PROGRESS REPORT

Development of Void Fraction Meter for Measuring of Gas Holdup at High Temperature and Pressure.

FILE: 06SQ 23440.9.9155
Canmet Coordinator: T.J.W. de Bruijn

February 28, 1991

INTRODUCTION

The development of the Void Fraction Capacitance Probe is now in Task No. 5, of Part No. 1. This report includes results from Task No. 3 and Task No. 4 which were performed at the University of Waterloo on a subcontract basis. Initial investigation into Task No. 5 has occurred at Arjay Engineering Ltd.

SUMMARY

The Void Fraction Probe designed and fabricated by Arjay Engineering in Task No. 2 was installed in the bubble column at the University of Waterloo. The 5 section probe allowed manual switching selection of the probe section to be monitored. Analog circuitry provided by Arjay translated the capacitance of the probe into a usable 4-20mA signal.

The tests conducted by The University of Waterloo, showed the capacitance probe designed by Arjay to be a viable and accurate method of monitoring gas holdup in the bubble column at the University. The results of these tests make up this report.

TASK NO. 5

Design and construction of a multi-section probe for application at high pressure and high temperatures.

After careful review of the report by the University of Waterloo and discussions with them, it was concluded that the project should continue into Task No. 5 because of the successful results of Tasks 1 through 4.

Informal meetings amongst Arjay personnel provided a number of scenarios with which to base further investigations. The final probe had many restrictions to efficient design and construction. Mainly; high temperature, high pressure, small in size.

It was decided that the physical manufacture of the probe would receive secondary priority, for if a non-conductive sheath was not available under the 3 main restrictions, the project parameters would require reworking.

Initially, the materials to be considered are:

1. Ceramics
2. Plastics
3. Coatings
4. Asbestos

Material: Initial Comments

1. Ceramics: With Temperature and pressure ratings within our specification requirements, ceramics shows possibility, however, the brittle nature of the material restrict machining and process connection joints. Initial tests using protection tubes with compression fittings failed by cracking the tubes.

   Ceramics will continue to be considered with alternative gland experiments.

2. Plastics: The material provides excellent machining and pressure capabilities as well as electrical insulation characteristics, but is limited by minimal operating temperature range.

   Plastics will not be considered with priority.

Continued...Page 2.

3. Coatings: A wide variety of coatings are available and attention will be devoted to this method of electrical insulation. Directive to firms affiliated with aerospace developments, transformer stations and high temperature manufacturing (ie. steel, brick, glass) will provide further reference material.

4. Asbestos: This material may prove useful as gasketing material in conjunction with a probe designed using another insulator.

We have concluded that a design incorporating a compression seal would be the best approach to consider initially. Materials exhibiting high temperature and high pressure characteristics tend not to allow reliable threading techniques for process connections

The investigation and design of the probe will occur over the next 3 months.

References used for Initial Investigation of Task 5.
(By Arjay Engineering)

1. SGL Auburn Spark Plug Co.
-manufactures of high temperature probes and plugs

2. Marks Handbook for Mechanical Engineers
-reference book for material specifications of thermoplastics, marble, limestone

3. Perry's Chemical Engineers Handbook, 6th Edition
-reference book for material specifications of ceramics, graphites, silicon carbide

4. Hydro-Pac Inc
manufacturers of high pressure glands

5. Roba Associates Ltd
- manufactures and suppliers of protection tubes

6. John Scientific Ltd, Industrial Division
-suppliers of ceramics protection tubes

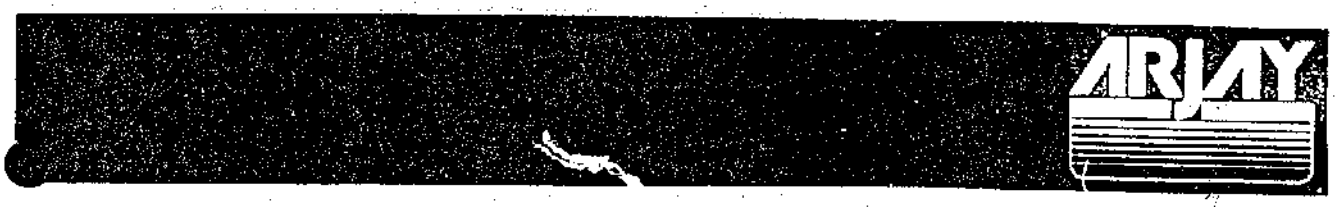
7. Thermic Engineering, Inc
manufactures of ceramics and ceramic banding materials

Continued...Page 3.

8. Thermo Electric Ltd
-manufactures of ceramic protection tubes

Complete investigative details will be concluded through further discussions and testing with the above referenced companies and additional firms sourced.

These details will form part of the final report to be supplied at the conclusion of Task 5.



Report from the
University of Waterloo

Tasks 3 and 4: Probe Tests

FINAL REPORT

DEVELOPMENT OF A VOID FRACTION METER FOR MEASUREMENT OF GAS HOLDUP AT HIGH TEMPERATURES AND PRESSURES

Contract Serial No. 06 SQ-23440-9-9155

Principal Investigator - Arjay Engineering

Testing of a Prototype Void Fraction Meter

University of Waterloo
Department of Chemical Engineering
D.S. Scott - Principal Investigator

August 27th, 1991

Testing of a Prototype Void Fraction Meter

by Piotr Majerski, R.D. MacIntyre and Donald Scott

Introduction

A meter, based on capacitance principles, was designed to give a series of readings proportional to gas holdup at regular axial positions in a bubble column. The initial concept and the first experimental model were developed by researchers in the University of Waterloo, Department of Chemical Engineering, under the supervision of Dr. Donald S. Scott in early 1989. The initial tests showed that the concept was valid, and that response was linear in void fraction (see Appendix 1). The meter gave an average value over a 50 cm length of column, and several such sensors could be connected together to give a complete axial gas holdup profile. Readings are not affected by colour, viscosity or surface tension of the liquid. Initial results were obtained in both oil and aqueous systems, although better performance was obtained in an oil system.

As a result of the success of these early tests, a contract was awarded to Arjay Engineering to design and construct a prototype meter for a bubble column. Testing of the meter was to be done at the University of Waterloo by Dr. Scott's research group.

Funds for this work were initially allocated to Arjay Engineering Ltd. on December 15th, 1991. The first prototype meter was built to our general specifications by Arjay Engineering Ltd. to allow installation in our 0.30 m diameter glass column. This meter was received on May 1st, 1990. Because of the difficulty in installing the meter, which required partial disassembly of the glass column, all other test work required to be done in this column was completed before the void fraction meter was installed and tested. Consequently, meter testing began in September, 1990, and was completed late in 1990. One progress report has been previously submitted in November, 1990, and an oral presentation of all results was made on November 27th, 1990, to CANMET and to Arjay Engineering Ltd.

The work statement for this contract as specified by CANMET set five tasks in the part of the work to be done by the University of Waterloo (memo of May 2nd, 1989 from T.J.W. de Bruijn). These Tasks are listed below as received by University of Waterloo.

Part 1 : University of Waterloo

Task 1

Design and construct a multi-sensor probe for use in the 15 and 60 cm diameter columns at the University of Waterloo --- 2 months

Task 2

Install and test the probe in the two bubble columns, using the Varsol/air system, at several gas rates and two liquid rates --- 1 month

Task 3

Redesign the probe based on the results from Tasks 1 and 2 and construct a new more unitized version --- 1 month

Task 4

Test new probe design in Varsol/air. Development of correlations to describe operating characteristics --- 1 month

Task 5

Tests with solids present. Glass beads and (if possible) an iron containing solid will be tested --- 1 month.

A budget was prepared and submitted for this part of the work. In the following months, it was decided to award the contract for the entire project to Arjay Engineering (originally a co-investigator with the University of Waterloo). The work at the University of Waterloo then became a sub-contract from Arjay Engineering Ltd. The final budget for the work at the University was only 60% of our estimate, and was totally inadequate for the above work. As a result, tests were carried out in only one bubble column,

and only one probe design was tested. Nevertheless, this design was given fairly complete testing for most of the operating conditions of interest, except that liquid flow was not used since it is known to have little effect on void fractions at the liquid rates of interest. Considerable testing was done to investigate gas holdup when use was made of a draft tube also, which was not required in the original work statement but was requested later.

In summary, the void fraction meter originally developed in our laboratory has performed well in hydrocarbon oil-air systems, without and with solids present, and is capable of giving accurate and reproducible averaged values of gas holdup over incremental sections of a bubble column.

Experimental

Installation and initial testing of the meter was carried out by Piotr Majerski. Details of meter construction and of the capacitance circuitry should be available from Arjay Engineering.

A sketch of the University of Waterloo glass bubble column is shown in Figure A. It is constructed of Pyrex glass sections, with an inside diameter of 0.30 m. Each glass section is 0.50 m long, and the sections are separated by teflon rings each 0.026 m thick. Thus, each section of the column is 0.526 m. The bottom section is a metal piece containing inlets for gas and liquid flows.

The column normally has ten sections. However, to gain enough headroom to insert the probe it was necessary to remove the top section and exit overflow fitting. Operation of the column was batch style, that is, continuous gas flow but no liquid flow. In order to allow some free board, the amount of liquid was limited so that the aerated mixture only filled the first eight sections.

The sparger used was of the type shown in Figure B. Initially, some holes were blocked, but after the first test all holes were open. The sparger was located at the first (bottom) teflon ring. The probe was located centrally along the vertical axis, with the bottom end of the probe at the sparger level. The aerated liquid depth over the probe was

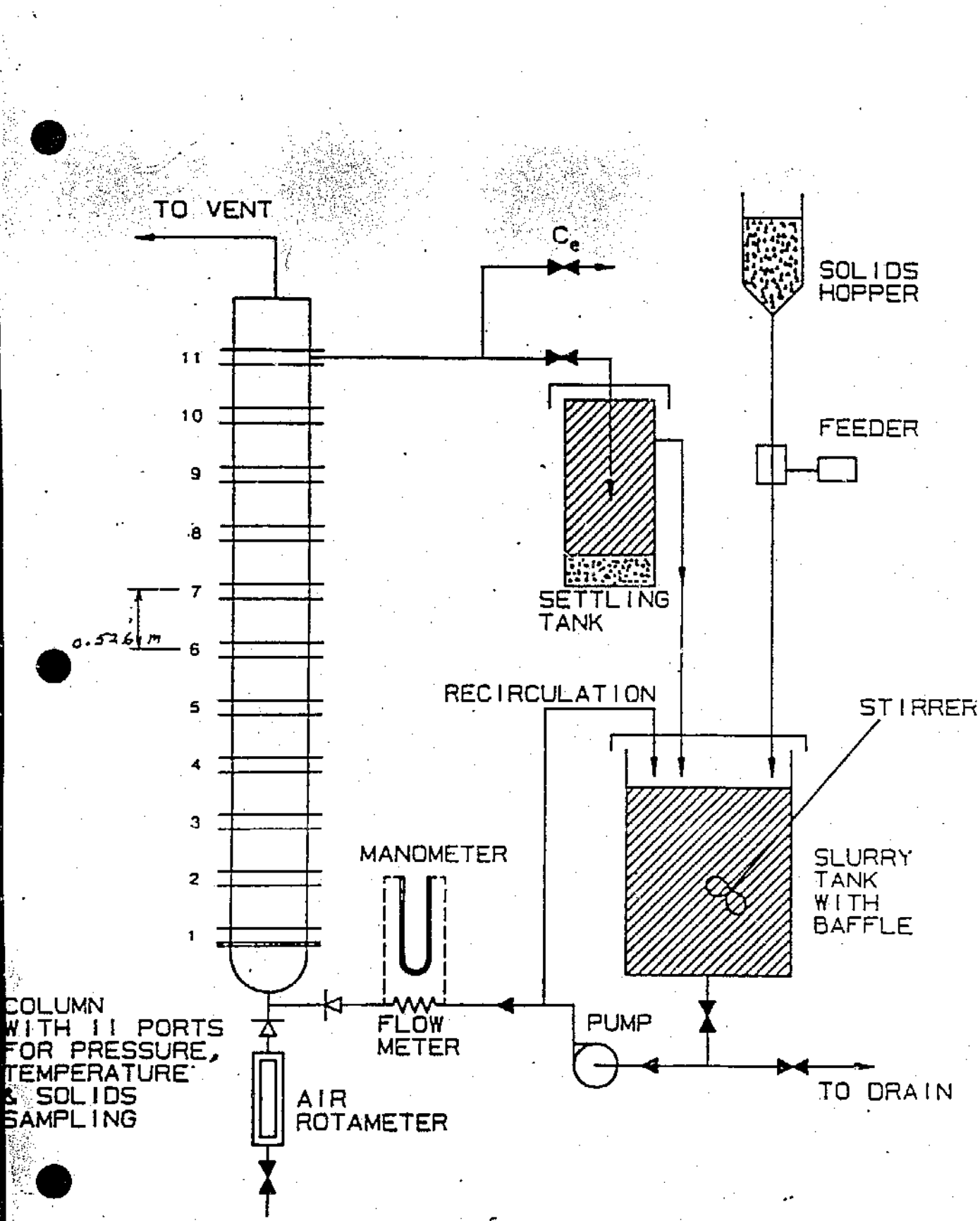
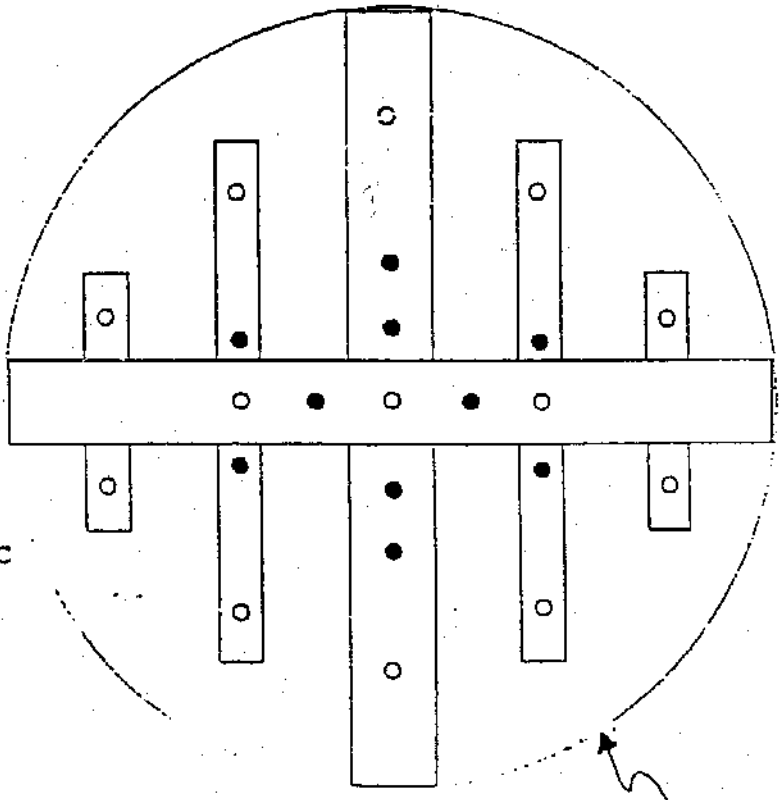


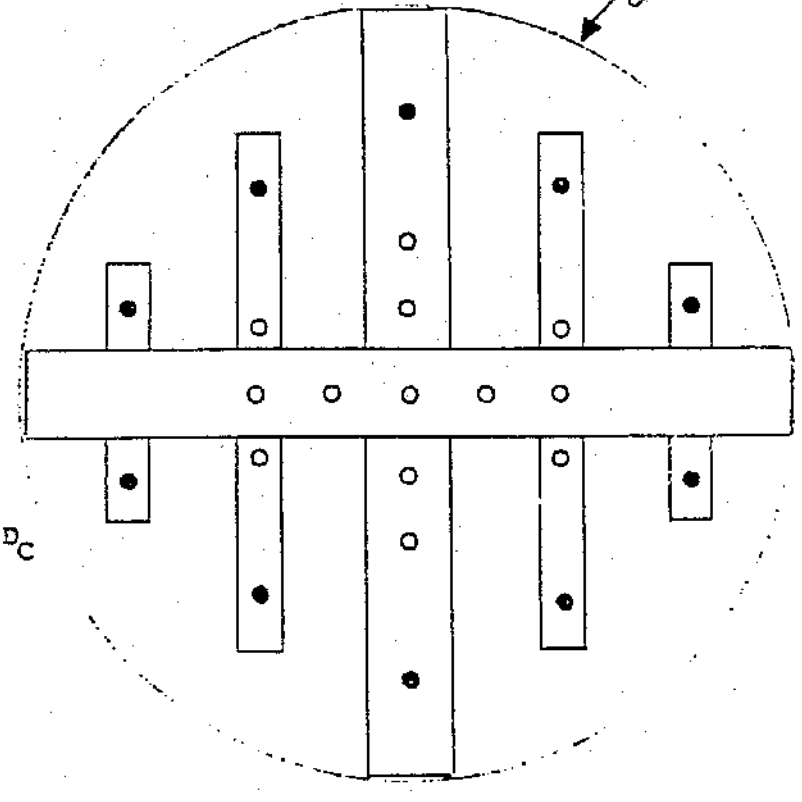
Fig. A - Schematic of experimental apparatus



Configuration
for $D_S = 0.5 D_C$

○ - Orifice open
● - Orifice plugged

0.6 D_C Draught Tube



Configuration
for $D_S = 0.25 D_C$

Figure 8 Details of Sparger used in Conjunction with Draught Tube in 0.30 m Diameter Column

8 x 0.526 = 4.208 m maximum, covering axial positions 1 to 9 because the top section was used for disengaging. Manometric readings were taken for each section to give a differential pressure profile along the column. Although the gas holdup in the first section above the sparger (position 1 to 2) was very heterogeneous and gave irregular values, pressure readings were taken over the seven sections (3.68 m), positions 1 to 8 (numbered 7 to 0 on data sheets). Each differential section of the probe, however, was one meter long, so that only four of the probe sensors could be immersed in the aerated liquid. As a result of these necessary modifications, seven axial holdup values could be obtained manometrically, but only four from the probe. Further, the last (bottom) probe section was exposed to the very heterogeneous region above the sparger, and may also have been influenced by the proximity of the metal sparger. All tests from Test No. 10 onward were done with a draft tube 1.46 m long in place as shown in Figure C (draft tube was made from PVC). Figure D shows the locations of the probe sections which gave holdup readings (Nos. 2 to 5) and the points at which manometer readings were taken (Nos. 0 to 7).

As discussed earlier, the limited flexibility of the probe built by Arjay Engineering, together with the limited headroom available above our 30 cm diameter glass column meant that two top sections of the column had to be removed

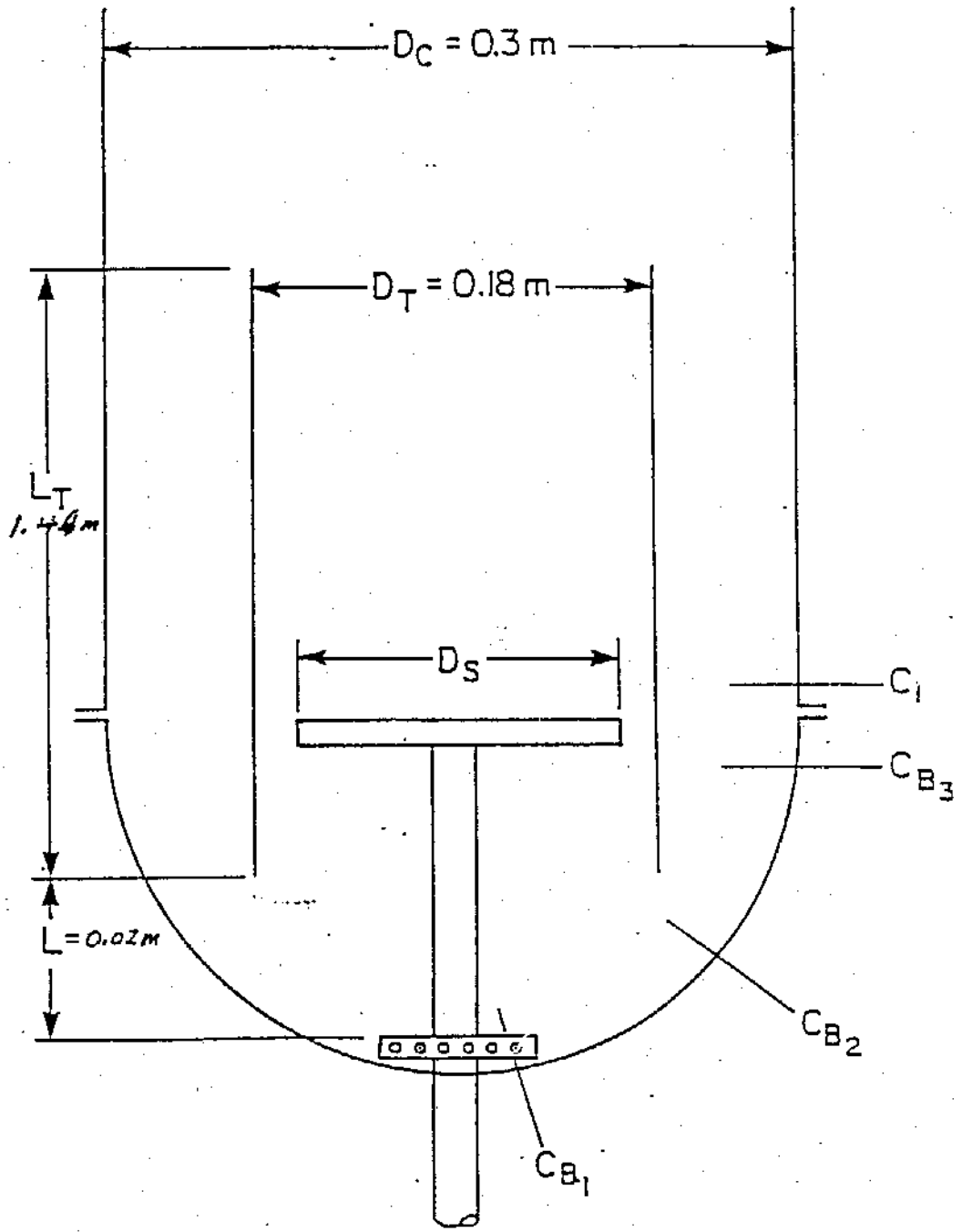
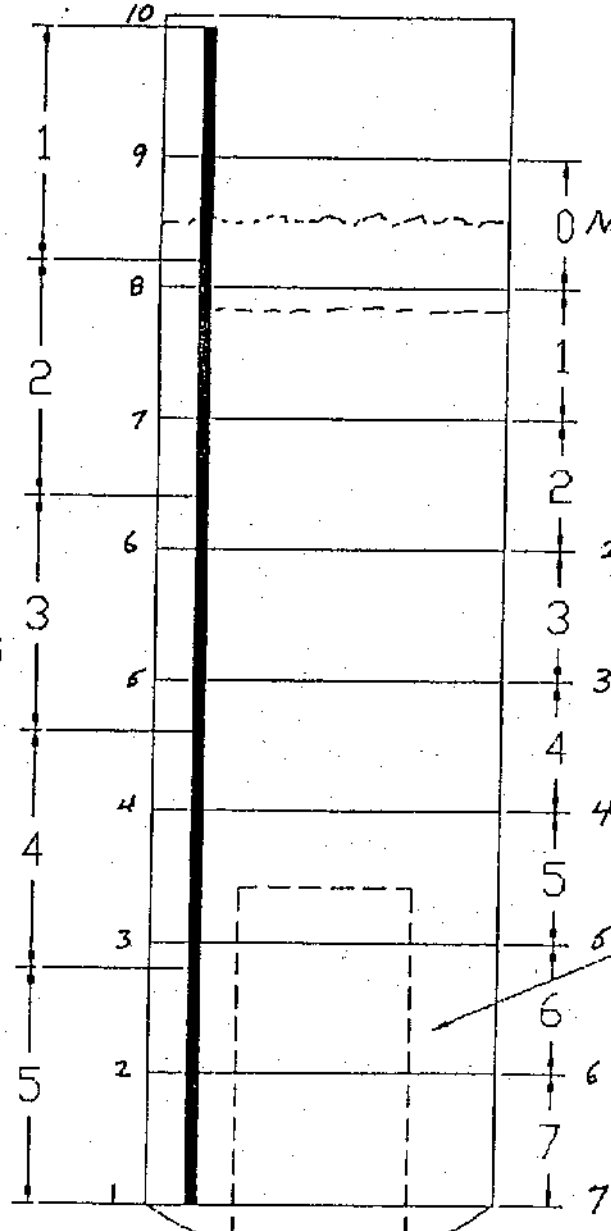


Figure C. Detail of Draught Tube Sparger. Lengths 1.46 m, = L_T in 0.30 m Diameter Column. Clearance L = 0.02 m (normally)



30 CM COLUMN	FIGURE 0	
P. MAJERSKI	11-21-1990	DR. NO 4
DEPT. CHEM. ENG.		

so that only four probe sections could be immersed. The bottom one metre section might be expected to give less accurate or consistent readings because of the heterogeneous nature of the gas-liquid dispersion near the sparger, and because of the greater proximity of many metal surfaces near the column bottom.

In all tests with the meter except Run 1, the span was adjusted before readings were taken by setting the reading in air at zero, and the reading in stagnant unaerated liquid at 100. Liquid used in all tests was Varsol DX 3641 which contained a small amount of a foaming agent (Dow Corning 200 Fluid), so that the solvent could be classed as moderately foamy. As is the usual case in our experiments in this type of system, the foam formed is unstable and quickly collapses if the gas flow is shut off.

Manometric readings were made at various column positions 1 to 8 (positions 0 to 7 in Figure D - see Figure A for column details), and the gas holdup in each section between the taps (about 50 cm) calculated. In this way, a holdup profile with seven values was determined for comparison with the four probe values, each taken over a one metre length of column.

All data are given in the attached graphs. Approximately, one SCFM represents superficial gas velocity of 0.665 cm/s at column mid-point conditions. Runs 1 to 5A

were done, therefore, at 3.3, 5.9, 6.5 and 12.0 cm/s superficial velocities.

Tests 1 to 5A were done in a column containing Varsol and air only. Tests 6 to 9 were done with 12.5 kgs of 170-230 mesh glass beads (density 2450 kg/m^3, mean particle size 71 microns). As the column volume was about 300 litres as used in these tests, this gave a solids content of 1.7 volume % or about 5.4% by weight at zero gas holdup.

Tests 10 to 16 were carried out with the draft tube in place, but with no solids added. Measurements were made both inside the draft tube and in the annulus. In tests 17 to 22 the measurements of tests 10 to 16 were repeated but with 12.5 kg of 170-230 mesh glass beads added. Test 23 was done at a high gas rate with the probe outside the draft tube with no solids added, at similar conditions to Tests 15 and 16, except for adjustment of the foaming properties of the Varsol used. Tests 24-26 were done at three different gas rates with iron oxide particles present and with the probe located outside the draft tube. The iron oxide used was a Knob Lake hematite concentrate (Schefferville, Que.)(density 4900-5300 kg/m^3) with a very fine particle size (32% +200 mesh, 68% -200 mesh).

Results

Two Phase System, Solvent-Air; No Draft Tube (Tests 1 to 5A)

Results of the first test (Run 1) are shown in Figure 1. The manometric values of holdup show a large scatter because of the low accuracy of the mercury manometer used. However, the two methods show general agreement for holdup values. In Run 2 (Figure 2), the manometer was filled with Meriam red oil (Sp.gr=1.75) and the improved accuracy of the manometric results is apparent. Also, the probe was re-zeroed and the span set as described previously. Figure 2 shows a very good agreement of gas holdup values by the two methods, with the only large difference near the bottom where non-uniform turbulence makes it difficult to get accurate differential pressure readings. The results in Figure 2 show that the assumed linear response of the probe to changes in gas holdup seems to be fully justified. In general, the capacitance probe gave values of gas holdup about 1.5 to 2.0 percentage points low (about 5% of the value).

Results shown in Figure 3 (Run 3) were done at a slightly lower gas rate (5.9 cm/s vs. 6.5 cm/s). The Petro-Canada type sparger used had some holes blocked for use at low gas rates. These were unblocked for Run 3 to give a more uniform gas dispersion near the column bottom. Agreement in gas holdup values by the two methods is very good with only about a one percentage point variance. However, unless the

Figure 1

GAS HOLDUP IN VARSOL RUN#1

AT 9.7 SCFM AIR (0.065 m/s)

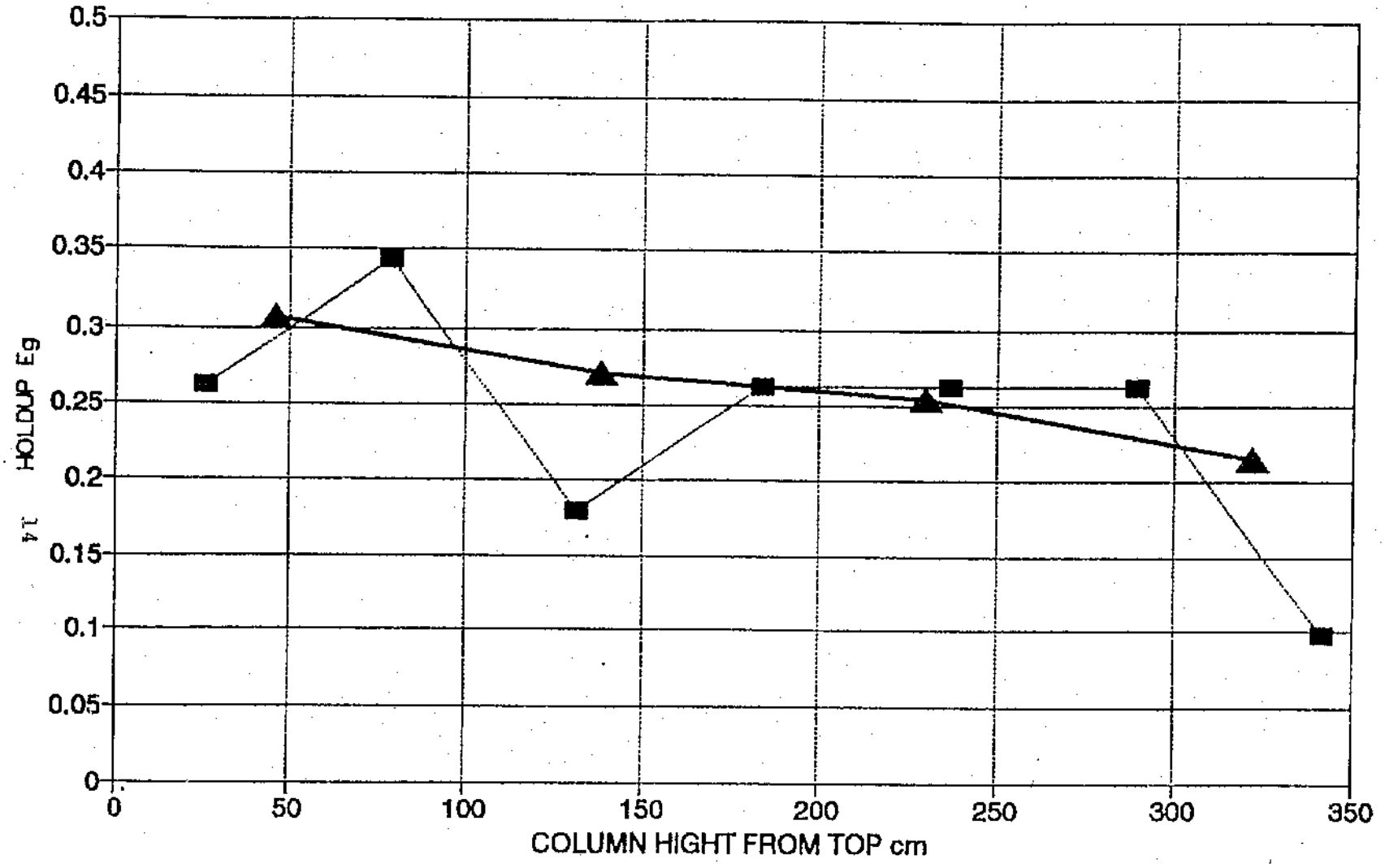


Figure 2.

GAS HOLDUP IN VARSOL RUN#2

AT 9.7 SCFM AIR (0.065 m/s)

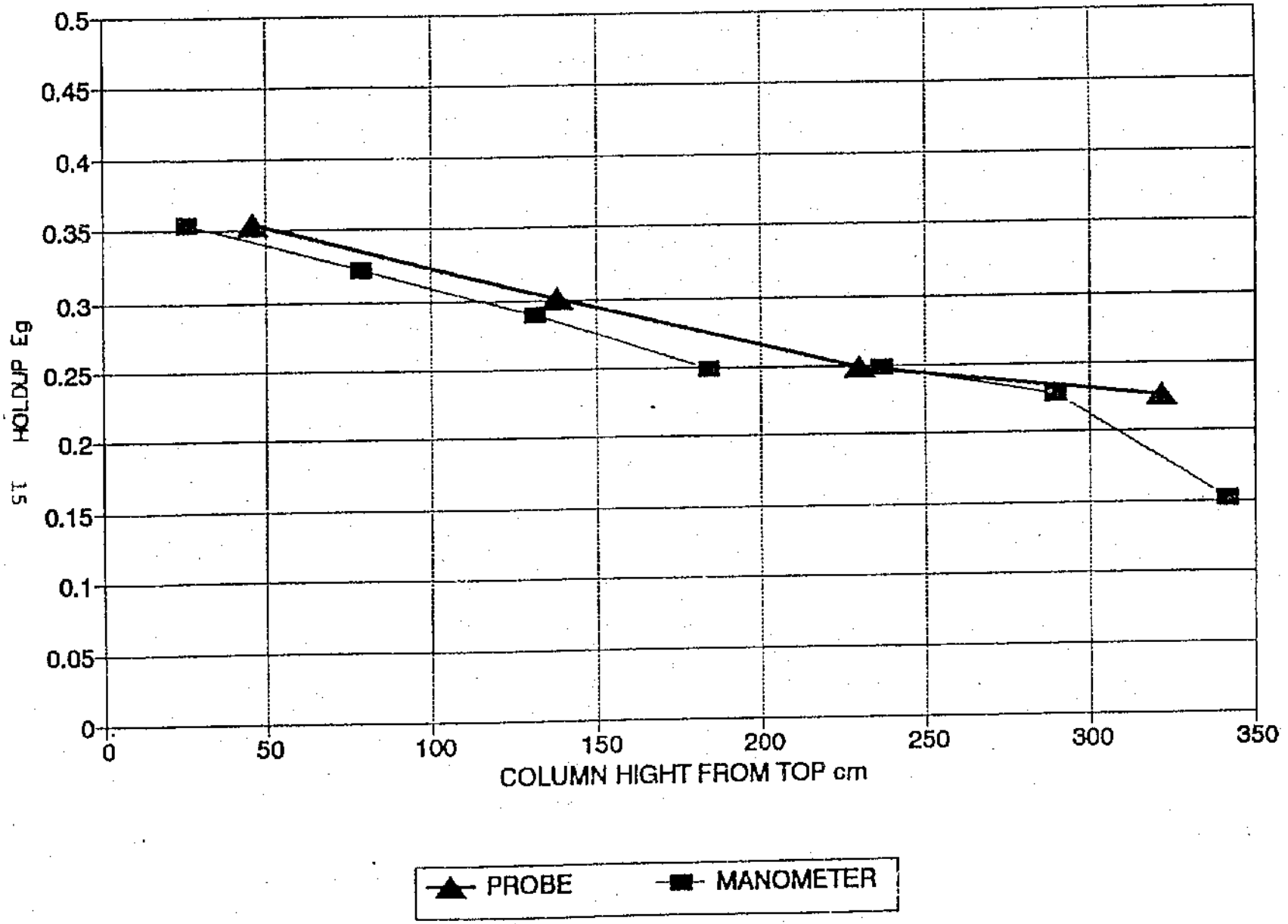
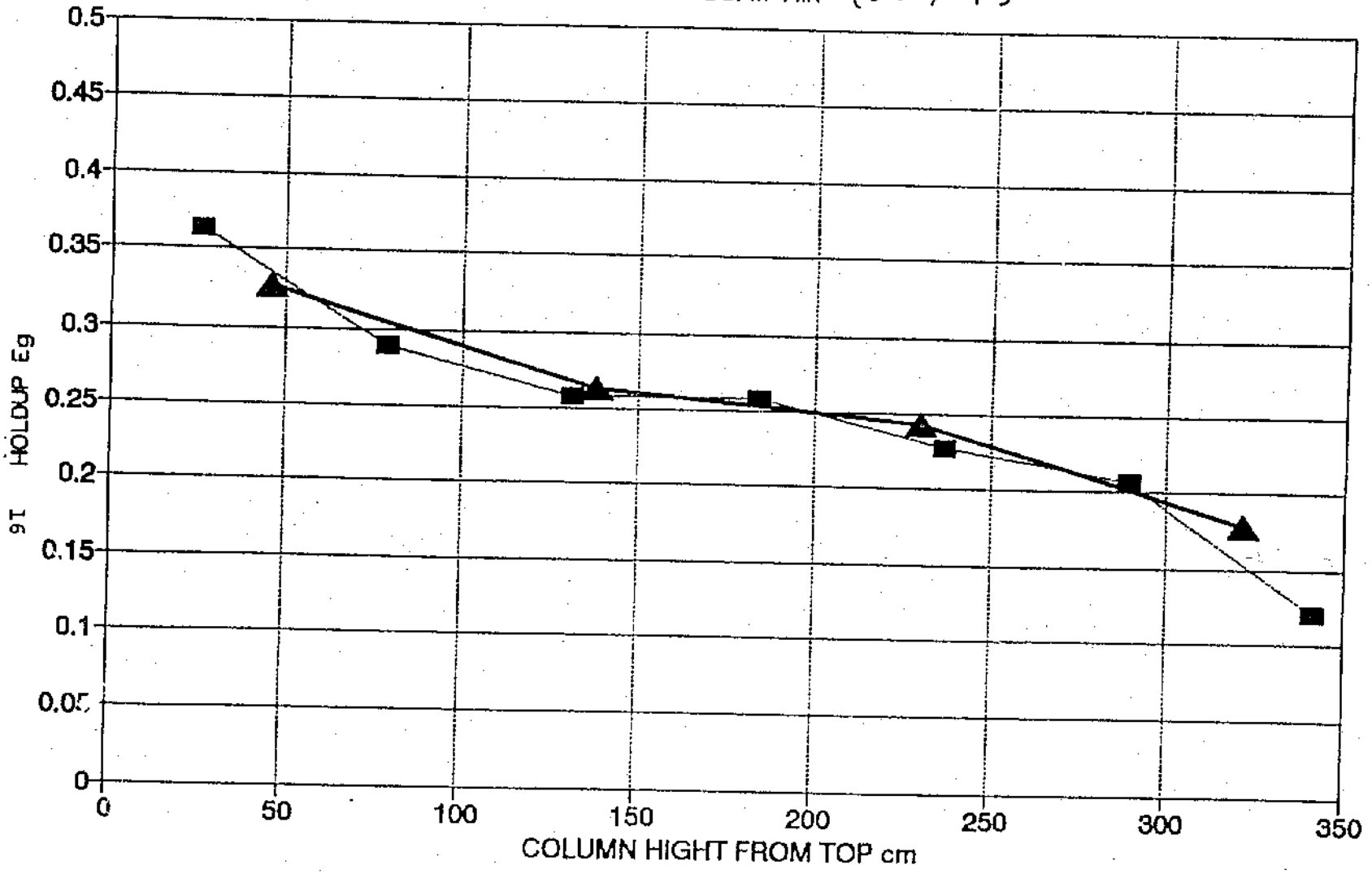


Figure 3

Run #1, 14/7

GAS HOLDUP IN VARSOL RUN#3

AT 8.8 SCFM AIR (0.059 m/s)



probe is zeroed and the span adjusted (that is, re-calibrated) before each run, agreement is not as good. A base line drift seems to occur in the readout device, inasmuch as the readings will differ by a constant amount at all levels. Figure 3 demonstrates the ability of the present design of the capacitance probe to give correct values for gas holdup at varying axial positions.

Run 4 was done at low air flow (3.3 cm/s), a value at which a foam interface often develops. In this test, as shown in Figure 4, a foam interface existed in the top section of the column, about 50 cm from the top. The individual probe sections are too coarse in this design to allow accurate location of the foam interface, but from Figure 4 it is apparent that it must be in the top one metre of the column. Figure 4a shows a repeat of Run 4 at the same conditions. Very similar results are obtained, with perhaps a little less foam formation. However, not only do the hold-up values for both runs from manometric and capacitance methods agree in the region below the foam layer, but the absolute values shown in Figure 4 and Figure 4a also are in very good agreement, showing the repeatability of the tests.

Figure 5 and Figure 5a show the results of tests at high gas rates (12 cm/s)(Runs 5 and 5a). In Run 5 the zero and span were not re-adjusted from the previous run. As Figure 5 shows, probe values were somewhat higher than manometric