas holdup results of the aqueous system as shown in Figure (2), failed to fit the data from kerosene/nitrogen system as demonstrated in Figure (1). The physical properties of kerosene were determined in our laboratory and summarized in Table (1). The viscosity value was questionable because the accuracy of the instrument (Brook's LVT viscometer) dropped considerably for viscosity less than 10 centipoise. If the actual viscosity was lower than the measured value of 3.6 cp., the difference between the data and the correlation would be reduced. In a hypothetical case if a viscosity of 1 centipoise (like water) was assumed, the fit was improved as shown by the dotted line in Figure (1) but not enough to account for the sizeable difference. This failure of Yoshida and Akita's correlation to fit the kerosene/nitrogen results signalled the alarm of its inapplicability for hydrocarbon system. Could this failure be associated with the special foaming characteristics of kerosene remained questionable. Other non-foaming hydrocarbon system should be investigated to fairly judge this correlation.

Effect of Pore Size

The dimension of pore opening had strong effect on gas holdup. Gas holdup in kerosene/nitrogen was studied with two other different pore opening spargers (60 and 100 microns), and summarized in Table (2). A decrease in gas holdup with increasing pore size was consistently observed at all gas velocities. Visual observation showed that accompanying the decrease in gas holdup, the bubble size increased with increasing pore size. These results consistently supported the importance of entrance effect on gas holdup. Furthermore these results definitely put some doubt on the general applicability of Deckwer et al's empirical correlation developed solely from one pore size sparger.

Effect of Solid Particles

The behavior of solid phase, be it in a settled mode or in suspension, made a sizeable difference on gas holdup measured in the presence of a porous plate. The results of holdup in water/air/sand in the presence of a 100-micron opening porous plate was shown in Figure (2). The 40-60 mesh sand particles (approximately 14 wt%) settled on the porous plate and totally suppressed the formation of fine bubbles. Instead, gas channelled through the settled bed forming larger bubbles. The gas holdup was drastically reduced and behaved as if the gas was fed through a single opening inlet as shown in Figure (2). On the other hand, suspended solid particles behaved differently. The results for kerosene/nitrogen/coal at two solid concentrations (8 wt% and 16 wt%) in the presence of the same 100-micron porous plate were summarized in Table (3). Although the solution was black, it was speculated that the 200 mesh minus coal particles were fully suspended. Our previous experience showed that 140 mesh minus sand particles were fully suspended in water. Since these sand particles were larger than the 200 mesh minues coal and sand was denser than coal, it was reasonable to assume complete suspension of the 200 mesh minus coal particles in kerosene. The results shown in Table (3) indicated a very small reduction in gas holdup due to the presence of solids. A two-fold increase of coal concentration did not further reduce the gas holdup. Since the particles were suspended, the barrier to form fine bubbles was removed. The insignificant reduction at the presence of the finely suspended particles could possibly be due to enhancement of bubble coalescence rate which was qualitatively consistent with our earlier findings in water/nitrogen/sand system. These results demonstrated the important role of solid particles to alter the characteristics of inlet which governs the gas holdup.

Recommendation

In view of the failure of Yoshida and Akita's correlation to fit the kerosene/nitrogen gas holdup results, a non-foaming hydrocarbon solution yet unidentified should be studied in the future. The question of foam formation in the process solvent, as suggested by Ed Givens, should also be investigated.

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Table (1)

Physical Properties of Kerosene

Density	0.812 gm/cm^3
Surface Tension	27.2 dynes/cm
Viscosity	3.60 centipoise

Table (2)

Effect of Pore Size on Gas Holdup for Kerosene/Nitrogen in a 5-inch Diameter Column

Superficial Gas Velocity (ft/sec)	Gas Void Fraction			
	40-micron Porous Plate	60-micron Porous Plate	100-micron Porous Plate	0.25-inch Single Inlet
.0053	.022	.017	.007	.006
.0142	.051	.047	.021	.013
.0303	.115	.105	.068	.036
.0495	.211	.168	.116	.058
.0680	-	.278	.171	.089

Table (3)

Effect of Coal Particles on Gas Holdup in Kerosene

with 100-micron porous plate

Superficial Gas Velocity (ft/sec)	Gas Void Fraction		
	No Solid	8 wt% Coal	16 wt% Coal
.0142	.017	.016	.015
.0303	.044	.039	.040
.0495	.084	.078	.079
.0680	.126	.123	.121
.0905	.176	.172	.170
.1123	.224	.222	.217

- The coal particles were 200 mesh minus.
- The column diameter was 5 inches,
- with 100-micron porous plate

$$Vf = \frac{1}{Solid}$$

Vf [illegible] Solid