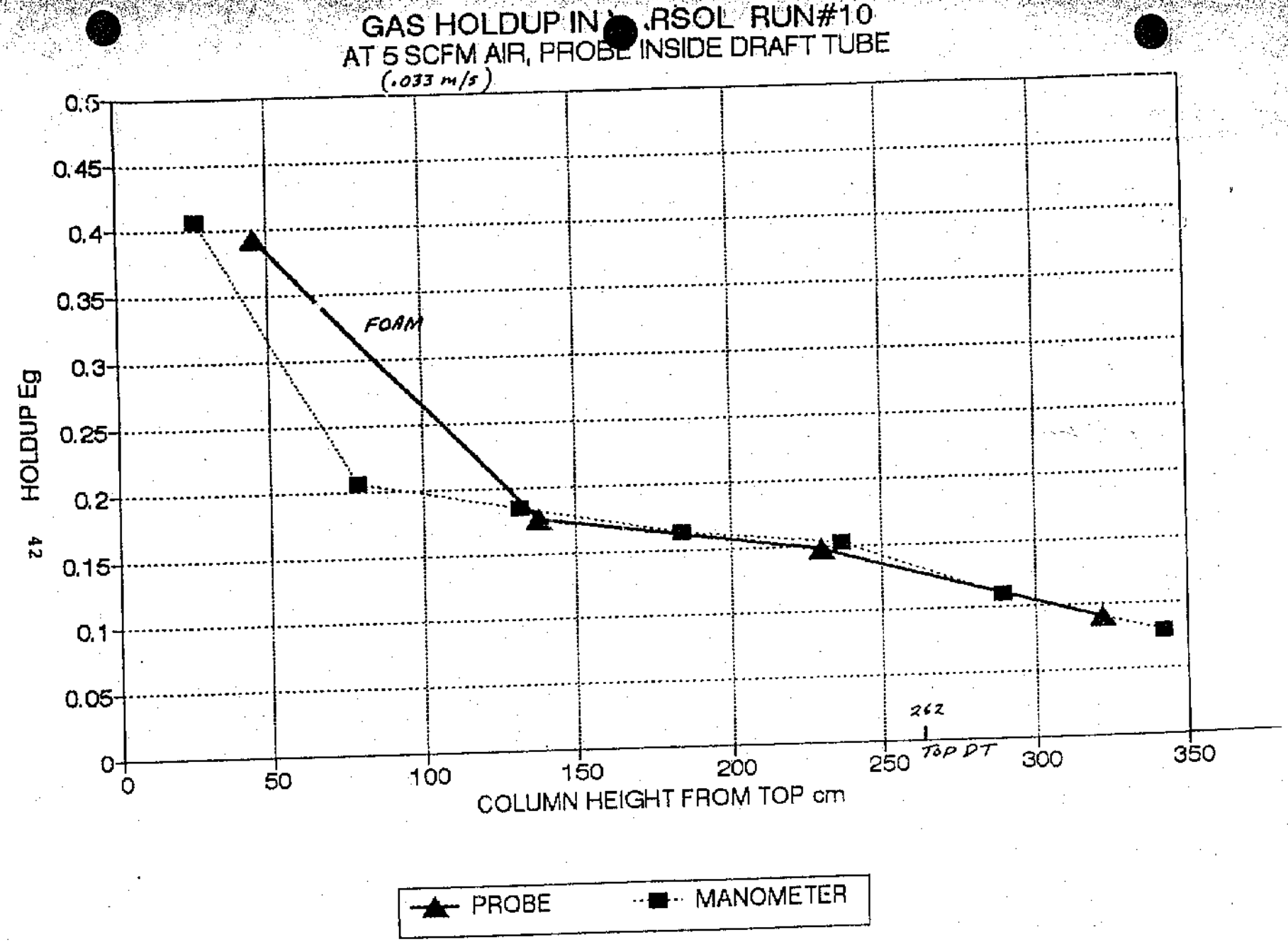
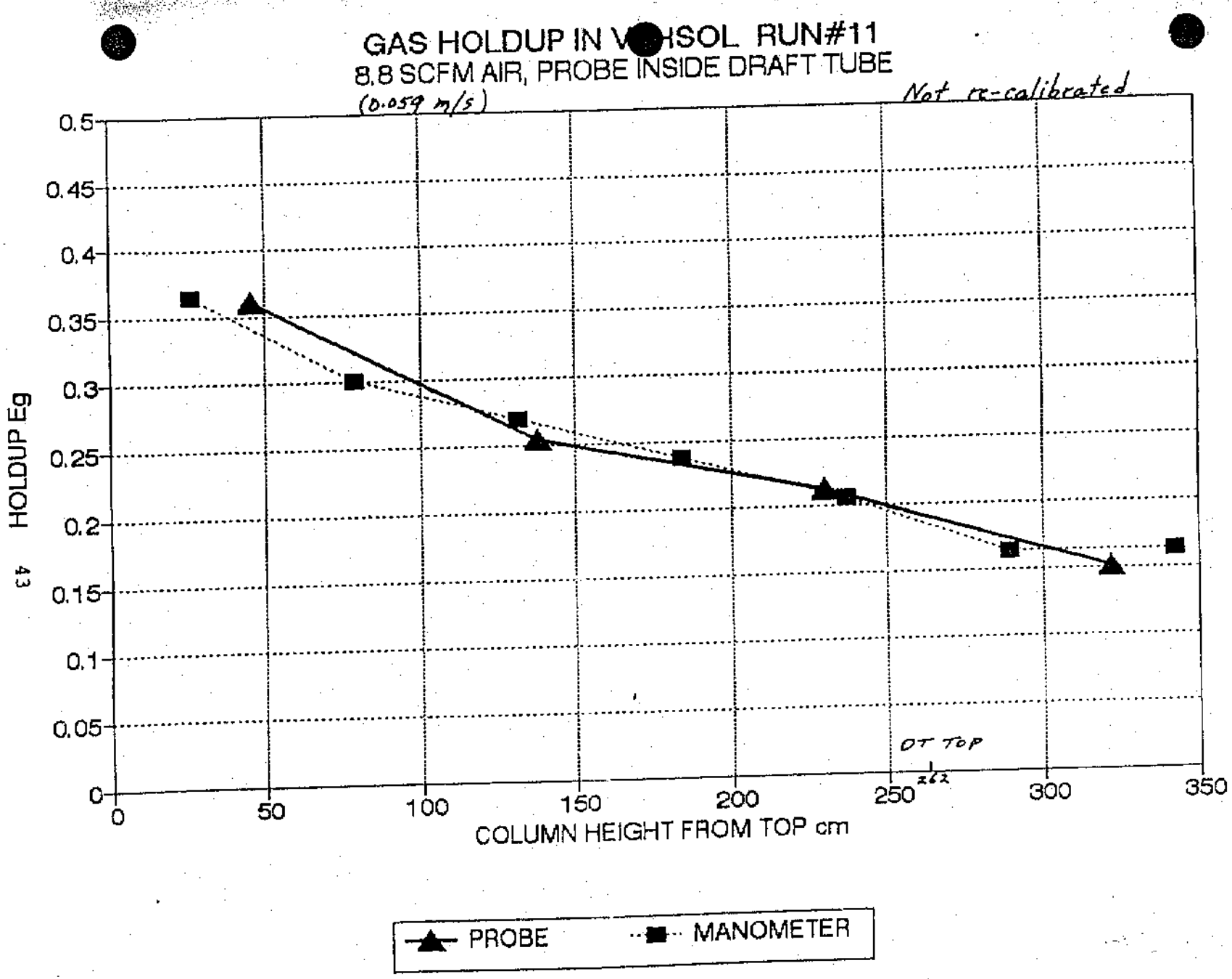
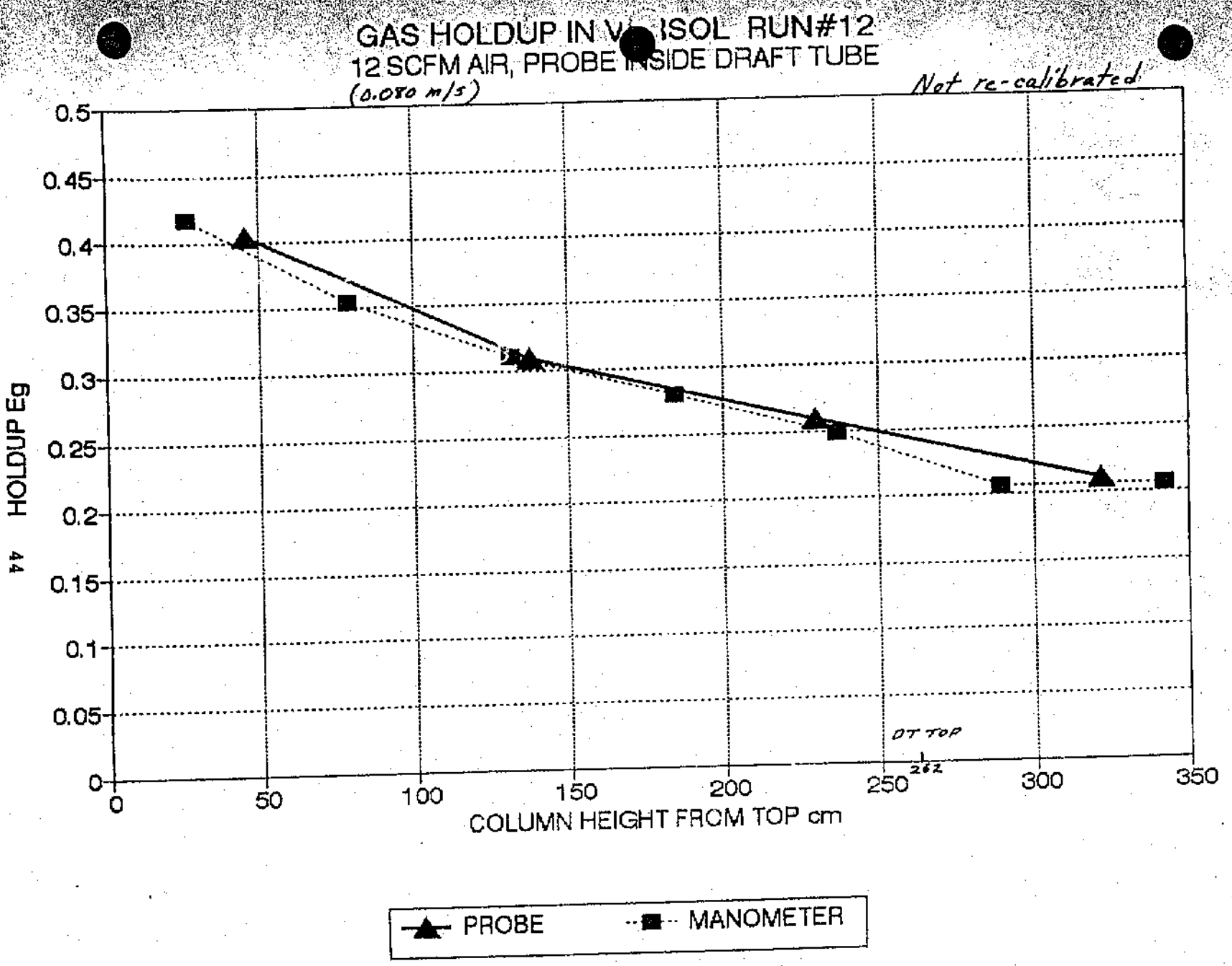
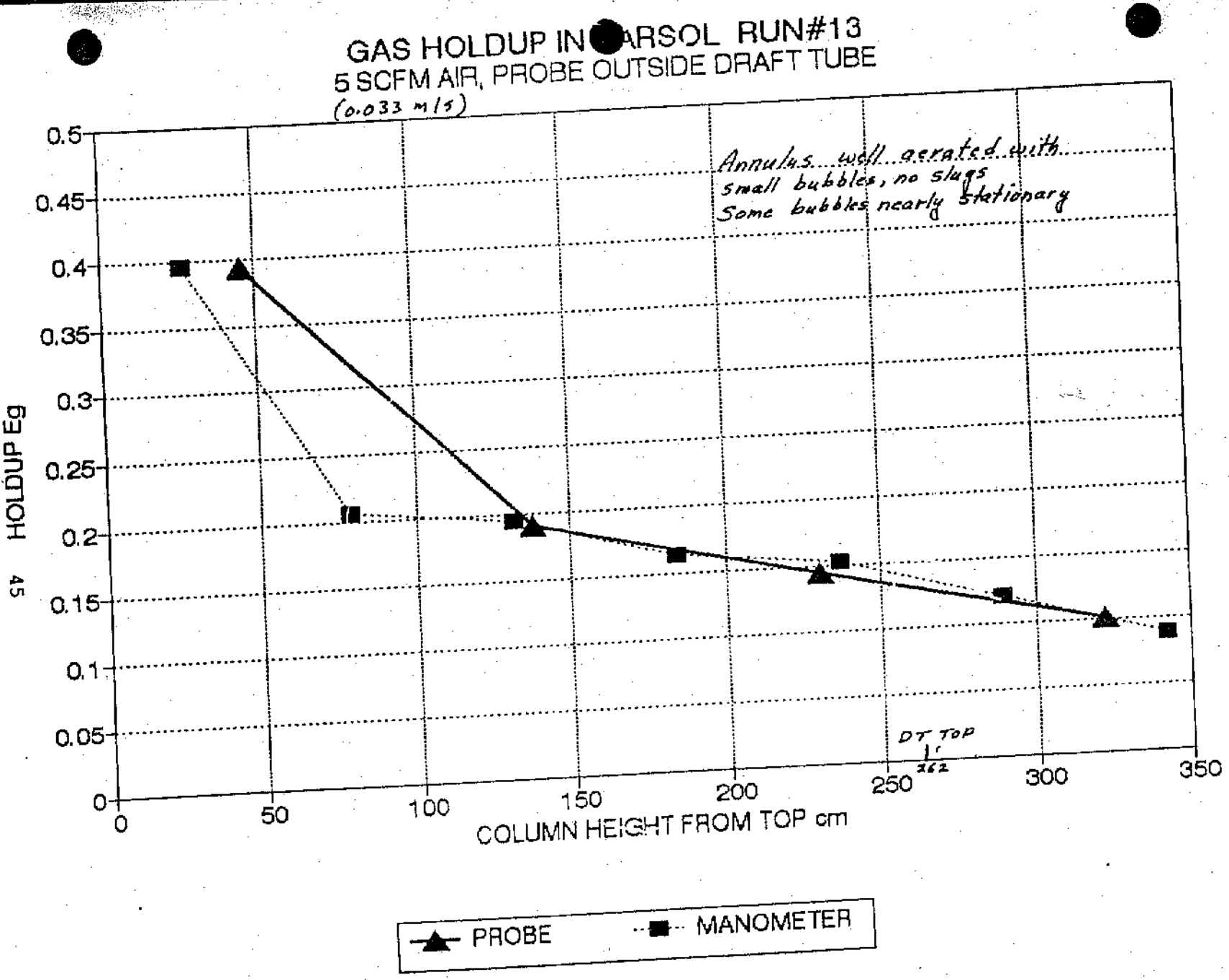
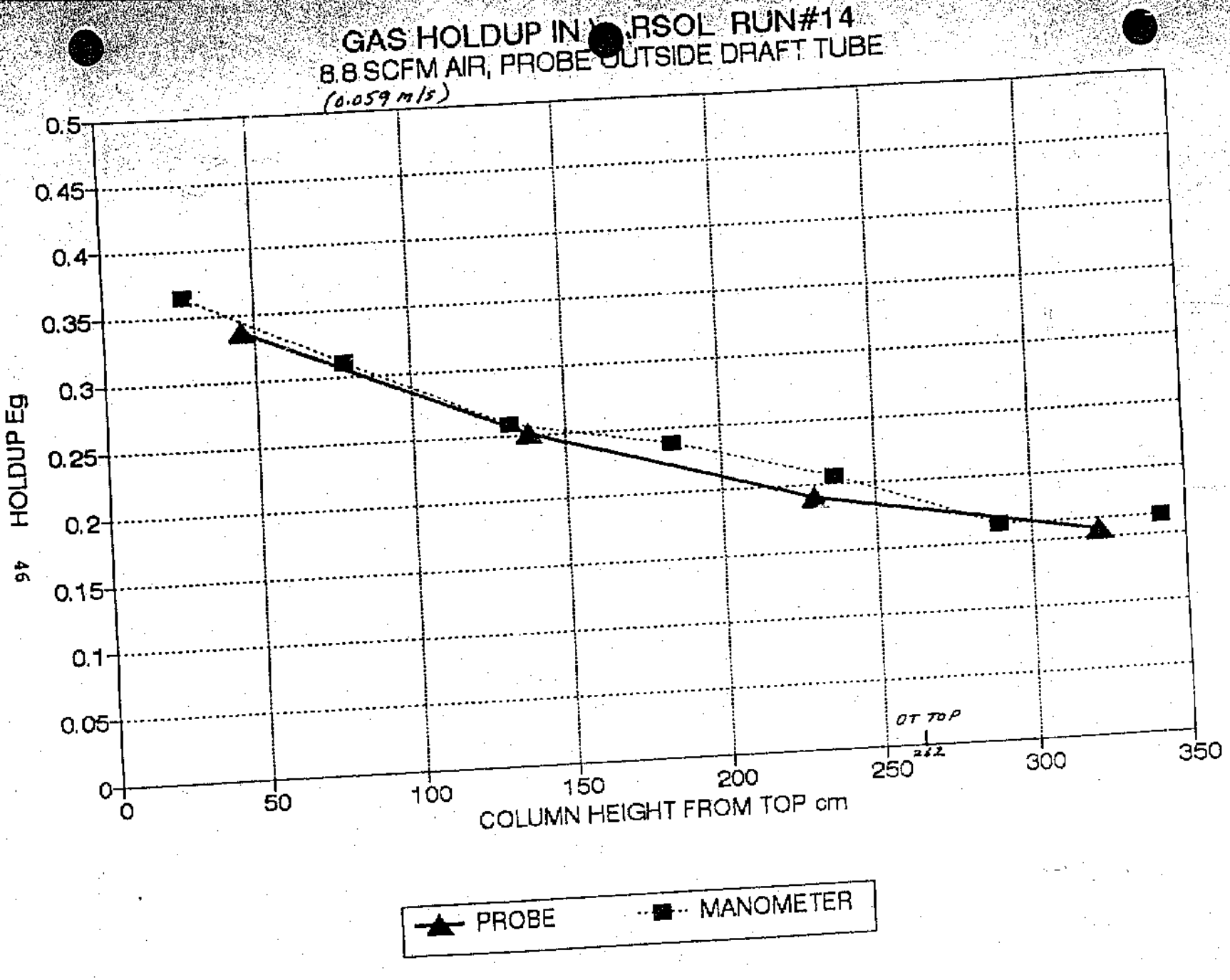
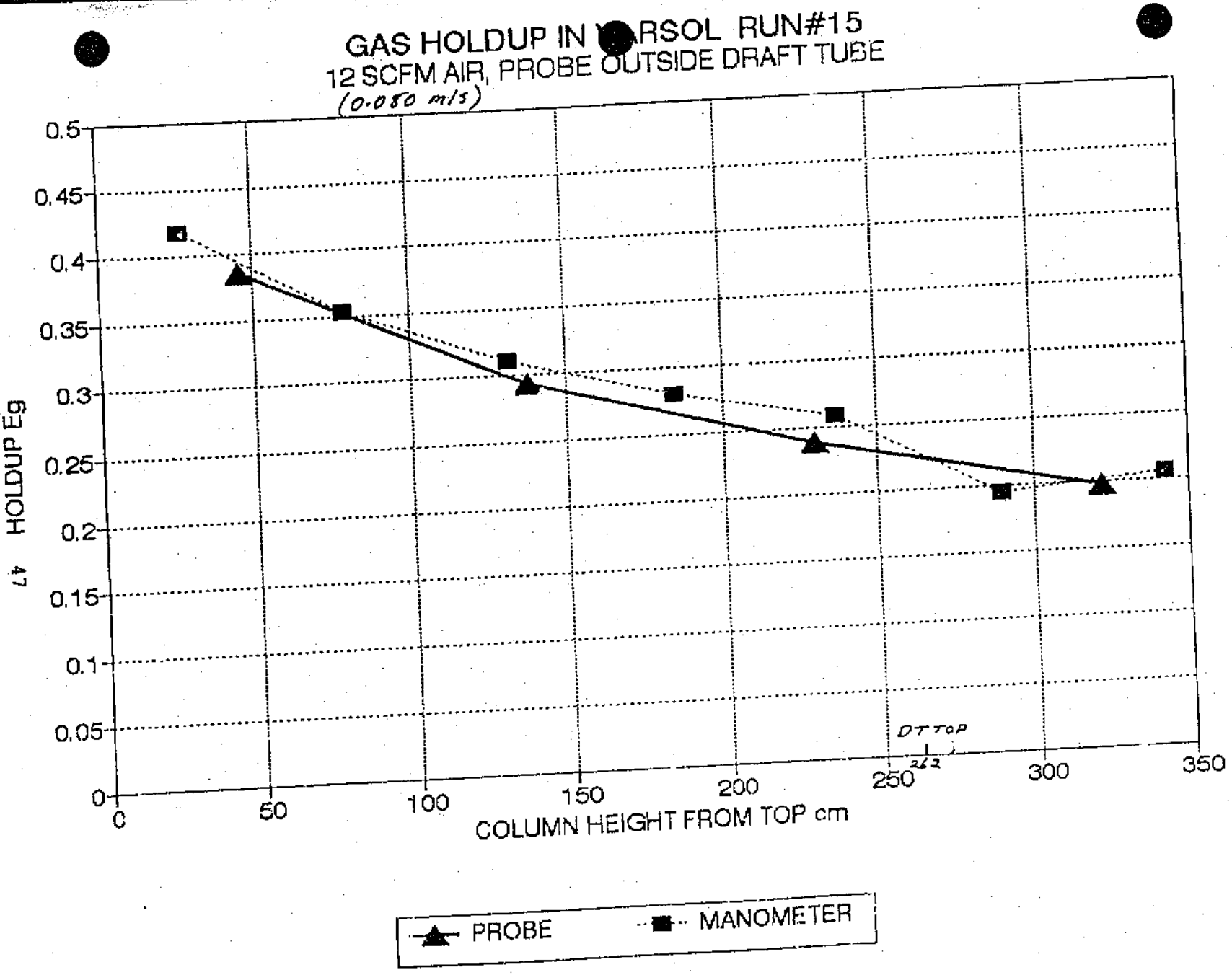

GAS HOLDUP IN ,RSOL RUN#10
AT 5 SCFM AIR, PROBE INSIDE DRAFT TUBE
(.033 m/s)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
HOLDUP Eg
FOAM
0
50
100
150
200
250
300
350
262
TOP DT
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

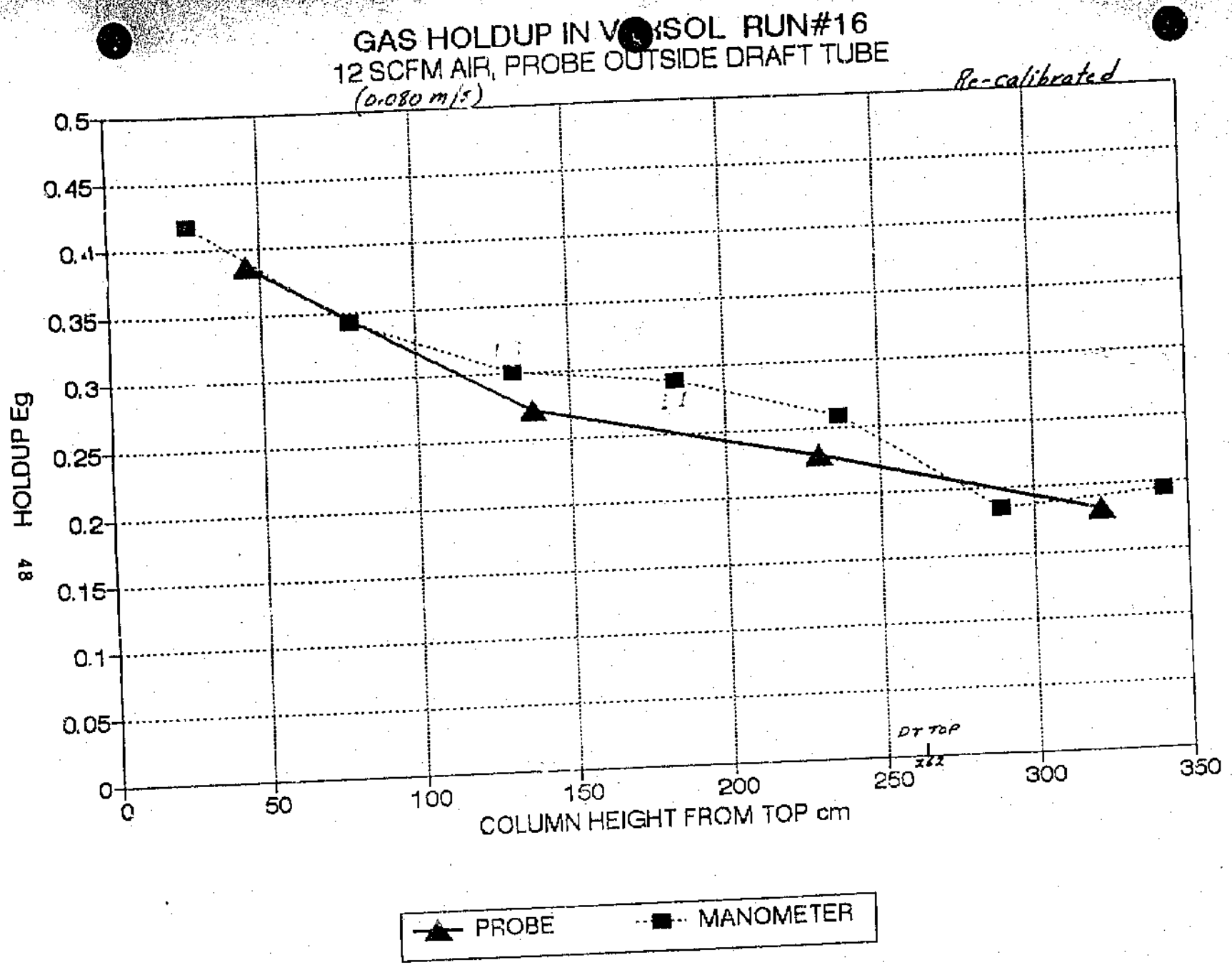

GAS HOLDUP IN V HSOL RUN#11
8.8 SCFM AIR, PROBE INSIDE DRAFT TUBE
(0.059 m/s)
Not re-calibrated
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
OF TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER


GAS HOLDUP IN V[illegible]SOL RUN#12
12 SCFM AIR, PROBE INSIDE DRAFT TUBE
(0.080 m/s)
Not re-calibrated
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
DT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

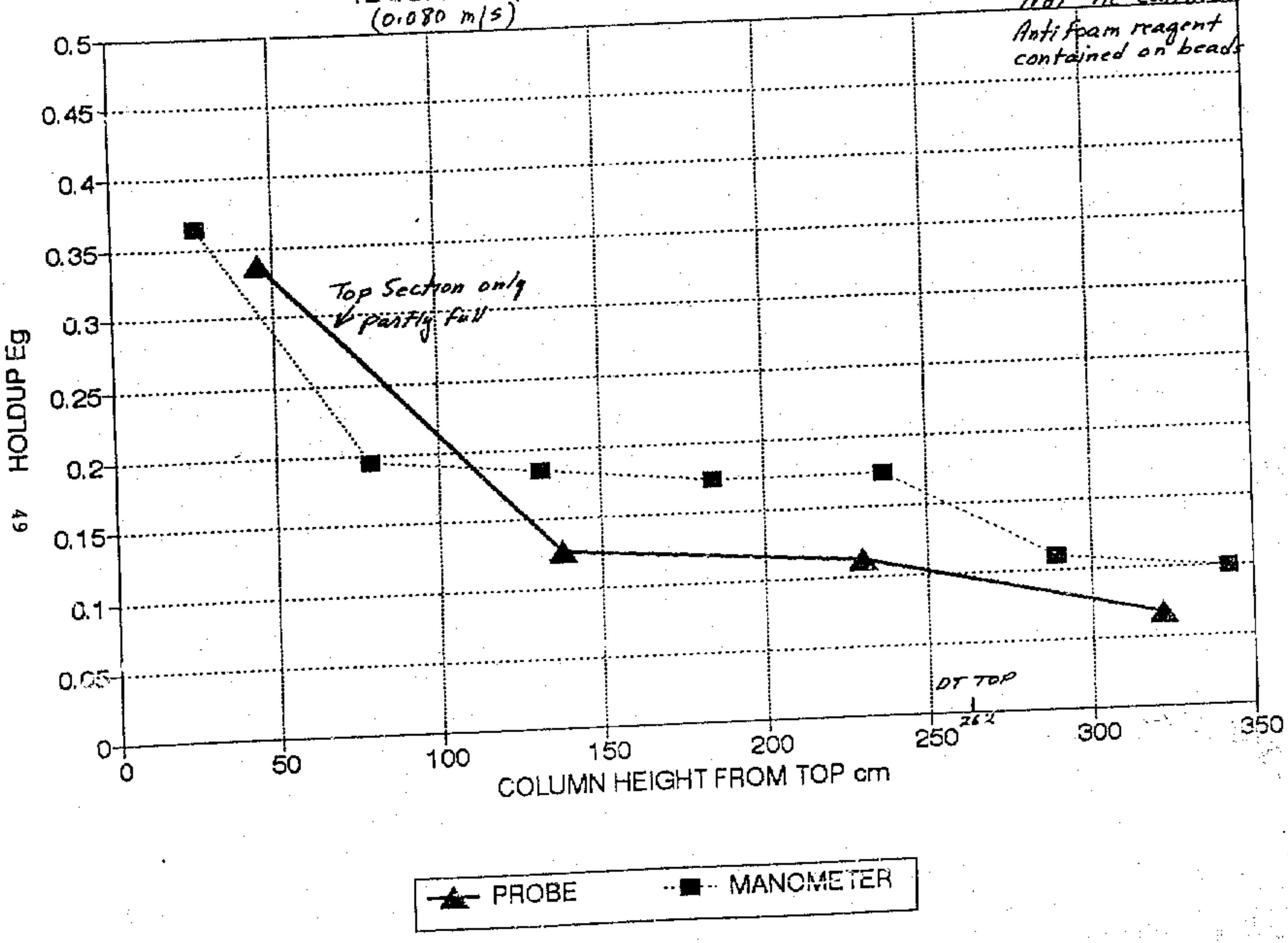

GAS HOLDUP IN ARSOL RUN#13
5 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.033 m/s)
Annulus well aerated with small bubbles, no slugs
Some bubbles nearly stationary
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
DT TOP
262
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

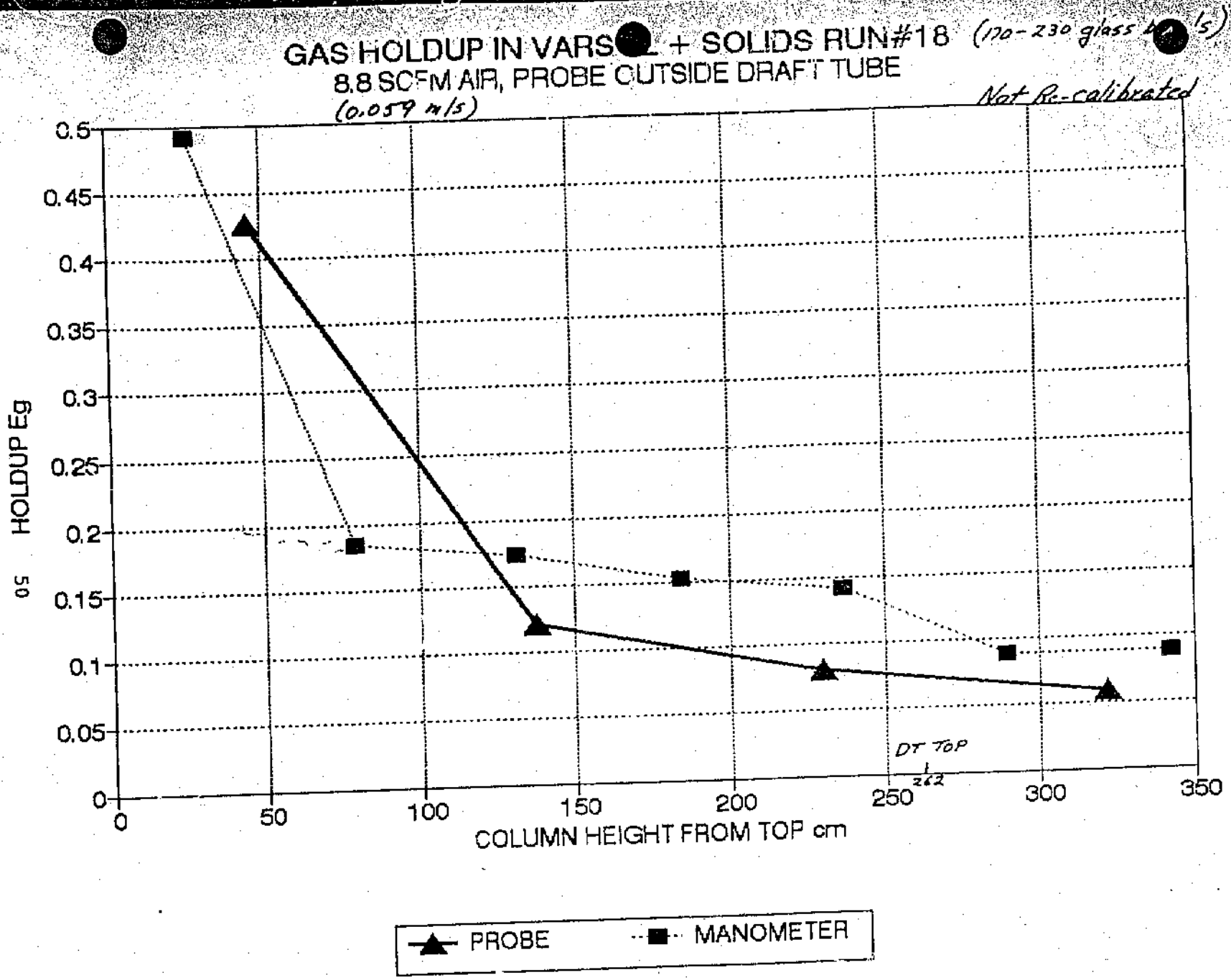

GAS HOLDUP IN ,RSOL RUN#14
8.8 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.059 m/s)
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
OT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

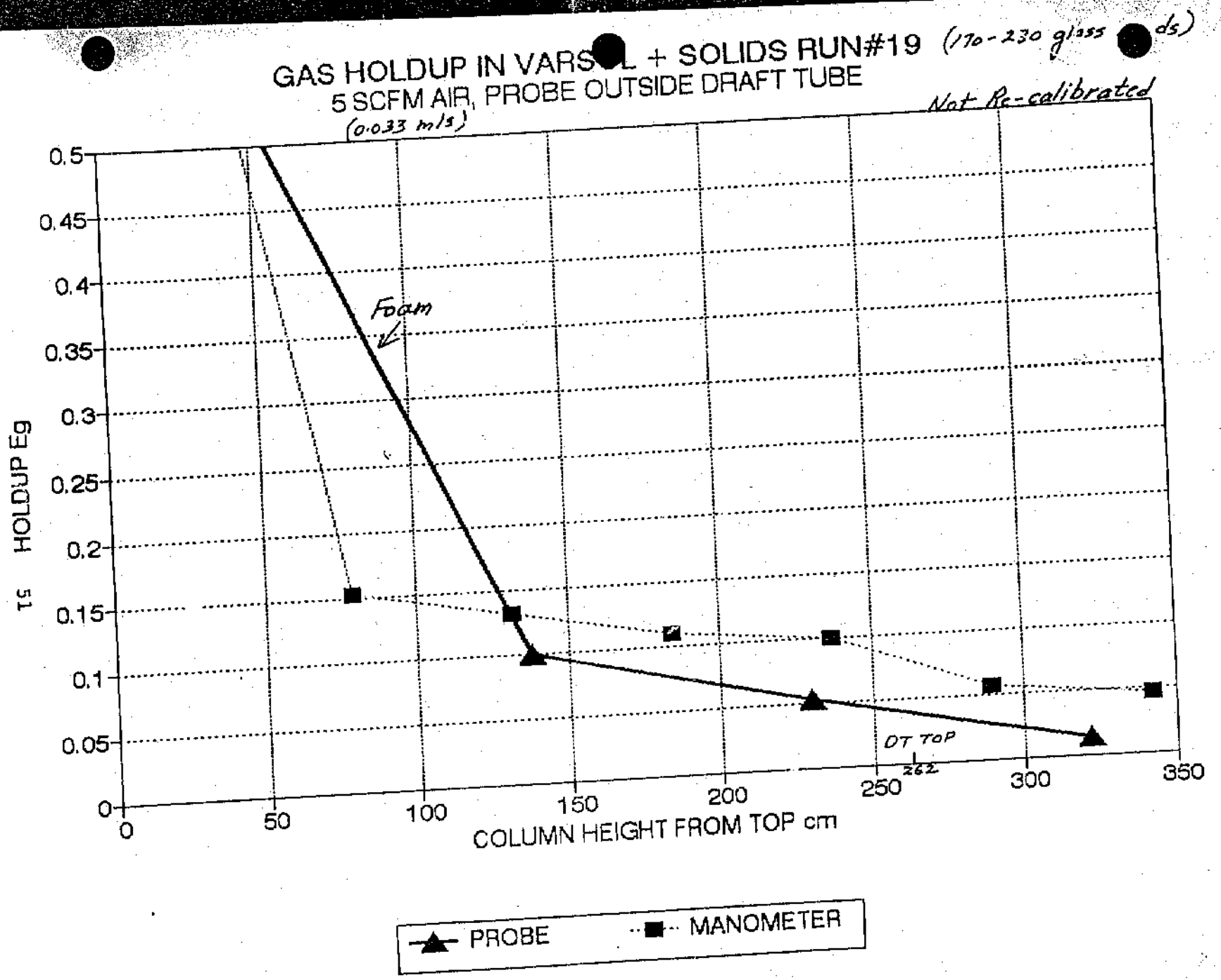

GAS HOLDUP IN ARSOL RUN#15
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.080 m/s)
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
DT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER


GAS HOLDUP IN V[illegible]SOL RUN#16
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.080 m/s)
Re-calibrated
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
DT TOP
222
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

GAS HOLDUP IN VARS[illegible] + SOLIDS RUN#17 (170-230 glass [illegible])
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.080 m/s)



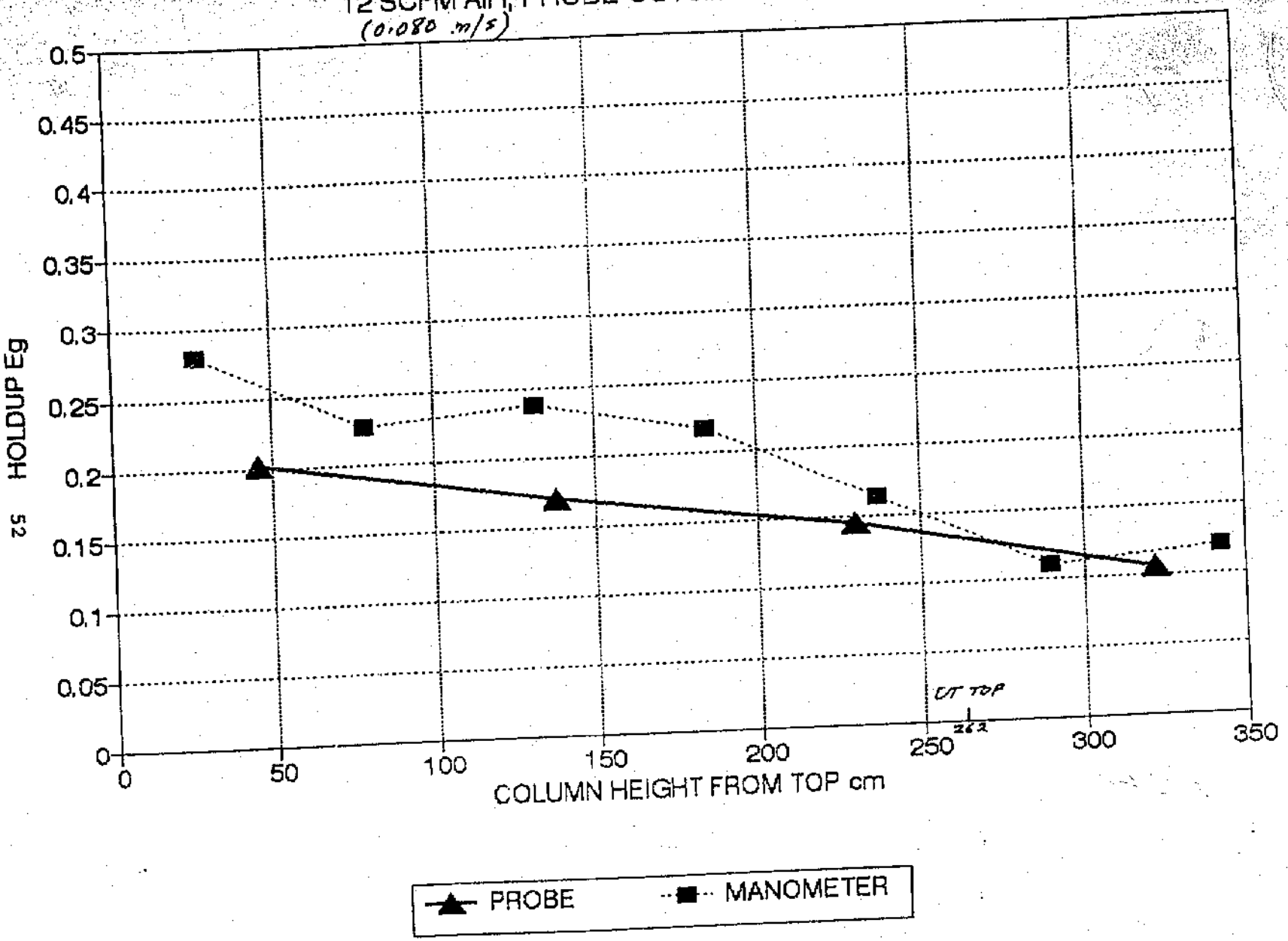

GAS HOLDUP IN VARSOL + SOLIDS RUN#18 (170-230 glass beads)
8.8 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.059 m/s)
Not Re-calibrated
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
DT TOP
242
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

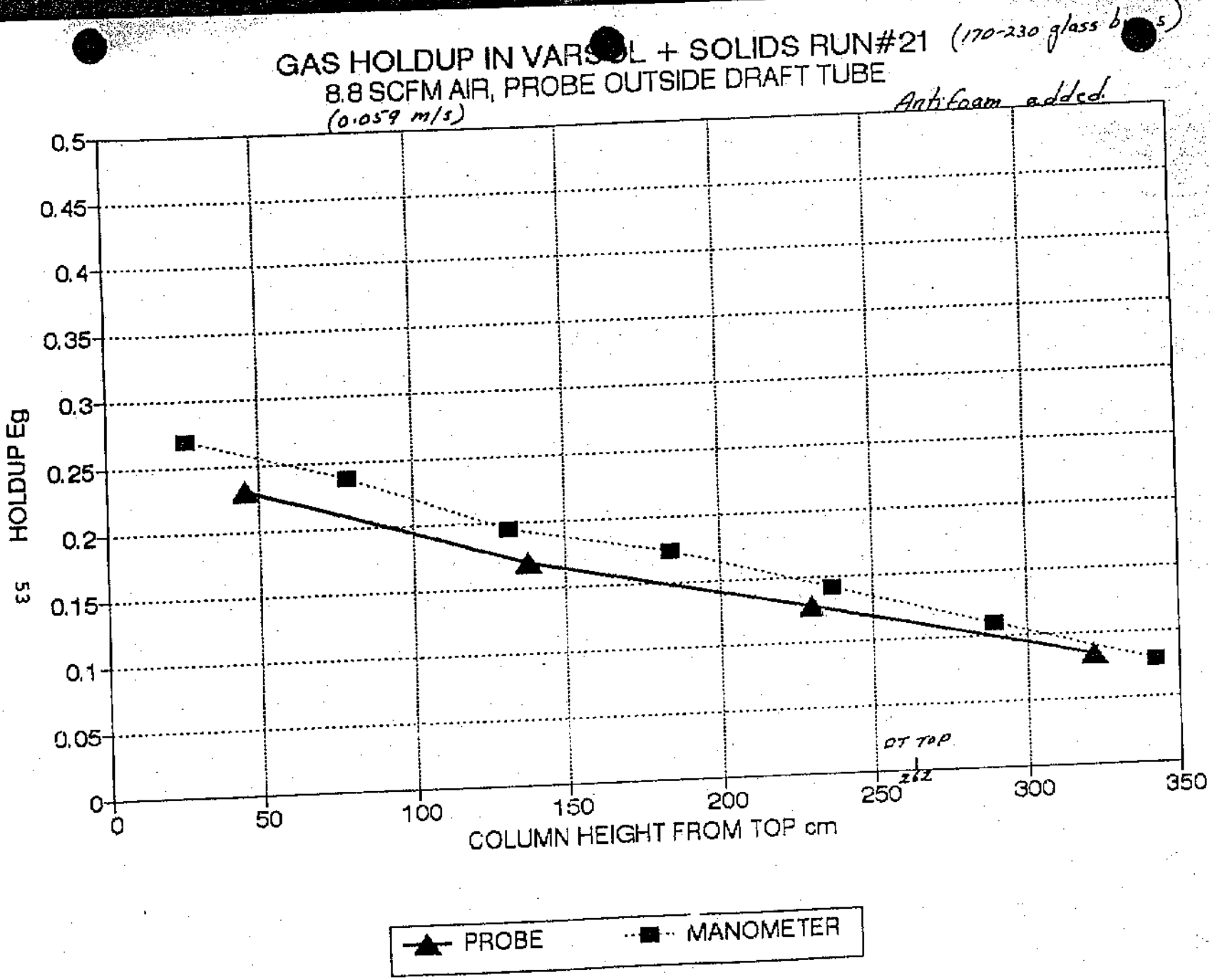

GAS HOLDUP IN VARSOL + SOLIDS RUN#19 (170-230 gloss ds)
5 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.033 m/s)
Not Re-calibrated
Foam
OT TOP
262
HOLDUP Eg
COLUMN HEIGHT FROM TOP cm
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
50
100
150
200
250
300
350
PROBE
MANOMETER

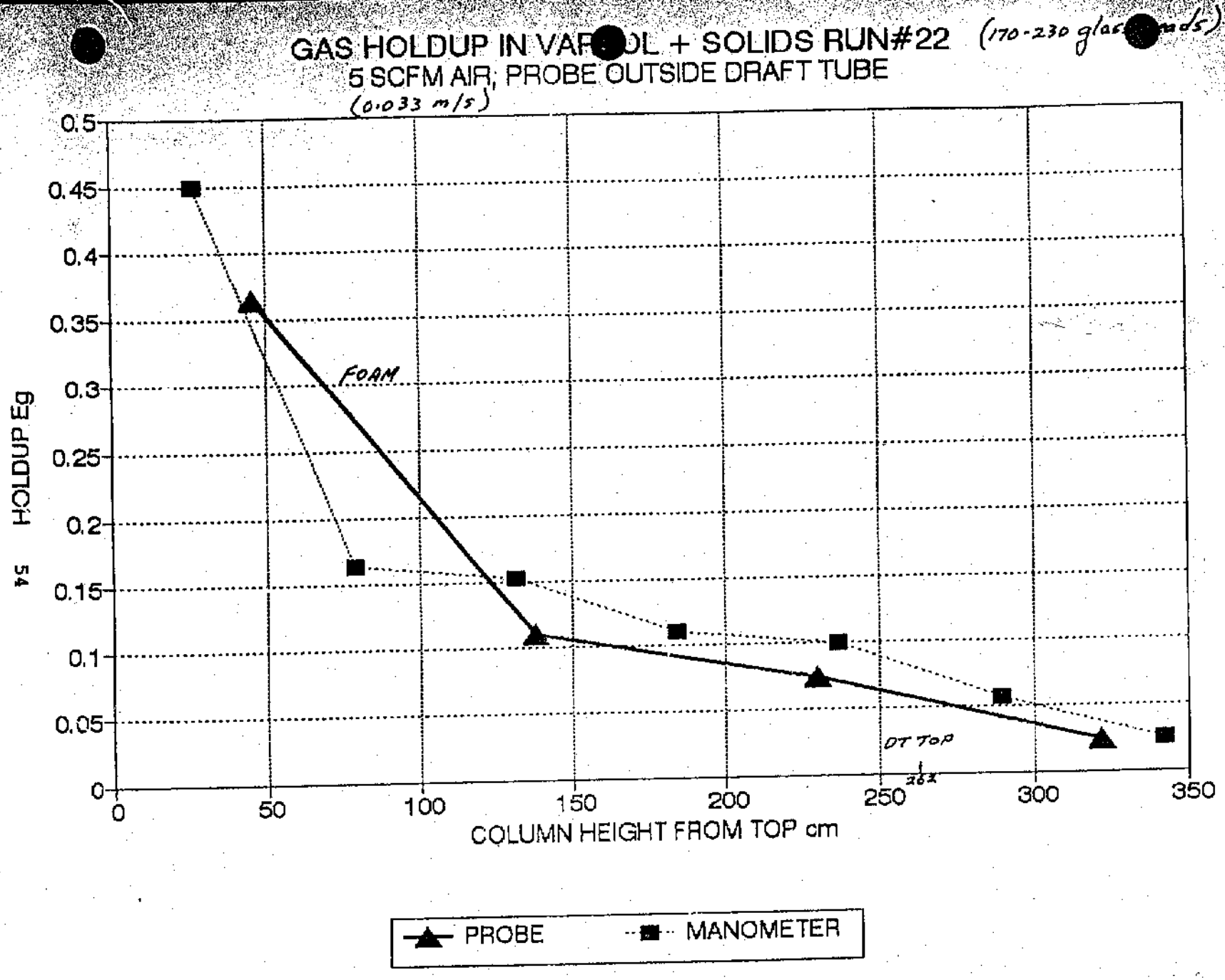
GAS HOLDUP IN VARSOL + SOLIDS RUN#20 (170-230 g/dscm 205)

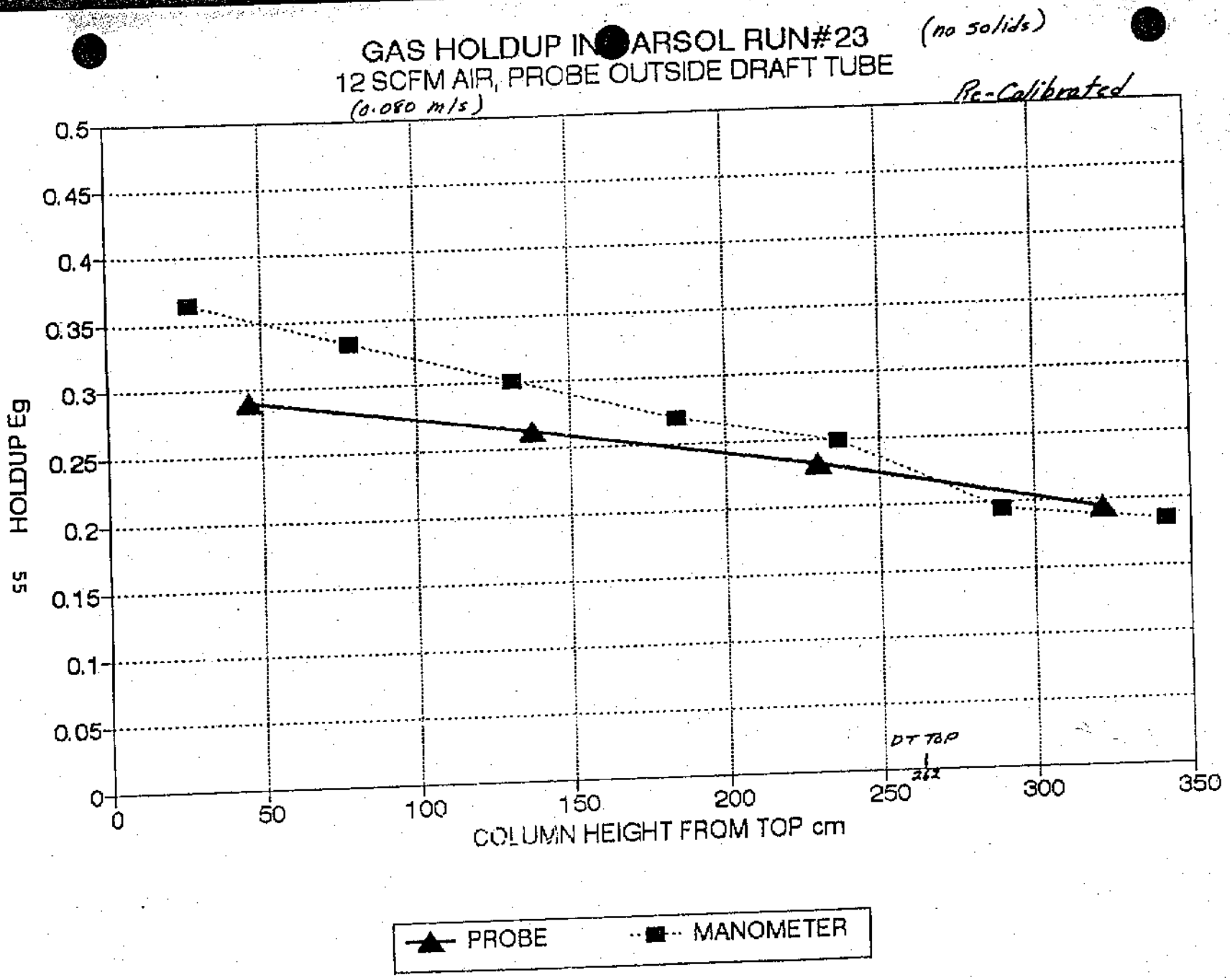
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE

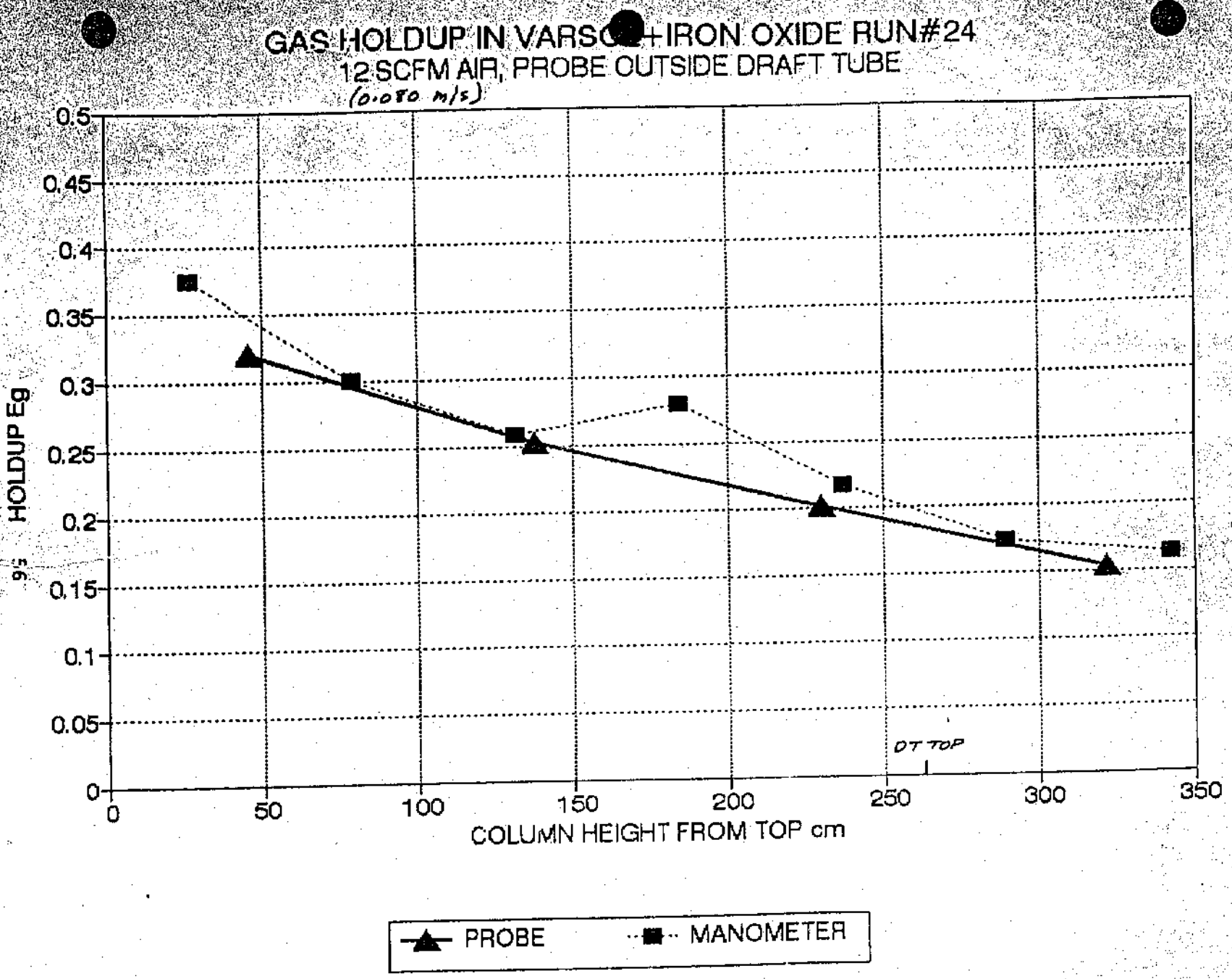
(0.080 m/s)

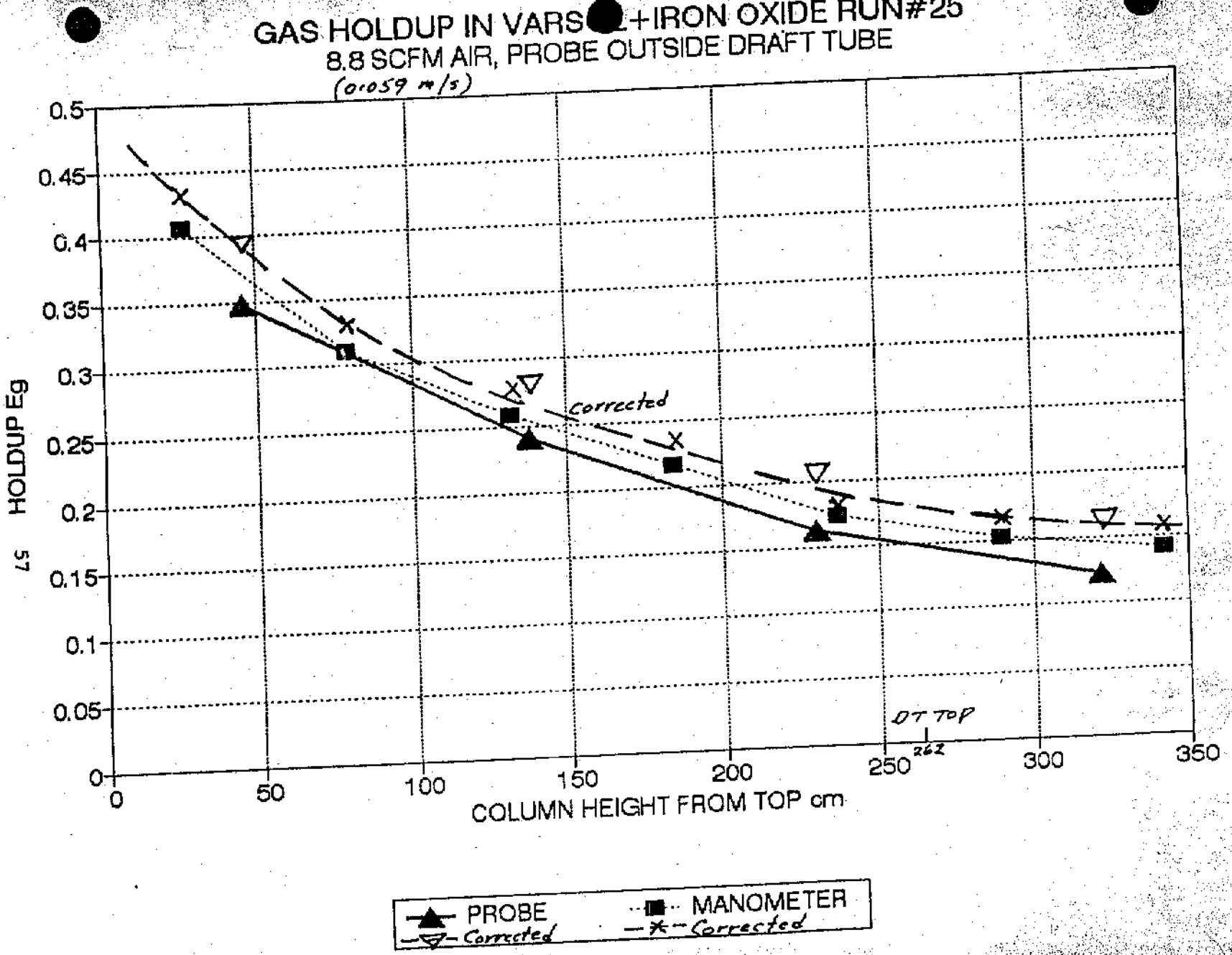


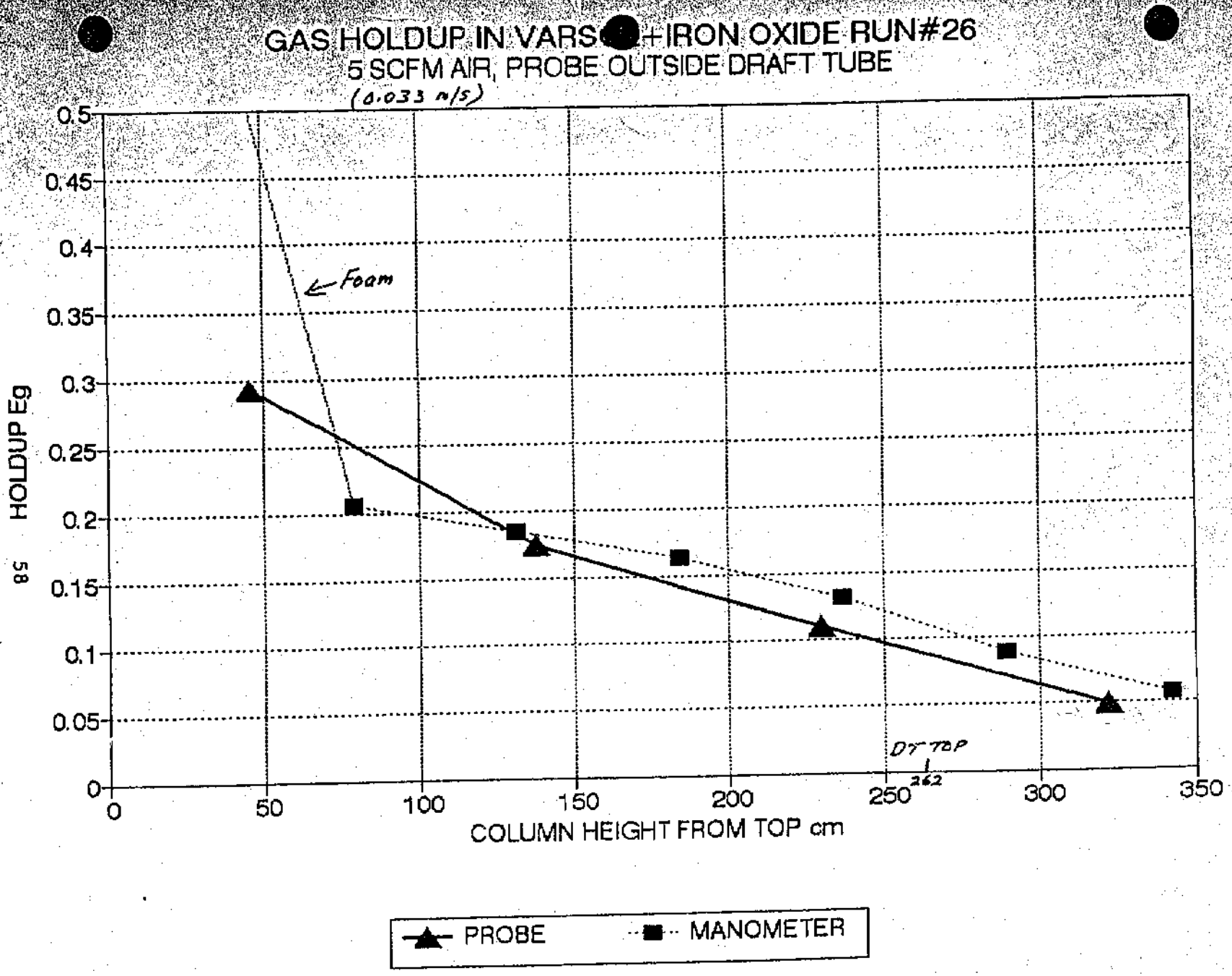

GAS HOLDUP IN VARSOL + SOLIDS RUN#21 (170-230 glass beads)
8.8 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.059 m/s)
Antifoam added.
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
DT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER


GAS HOLDUP IN VAP OL + SOLIDS RUN#22 (170-230 glas mds)
5 SCFM AIR; PROBE OUTSIDE DRAFT TUBE
(0.033 m/s)
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
FOAM
DT TOP
PROBE
MANOMETER


GAS HOLDUP IN ARSOL RUN#23
(no solids)
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.080 m/s)
Re-Calibrated
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
HOLDUP Eg ss
0
50
100
150
200
250
300
350
DT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER


GAS HOLDUP IN VARSOL+IRON OXIDE RUN#24
12 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.080 m/s)
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
DT TOP
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER


GAS HOLDUP IN VARSOL+IRON OXIDE RUN#25
8.8 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.059 m/s)
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
corrected
OT TOP
262
0
50
100
150
200
250
300
350
COLUMN HEIGHT FROM TOP cm
PROBE
Corrected
MANOMETER
Corrected

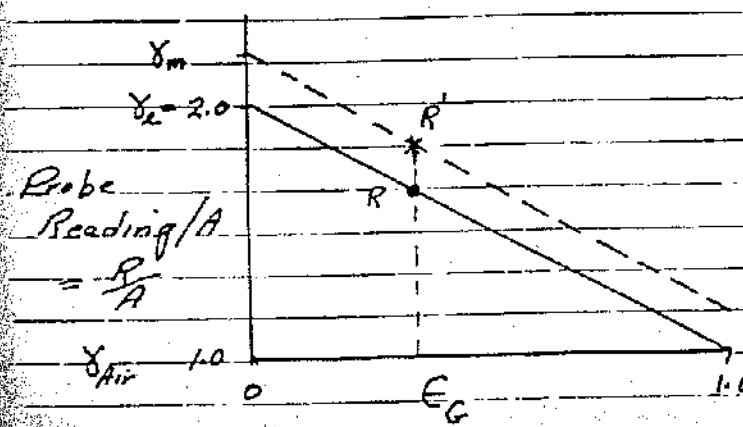

GAS HOLDUP IN VARSOL+IRON OXIDE RUN#26
5 SCFM AIR, PROBE OUTSIDE DRAFT TUBE
(0.033 m/s)
HOLDUP Eg
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Foam
DT TOP
262
0
50
100
150
200
250
300
350
COLUMN HEIGHT FROM TOP cm
PROBE
MANOMETER

APPEMDIX

APPENDIX

1. Correction of Probe Readings for Presence of Solids

A method is developed to correct the probe reading for the increase in dielectric caused by the presence of solids (glass beads)



γ_m - dielectric of slurry
γ_L = dielectric of liquid = 2.0
γ_a - dielectric of air = 1.0
A - calibration factor
γ_s - dielectric of glass beads = 4.7

When a slurry is present, at a gas holdup of ϵ_G, reading of probe is at R'. However, calibration of the solid line, so R' must be corrected so calibration factor for air - liquid only can be used

To calculate the corrected readout, R

$$\gamma_m = \gamma_L \epsilon_L' + \gamma_s \epsilon_s'$$

where ϵ_L', ϵ_s' are volume fractions of liquid and solids respectively in slurry

But $\epsilon_L' + \epsilon_s' = 1.0$

so $\gamma_m = \gamma_L (1 - \epsilon_s') + \gamma_s \epsilon_s' = \gamma_L + \epsilon_s' (\gamma_s - \gamma_L)$

$$\epsilon_s' = \frac{\epsilon_s}{1 - \epsilon_G}$$

ϵ_s = volume fraction of solids in the bubble column.

$$\therefore \text{and } \gamma_m = \gamma_L + \frac{\epsilon_s}{1 - \epsilon_G} (\gamma_s - \gamma_L)$$

With solids present, readout is

$$\frac{R'}{A} = \epsilon_G \gamma_a + (1 - \epsilon_G) \gamma_m = \epsilon_G \gamma_A + (1 - \epsilon_G) \left[\gamma_L + \frac{\epsilon_s}{1 - \epsilon_G} (\gamma_s - \gamma_L) \right]$$

With no solids present, readout is

$$\frac{P}{A} = \gamma_e(1-\epsilon_G) + \gamma_a \epsilon_G$$

$$= \epsilon_G(\gamma_a - \gamma_e) + \gamma_e$$

At the same value of ϵ_G, correction is

$$\frac{R'-R}{A} = \epsilon_G \gamma_A + (1-\epsilon_G)\left[\gamma_e + \frac{\epsilon_s}{1-\epsilon_G}(\gamma_s - \gamma_e)\right]$$

$$-\left[\epsilon_G(\gamma_A - \gamma_e) + \gamma_e\right]$$

$$= (1-\epsilon_G)\left[\frac{\epsilon_s}{(1-\epsilon_G)}(\gamma_s - \gamma_e)\right] = \epsilon_s(\gamma_s - \gamma_e)$$

For the tests with glass beads

12.5 kg of beads @ 2450 kg/m^3 = 0.00510 m^3

Column volume = 300 l

$$\epsilon_s' = \frac{.00510\ m^3}{(.300\ m^3)(1-\epsilon_G)} = \frac{0.0170}{1-\epsilon_G}$$

and since $\epsilon_s' = \frac{\epsilon_s}{1-\epsilon_G} = \frac{0.0120}{1-\epsilon_G}$ $\epsilon_s = 0.0170$

Then $\frac{R'-R}{A}$ Correction is $0.0459\ A$, where A is the experimental span.

If a constant solids concentration is assumed, as a first approximation, then the above correction is constant because ϵ_G is constant.

The assumption of constant ϵ_s is less in error for tests with a draft tube because of the improved mixing.

The true correction factor would be smallest at the top of the column and greatest at the bottom.

Since for the conditions used the solids concentration (no draft tube) may vary by a factor of 2 from top to bottom, this means that the correction factor could vary from the mean values used by ± 33 %.

For tests with iron oxide

Dielectric of hematite = 14.2

Density of hematite = 4900 - 5300 kg/m^3

Amount of hematite used = 5.835 kg

Assuming ρ = 5200 kg/m^3

Volume of iron oxide = $\frac{5.835}{5200} = 0.001122$ m^3

$$\epsilon_s = \frac{.001122 \text{ m}^3}{.300 \text{ m}^3} = 0.00374$$

Then correction to probe reading

$$\frac{R' - R}{A} = 0.001122\left(14.2 - 2.0\right) = 0.0456$$

This value is almost identical to that for the glass beads. However, because of the small diameter of the iron oxide, solid concentrations especially with a sharp bed will tend to be more axially uniform.

Corrections to Manometer Readings due to Solids

Total column volume (2.5 sections + bottom) = 300 litres

Solids samples were not taken, so the same assumption as previously will be made, that is, axial solids concentration is uniform. This assumption will give too small a correction (+) near the bottom and too large a correction (+) near the top.

Liquid void fraction calculated with solids (ϵ_{se}) and assuming no solids (ϵ_e'). The no solids assumption uses the liquid density and is the one reported on the data sheets.

$$\epsilon_{se} = \frac{\rho_{man}\, g\, \Delta h_{man}}{\rho_{se}\, \Delta L\, g}$$

$$\epsilon_e' = \frac{\rho_{man}\, g\, \Delta h_{man}}{\rho_e\, \Delta L\, g}$$

where ρ_{man} = manometer fluid density
h_{man} = manometer reading
ρ_{se} = density of the slurry (average)
ρ_e = density of the liquid
ΔL = column increment between measuring points

Then $\frac{\epsilon_e'}{\epsilon_{se}} = \frac{\rho_{se}}{\rho_e} = \frac{1-\epsilon_{G\,calc}}{1-\epsilon_{G\,corr}}$

For the Varsol used $\rho = 798\ kg/m^3$

and $\epsilon_{G\,corr} = 1 - \frac{798}{\rho_{se}}\left(1-\epsilon_{G\,calc}\right)$

To find ρ_{se} ——— $\epsilon_s = \frac{12.5\,kg}{(2450)(.300\,m^3)} = 0.017$

Volume of slurry = $0.300\,(1-\epsilon_G)$

Volume of liquid = $0.300(1-\epsilon_G-\epsilon_S) = 0.295\,(1-\epsilon_G)$

Then $\rho_{se} = \dfrac{798\,(.295)(1-\epsilon_G) + 12.5}{.300(1-\epsilon_G)} = 784.7 + \dfrac{12.5}{(.3)(1-\epsilon_G)}$

$$= 784.7 + \frac{41.67}{(1-\epsilon_G)}$$

The Table below gives values of this manometric correction factor for the 170/230 glass beads.

True ϵ_G	ρ_{se} kg/m^3	$\epsilon_{G\,calc.}$	$\epsilon_{G\,corr}$	Δ (+)
0.05	828	0.05	0.084	.034
0.10	831	0.10	0.136	.036
0.15	834	0.15	0.187	.037
0.20	837	0.20	0.237	.037
0.25	840	0.25	0.288	.038
0.30	844	0.30	0.338	.038
0.40	854	0.40	0.439	.039

As can be seen, this correction factor is nearly constant over a wide range of gas holdup and slurry solids concentrations. The value of the correction factor is nearly equal to that for the dielectric effect (about 80% as much). As a result, both probe and manometric readings of the gas holdup are corrected (increased) by nearly the same amount.

Manometric Correction for Iron Oxide Slurry:

For the iron oxide (5.835 kg, density 5200 kg/m³) as developed earlier

$$\rho_{sl} = \frac{(998)(.298)(1-\epsilon_G) + 5.835}{(0.300)(1-\epsilon_G)}$$

The Table below gives calculated gas holdup corrections

True ϵ_G	ρ_{sl} kg/m³	ϵ_G calc.	ϵ_G corr.	$\Delta(+)$
.05	813	.06	.0675	.0175
.10	814	.10	.118	.018
.15		.15		
.20	817	.20	.219	.019
.25		.25		
.30	820	.30	.319	.019
.40	825	.40	.420	.020

This is a considerably smaller correction to the manometric readings than that for glass beads.