Figure 4

GAS HOLDUP IN VARSOL RUN#4
AT 5 SCFM AIR (0.033 m/s)

COLUMN HIGHT FROM TOP cm

HOLDUP Eg

Foam
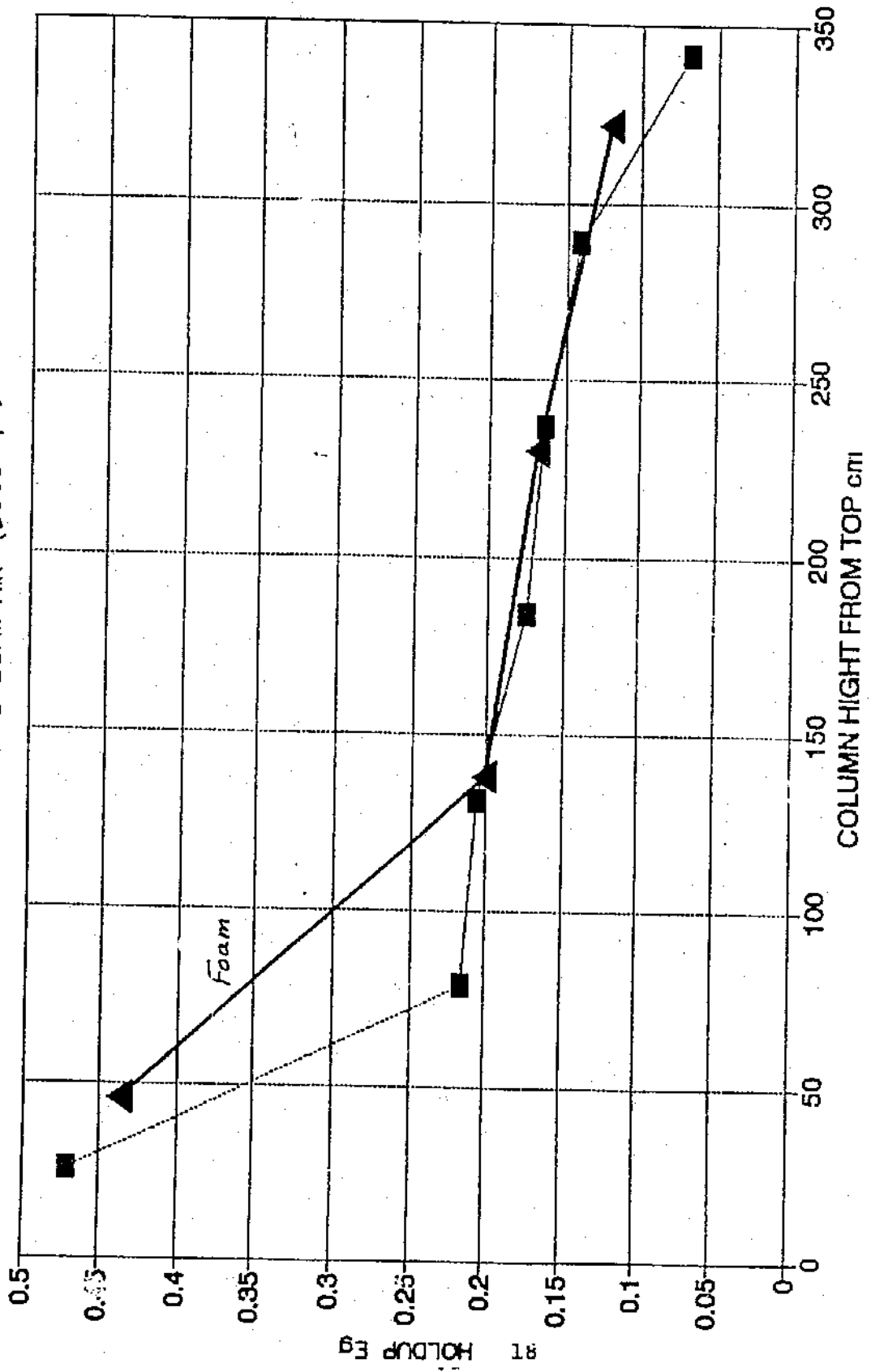
PROBE   MANOMETER

Figure 4a

GAS HOLDUP IN AERSOL RUN#4a
AT 5 SCFM AIR $(0.033 \ m/s)$

Foam

COLUMN HIGHT FROM TOP cm
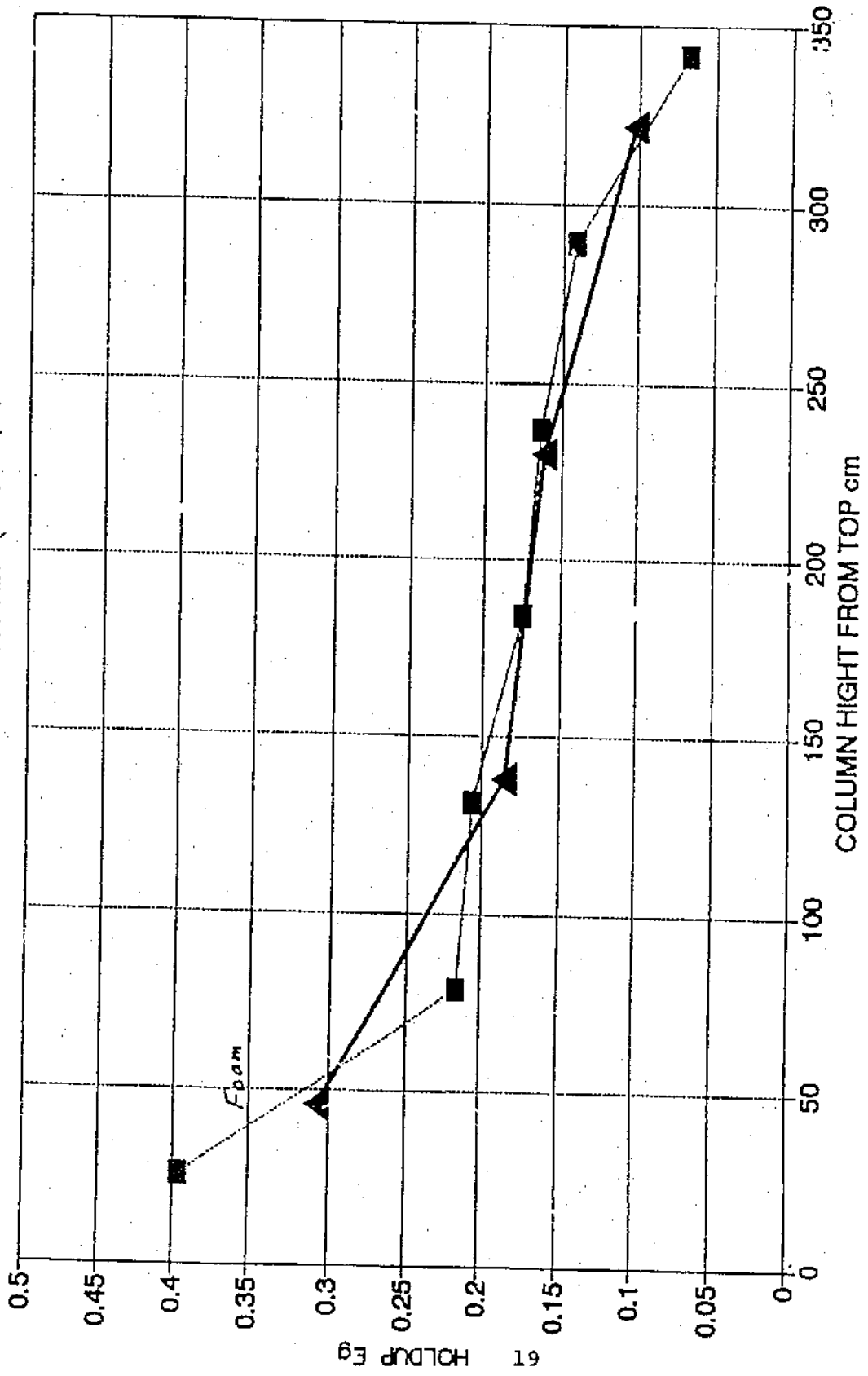
HOLDUP Eg

PROBE   MANOMETER

Figure 5

GAS HOLDUP IN VARSOL RUN#5
AT 18 SCFM AIR (0.12 m/s)

PROBE — MANOMETER

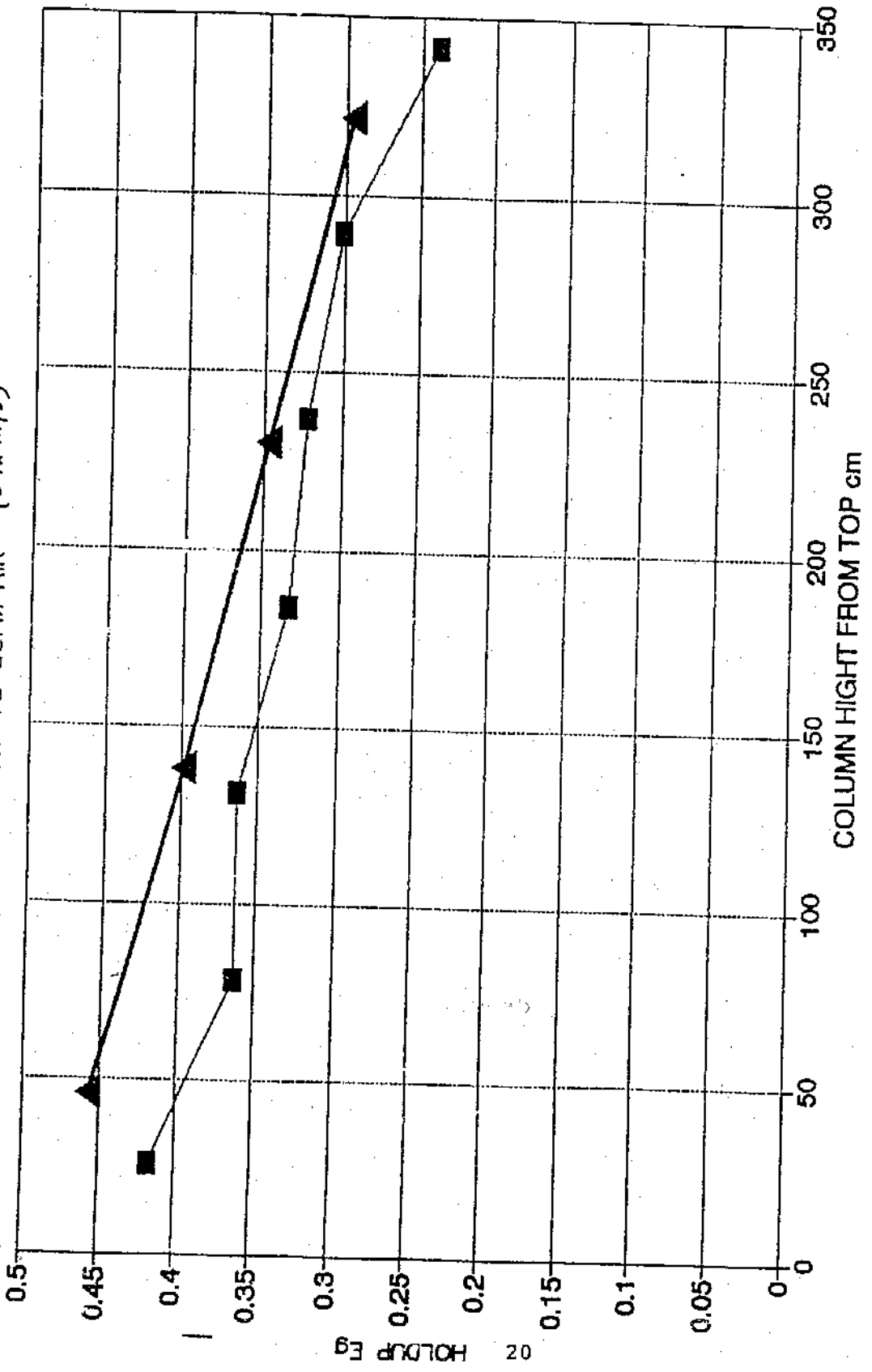COLUMN HIGHT FROM TOP cm

HOLDUP Eg

Figure 3a

GAS HOLDUP IN VARSOL RUN#5a
AT 18 SCFM AIR (0.12 m/s)

COLUMN HIGHT FROM TOP cm
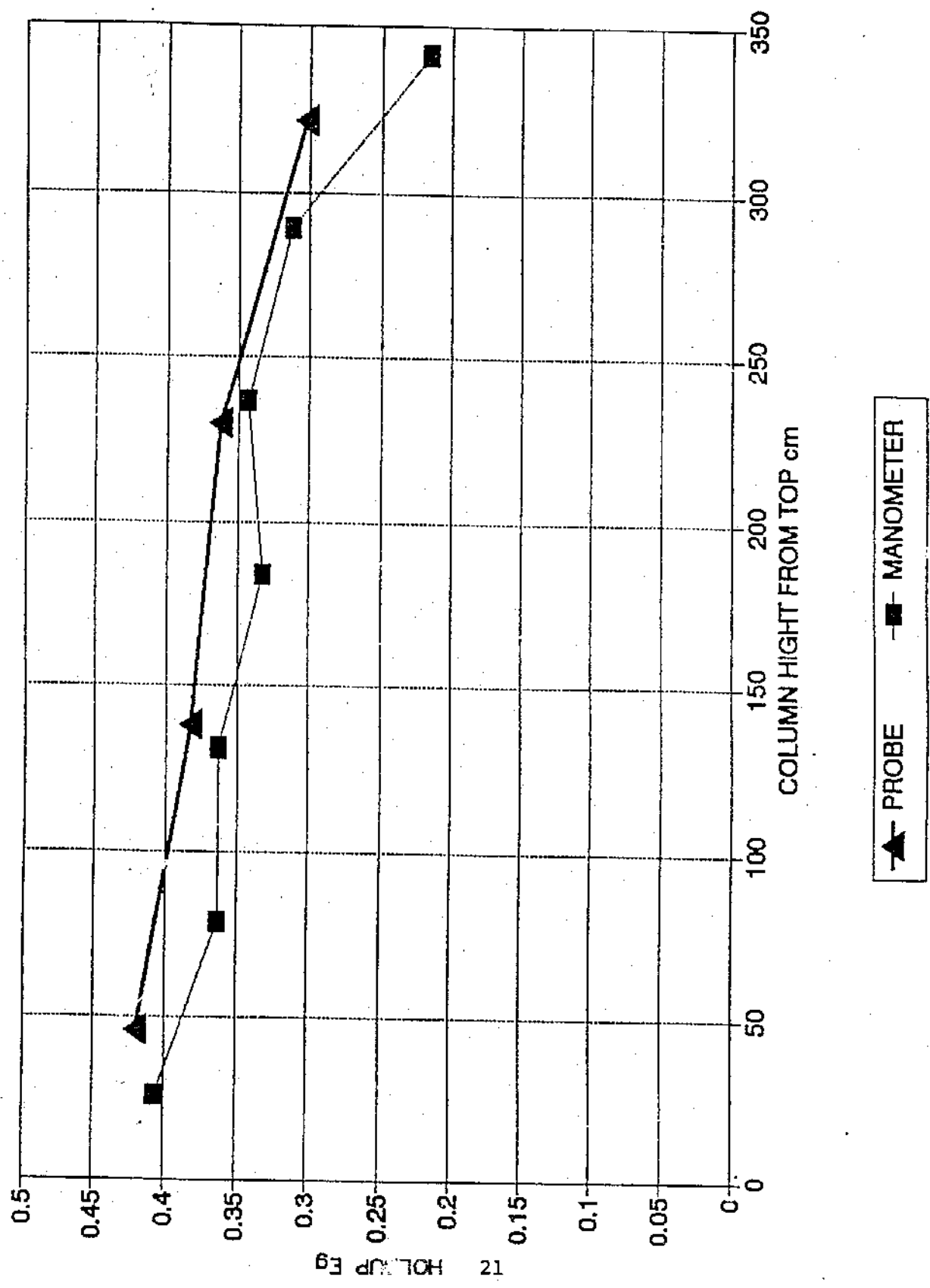
HOLDUP Eg

PROBE   MANOMETER

3 ~ 12 cm/s =

values by 3 to 5 percentage points (about 10% of reading).
This difference was larger in the higher holdup regions.
Run 5a repeated Run 5 but the probe was recalibrated.
Agreement of the two methods improved, but capacitance values
were still a little higher than the manometric values, by
about 2 percentage points.

It can be concluded that over the range of superficial
gas velocities from 3 to 12 cm/s at least, the present
capacitance probe gives correct and acceptably accurate
averaged gas holdup values over a holdup range of 10% to 45%
or more. Some instability causing zero drift may be
occurring, and this aspect should be checked.

Three Phase System - Solvent-Air-Glass Beads, No Draft Tube

The void fraction probe was tested in Runs 6 to 9 in the
presence of glass beads. No draft tube was used in these or
in the preceding two-phase tests. The glass beads used were
the size designated as 170/230 with a mean particle diameter
of 71 microns and a settling velocity in the solvent at 25°C
of 0.37 cm/s. Solid density was 2450 kg/m^3. After
calibration in quiet liquid, air flow was started at 3.8 scfm
and a batch of 12.5 kg of beads was added giving an average
solids concentration at 30% void fraction above the sparger
of 69 kg/m^3 (about 3% of the slurry volume). While this is
dilute, it should be enough to detect any serious effect, and

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is in the range of practical values.

Results in Run 6 are shown in Figure 6 for the first test at 8.8 scfm (5.9 cm/s). The probe and manometric methods show excellent agreement, and suggest that the glass bead content at this level does not significantly affect the readings. The solvent used in Run 6 appeared to be more foamy than the first batch, possibly because of additional foamer from earlier tests adhering to the beads. This extra dispersing characteristic is probably responsible for the greater change in gas holdup from bottom to top in Run 6 as compared to Run 3 at the same conditions.

Because of the extra foaming, some antifoam (Dow Corning FS-1265 Fluid) was added before Run 7. Also, it was not possible to rezero or to adjust the span before this run, because if the air was shut off all the beads would settle out and could not be completely resuspended. Run 7 at 12 scfm (8 cm/s) still shows good agreement between the two holdup measurements, although the probe values are on the average about 2 percentage points below the manometric ones.

The next test, Run 8, was a repeat of Run 6, to check the possibility of a zero drift. Manometric values show less variation from bottom to top because of the addition of the antifoam agent. Probe values in the two runs are about the same, so that in Run 8 the probe values fall below the manometric values by an average of about 3 percentage points.

Run 9 was at a low gas rate of 5.5 scfm (3.7 cm/s). The formation of a foam layer (also observed visually) near the top of the column is apparent, located in the top 50 cm. The probe is too coarse to detect this interface with any accuracy beyond locating it in the top 90 cm of the column. However, if the foam layer is assumed to have a gas holdup of 80%, then simple ratios with the experimental values given in Figure 9 and assuming linearity gives the foam interface location as 22 cm from the top for the manometric method and 28 cm from the top from probe readings. This agreement is good considering the assumptions made. For the region below the foam interface, the probe readings are on the average 4 to 5 percentage points below the manometric values, indicating a continuing zero drift. This aspect needs to be improved if possible, even though the probe was working near its limit of sensitivity in these tests.

It should be pointed out, also, that the manometric results and the capacitance results shown in Figures 6 to 9 require small corrections. The manometric results are somewhat low, because a higher fluid density exists when solids are added. Similarly, the probe results are also somewhat low because of the increase in dielectric constant of the fluid due to the presence of solids. The results suggest that these two corrections are of the same order.
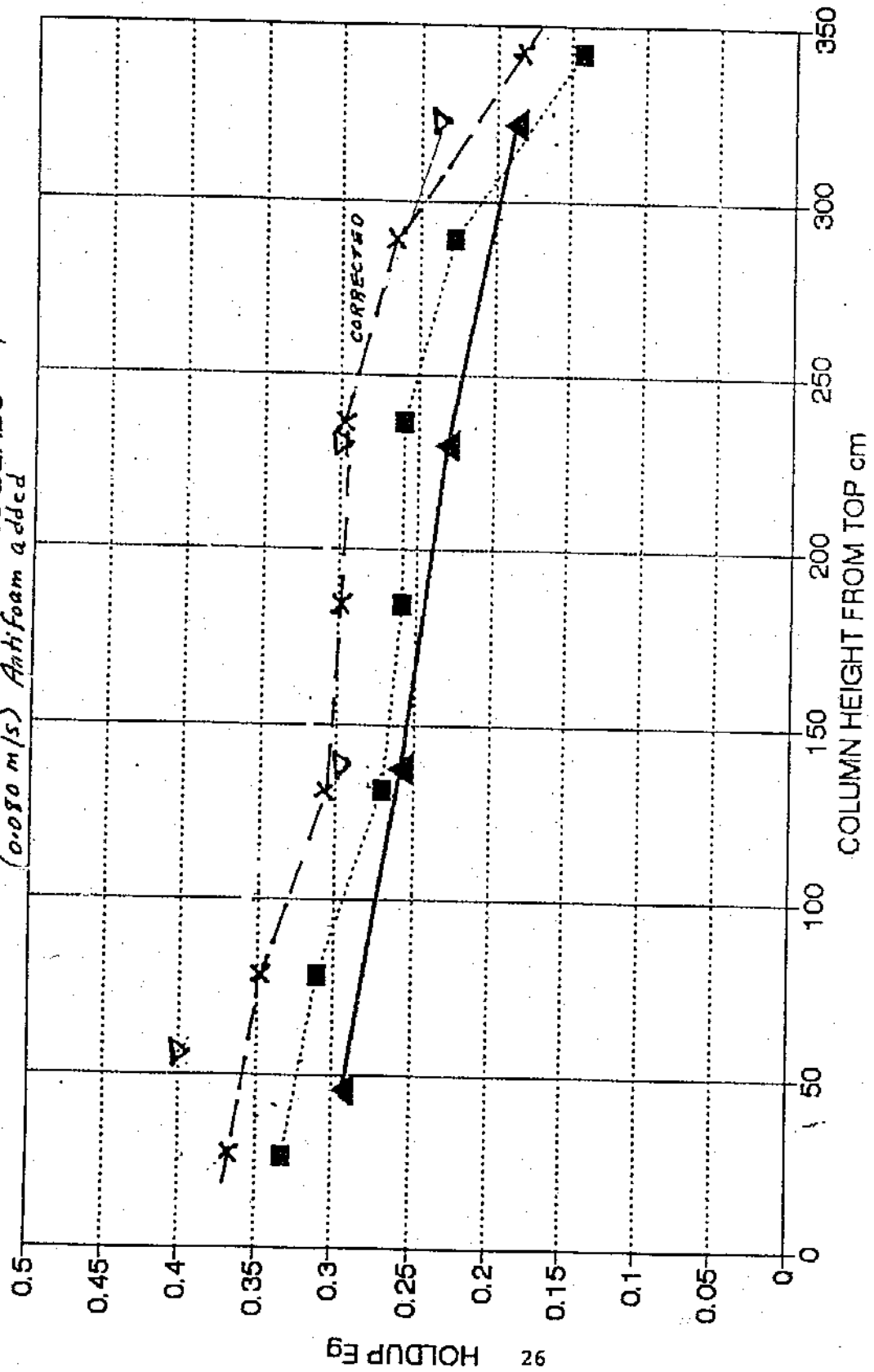
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Figure 6

GAS HOLDUP IN ●ARSOL RUN#6 170/230
AT 8.8 SCFM AIR WITH GLASS BEADS
(0.059 m/s) Higher Foaming

HOLDUP Eg   25

COLUMN HEIGHT FROM TOP cm
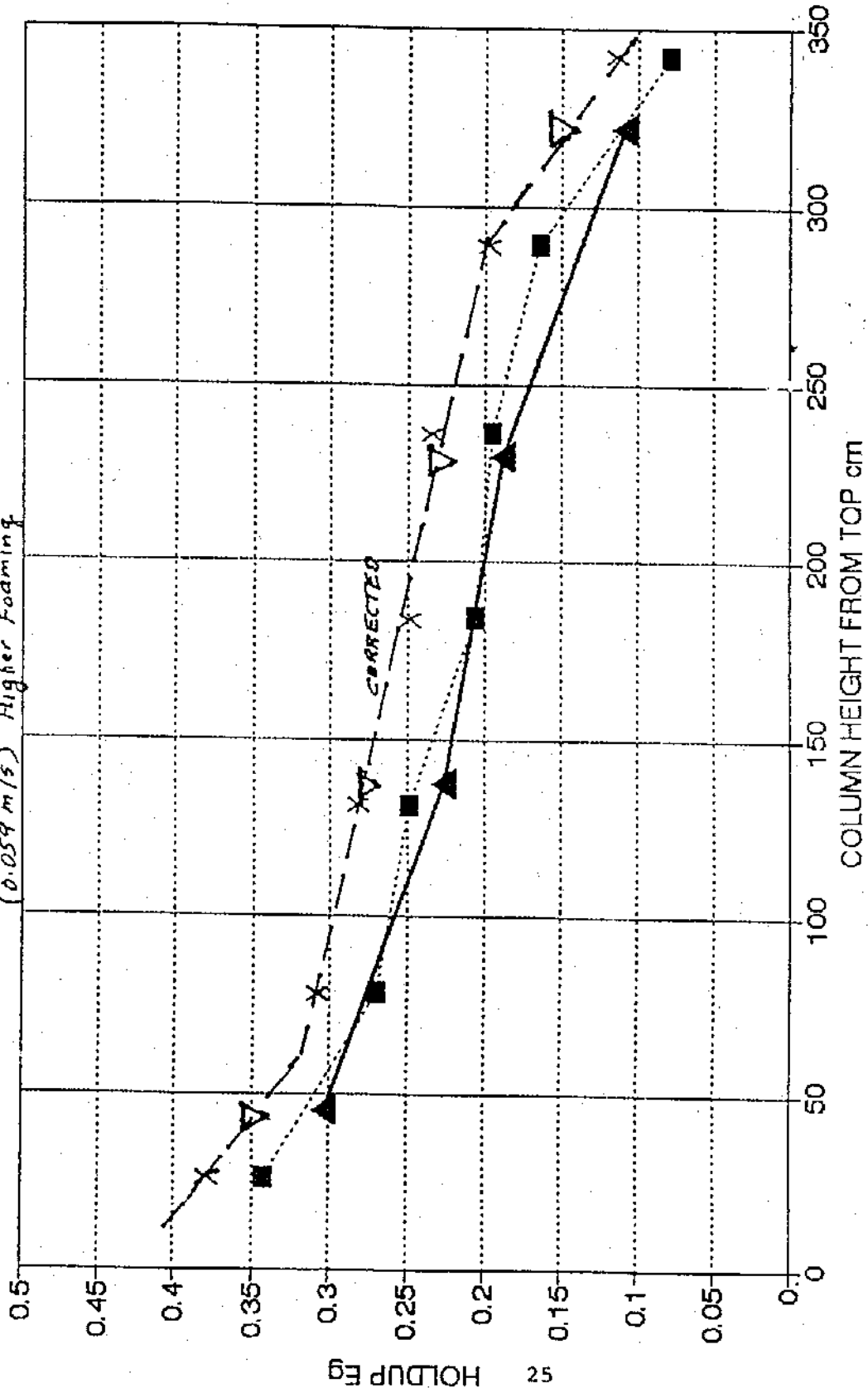
PROBE CORRECTED   MANOMETER CORRECTED

Figure 7

GAS HOLDUP IN VARSOL RUN#7
AT 12 SCFM AIR WITH GLASS BEADS 170/230
(0.080 m/s) Antifoam added
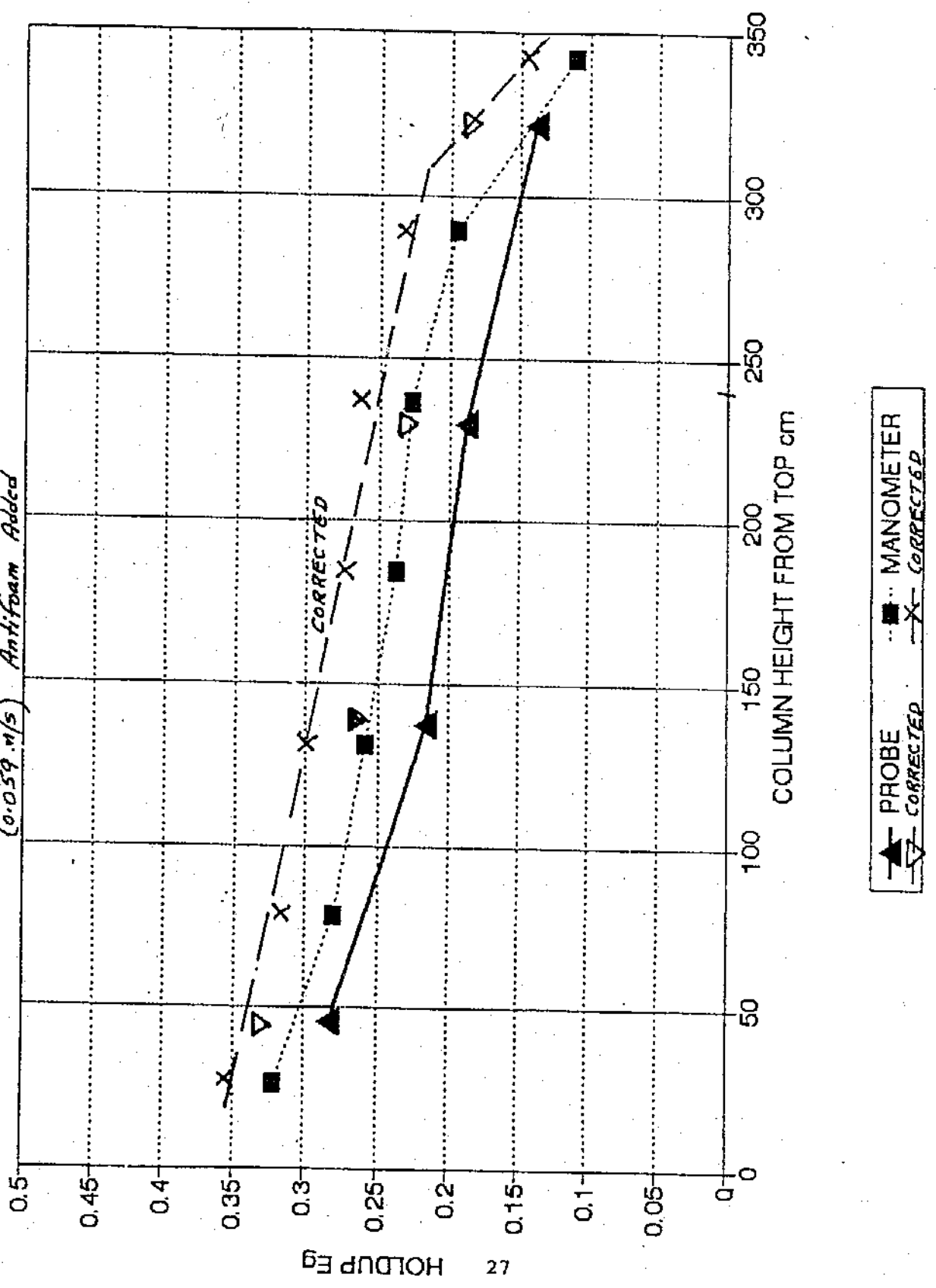
CORRECTED

COLUMN HEIGHT FROM TOP cm

HOLDUP Eg

26

PROBE .... MANOMETER
—△— CORRECTED   —✕— CORRECTED

Figure 9

GAS HOLDUP IN VARSOL RUN#8 170/230
AT 8.8 SCFM AIR WITH GLASS BEADS
(0.059 m/s) Antifoam Added

Figure 0

GAS HOLDUP IN 〇ARSOL RUN#9
AT 5 SCFM AIR WITH GLASS BEADS 170/230
(0.033 m/s) Antifoam added

CORRECTED

Foam

HOLDUP Eg

0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

0   50   100   150   200   250   300   350

COLUMN HEIGHT FROM TOP cm

PROBE ▲   MANOMETER ■
CORRECTED ▽   CORRECTED X

28
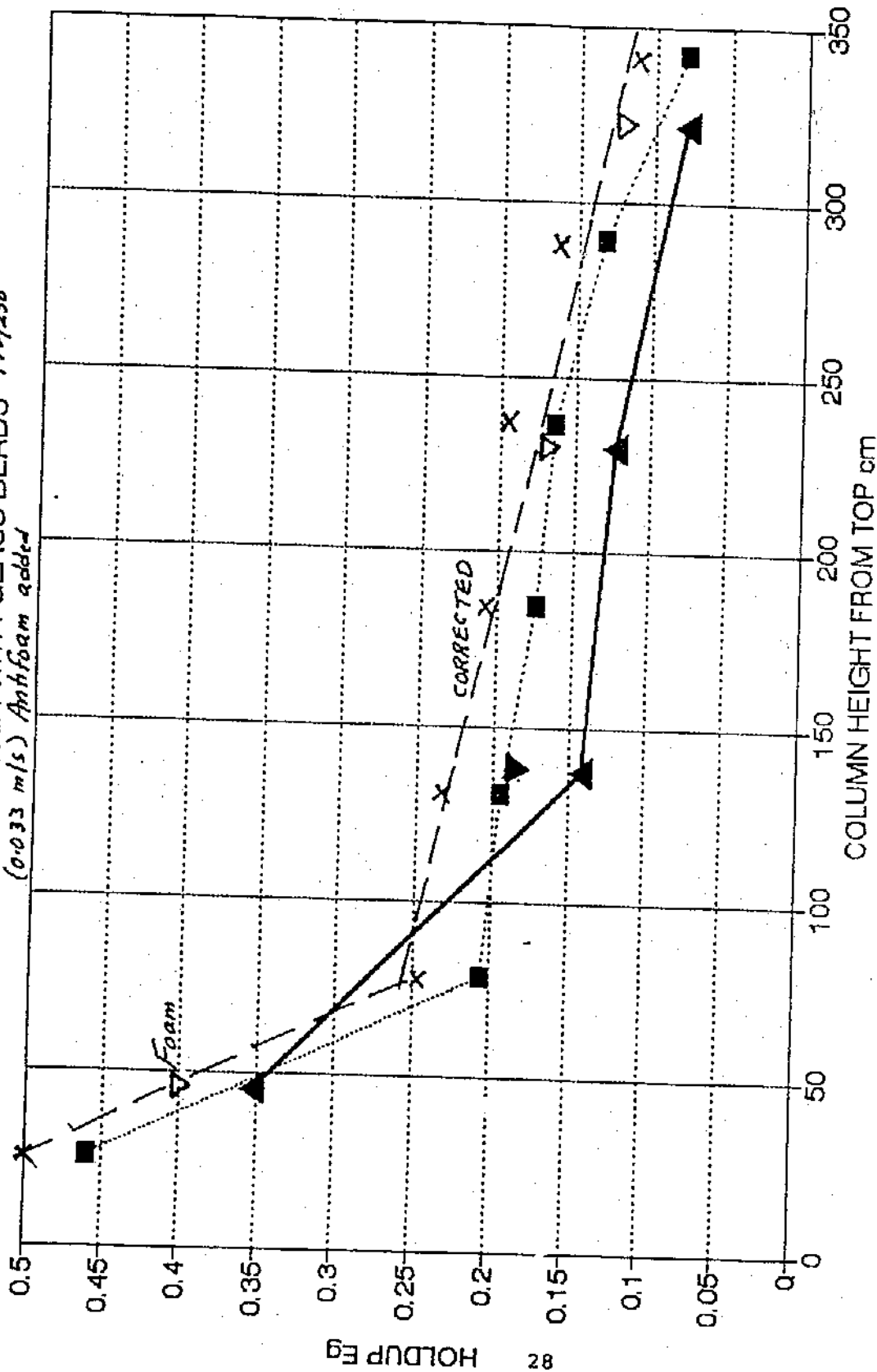
However, revised values were calculated using averaged corrections, that is, assuming an axially uniform slurry concentration and density. Since an axial solid concentration gradient does exist, use of the averaged values of slurry concentration does not give an exact correction except at one point. However, the corrections are not large, and inasmuch as the objective of the work was to validate the void meter performance, and not to fine tune the accuracy of the reading, the averaged approach was considered adequate for this purpose.

Figures 6 to 9 show both the values calculated from measured values assuming no effect of the glass beads on slurry density or dielectric. The dashed lines show corrected values. The development of the correction factors is given in the Appendix. The correction for the effect of glass beads on the dielectric was checked by a simple transient experiment, described in the next section. Figure 9A shows the overall average correction factor chart for solids in Varsol to be applied to the calculation of values of holdup for pure solvent.

The capacitance type gas holdup measuring probe performs as designed, and gives accurate and sufficiently precise readings of average gas holdup in two and three phase systems when the liquid and solids are non-conductive. The present unit may have a zero drift and appears to require frequent recalibration, and this aspect could be improved.
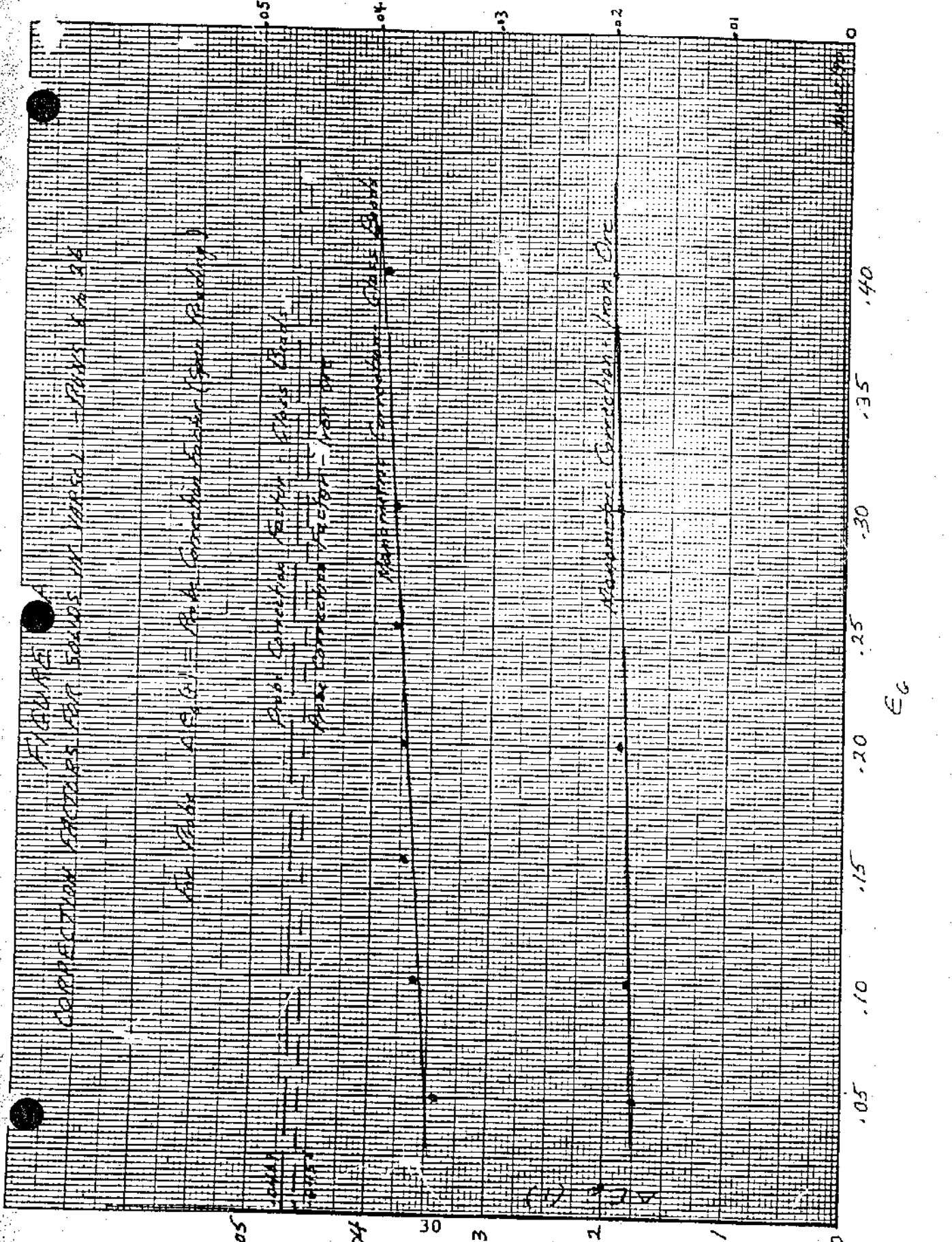
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CORRECTION FACTORS FIGURE

Correction Factors for Errors in Wheel · Fig 13 b 24

Cul Cbr x B(G) — Bulk correction factor (gpm Recity)

Prob Correction Factor Coils Bucks

Max Correction Factor — Iron Ore

Maximum Correction Factor — Iron Ore

Maximum Correction Iron Ore

E_G

.05   .10   .15   .20   .25   .30   .35   .40

.05   .04   30   .03   .02   .01   0

Results with Draft Tube

Experimental

As described previously, a PVC draft tube 1.46 m long by 0.18 m diameter (0.178 m inside diameter) was installed in the 0.30 m diameter glass column. Clearance under the draft tube (slot width) was 0.023 m. Dimensions and sparger arrangement are shown in Figure E. Figure F shows the details of the mounting of the probe with the flat aluminum bar used as the second plate.

Tests were done with the probe located both inside the draft tube and in the annulus. These probe locations are shown in Figures G and H, respectively.

Readings of both the probe and manometer were converted to gas holdup values in every case by use of the factors with no solids present. Therefore, values measured with solids present require a correction to the gas holdup. Approximate corrected data are also shown and the method of calculating the corrections is given in the Appendix.

Normally, the probe was calibrated for 100% span in air and in quiescent liquid. When solids were present this calibration was not possible. However, a test was done to check the effect of solids on the readings obtained. For Run 22 done at a gas velocity of 0.033 m/s with 170/230 glass beads and the probe located in the annulus of the draft tube, the readings of one probe section at the bottom were recorded
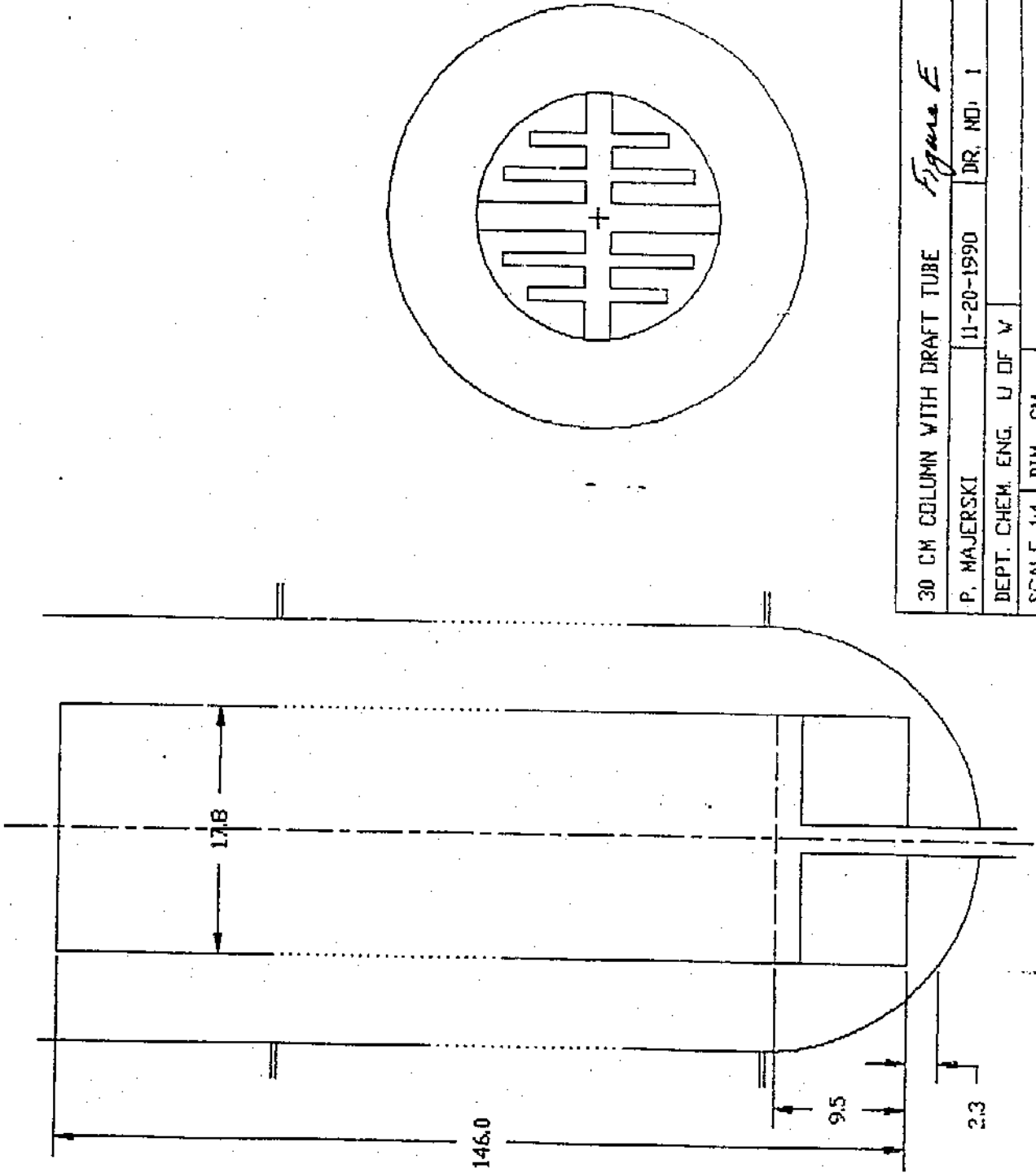
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30 CM COLUMN WITH DRAFT TUBE *Figure E*
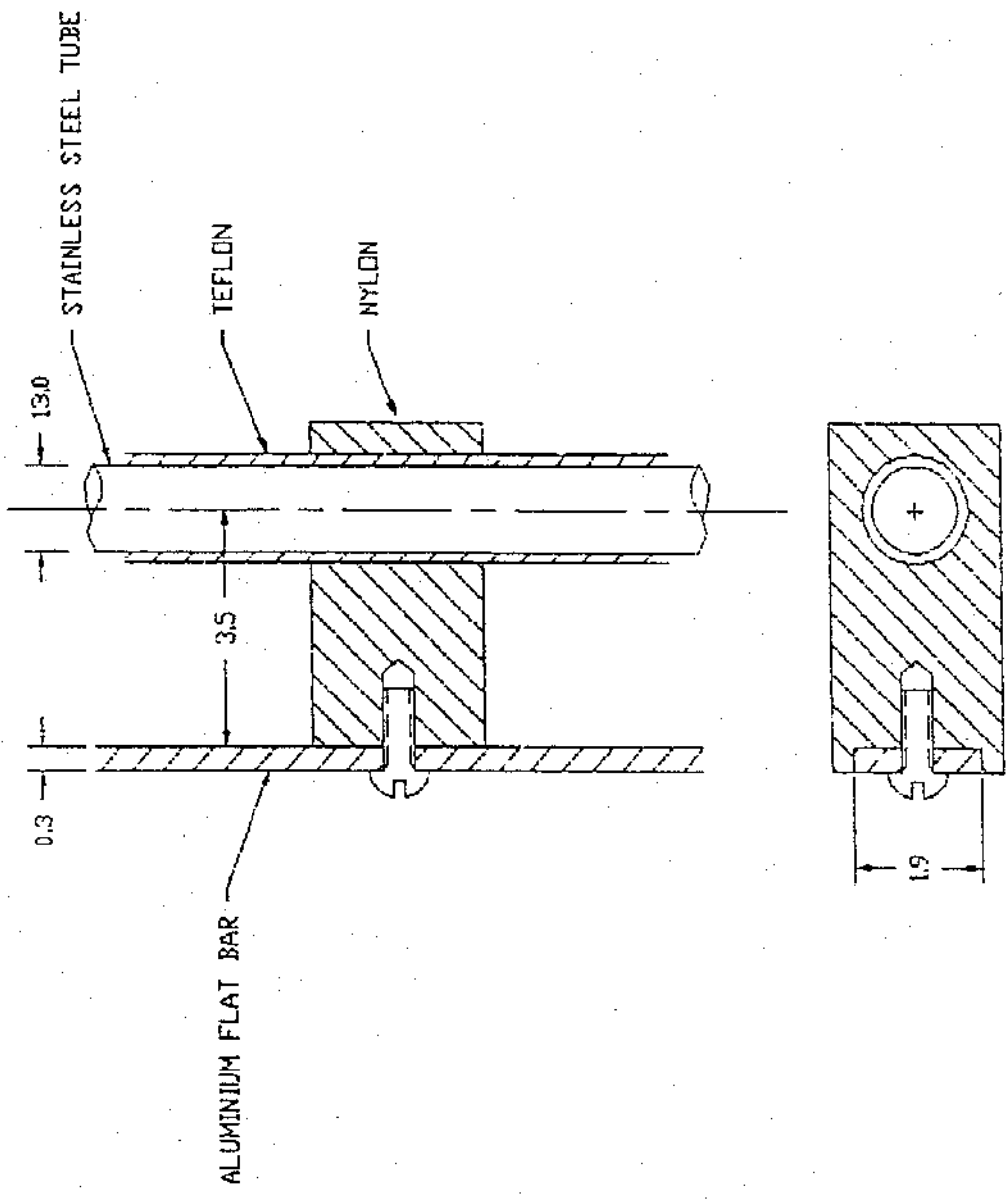
P. MAJERSKI	11-20-1990	DR. NO. 1
DEPT. CHEM. ENG. U OF W	
SCALE 1:4	DIM CM

146.0

17.8

9.5

2.3

STAINLESS STEEL TUBE

TEFLON

NYLON

13.0

3.5

0.3

1.9

ALUMINIUM FLAT BAR

33

Figure 6

3.8

52.6

92

PROBE BOTTOM SECTION
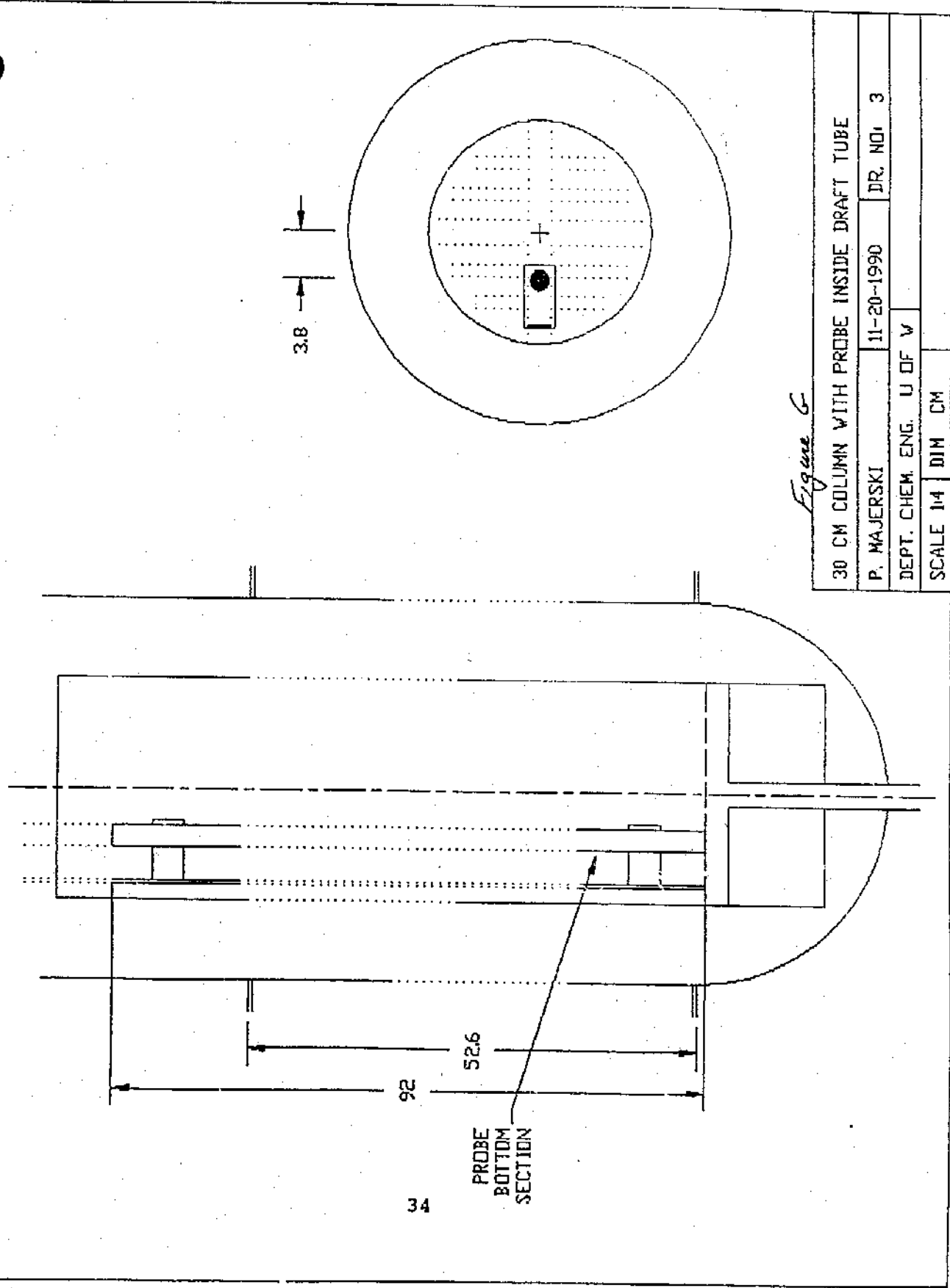
30 CM COLUMN WITH PROBE INSIDE DRAFT TUBE		
P. MAJERSKI	11-20-1990	DR. NO: 3
DEPT. CHEM. ENG. U OF W		
SCALE 1:4	DIM CM	
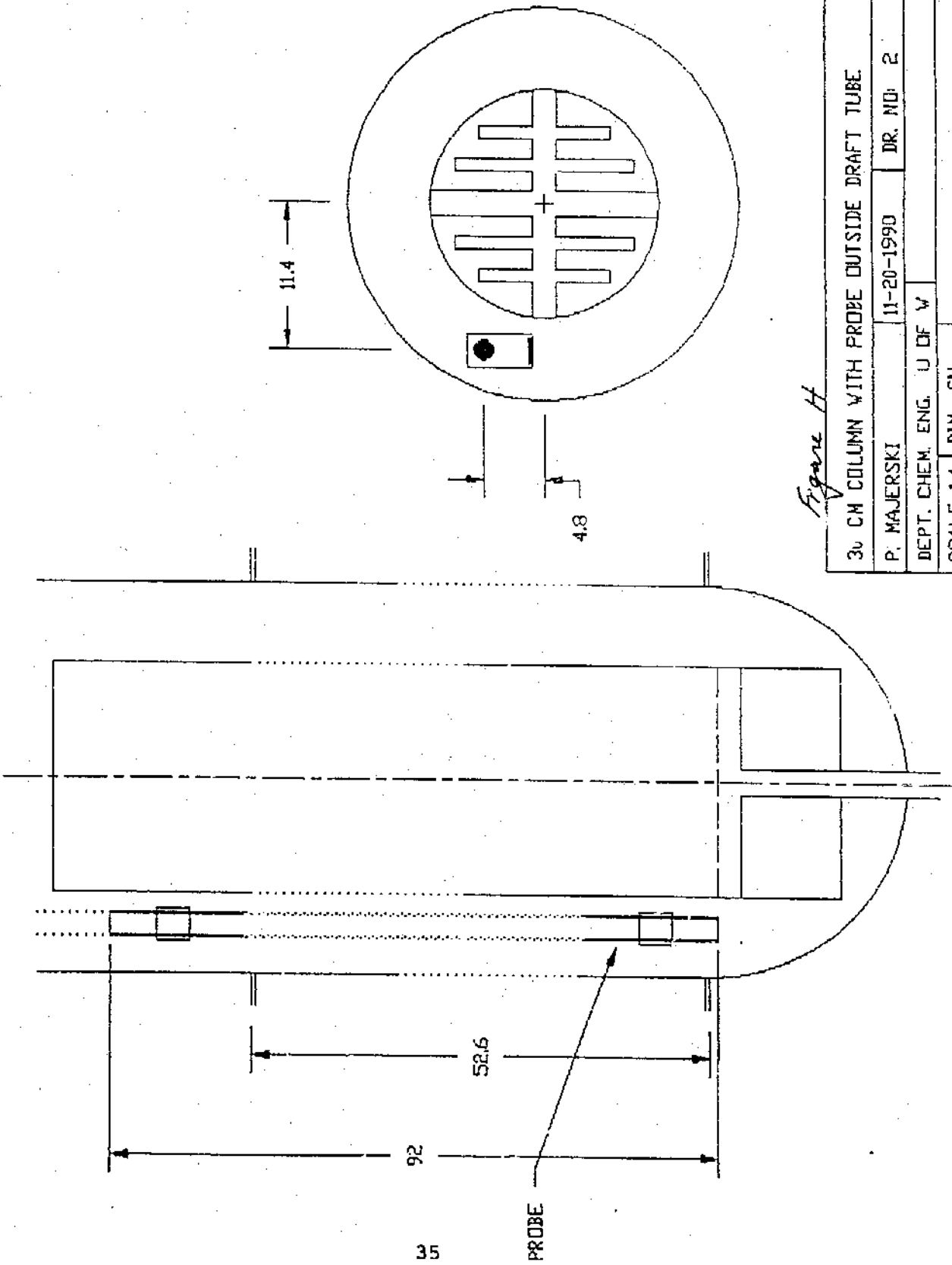
Figure H

3ᵤ CM COLUMN WITH PROBE OUTSIDE DRAFT TUBE

P. MAJERSKI	11-20-1990	DR. NO: 2
DEPT. CHEM. ENG. U OF W		
SCALE 1:4	DIM CN.	

11.4

4.8

52.6

92

PROBE

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as a function of time after the gas was shut off. The probe recording then showed the change in readings as solids settled out and a final quiescent liquid was obtained. This probe recording is shown as Figure J. Run 9 and Run 22 were done at the same conditions except for the presence of the draft tube in Run 22.

For Run 9 at probe section 5, read out was 14.8 ma. Span for section 5 was 15.60 ma (full) – 5.45 ma (air) = 10.15 ma. Since the dielectric $r_s - r_a = 2.0 - 1.0 = 1.0$, then the calibration factor is $10.15/1.0 = 10.15 = A$.

From the Appendix, probe read-out correction is $R^1 - R = 0.0456\ A = 0.467$ ma. Then the corrected read-out is 14.8 (measured read-out) – 0.47 = 14.33 ma.

The corrected value of ϵ_G given by

$$\epsilon_G = \frac{\text{Full ma} - \text{Read out ma (corrected)}}{\text{Span ma}} = \frac{15.60 - 14.33}{10.15} = 0.125$$

Apparent uncorrected value of ϵ_G

$$= \frac{15.60 - 14.8}{10.15} = 0.079$$

Using the recorder chart change in read-out for Run 22 from fully suspended solids to quiescent liquid –

Liquid only read-out   = 9.24
Liquid + solid read-out = 9.52

Read-out 928 Liquid Only

Solids settling past Probe Section #5

932 Liquid-Solid Only

Gas out

905 Read-out 3-Phase

CHART SPEED 12"/min

GAS OFF

PROBE SECTION #5 — 5 SCFM AIR WITH 12.5 Kg GLASS BEADS — CHART SPEED 1"/min — RUN 22

FIGURE J

PROBE RECORDING FOR SOLIDS SETTLING TEST

37.

CHART NO.5276-1016

Scale factor between Runs 9 and 22 = $\dfrac{\text{Full read-out for Run 9}}{\text{Full read-out for Run 15}}$

$$= \frac{15.60}{9.24} = 1.688$$

Read-out difference for (liquid + solid)-(liquid only)
$$= 9.52 - 9.24 = 0.28$$

Scaled difference = 0.28 (1.688) = 0.473

and experimentally read-out should be corrected by 0.473 ma.

Predicted correction to read-out = 0.467 ma.

Therefore, the method of correcting read-outs for the presence of solids is verified experimentally.

In runs done with iron oxide, a manometric correction is also required. These corrections are given in the Table in the Appendix, and are considerably smaller than the manometric correction due to the presence of glass beads.

Results

Runs 10-16 show gas holdups as measured by the probe and manometrically for the probe in the draft tube or in the annulus with no solids present. Manometric values are averages over the column cross-section. Runs 10, 11 and 12 show excellent agreement between probe readings inside the draft tube and the overall void fraction. Runs 13, 14, 15 and 16 show results with the probe outside the draft tube in the annulus. Again, agreement of the two methods is very good, indicating a fairly homogeneous bubbly flow inside and outside the draft tube. Comparing Run 3 at 0.059 m/s and no

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draft tube to Run 14 (probe outside draft tube) and Run 11 (probe inside draft tube) at the same superficial gas velocity shows good agreement not only between the two measurement methods, but in absolute values of the holdup. In particular, Runs 11 and 14 show nearly identical gas holdups, so the varsol-air system in slightly foamy solvent appears to give a very homogeneous circulating bubbly system when a draft tube is used.

Runs 15 and 16 represent identical tests, but the probe was recalibrated for Run 16. Agreement is good in the two runs, although a slightly larger scatter results when the data for both runs are combined. A maximum total spread for all data (both methods, both runs) of only ± .02 is evident, that is, about ± 8% variation in the gas holdup value. This degree of agreement in gas holdup values in duplicate runs and different methods is considered to be very satisfactory. As far as is known, these data represent the only available direct measurement of gas holdup in different zones of a draft tube.

In Run 17, 12.5 kg of 170/230 glass beads were added. These beads contained residual adsorbed antifoaming agent. The effect of the antifoam addition can be seen by comparing Runs 16 and 17, Run 17 having significantly lower gas holdups. All of the tests with solids in the draft tube configuration were done with the probe in the annulus. All

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data in Runs 17-26 are shown uncorrected, since the correction factor is nearly the same for both methods. Corrected gas holdup values are shown also only for Run 25, since for iron oxide the manometric and probe corrections are significantly different, and this effect is demonstrated in Figure 25.

In Runs 17 to 22, the probe readings are generally below the manometric values; in most cases by somewhat more than the difference in correction factors. As pointed out earlier, it was not possible to re-calibrate the probe elements when solids were present, and so much of the discrepancy may be due to a base line drift. Run 23 was done with no solids and at the same conditions as Run 15 and 16. However, the batch of Varsol used was not identical in Run 23, so some differences in gas holdup are evident. Although probe readings in Run 23 appear to be low at the top of the column, agreement with manometric values is good elsewhere.

Tests with iron oxide show reasonable agreement of the two methods in Run 24 (Figure 24) at high gas rates, with uncorrected probe readings being low. In Figure 25, the data is shown corrected at a gas rate of 0.059 m/s. Agreement of the two methods of measurement is very good when corrected. Run 26 shows a low gas rate, and again good agreement of the corrected data would be expected.

Summary

The void fraction probe has been shown to give values of gas holdup of satisfactory accuracy in Varsol-air mixtures, with and without added solids. It is possible to apply a calculated correction factor for the presence of solids to each probe element to obtain a corrected gas holdup profile if axial solids concentrations are known or can be predicted. The correction factor for solids can also be determined experimentally for each probe element, if desired. Use of two solids of greatly different dielectric showed that correction factors for the probe as developed in this work are reasonable.

In large scale equipment, this void fraction meter would give direct and reliable values of gas holdup at different axial positions in a column.

Results showed also that in a hydrocarbon system with some foaming tendencies, the use of a draft tube generates a surprisingly homogeneous bubbly fluid circulation around the draft tube.