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

MASTER

Technical Progress Report

December 1, 1981 to February 28, 1982

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MULTIPHASE FLOW
TECHNICAL PROGRESS REPORT
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I. HIGHLIGHTS

A major portion of the time spent on this project for this quarter involved ordering the equipment required to construct the 15 inch inside diameter column. The superstructure for this column has been constructed and all major equipment has been ordered. The acrylic column is now being machined and assembled. Tests have been performed on the six inch column, using air and water to help determine a procedure for holdup measurements. A non-Newtonian fluid has been selected for initial experiments. The pseudoplastic fluid will be a mixture of carboxymethylcellulose and water.

II. OBJECTIVES

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 understanding 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 regime boundaries in the operative

region of direct coal liquefaction reactors. The characterization would include both empirical and theoretical models.

3. to develop empirical expression for the holdup in the flow regimes of interest. This objective would focus on non-Newtonian liquids that follow some elementary models for constitutive behavior.

III. EQUIPMENT

A. 6 INCH ID COLUMN

A six inch inside diameter clear acrylic column with an overall height of about twenty feet was available at the beginning of this research program. Accessories available included meters, filters tanks and a pump. New manometers are being added to improve the ability to measure axial and total holdup in the column. Figure 1 is a schematic of the 6 inch system. Much of the piping was converted to copper tubing.

B. 13 INCH ID COLUMN

A thirteen inch inside diameter column of clear acrylic with an overall height of about twenty feet is presently being constructed. The column, structure, flow meters, centrifugal pumps, tanks, pressure regulators, control valves, filters, tubing, and gas distributors, have been received. The superstucture has been assembled. The column is now being machined and assembled. The construction should be completed shortly. Initial tests will be with air and water. This will allow comparison with literature values of holdup. A schematic of the column is pesented in Figure 2 and a layout of the equipment is presented in Figure 3. The purchased equipment list is presented in Table 1.

IV. SELECTION OF A NON-NEWTONIAN FLUID

A non-Newtonian fluid for initial measurements of holdup in both columns has been selected. The fluid is a solution of a polymer, carboxymethylcellulose, in water. The concentration of CMC will be low. The aqueous solution is a pseudoplastic and can be described either with the power law model

$$\tau_{yx} = - a \left| \frac{dv_x}{dy} \right|^{n-1} \frac{dv_x}{dy} \qquad (1)$$

or with the Ellis model

$$- \frac{dv_x}{dy} = (a + b |\tau_{yx}|^{n-1}) \tau_{yx} \qquad (2)$$

The parameters for these models can be found in the literature and are presented in Tables 2 and 3.

V. EXPERIMENTAL SET UP-DESCRIPTION

The schematic diagram of the experimental setup for the 6" column is depicted in Fig. 1. The bubble column is constructed of plexiglas and its inside diameter is 0.1524m(6") with a wall thickness of 0.0127m(1/2"). The total height of the column is 5.32m, consisting of four 1.33m sections flanged togetner. The gas distribution system occupies 0.152m of the column, making the effective height of the column equal to 5.17m. A total of eleven pressure taps are in the column, the lowest being 0.1016m(4") above the distributor. The distances between the bottom five taps is 0.3048(12") and the remaining pressure taps are 0.6096m(24") apart. This enables the study of local holdup. The pressure taps have been drilled with great care to reduce possible velocity head effects. A 0.8mm(1/32") hole has been drilled in the column wall and the inner surface polished to remove any burrs (eliminate velocity and friction heat effects). The tappings are all connected to a

manometer board by means of flexible polypropylene tubing. The manometric board consists of 10 U-tube manometers filled with a manometric oil as the manometric fluid. The connecting lines are filled with the column liquid.

Air is supplied by an existing compressor through a pressure regulator, air filter, rotameter, and a control valve to regulate the gas flow rate. Tap water is pumped from a 0.3785m (100 gallon) tank, through a water filter, control valve and a rotameter. Air enters the column at the bottom, through the gas distributing region. Three different positions for the liquid entrance directly to the column are located 0.0508m(2"), 0.06096m(24") and 1.371m(54") above the distributor plate. The air-water mixture flows up the column, and then into a gas-liquid separation tank, where the air is vented and the water recirculated back to the storage tank. Quick closing ball values are attached to the entrance (both air and water) and exit section of the column. The air rotameter has been calibrated using an air flow meter, while the water rotameter has been calibrated by collecting the water in a tank for a specific time and measuring its volume.

The gas distribution system, consists of a conical section packed with 3.5mm borosilicate glass beads, and a 0.127m(5") diameter distributor plate placed on top. The distributor plate is fitted, so as to make sure air enters only through the distributor plate, and not through the side of the plate. Air entering from the sides, usually in the form of big bubbles, disrupts the flow regime, especially in the case of uniform bubbling.

VI. EXPERIMENTAL PROCEDURE

The experiment is started by filling the column with water, and flushing the connecting lines (to the manometers) to get rid of any existing air bubbles. The lines are then connected to the manometers. Before the air is bubbled through the column, there should be no pressure difference registered by the manometers, as the density of the column fluid and the connecting lines fluid are equal. After removing all air bubbles from the connecting lines, the air control valve is opened, and the air pressure regulator set to 30psig. The air and the water flow rates are adjusted to a desired value and the system is allowed to equilibrate for about 300 to 600s or when the manometers indicates a steady reading. The air and water flow rates along with manometer readings are noted. The temperature of the column is not controlled independently; thus a small temperature variation can take place during the course of the work. Since all the experiments will be performed inside it is expected that the temperature will vary between 20-25^{o}C. The experiment will be repeated for different liquid flow rates and also for no liquid flow. At each liquid rate, measurements will be taken for a number of different gas rates. The gas and liquid flow rates will be chosen, such that the superficial gas and liquid velocities are in the bubble and bubble-slug flow regime of the flowmap (Fig. 4). The flow patterns will be characterized by visual observations.

VII. MANOMETRIC MEASUREMENTS

In case of bubble columns, with negligible liquid flow, ie. neglecting velocity and friction head effects, the variation of pressure with height is entirely due to hydrostatic head. The hydrostatic head is

measured by using a manometer and can be related to the gas holdup by taking a static pressure balance as shown below (See Figure 5)

Pressure drop along the column, entirely due to hydrostatic head

$$P_1 - P_2 = P_m (z_1 - z_2) g \quad \text{.....I}$$

Static pressure balance at point A

$$P_1 + (z_2 - z_3) P_w g + (z_3 - z_4) P_m g = P_2 + (z_1 - z_4) P_w g$$

Solving for $P_1 - P_2$

$$P_1 - P_2 = (z_1 - z_2) P_w g + (z_3 - z_4) (P_w - P_m) g \quad \text{.....II}$$

Equating I and II

$$P_m (z_1 - z_2) g = (z_1 - z_2) P_w g + (z_3 - z_4) (P_w - P_m) g$$

Rearranging to give

$$(z_1 - z_2) (P_w - P_m) = (z_3 - z_4) (P_m - P_w) \quad \text{.....III}$$

But $P_m = P_G E_G + P_w (1 - E_G) \simeq P_w (1 - E_G)$ Since $P_w \gg P_G$

Substituting in III

$$(z_1 - z_2) (P_w E_G) = (z_3 - z_4) (P_m - P_w)$$

$$E_G = \frac{P_m - P_w}{P_w} \quad \frac{(z_3 - z_4)}{(z_1 - z_2)}$$

$$E_G = \frac{P_m - P_w}{P_w} \quad \frac{\Delta h_m}{\Delta z}$$

In the differential form

$$E_G = \frac{P_m - P_w}{P_w} \quad \frac{dh_m}{dz}$$

The manometric measurements of gas holdup were cmpared to measurements of the expanded bed and of the bed with the flows off and similar results were found. See Figs. 6 and 7.

TABLE 1
Equipment List For 13" Column

Name	Number	Specifications	Company	Order Date	Delivery Date
1) Acrylic Column	4	13.125" I.D 52" long	Cadillac Plastic	10/19/81	Jan. 82
2) Dexion				available in the lab	
3) Liquid filter with Cartridges	2 10	Double size sediment filter 23" high, 5" dia.	Sears	12/15/81	1/29/82
4) Plastic Tanks	2	180 gal 36 gal	Terracon Corporation	12/14/81	1/22/82
5) Pressure gauges	6	0-100 Psig.	Matheson	12/17/81	1/15/82
6) Centrifugal pumps	2	1Hp, 3450 rpm 115/230V	Gelber	12/17/81	1/27/82
7) Control valves	3 1	1" 115V, 55 cycle time 4" 115V, 55 cycle time	CPI Controls	12/22/81	2/16/82
8) Manometers	10		Dwyer Instruments	12/31/81	Shipping Date 3/5/82
9) Red Fluid					Jan. 82
10) Pressure Regulator	1	Dome regulator Model 44-2020-24-002	Tescom Corporation	1/28/82	
11) Rotameter parts 1 Tube, 1 Float 1 Tube, 1 Float	 2 2	Tube R-8M-25-4 Float 8-LJ-48 20-4000 Tube 4-HCF b Float 40-J St. Steel	Brooks Schutte & Koerting	1/27/82 2/1/82	Feb. 82 Feb. 82
12) Distributor		Porous Plates	Carborundum (Catalog)	Called 1/19/82 Recalled 2/3/82	
13) Air Filter			Granges (Catalog)	Called on 1/26/82	

TABLE 2
Power Model Parameters For Aqueous Solutions of CMC[1]
At room Temperature[2]

Composition (weight %)	a (lb_f-sec^n-ft^{-2})	n (dimension less)
0.67	0.00634	0.716
1.5	0.0653	0.554
3.0	0.194	0.566

(1) Carboxymethylcellulose

(2) Metzner, A. B., Advances in Chemical Engineering, Vol. I, Academic Press, New York (1956) p. 103.

TABLE 3
Ellis Parameters For Aqueous
Solutions of CMC At 85°F(1,2)

Composition (Weight %)	Molecular Weight	a (cm^2/sec-dyne)	b (cm^{2n}/sec-$dyne^n$)	n (dimensionless)	Experimental Range of Shear Stress (dyne/cm^2)
4.0	Low	0.1377	0.3211	1.170	8 to 440
5.0	Low	0.00	0.0521	1.337	6 to 1010
1.5	Medium	0.4210	0.2724	1.185	6 to 300
2.5	Medium	0.0385	0.0181	1.412	17 to 1720
0.6	High	0.2891	0.0280	1.707	8 to 270

(1) Slattery, J. C., Doctoral Thesis, University of Wisconsin (1959), p. 79a.

(2) Bird, R. B., Stewart, W. E., and Lightfoot, E. N., Transport Phenomena, John Wiley and Sons, Inc., New York, (1960) p. 13.

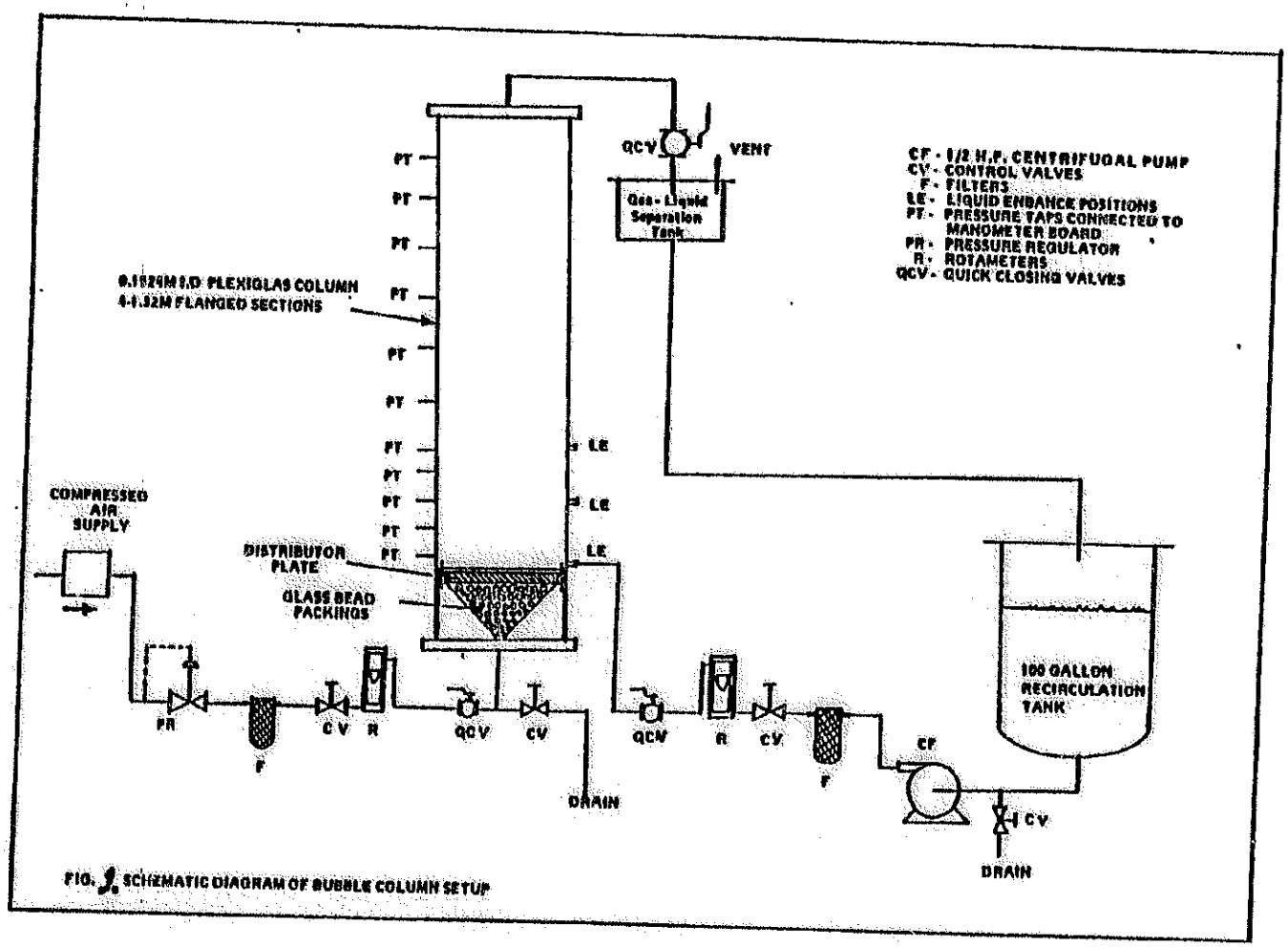
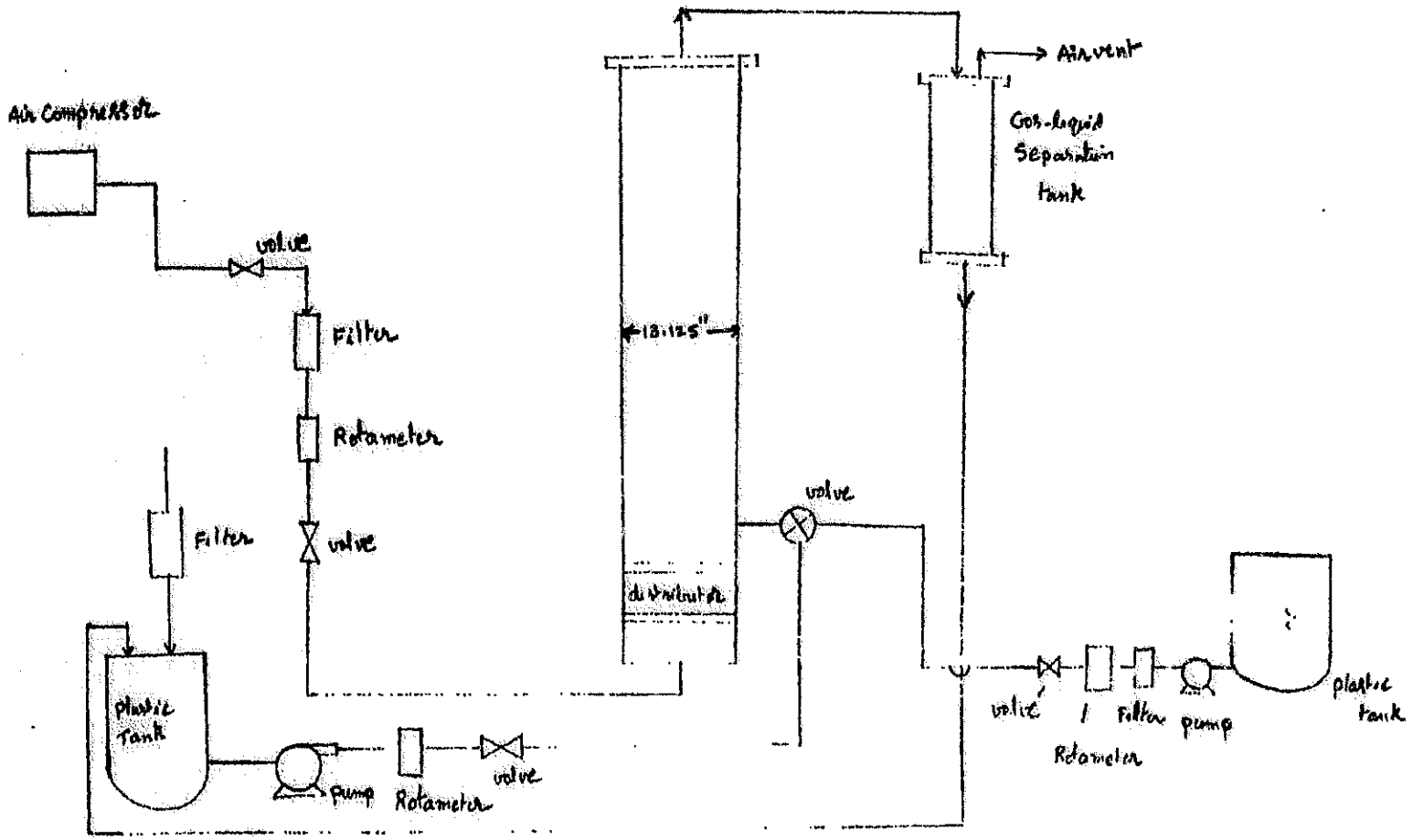


FIG. 3. SCHEMATIC DIAGRAM OF BUBBLE COLUMN SETUP

Schematic Diagram of Bubble column Set up.

FIGURE 2.



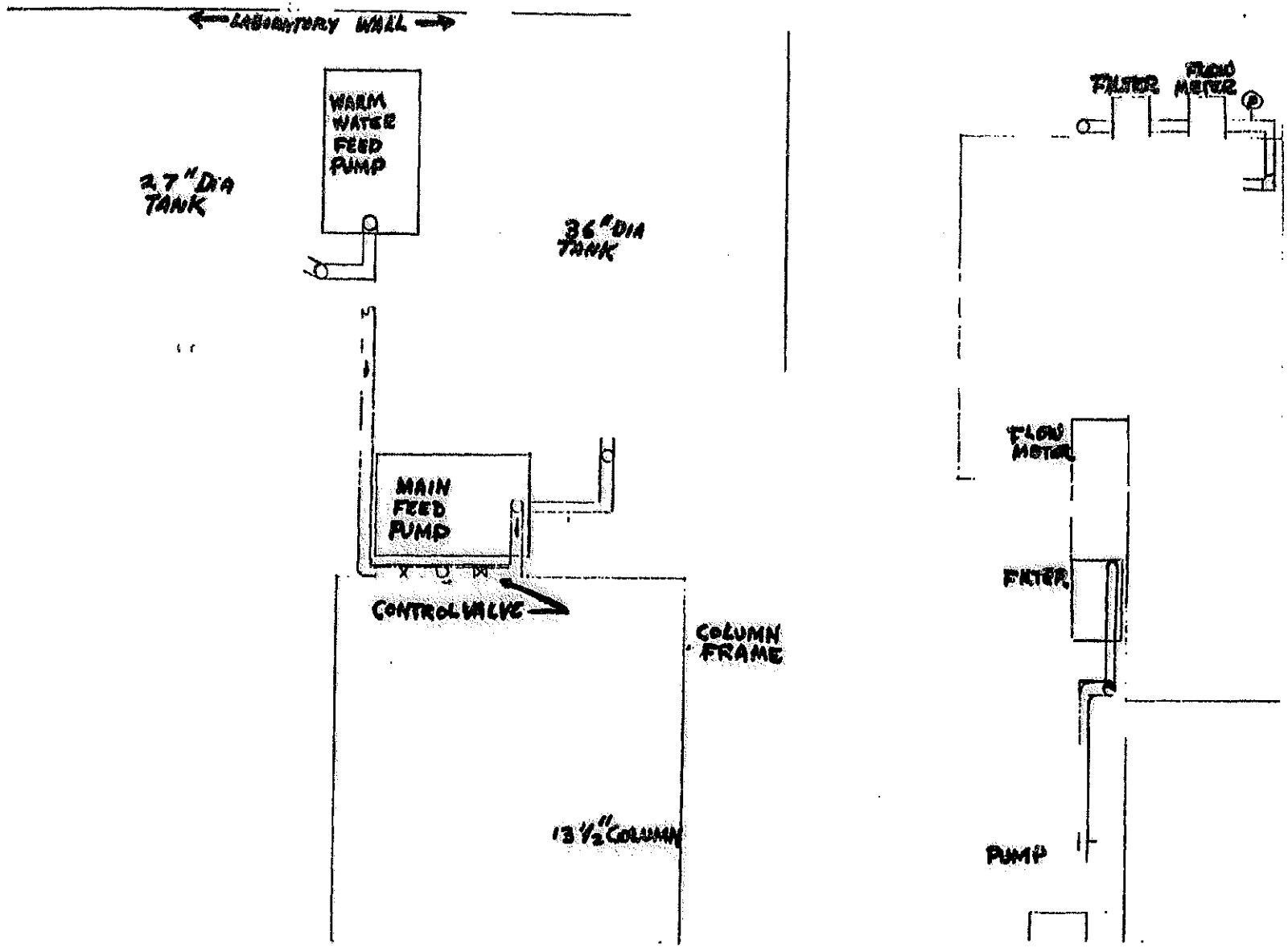


FIGURE 3

13" Bubble Column System Layout Scale 10 inches per inch

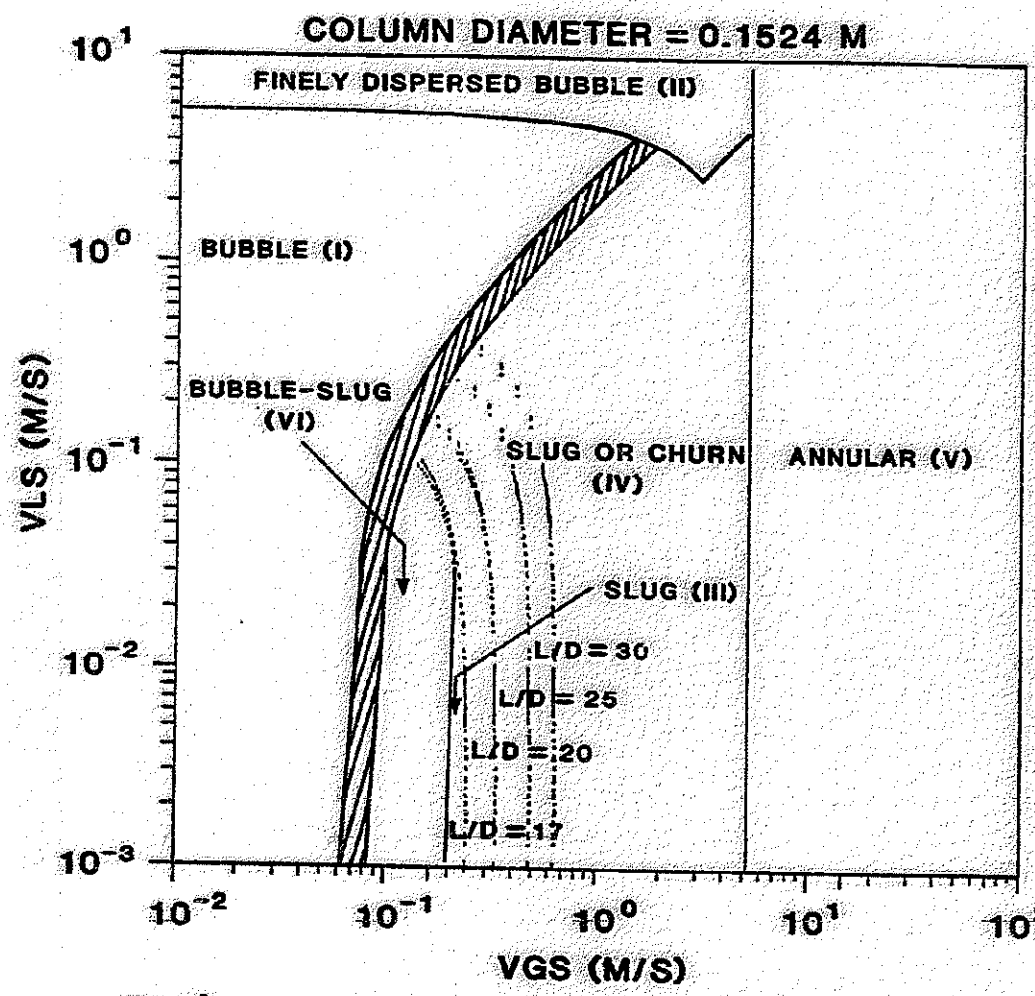


FIG. 4

FLOWMAP WITH PROPOSED CORRELATION INDICATING ZONE OF TRANSITION – AIR – WATER SYSTEM, 22° C, 1 ATM (1, 2)

1) KNICKLE, + KAMAT Submitted For Presentation at the Los Angeles AIChE Meeting, November 1982

2) KNICKLE + KIRPEKAR. Presented at the Orlando AIChE Meeting, March 1982

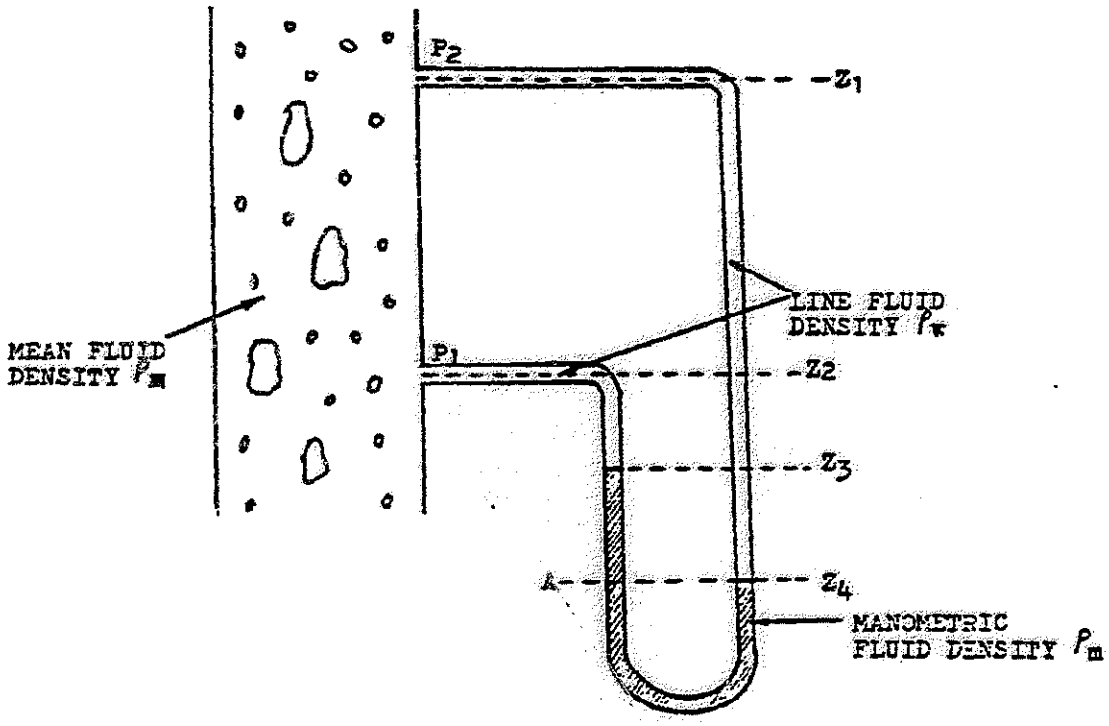


FIG. 5- MEASUREMENT OF PRESSURE DROP IN TWO PHASE FLOW SYSTEMS

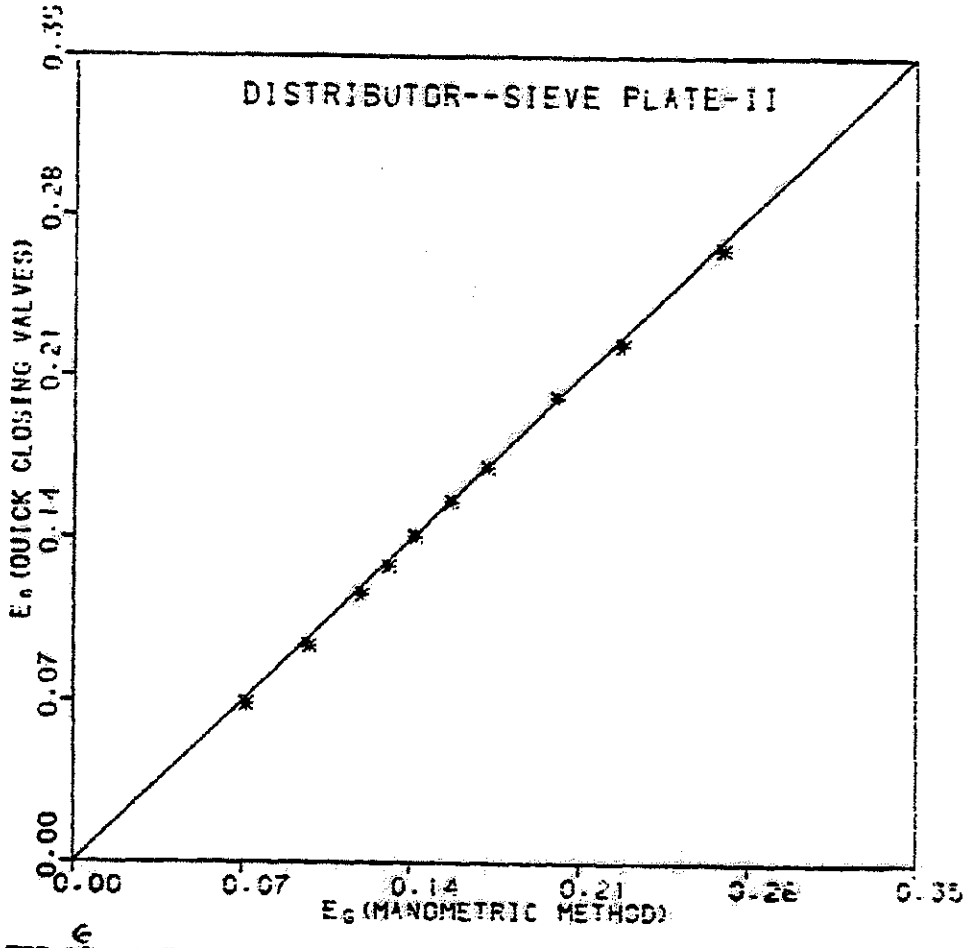


FIG. GAS HOLDUP-QUICK CLOSING VALVES VS. MANOMETRIC METHOD FOR SIEVE PLATE-II

KNICKLE & KAMAT

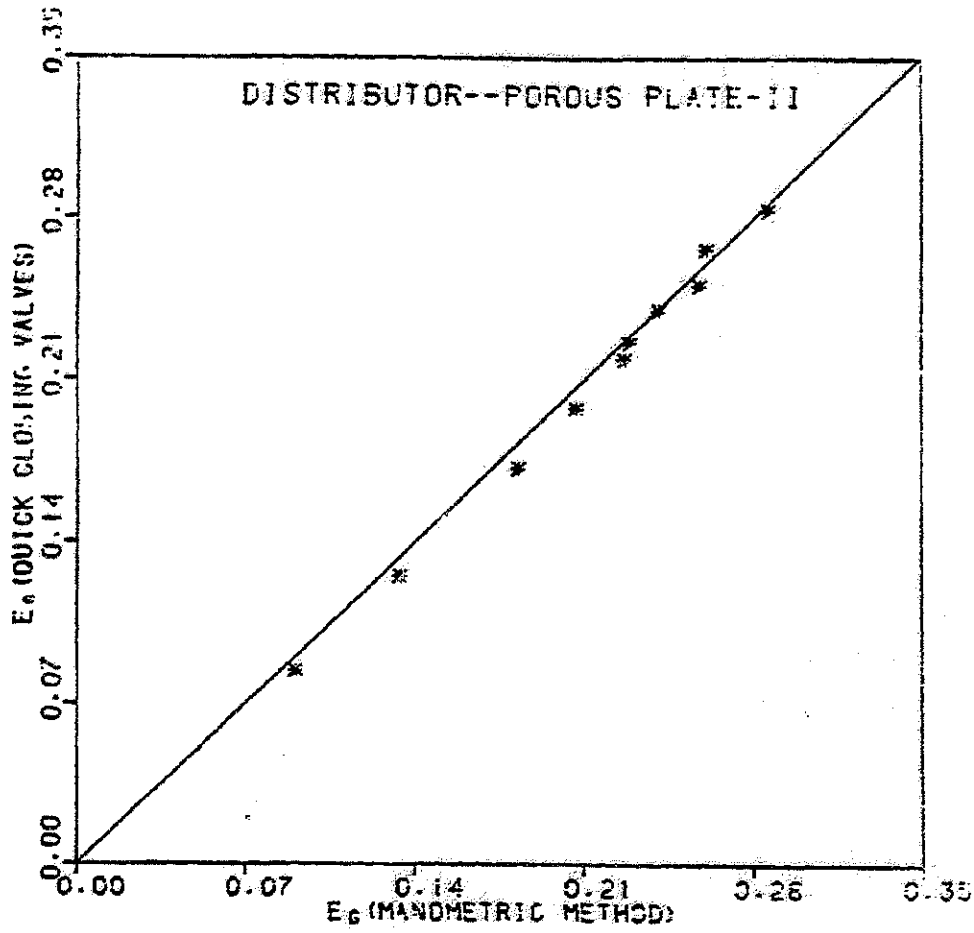


FIG. 7 GAS HOLDUP-QUICK CLOSING VALVES VS. MANOMETRIC METHOD FOR POROUS PLATE-II

KNICKLE & KAMAT