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Study of Multiphase Flow Useful to Understanding Scaleup of Coal-Liquefaction Reactors

Technical Progress Report

March 1, 1983 to May 31, 1983

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MULTIPHASE FLOW
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I. HIGHLIGHTS

Gas-holdup measurements for air and aqueous carboxy methyl cellulose solutions have been performed using the 13-inch acrylic column. The experimental data has been plotted and some is reported here. Analysis is continuing. A 1/4-inch-thick porous plate with 70-micrometer pores made of polyethylene and an acrylic sieve plate with 1/8-inch-diameter holes were used as gas distributors. Holdup was measured at different axial positions and compared to total holdup measurements by summing. The gas velocity range extended over the bubble and bubble-slug patterns. Analysis of these experiments will be reported later.

Gas holdup measurements in the six-inch column have been measured for air-water mixtures using 17 different gas distributions. The results have been analyzed for the effect of the distributor on holdup in a bubble column. The variables included thickness, material, hydrophobic versus hydrophylic, and porosity. The major difference in gas-holdup measurements occurred when comparing sieve plates and porous plates. Specific differences were found when comparing the porous plates at the transition between bubble and bubble-slug flow patterns. The gas holdup at the transition varied between 0.21 and 0.34. Thus, the slope of the gas in the bubble also varied. The holdup in the transition range also varied. Gas velocity at the transition ranged between 0.055 to 0.085 m/s for different porous distributions. Conclusions from these experiments are reported here.

II OBJECTIVES AND SIGNIFICANCE

There are three major objectives for this proposed study. These objectives are basic to the understanding needed to develop a rationale for scale up in bubble columns. This understanding is the key to improving our scientific and technical knowledge of the fundamental process involved in complex two and three phase flows.

These objectives are:

1. to properly characterize two phase flow patterns in the region of interest that direct coal liquefaction reactors will be operated.
2. to characterize for viscous liquids, Newtonian and non-Newtonian, the flow pattern boundaries in the operating region of direct coal liquefaction reactors. The characterization would include both empirical and theoretical models.
3. to develop empirical expressions and models for the gas holdup in the flow regimes of interest. This objective would focus on non-Newtonian liquids that follow some elementary models for constitutive behavior.

The significance to the fossil energy program includes:

1. Flow pattern prediction will aid in the design and scaleup of coal liquefaction reactors.
2. Gas holdup and estimates of bubble diameter will be useful in predicting interfacial area.
3. Hydrodynamic modelling of the bubble column will be useful in predicting backmixing and residence times.

III. EQUIPMENT

A six inch inside diameter clear acrylic column with an overall height of about twenty feet is being used in this research program and has been described in earlier quarterly reports. Also, a thirteen inch inside diameter column of clear acrylic with an overall height of about twenty feet is now being used. Schematics of the equipment have been included in earlier reports.

IV. AQUEOUS CARBOXY-METHYL-CELLULOSE SOLUTIONS

Measurements of viscosity and surface tension for aqueous CMC solutions were reported last quarter. The power law model parameters for various solutions are presented in Table 2. Absorbance of different concentrations is reported in Figure 1.

V. EXPERIMENTAL MEASUREMENTS

Gas holdup measurements and flow pattern observations are completed for the 13 inch column. Data using a sieve plate and porous plate gas distributors and the aqueous CMC solutions are displayed in Figure 3. These can be compared to the experiments of Schumpe and Deckwer presented in Figure 2. Photographs are being analyzed to predict bubble size distribution.

Tests have been completed on eight different carboxy-methyl cellulose (CMC), isopropyl alcohol, and water, solutions (See Table 1 and 2). Tests included measurement of axial and overall holdup at various gas and liquid velocities in the 13 inch bubble column. 35 mm photographs have been taken of the bubbles and they are being analyzed. Pictures inside the column have been taken with a Borescope, an experimental plan is being developed and analysis of early results is underway.

The effect of distributor thickness was studied for hydrophilic and hydrophobic characteristics of the plate. Holdup increased with increase in the distributor thickness. The increase in holdup was about 35% in the bubble flow and about 9% in the bubble-slug and the churn-slug flow patterns. Gas holdup data obtained was more sensitive to pore size, distributor thickness, and plate characteristics at low gas velocities, ie., bubble flow pattern, than bubble-slug and churn-slug flow patterns. This may be due to the gas velocity distribution, which was more uniform in the bubble flow than in the bubble-slug and the churn-slug flow patterns.

There was no effect of liquid velocity and liquid entrance position on gas holdup for a polyethylene plate which was in agreement with Kamat's results. Holdup at the transition was increased with liquid velocity, the maximum difference being 34.8%.

Gas holdup for air water system was correlated by the equation,

$$E_G = B\ VGS^n$$

for three flow patterns for different porous plates.

Holdup data was calculated from the proposed correlations at different superficial gas velocities nn bubble, bubble-slug and churn-slug flow patterns. The effect of gas distributor on holdup was calculated from this correlation and the results obtained were in agreement with experimental results. The correlation coefficient was about 0.97 to 1.00.

There was no axial variation of holdup except for end effects. End effects were greater in the churn-slug flow pattern due to the turbulence in the column at high gas velocities. The maximum entrance region was about 1.5m above the distributor in all three flow patterns.

IV Results from Six-Inch Column Experiments

Holdup and flow pattern studies were made in a 0.1524m diameter bubble column for the air-water system using different porous plate gas distributors. The bubble column was operated in bubble, bubble-slug, and churn-slug flow patterns. The bubble to bubble-slug transition occurred between 0.054 to 0.085m/s depending upon the gas distributor. The gas holdup at the transition ranged between 0.2 and 0.33 for different gas distributors. Holdup increased linearly with superficial gas velocity and dropped suddenly at the transition due to coalescence of bubbles. Churn slug flow transition occurred above 0.22 m/s for all the porous plate distributors. This transition superficial gas velocity is obtained from the modified Taitel et al flow map.

Holdup increased with increase in pore size in bubble and bubble-slug flow patterns. The increase in holdup was about 15% in the bubble flow pattern and about 8% in the bubble-slug flow pattern. The variation in holdup in the churn-slug flow pattern was less than 5% and was within the experimental error. Distributor plates with hydrophobic characteristics gave higher holdup than with hydrophilic characteristics in the bubble flow pattern. The variation was about 11% in the bubble flow pattern and about 7% in the churn-slug flow pattern. Variation in the bubble slug pattern was within experimental error.

Polypropylene with hydrophilic characteristics gave higher holdup than polyethylene with hydrophilic characteristics. The percentage difference in the bubble pattern was about 11. But holdup for the polypropylene plate was less than that of polyethylene with hydrophobic characteristics, probably because of different wetting characteristics of the distributor.

Bubble size, shape and bubble distribution were observed visually and also by taking photographs at three axial positions. Ellipsoidal bubbles and spherical bubbles were formed when air was introduced through a porous plate distributor into water. Bubble size was dependent on distributor pore size, gas velocity and column height. These results are in agreement with Akita and Yoshida's experimental results. Bubble size did not vary with distributor thickness and material as observed from photographs. Bubble sizes ranged from 0.001 to 0.006m in the column. Though holdup varied with the distributor thickness, the transition superficial gas velocity did not vary. The observed flow patterns were the same for all porous plate distributors with the bubble to bubble-slug transition occuring between 0.054 and 0.085 m/s and churn-slug transition occurring above 0.22 m/s.

V. BOROSCOPE
EXPERIMENTAL PLAN

VARIABLES:

Gas velocity, liquid velocity, liquid solution, distributor, axial position of borescope, radial position of borescope, borescope focus.

FIXED PARAMETERS:

a- Liquid solutions, only CMC solutions.

b- Liquid velocity, V = 0.

c- Axial position of boroscope, at 56 in. above the distributor.

d- Distributor, porous plate (70 m).

e- Focus on 2-3 mm from boroscope tip.

VARIABLES LEFT AND RANGE:

a- Gas velocity: 0.01, 0.025, 0.040,0.055, 0.065, 0.075, 0.085 and 0.10 .

b- CMC solutions: 0.25% w, 0.50% w, 1.0% w. 1.5% w, 2.0% w .

c- Borescope radial position: center, 1,2,3 and 5 in. from the wall.

TENTATIVE EXPERIMENTAL SEQUENCE:

DAY	
1	CMC solution preparation. Time increases with CMC concentration. Starting with the most diluted.
2	Four different gas velocities are tested. Takes more time to develop the roll and see if the pictures came out good. The film is only developed.
3	Four more gas velocities are tested, and same procedure as before is followed.
4-5	All pictures have to be printed in order to recheck if everything came out as expected. Also the bubble size is briefly analyzed and after no doubts about the present raw data exist, next CMC concentrations should be tested.
6	Flow Curve of the solution is tested by using 3 different samples taken at different times during the experiment. This with also density and surface tension is measured at the same column temperature.

PROCEDURE:

With any one CMC solution and setting a specific gas velocity , the radial position of the boroscope is varied from the center of the column toward the wall, as explained before. Aproximated 15 pictures will be taken in every single position. The same procedure is follwed again using the values chosen for the gas velocities and after the whole range is completed, another CMC solution will be tested following the same procedure.

For each gas velocity, the total holdup will be measured and also the gas disengagement for 10, 15, 20 and 25 sec. after the gas valve has been turned off (25 sec. is taken as the highest time for a bubble swarm to reach the top of the column , for this an estimated value for minimum bubble swuarm velocity is found from A. Kumar et al, Can J. Chem. Eng. 54, 1976(503) with an extrapolation to non- Newtonian liquids).

Temperature of the column has to be constantly checked for system properties.

RESOURCES NEEDED:

a- 14 2.5 Kg CMC Jars (based on 170 Gal. solutions)

b- 3 boxes of photograph paper.

c- 100 rolls of film PX 135-36 .

d- 3 ionic resin cartridges (1 every 2 solutions).

e- Chemicals for developing and printing.

POSSIBLE STARTING DATE:

7/27/83

TABLE 1

Fluid Velocities Used in Bubble Column Hodup Experiments

Aqueous Carboxy Methyl Cellulose Solutions and Air

GAS VELOCITIES	LIQUID VELOCITIES
0.004	0.0
0.01	0.005
0.02	0.012
0.03	
0.04	
0.05	
0.06	
0.09	
0.12	

TABLE 2

Variables of ExperimentalHoldup Runs Using Aqueous CMC

RUN	CMC CON. (wt%)	IPA CON. (wt%)	LIQ VEL. (m/s)	RUN	CMC CON. (wt%)	IPA CON. (wt%)	LIQ VEL (m/s)
2	0.0	0.0	0.0	1	0.0	0.0	0.0
3	0.5	8.0	0.0	6	0.5	8.0	0.0
4	0.5	8.0	0.005	7	0.5	8.0	0.005
5	0.5	8.0	0.012	8	0.5	8.0	0.012
12	0.25	8.0	0.0	9	0.25	8.0	0.0
13	0.25	8.0	0.012	10	0.25	8.0	0.005
14	0.25	8.0	0.005	11	0.25	8.0	0.012
18	1.0	8.0	0.0	15	1.0	8.0	0.0
19	1.0	8.0	0.005	16	1.0	8.0	0.005
20	1.0	8.0	0.012	17	1.0	8.0	0.012
21	0.75	8.0	0.0	23	0.75	8.0	0.012
22	0.75	8.0	0.005	24	0.75	8.0	0.0
29	0.25	0.0	0.0	25	0.75	8.0	0.005
30	0.25	0.0	0.005	26	0.25	0.0	0.0
31	0.25	0.0	0.012	27	0.25	0.0	0.005
32	0.5	0.0	0.0	28	0.25	0.0	0.012
330.5		0.0	0.005	35	0.5	0.0	0.0
34	0.5	0.0	0.012	36	0.5	0.0	0.005
41	0.75	0.0	0.0	37	0.5	0.0	0.012
42	0.75	0.0	0.005	38	0.75	0.0	0.0
43	0.75	0.0	0.012	39	0.75	0.0	0.005
44	1.0	0.0	0.0	40	0.75	0.0	0.012
45	1.0	0.0	0.005	47	1.0	0.0	0.0
46	1.0	0.0	0.012	48	1.0	0.0	0.005
				49	1.0	0.0	0.012

TABLE 3

Power Law Model Coeffiecients for Non Newtonian Aqueous Carboxy Methyl Cellulose Solutions Measured Using a Rheometer

SAMPLE	INDEX,n	COEFFICIENT,K
0.5 CMC	1.04	0.008
1.0 CMC	0.865	0.062
1.5 CMC	0.821	0.157
2.0 CMC	0.772	0.333
0.5 CMC, 10 IPA	1.02	0.013
0.5 CMC, 8 IPA	0.544	0.476
1.0 CMC, 10 IPA	0.980	0.042
1.5 CMC, 10 IPA	0.832	0.192
2.0 CMC, 10 IPA	0.719	0.748
0.25CMC, 8 IPA(1)	0.992	0.008
0.25CMC, 8 IPA(2)	0.913	0.014
0.5 CMC, 8 IPA(1)	0.789	0.066
0.5 CMC, 8 IPA(2)	0.887	0.029
1.0 CMC, 8 IPA(1)	0.837	0.074
1.0 CMC, 8 IPA(2)	0.913	0.046

$$\tau_{yx} = K\left(\frac{dv_x}{dy}\right)^n$$

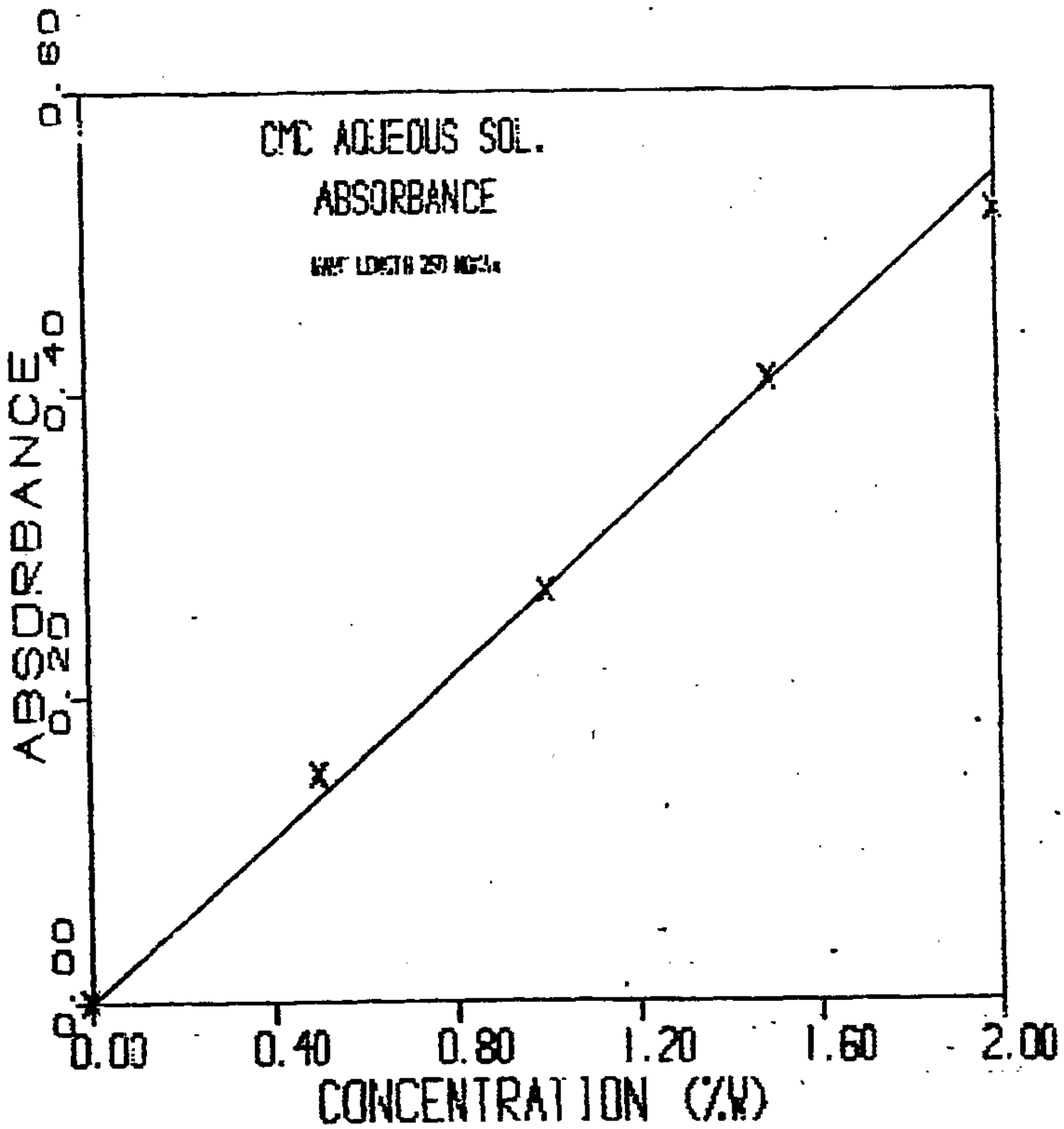
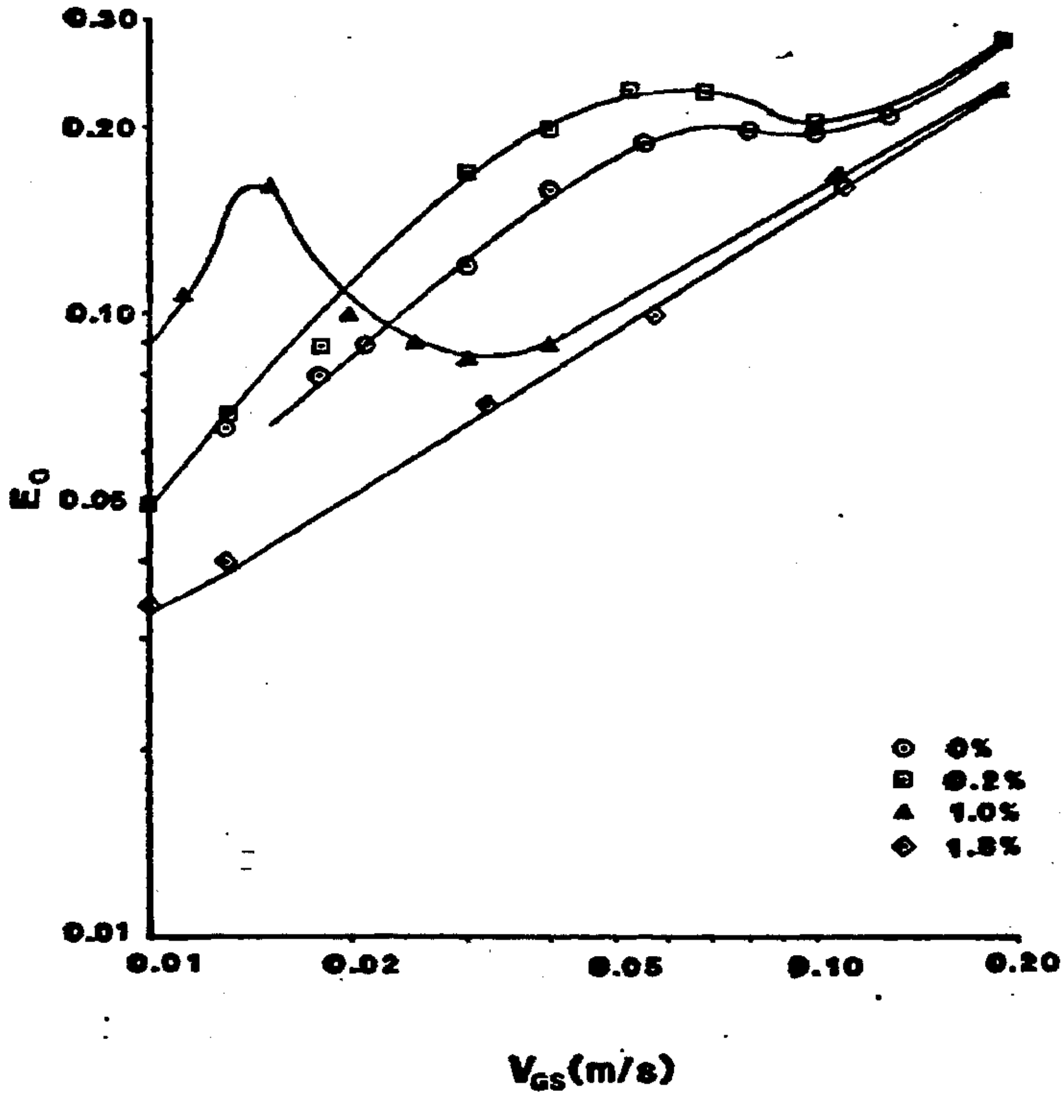

CMC AQUEOUS SOL.
ABSORBANCE
ABSORBANCE
0.00
0.20
0.40
0.60
0.00
0.40
0.80
1.20
1.60
2.00
CONCENTRATION (%W)

FIGURE 1

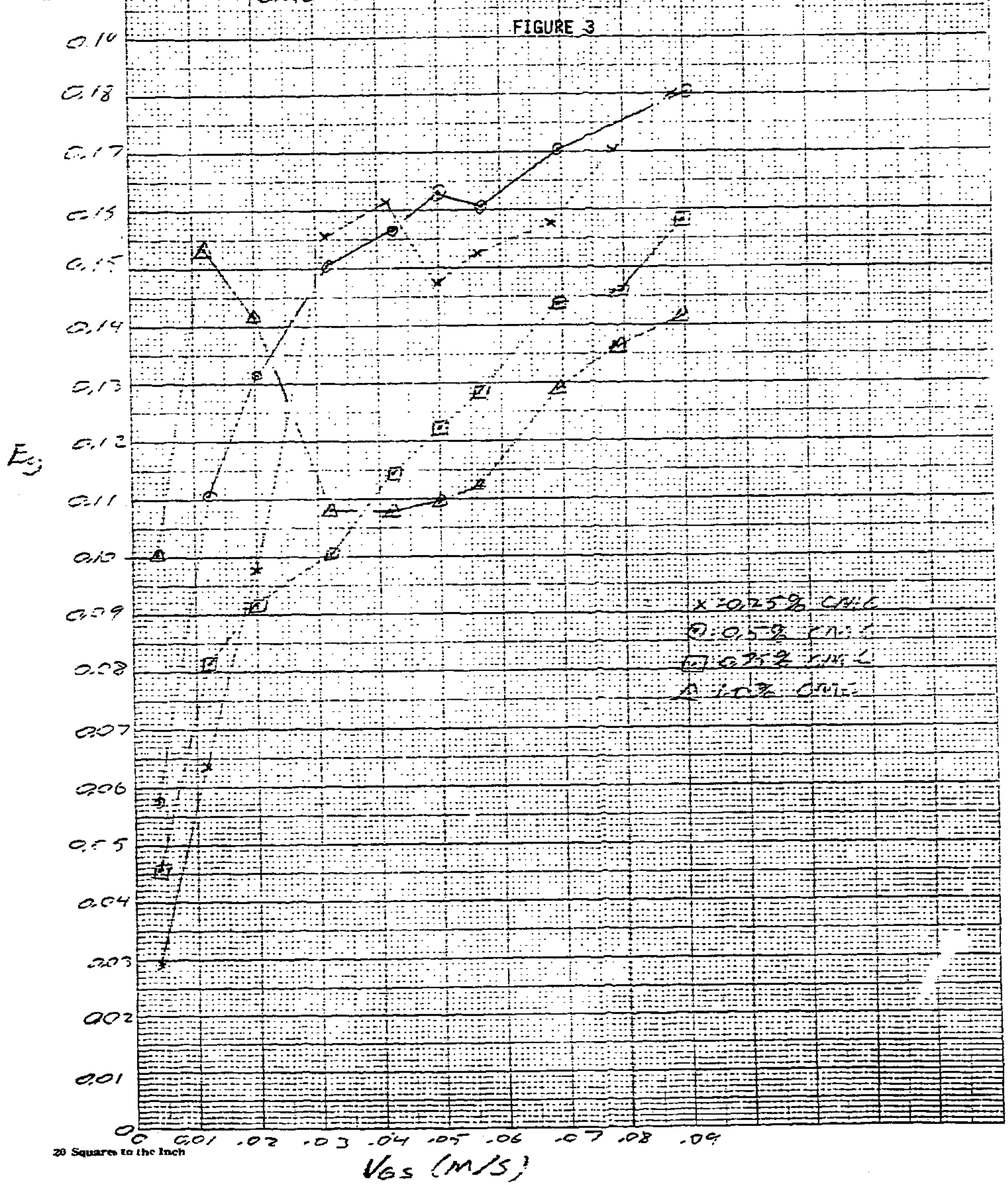


GAS HOLDUP VS. SUPERFICIAL VELOCITY FOR VARIOUS CONCENTRIATIONS OF CARBOXYMETHYL-CELLULOSE (SCHUMPE AND DECKWER)

FIGURE 2

Gas Holdup vs Superficial Gas Velocity for Various CMC concentrations

FIGURE 3



20 Squares to the Inch