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TECHNICAL DIVISION
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Results of Sludge Slurry Pipeline Pluggage Tests

SUMMARY

Test results of sludge slurry transport through the Interarea Transfer Line Mock-up Facility showed little risk of plugging the interarea pipelines with sludge slurry. Plug-free operation of the pipeline was successfully demonstrated by worst case IAL operating scenarios.

Pipeline pressure gradients were measured vs. flow rate for comparison with a computer model over a range of sludge slurry rheological properties. A mathematical computer model developed by L. M. Lee is included in this report which will predict pressure drop for Bingham plastic fluid flow in a pipeline. IAL pluggage situations and pumping requirements may be realized from this model.

DISCUSSION

The Interarea Transfer Line Mock-up Facility models the hydraulic characteristics of the F to H and H to S Interarea Transfer Lines (IAL's). Transport of a sludge slurry simulant through the mock-up facility transfer line under various operating conditions was completed to evaluate the risks of plugging the IAL. A detailed description of the mock-up facility can be found in Reference 1. Basically the line is 550 feet long constructed of 3 inch stainless steel pipe. Transparent plexiglass viewing sections have been installed for observation of the slurry flow and settling behavior. The chemical composition of the sludge slurry simulant used during the testing is listed in Table 1.

Resuspendability Tests

The resuspendability of sludge slurry left stagnant in the IAL was evaluated with concentrated and dilute sludge. Slurry was pumped through the pipeline, noting the total line pressure drop and flow rates, then left to settle for seven days. Valves at either end of the pipeline were closed to prevent line drainage. Observations were made periodically through the plastic viewing sections to evaluate settling rates. The viewing sections are located in line segments sloped at 0.5% and 4.0%. The majority of the H to S area IAL's sections are sloped at 0.5%. For the concentrated slurry, little to no settling was observed. The dilute slurry, however, settled to approximately 40% sludge and 60% clear liquid as seen through the viewing sections. At the conclusion of the settling period, the transfer pump was started and flow was immediately established. The seven day settling period was considered more than adequate based on laboratory settling tests, Figure 1.

Gravity Drainage Tests

Gravity drainage tests were completed in order to determine the extent to which the sludge slurry would gravity drain. Tests were conducted at the higher sludge slurry concentrations and yield stress in the segment of pipeline sloped at 0.50%. At sludge slurry concentrations greater than 19 wt% total solids or a yield stress of 40-50 dynes/cm^2, gravity drainage would cease. Slurry density was 1.17 grams/cc.

At lower slurry concentrations the line would obviously drain to a greater degree. These test results are based on the observations made through the plastic viewing section in the 0.5% sloped pipeline. Since transfers of sludge slurry from H to S area will be at the higher slurry concentrations, the line is, therefore, not expected to gravity drain.

Water Vapor Diffusion Test

As a result of the sludge slurry remaining in the pipe line, tests were conducted to simulate the effect of an air purge through the pump tank on the sludge slurry in the line. Plans are to purge the auxiliary and low point pump pits with air at a maximum rate of 75 CFM. The concern was that the sludge slurry would concentrate by water vapor diffusing from the slurry into the air, resulting in a plug at the inlet to the pump tanks. Concentrated sludge slurry was pumped through the mock-up facility and allowed to sit in the pipeline for greater than 86 hours, simulating the normal cycle time for a SRAT batch. During this time period, a steam vacuum jet provided a purge air flow of 75 CFM through the pump tank.

Following one cycle period, the transfer pump was started while monitoring pressure and flow instrumentation. No indications of a plugged or partially plugged pipeline were observed. A direct air purge into the end of the pipeline was then provided for additional slurry concentration tests. Again, the air purge did not cause the pipeline to plug.

Vertical Plugging Test

In order to simulate the plugging potential of sludge slurry in a section of the IAL blanked or valved off, such as in a jumper or valve box, slurry was pumped into a 10 foot vertical section of pipe and allowed to settle for a period of one week. Although no flow or pressure instrumentation was available on this section of line, it was obvious from the pipe discharge that no pluggage had occurred when the pump was started.

Dilute Slurry Transfer Tests

When observed through the transparent viewing sections, dilute sludge slurry transfers showed no evidence of solid deposition over all flow regimes. Particle size analysis of the sludge slurry simulant used for all these tests are shown in Figure 2. At this particle size of less than 22 microns, the tests results are consistent with the literature shown in Figure 3[2]. Although the actual sludge slurry may have larger solids (1-80 microns)[3], the planned flow velocities of 3-4 ft/sec should be sufficient to ensure flow as homogeneous suspension.

Dilute Slurry Flushing Tests

Dilute sludge slurry flushes were somewhat effective in flushing the pipeline as long as the sludge slurry was diluted to the extent that it did not exhibit any yield stress. Total solids concentration was less than 15 wt%. Under these conditions the slurry would gravity drain from the line leaving only a very small volume in the line. After several days the slurry would tend to dry out in the line during the hot summer days but was easily flushed from the line, seen as small flakes through the transparent viewing section.

Measurement of Pipeline Pressure Drop

Additional pressure drop vs. flow measurements were taken during sludge slurry runs made in August and September, 1986 over the range of rheological properties shown in Table 2. Figures 4 through 11 compare the measured pressure drops with predicted values based on the mathematical computer model shown in the Appendix. This model was developed by L. M. Lee and is discussed in Reference 4. Initial slurry runs made in May, 1986 showed very good agreement between the measured pressure drop and predicted values based on L. M. Lee's model[4]. However, when the pressure drop measurements shown in Figures 4 thorugh 10 are compared to the model, large discrepancies are seen in the laminar flow region. It seems inconsistent that the discrepancies would be in the laminar flow region which is modeled by the well-known Buckingham equation and not in the less predictable turbulent flow region. However, it could be expected after looking at the rheograms for the recent slurry runs.

Figure 11 shows a typical rheogram for these runs. The large spikes seen at the lower shear rates, which were not present in the earlier runs, indicate the presence of larger particles in the slurry. Formation of larger particles could have occurred when the sludge slurry was reconcentrated by evaporation. Concentration of the slurry was necessary since the slurry had been diluted with water during the previous tests. The high temperatures would cause some of the smaller particles to dissolve and when cooled, crystalize, to form larger particles and possibly changing the slurry's rheological properties at the lower shear rates. Consequently, the pressure drop measurements taken at the lower flow rates (lower shear rates) were higher than the predicted values, possibly due to the influence of the larger particles in the slurry. However, since the actual radioactive sludge slurry will not be concentrated by evaporation and a review of many Tank 18 and 42 sludge slurry rheograms mainly showed good Bingham plastic behavior, the rhoeological properties are not expected to change and pressure gradients should be predictable with the model to within 10%. By knowing equivalent lengths of pipeline and sludge slurry rheological properties, this model will aid in detecting a plugging condition.

REFERENCES

1. Fazio, J. M., "Interarea Transfer Line Mock-up Facility Sludge Slurry Tests", DPST-86-652, September 3, 1986.

2. Gouier, G. W. and K. Azis, "The Flow of Complex Mixtures in Pipes", Robert E. Krieger Publishing Company, Inc., Florida.

3. Churnetski, B. V., "Effective Cleaning Radius Studies", DPST-81-282, February 19, 1981.

4. Lee, L. M., "Mathematical Model for Interarea Transfer of Waste Slurry", DPST-87-215, January 30, 1987.

TABLE 1. Sludge Slurry Simulant Composition

Insoluble Solids	Wt% Total Solids
$Fe(OH)_3$	44.6
$Al(OH)_3$	18.4
MnO_2	8.8
$CaCO_3$	6.9
SiO_2	4.9
$Ni(OH)_2$	4.0
Zeolite	2.4
CuO	0.4
Cr_2O_3	0.4
Soluble Solids	
NaOH	5.0
$NaNO_3$	2.8
$NaAl(OH)_4$	0.3
Na_3PO_4	0.1

TABLE 2. Sludge Slurry Simulant Fluid Properties

Slurry Run No.	Density g/cc	Wt% Total Solids	Yield Stress dynes/cm^2	Consistency Cp
2A	1.22	23.1	202	23
3A	1.20	21.8	138	14
4A	1.19	21.5	84	10
5A	1.18	20.5	64	6
6A	1.17	19.6	48	6
7A	1.16	19.0	33	6
8A	1.15	18.3	25	5

FIGURE 1

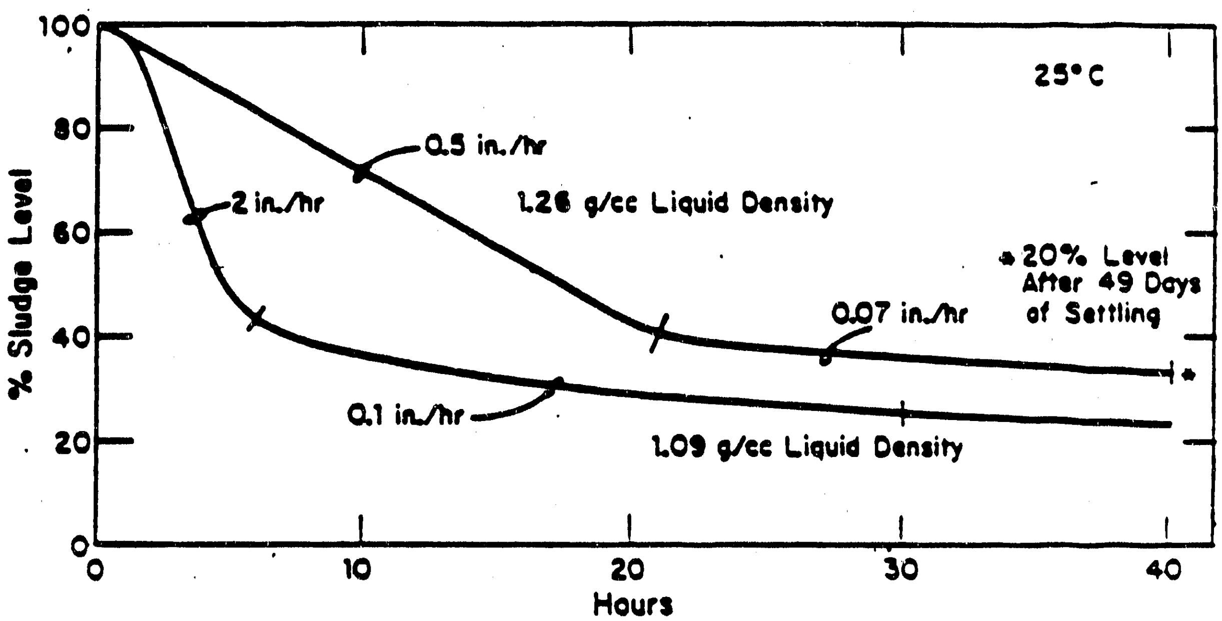


FIGURE 2.5. Settling of Synthetic Sludge in a 4-Liter Graduate

FIGURE 2

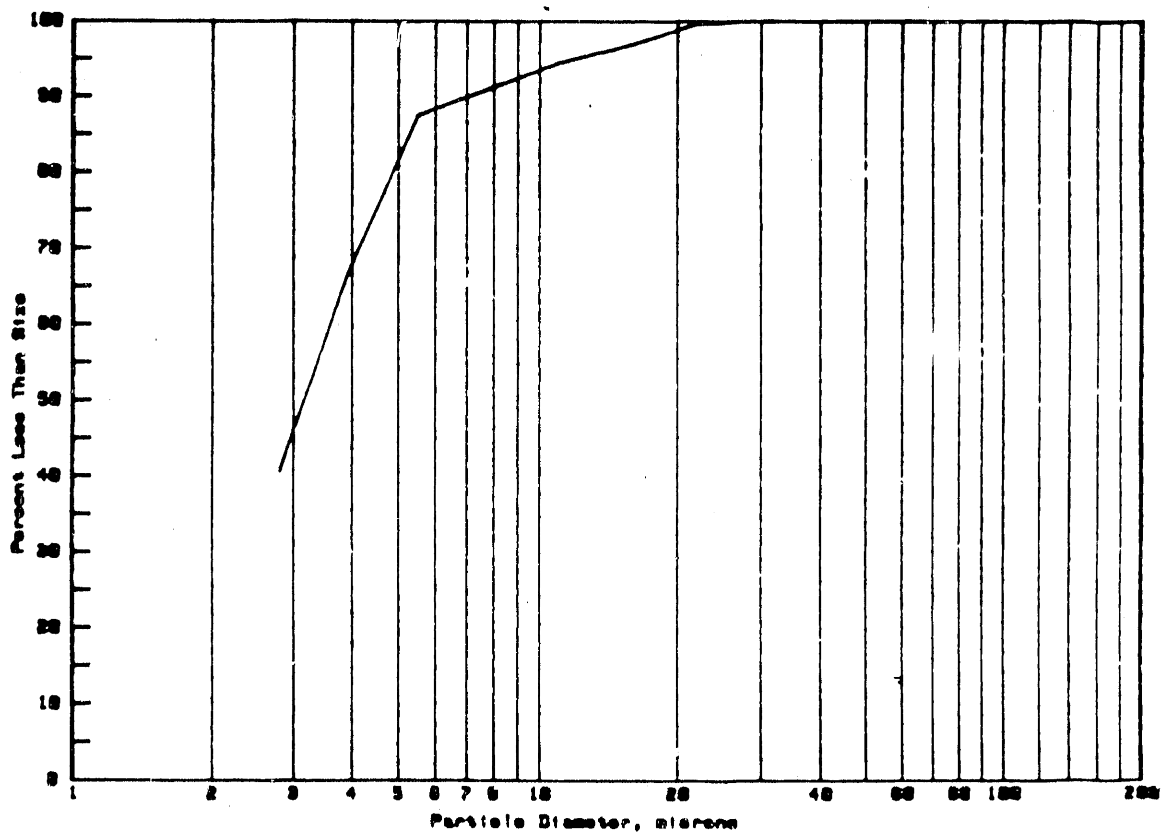
OAK RIDGE GASEOUS DIFFUSION PLANT
POST OFFICE BOX P
OAK RIDGE, TENNESSEE 37831

MICROMERITICS LABORATORY
Bldg: K-1004L, MS 265
Ph. (615) 574-9400

Originator: STEWART
Sample: 92650
Material:
Report date: 11/3/86
Reference: 10475H
Test system: MICROTRAC

Mean vol. dist. = 4.3
90th Percentile = 7.0
50th Percentile = 3.1
10th Percentile = 2.10

Particle Diameter, microns	Cumulative Distribution, percent	Incremental Change, percent
2.8	40.7	40.7
3.9	66.4	25.6
5.5	87.5	21.0
7.8	91.0	3.5
11.0	94.4	3.4
16.0	96.9	2.5
22.0	99.6	2.7
31.0	100.0	.4
44.0	100.0	0.0
62.0	100.0	0.0
88.0	100.0	0.0
125.0	100.0	0.0
176.0	100.0	0.0



Distribution for Sample 92650
Figure 2

FIGURE 3

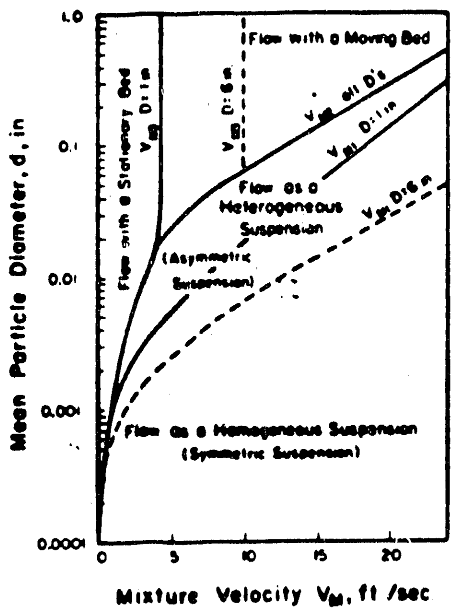


Figure 11.29. Newitt *et al* flow pattern map (Redrawn from Newitt, D. M. J. F. Richardson, M. Abbott, and R. B. Turtle *Trans Inst Chem. Engrs*, 33, 93, 1955.)

FIGURE 4

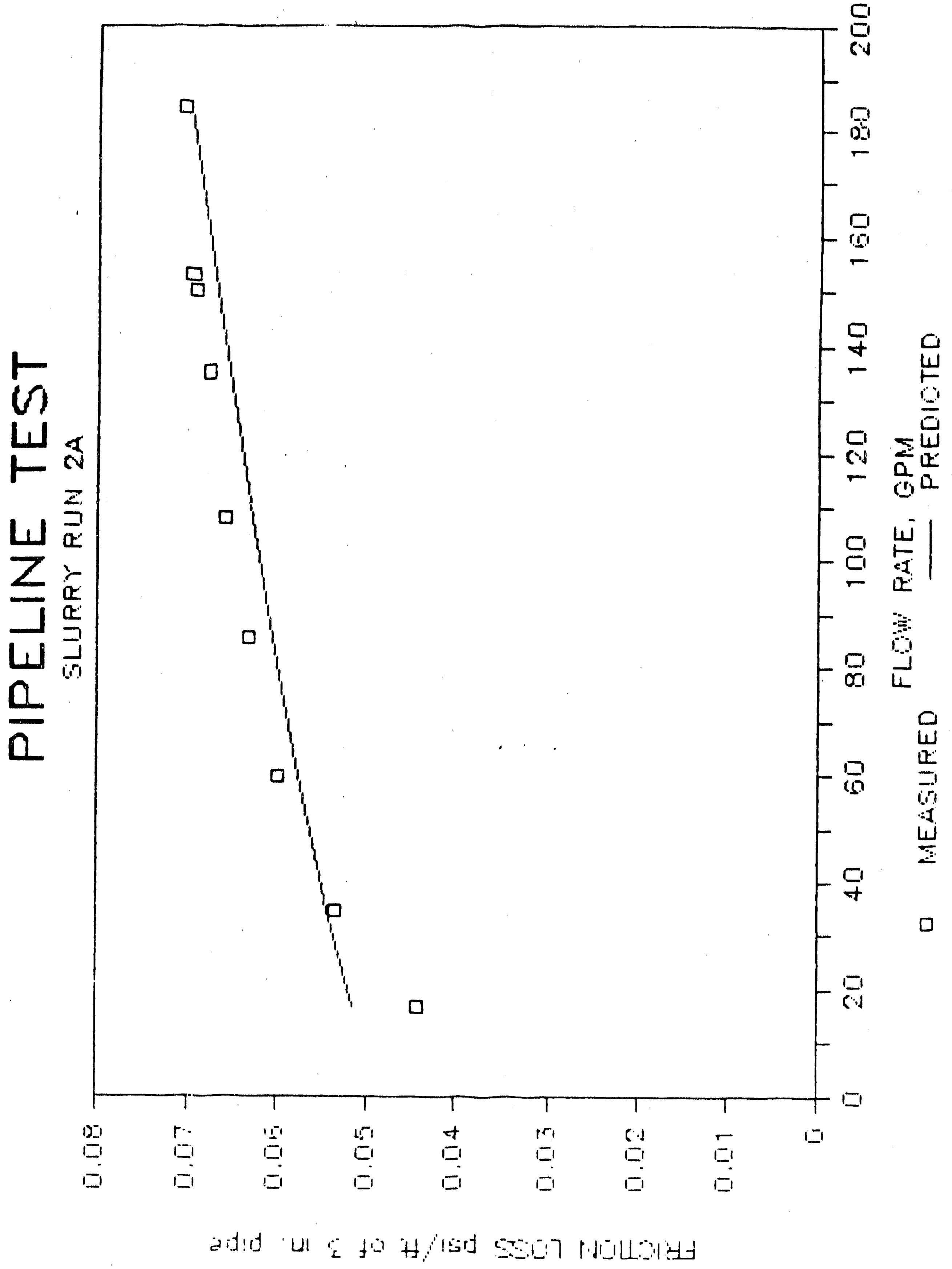

PIPELINE TEST
SLURRY RUN 2A
FRICTION LOSS psi/ft of 3 in. pipe
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
140
160
180
200
FLOW RATE, GPM
MEASURED
PREDICTED

FIGURE 5

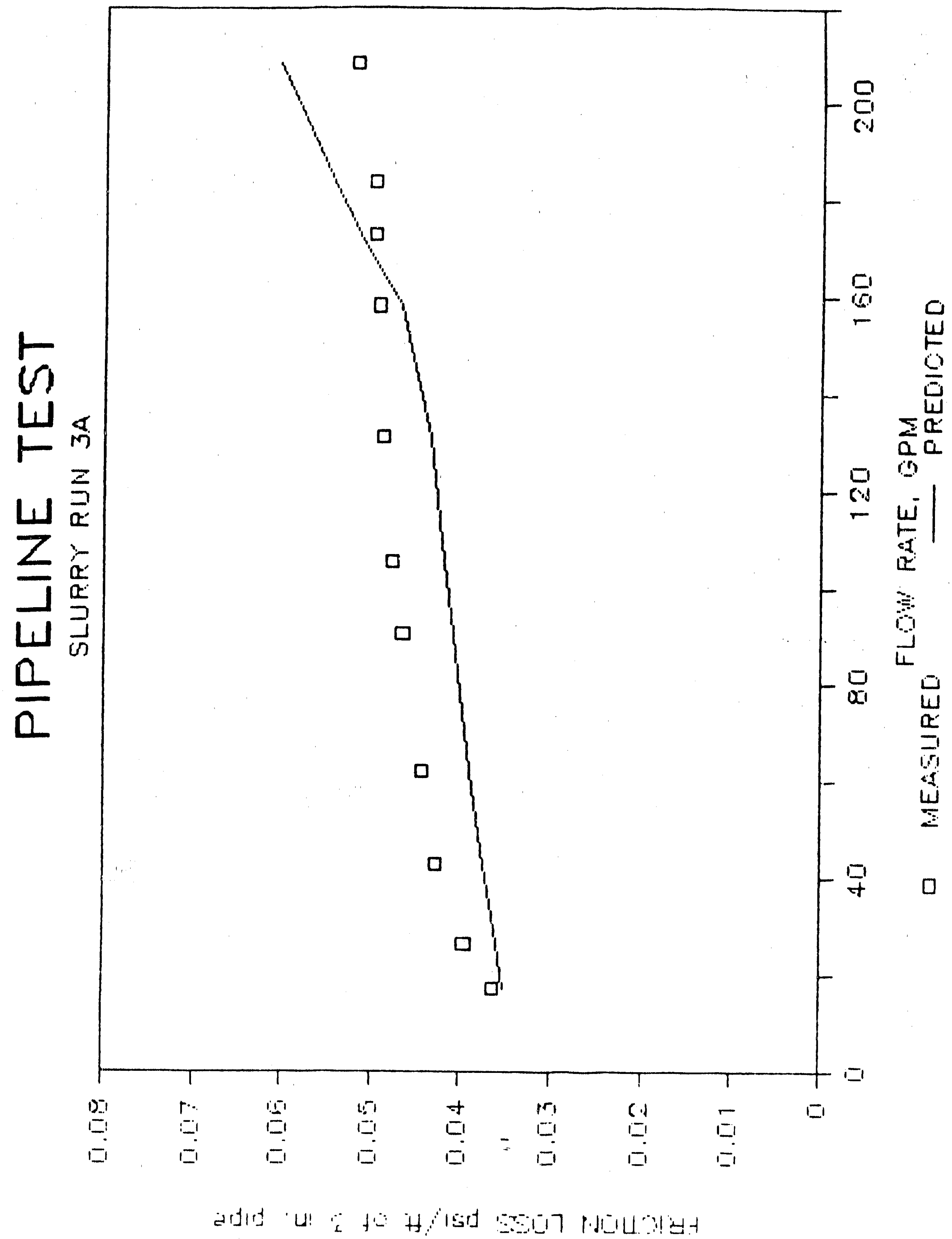

PIPELINE TEST
SLURRY RUN 3A
FLOW RATE, GPM
MEASURED
PREDICTED
0
40
80
120
160
200
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

FIGURE 6

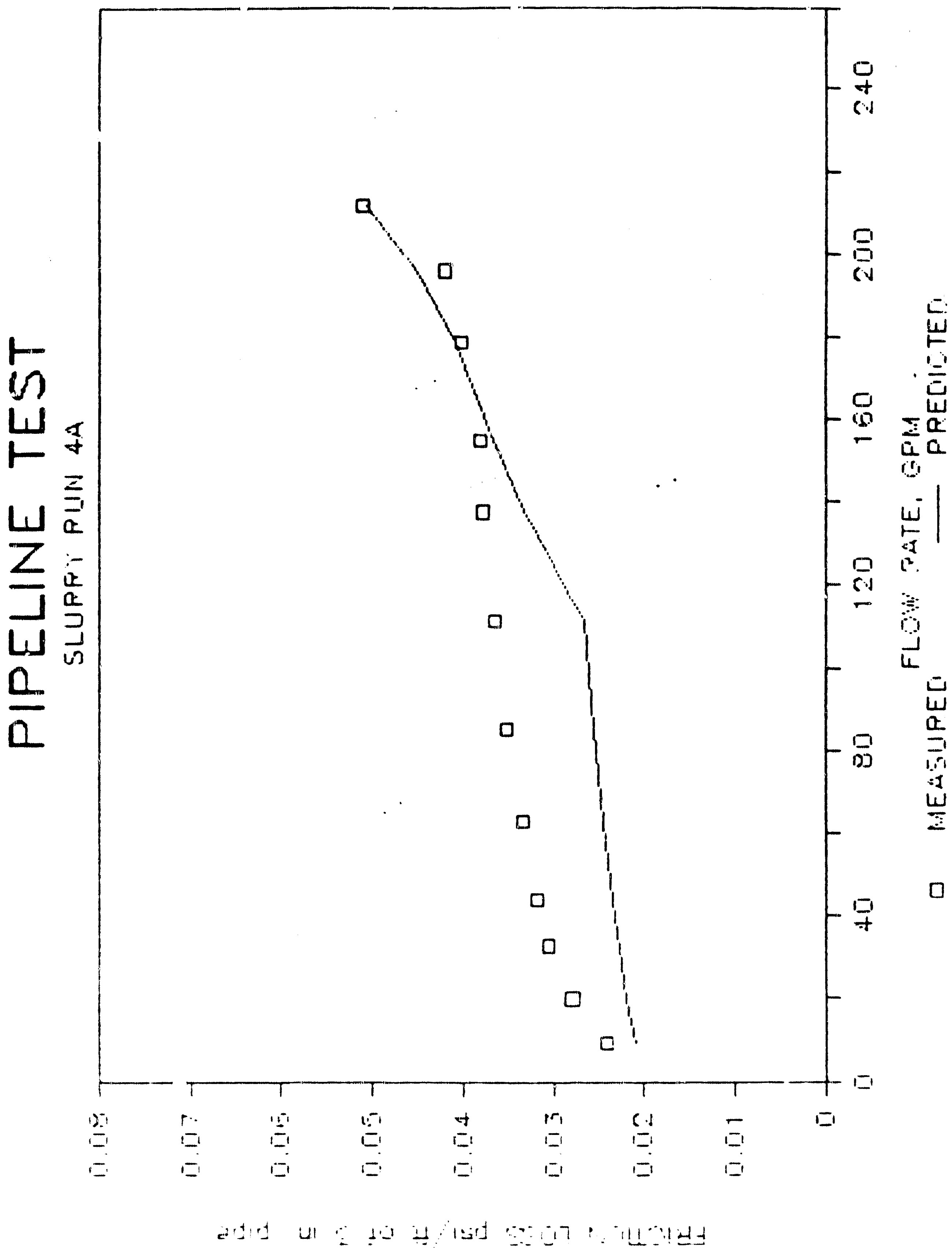

PIPELINE TEST
SLURRY RUN 4A
FLOW RATE, GPM
MEASURED
PREDICTED

FIGURE 7

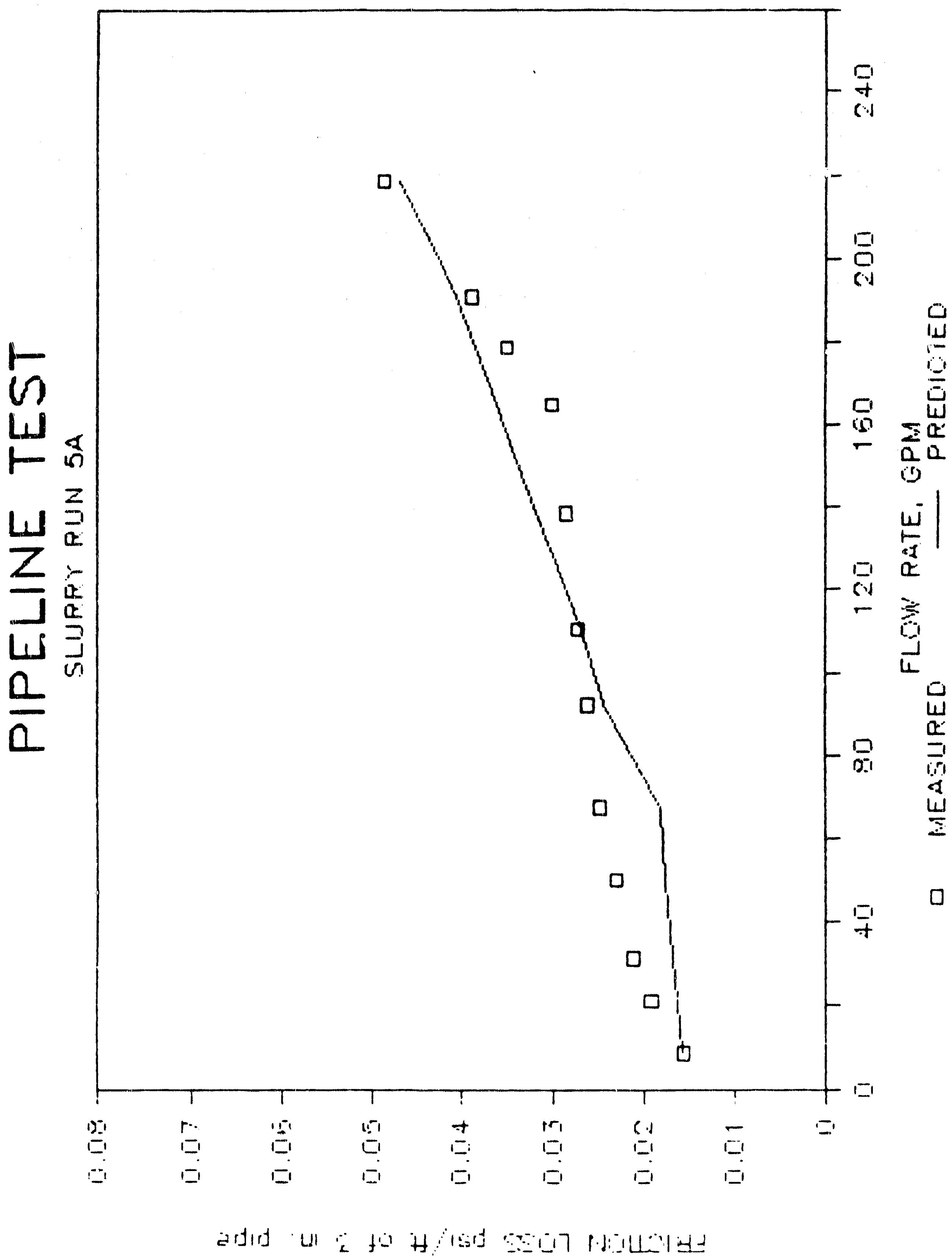

PIPELINE TEST
SLURRY RUN 5A
FLOW RATE, GPM
MEASURED
PREDICTED
0
40
80
120
160
200
240
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
FRICTION LOSS psi/ft of 2 in. pipe

FIGURE 8

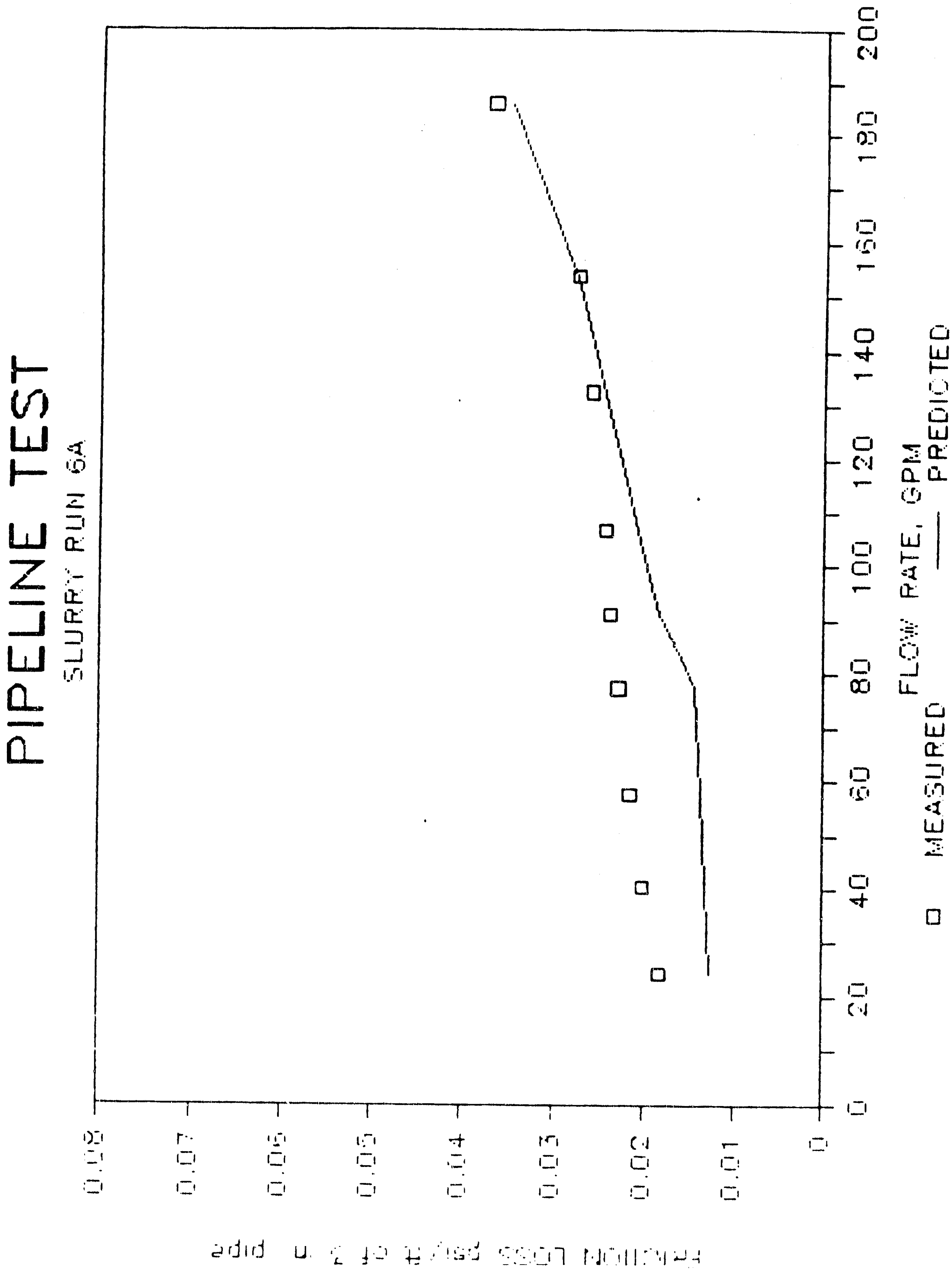

PIPELINE TEST
SLURRY RUN 6A
FLOW RATE, GPM
0
20
40
60
80
100
120
140
160
180
200
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
FRICTION LOSS psi/ft of 2 in pipe
MEASURED
PREDICTED

FIGURE 9

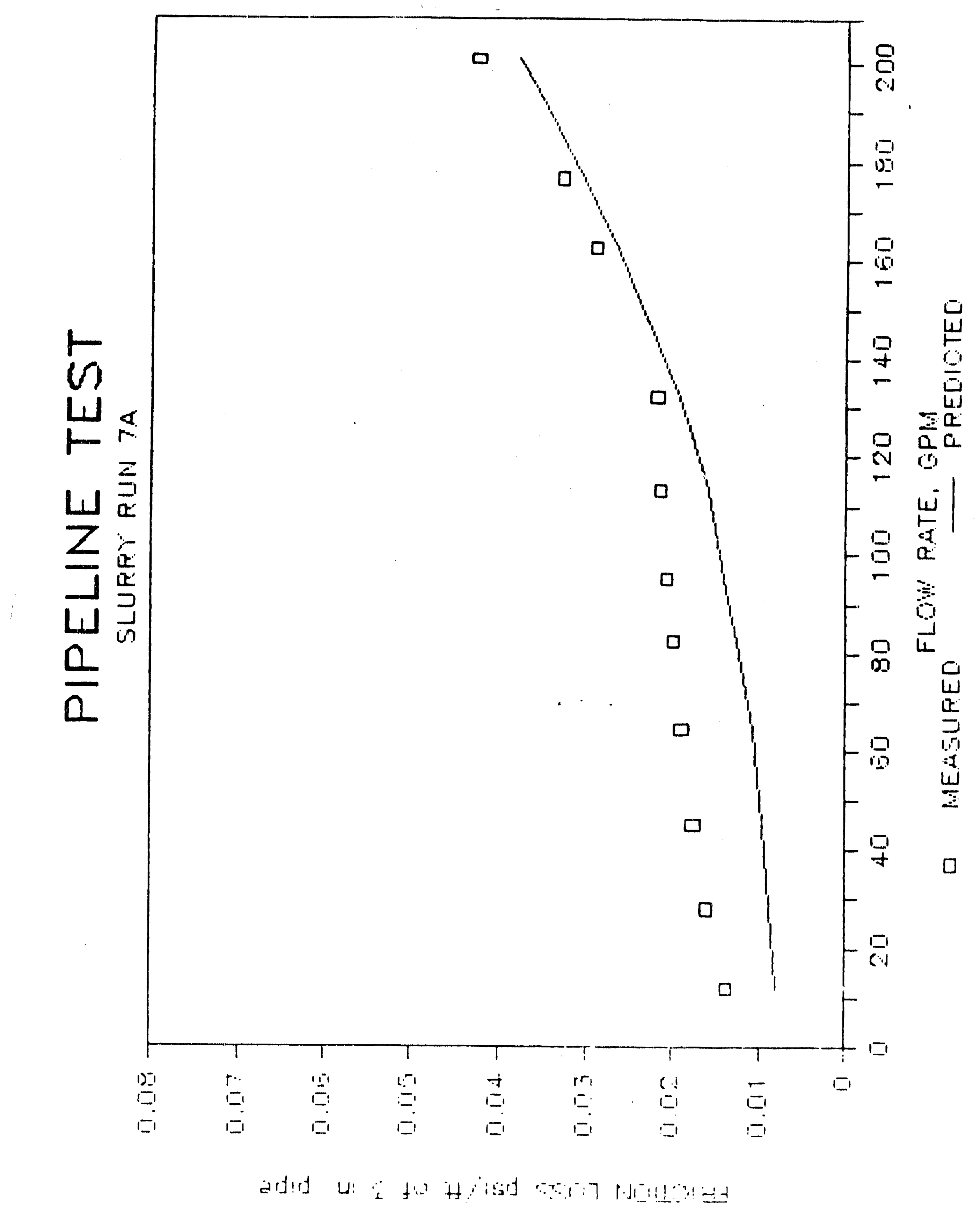

PIPELINE TEST
SLURRY RUN 7A
FLOW RATE, GPM
MEASURED
PREDICTED
0
20
40
60
80
100
120
140
160
180
200
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

FIGURE 10

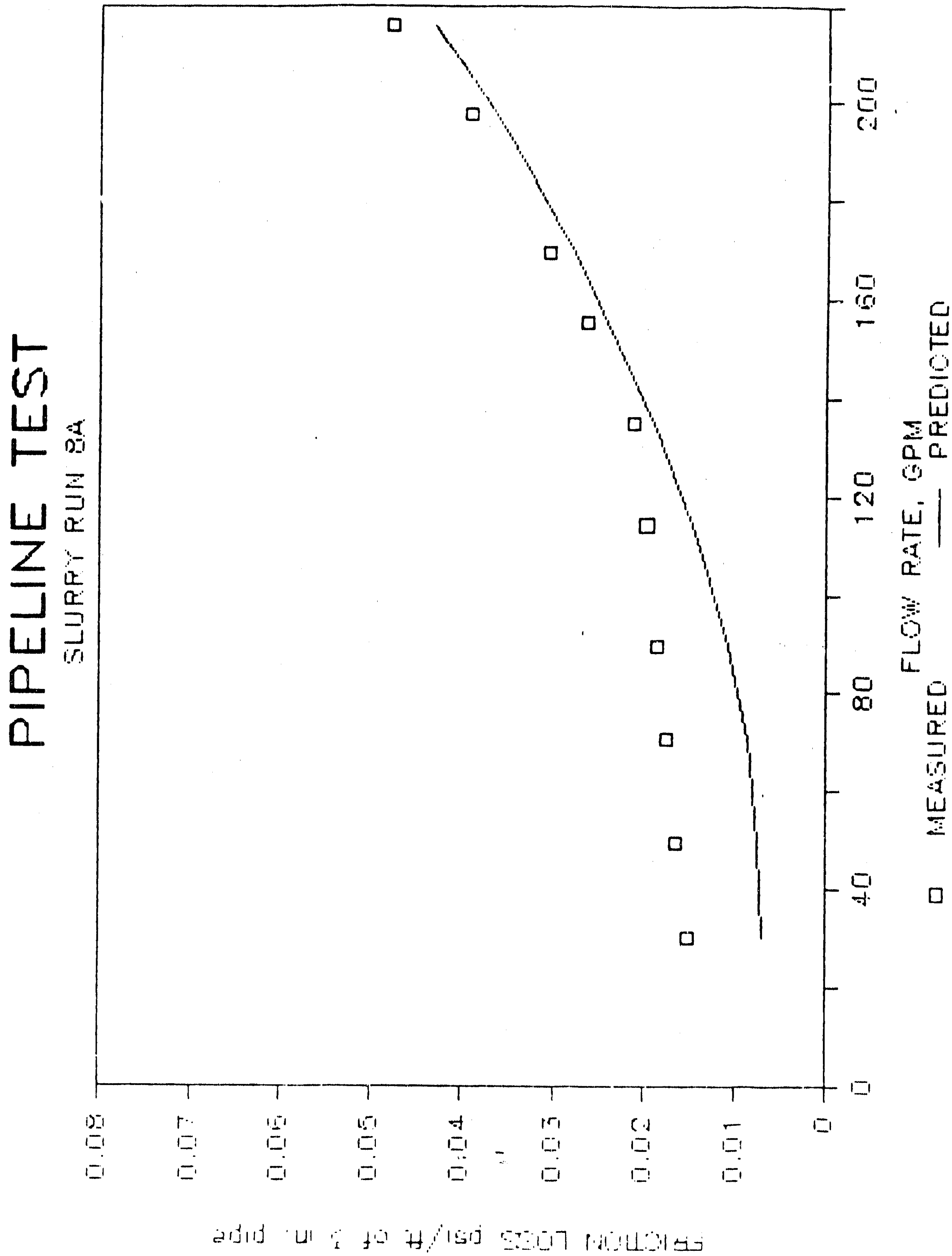
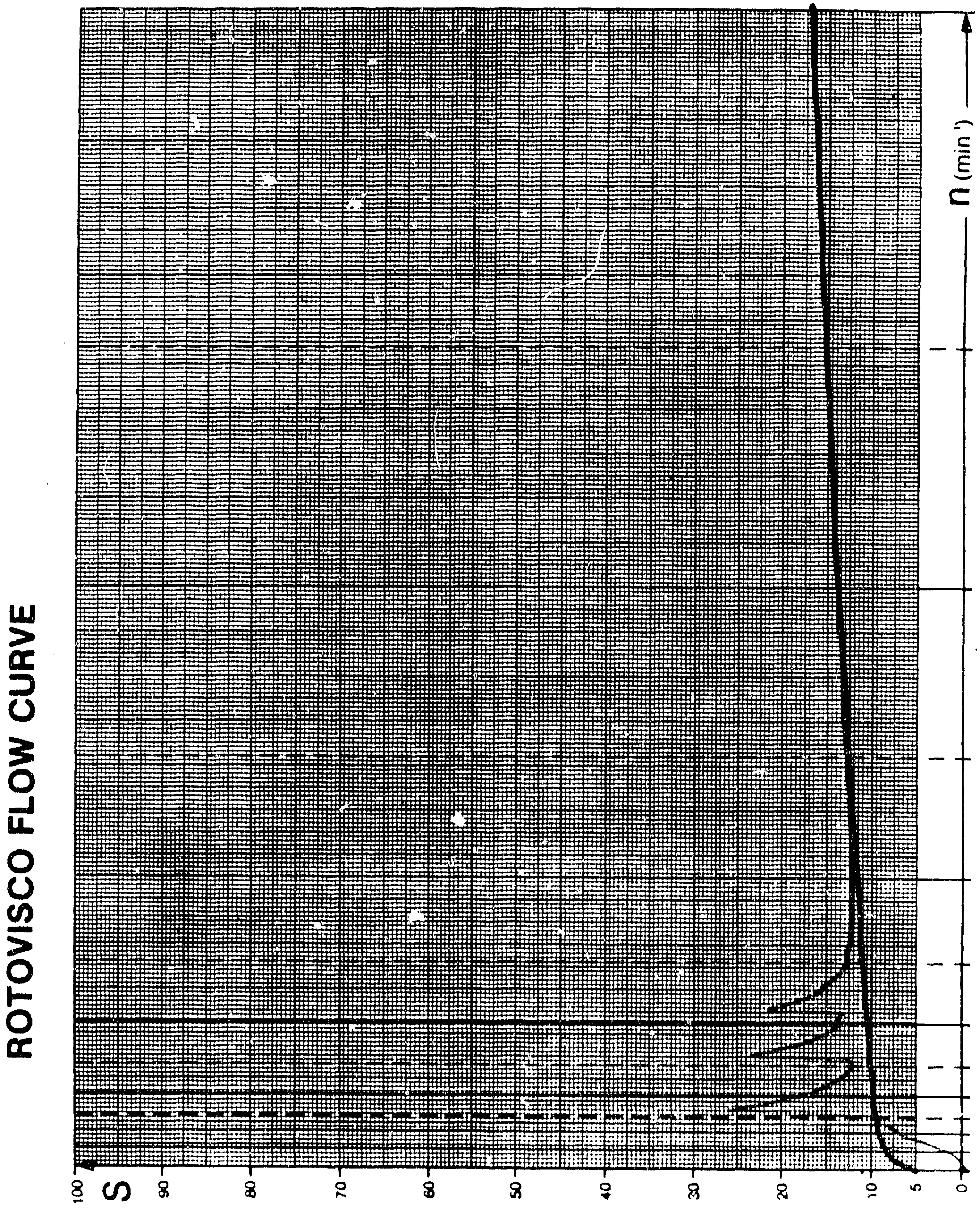

PIPELINE TEST
SLURRY RUN 8A
FLOW RATE, GPM
0
40
80
120
160
200
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
MEASURED
PREDICTED
FRICTION LOSSES psi/ft

FIGURE 11



APPENDIX

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10 'THIS PROGRAM IS TO CALCULATE FLOW RESISTANCE OF BINGHAM PLASTIC FLUID IN A P
IPE LINE.
20 'THE CALCULATION ARE IN CGS UNIT EXCEPT PRESSURE DROP AND HORSE POWER CALCULA
TION WHICH ARE IN BRITISH UNIT.
30 'BUCKINGHAM EQUATION IS USED FOR LAMINAR FLOW REGION, HANKS & PRATT EQUATION
IS USED FOR CRITICAL REYNOLD NUMBER CALCULATION.
40 'THE DIVISION BETWEEN LAMINAR AND TURBUENT FLOW IS BASED ON EQUATIONS DEVELOP
ED BY HANKS & PRATT.
50 DEFINT I-N
60 'INPUT REQUIRED DATA
70 PRINT "D = PIPE DIAMETER, INCHES; Q = FLOW RATE, GPM; ZO = SPECIFIC GRAVITY;E
TA = CONSISTANCY, CP; TAOY = YIELD STRESS, DYNE/CM/CM;DZ = ELEVATION IN FEET,+ F
OR ELEVATION;PL = PIPE LENGTH, FT;LP = 0 OR 1, LINE PRINTER USED 1, ELSE 0
80 READ D,Q,ZO,ETA,TAOY,DZ,PL,LP
90 DATA 3.068,213.9756,1.15, 7, 59,40,5000,0
100 'CALCULATE REYNOLD'S NUMBER
110 DM = D * 2.54 'PIPE DIAMETER IN CENTIMETERS
120 U = 3785 *Q/60/3.14/DM/DM*4  'VELOCITY IN CM/SEC
130 UM = U/30.48
140 PRINT UM
150 ETAM = ETA/100  'CONSISTENCY IN POISES
160 RE = DM*U*ZO/ETAM 'REYNOLD'S NUMBER
170 'CALCULATE HEDSTROM'S NUMBER
180 H = TAOY*DM*DM*ZO/ETAM/ETAM      'HEDSTROM'S NUMBER
190 'PRINT OUT INPUT DATA, REYNOLD AND HEDSTOM'S NUMBER
200 PRINT "      PIPE DIAMETER = ";D;" INCHES"
210 PRINT "      FLOW RATE = ";Q;" GPM"
220 PRINT "      SPECIFIC GRAVITY = ";ZO
230 PRINT "      YIELD STRESS = ";TAOY;" DYNES/CM/CM"
240 PRINT "      CONSISTENCY = ";ETA;" CENTI-POISES"
250 PRINT "      ELEVATION OF PIPELINE = ";DZ;" FEET"
260 PRINT "      LENGTH OF PIPELINE = ";PL;" FEET"
270 PRINT "      REYNOLD'S NUMBER = ";RE;"  HEDSTROM'S NUMBER = ";H
280 IF LP = 0 THEN GOTO 370
290 LPRINT "      PIPE DIAMETER = ";D;" INCHES"
300 LPRINT "      FLOW RATE = ";Q;" GPM"
310 LPRINT "      SPECIFIC GRAVITY = ";ZO
320 LPRINT "      YIELD STRESS = ";TAOY;" DYNES/CM/CM"
330 LPRINT "      CONSISTENCY = ";ETA;" CENTI-POISES"
340 LPRINT "      ELEVATION OF PIPELINE = ";DZ;" FEET"
350 LPRINT "      LENGTH OF PIPELINE = ";PL;" FEET"
360 LPRINT "      REYNOLD'S NUMBER = ";RE;"  HEDSTROM'S NUMBER = ";H
370 'CALCULATE CRITICAL REYNOLD NUMBER
380 XOC = .5 'INITIAL GUESS FOR TAOY/TAOW AT CRITICAL REYNOLD NUMBER
390 F3 = (1-XOC)^3*H/16800-XOC  'XOC EXPRESSION
400 F3P = -3*(1-XOC)^2*H/16800-1   'DERIVATIVE OF XOC EXPRESSION
```

```
410 DXOC = F3/F3P  'DELTA IN ROOT ITERATION FOR XOC
420 XOC = XOC - DXOC  'NEW ROOT FOR XOC
430 IF ABS(DXOC/XOC) > .0001 THEN GOTO 390
440 REC=H*(1-1.3333*XOC+.3333*XOC^4)/XOC/8  'CRITICAL REYNOLD NUMBER
450 'CALCULATE BOUNDARY BETWEEN LAMINAR FLOW AND TURBULENT FLOW
460 IF RE>REC THEN GOTO 620  'TURBULENT FLOW
470 'CALCULATE TAOW FOR LAMINAR FLOW
480 PRINT "      THE FLOW IN THE PIPE IS IN LAMINAR FLOW REGION"
490 IF LP = 0 THEN GOTO 510
500 LPRINT "      THE FLOW IN THE PIPE IS IN LAMINAR FLOW REGION"
510 TAOW = TAOY/.5 'INITIAL GUESS OF SHEAR STRESS AT WALL
520 F1 =TAOW/ETAM*(1-1.3333*TAOY/TAOW+.3333*(TAOY/TAOW)^4)-8*U/DM
530 F1P =1/ETAM*(1-(TAOY/TAOW)^4) 'DERIVATIVE OF BUCKINGHAM EQUATION
540 DTAOW = F1/F1P 'DELTA IN ROOT ITERATION FOR TAOW
550 TAOW = TAOW - DTAOW ' NEW ROOT FOR TAOW
560 IF ABS(DTAOW/TAOW) > .0001 THEN GOTO 520
570 'CALCULATE PRESSURE DROP AND SHAFT HORSE POWER
580 DP =4*TAOW*PL*30.48/DM/980/453.6*30.48*30.48/144+DZ*ZO*62.4/144'PRESSURE DRO
P IN PSI
590 SW =(DP/ZO/62.4*144*Q/60*.13368*ZO*62.4)/550' SHAFT HORSE POWER
600 F =(DP-DZ*ZO*62.4/144)*453.6*980/2.54/2.54/PL/30.48*DM/ZO/U/U/2'FANNING FRIC
TION FACTOR
610 GOTO 890
620 'CALCULATE TURBULENT FLOW TAOW
630 PRINT "      THE FLOW IN THE PIPELINE IS IN TURBULENT FLOW REGION"
640 IF LP =0 THEN GOTO 660
650 LPRINT "      THE FLOW IN THE PIPELINE IS IN TURBULENT FLOW REGION"
660 B1= 157.5/H^.151  'COEFFICIENT B1
661 RER =(REC/14500)^2*20000'BEST PREDICTION OF HANKS MODEL AT THIS RE
662 B1 =(RE/RER)^1.3*B1  'THE CALCULATED B VALUE FOR SLUDGE
663 IF B1 > 35 THEN B1 = 35
669 PRINT B1
670 RC =(2*H/XOC)^.5'Re *F^.5 AT CRITICAL REYNOLD NUMBER
680 XO = .6  'INITIAL GUESS FOR TAOY/TAOW
690 R =(2*H/XO)^.5  'Re *F^.5
700 PHI =(R-RC)/2.8284/B1 'PHI FUNCTION
710 'INTEGRATE THE G FUNCTION
720 DEF FNG(X) =(X^2*(X-XO))/(1+(1+.0648*R*R*(X-XO)*(1-X)^2*(1-EXP(-PHI*(1-X)))
2)^.5) 'NEW G FUNCTION X*X*G
730 AREA = 0  'INITIATION OF INTEGRAL
740 FOR I = 0 TO 29 'INTEGRATE BY DIVIDED INTO 30 INTERVALS
750 A = (1-XO)/30*I+XO  'LOWER INTEGRATING LIMIT
760 B = A+(1-XO)/30 'UPPER INTEGRATING LIMIT
770 GOSUB 1000  'LEGENDRE-GAUSS INTEGRATION SUBROUTINE
780 AREA = AREA + GXS
790 NEXT I
800 XON = H/RE*AREA  'NEW VALUE OF XO
```

```
801 PRINT XON
810 IF ABS((XON-XO)/XON) <.001 THEN GOTO 840
820 XO =(XON + XO)/2
830 GOTO 690
840 XO =(XON + XO)/2
850 TAOW = TAOY/XO
860 DP =4*TAOW*PL*30.48/DM/980/453.6*30.48*30.48/144+DZ*ZO*62.4/144'PRESSURE DRO
P IN PSI
870 SW =(DP/ZO/62.4*144*Q/60*.13368*ZO*62.4)/550' SHAFT HORSE POWER
880 F =(DP-DZ*ZO*62.4/144)*453.6*980/2.54/2.54/PL/30.48*DM/ZO/U/U/2'FANNING FRIC
TION FACTOR
890 'PRINT OUT THE RESULTS
900 PRINT "       FANNING FRICTION FACTOR = ";F
910 PRINT "       TOTAL PRESSURE DROP = ";DP;" PSI"
920 PRINT "       TOTAL SHAFT HORSE POWER REQUIRED = ";SW;" HORSE POWER"
930 IF LP = 0 THEN GOTO 970
940 LPRINT "       FANNING FRICTION FACTOR = ";F
950 LPRINT "       TOTAL PRESSURE DROP = ";DP;" PSI"
960 LPRINT "       TOTAL SHAFT HORSE POWER REQUIRED = ";SW;" HORSE POWER"
970 END
1000 'SUBROUTINE FOR LEGENDRE-GAUSS INTEGRATION
1010 Y =(A+B)/2  'CALCULATE INTERVAL MIDPOINT
1020 Z = ((B-A)/2)*SQR(3/5)  'CALCULATE Z FOR REMAINING ABSCISSAS
1030 GXS=((B-A)/18)*(5*FNG(Y-Z)+8*FNG(Y)+5*FNG(Y+Z)) 'LEGENDRE-GAUSS INTEGRATION
 FORMULA
1040 RETURN
```

END

DATE FILMED

01 / 10 / 91