This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

DISCLAIMER

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED

ATOMIC ENERGY DIVISION
SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29808-0001
(TWX 810-771-2670 TEL 803-725-6211 WU AUGUSTA GA)

DPST-84-850-TL
Project S-1780
LP No. 10212 142288
ACC. NO. ~~146395~~

CC: D. L. McIntosh, 703-A
W. R. Stevens, III, 773-A
E. O. Kiger, 703-A
J. B. Mellen, SF (5)
R. B. Ferguson, 773-A
M. D. Boersma, 676-T
H. D. Martin, 704-T
M. A. Ebra, 773-A
D. C. Witt, 676-1T
M. J. Plodinec, 773-A
E. B. Warming, L11W09
SRL Records (4)

October 31, 1984

J. T. GRANAGHAN, PLANT MANAGER
SAVANNAH RIVER PLANT

ATTENTION: D. C. NICHOLS, 773-29A (5)
SUPERINTENDENT, DWPF LIAISON

DWPF SAMPLING DEVICE DEVELOPMENT
TEST RESULTS AND DESIGN RECOMMENDATIONS

The attached memorandum by M. A. McNeil summarizes the development and testing of a sample device for the DWPF sample cells. The clamp actuated manual Hydraguard valve used in conjunction with the concentric needle fill device is recommended for use in the DWPF. This is based on test results which indicate that this sampler is capable of obtaining samples within 5% of the solids concentration of the process stream at flow rates from .5 to 3.5 gpm. Additional work is underway to demonstrate the sampler throughout the full BDR range. When this work is completed, results will be transmitted. Any questions should be directed to Mark McNeil (725-6430).

G W Wilds

G. W. WILDS, RESEARCH MANAGER
WASTE PROCESSING TECHNOLOGY DIVISION

MAMcN:tks
Att

DPST-84-850
ACC. NO. 146395
Keywords: Sampling
Hydraguard
Fujikin
Concentric Needle

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

CC: W. R. Stevens, III, 773-A
G. W. Wilds, 773-A
M. D. Boersma, 676-T
M. J. Plodinec, 773-A
D. C. Witt, 676-1T
M. A. Ebra, 773-A
L. F. Landon, 704-T
J. R. Fowler, 704-T
F. M. Heckendorn, 704-T
SRL Records (4)

October 29, 1984

M E M O R A N D U M

TO: H. D. MARTIN, 704-T

FROM: M. A. McNEIL, 704-T Mark

DWPF SAMPLING DEVICE DEVELOPMENT
TEST RESULTS AND DESIGN RECOMMENDATION

Summary and Recommendations

Candidate sampling devices were tested in the Sample Loop Demonstration Facility at TNX. Test results show that the Hydraguard and Fujikin devices tested are capable of obtaining samples whose weight percent solids vary no more than 5% from that of the sample stream when a flow velocity is mainted between .42 and 4.7 fps through 3/4" tube. However, a velocity of up to 10 fps is allowed in the DWPF basic data. Testing has indicated that with low rheology slurries (τ_y = 130 dynes/cm^2) the weight percent solids of the captured sample decreased with increasing velocity

and extrapolation of the data thus far collected indicates that an error of -10% may result with thin slurries at the maximum 10 fps velocity. Further work in this area is recommended. The sampling results discovered during high rheology tests suggest that piping configuration upstream of the sampler affect the performance of the sampler.

The lighter weight and compact size of the manual Hydraguard has made it the leading candidate for the sample valve. Containerization - filling the 15 ml sample vials - has been demonstrated using a concentric needle device developed specifically for this application. The unit was used in all tests and on the rare occasion of pluggage, this could usually be attributed to deviation from prototypic standard in terms of its operation or installation. Figure 4 shows the installation recommended for the DWPF.

Introduction

The program objective was to develop and demonstrate a device capable of obtaining representative samples of DWPF process streams using highly reliable equipment with the simplest reasonable operation. In the DWPF, small 3-10 gpm sample streams are pumped from each of the canyon vessels to a sample cell using a recirculating loop centrifugal pump as indicated in Figure 6. In the sample cell manipulators are used to operate in line samplers mounted on each process stream coming from the canyon. This report addresses work done on the development of that device.

The sampling device must serve two functions; extraction - removal of a volume of material from the process line, and containerization - the admission of a sample volume into the sample vial. Three extraction devices were tested and one containerization scheme was used for all tests. For each series of tests the accuracy and precision of each device was measured using weight % solids analysis as the primary basis.

Equipment

Four different extraction devices were tested. However, three of them were different versions of a single concept. The four devices tested are listed here:

Extraction Device	Tests
1. Commercial Hydraguard (Figure 1)	Low Rheology
2. Pneumatic Modified Hydraguard (Figure 2)	High Rheology
3. Manual Modified Hydraguard (Figure 3)	High Rheology
4. Fujikin Ceramic Valve (Figure 7)	High Rheology

Hydraguard Valve:

The Hydraguard valve (Unit #1) is a commercially available device which was modified by shortening the barrel length for the low rheology tests. The unit was completely redesigned to make it smaller and easily installed in a tubing system using Swagelok fittings. The reworked versions were purchased in a manual and pneumatic format (Units #2 & 3). Unit #4 is simply a Fujikin 2-way ball valve, which is the leading candidate for on/off valve application in the DWPF. The units were installed as indicated in Figures 1 and 5.

Mechanically, all units performed well. The manual Hydraguard did not seal completely against water although no leaks were noted in slurry service. This could have been the result of damage inflicted as the unit was modified for installation or it may be that the force of the spring does not create a tight enough seal. This problem led to the development of a manual Hydraguard with a clamp type closure mechanism (Figure 4) which allows the user to supply significantly more closure force. Both a manual and a pneumatic Hydraguard were tested. No difference in results were anticipated since the process flow paths of both units were essentially identical. The Hydraguard valve is easily installed using a standard 3/4" Swagelok tee. A complete manual Hydraguard installation is 5# lighter than the Fujikin valve (see Appendix A).

Fujikin Valve:

The Fujikin valve is a simpler device than the hydraguard and has the advantage of already being used elsewhere in the sample cell. This valve is the leading candidate for on-off valve service in the sample cell and has performed well as a sampling valve. In this valve, sealing is accomplished by a ceramic ball forced by line pressure against a ceramic seat. The use of Al_2O_3 ceramic makes the valve far less susceptable to frit erosion. However, the valve's sealing ability under low line pressures is suspect.

The chief mechanical disadvantage of the Fujikin valve is the requirement of flange and gasket use due to its sandwich type construction. It also does not lend itself as well to installation in a vertical run of pipe. Figure 5 shows that a longer length of vertical pipe is required for installation. A pneumatic version of the Fujikin valve was used but no difference is anticipated using a manual valve.

Using pneumatic actuation for either type sampler can simplify the sampling operation as electronic controls could then be used to open the device, allow recirculation for a set length of time and then close the device - all with the "push of a button". The pneumatics would however add complexity and additional tubing to an already overcrowded condition in the sample cell. The problem of additional pipe could be avoided by using a solenoid actuated hydraguard. However, one of this type has not been tested.

Containerization Device:

The containerization device used is a modification of a concentric needle device currently in use at Oak Ridge National Laboratory and is indicated in Figure 8 and detailed in Figures 9, 10, and 11. The chief concern with the use of this device centered around the size of its flow paths which are as small as .0825". Despite this, the unit performed quite well plugging fewer than 10 times out of more than 270 times that samples were taken. In all but three instances the plug could be freed by either forward or back flushing. Only forward flushing is available in DWPF. In three instances the device had to be rodded by inserting a probe through the flow path of the smaller needle. This was easily accomplished and it is conceiveable that this could be done by a manipulator if necessary.

One characteristic of this device is that with high rheology slurries the sample vial was routinely not completely filled with slurry. In essentially every case approximately 25% of the volume of the vial was air. This turned out to be advantageous from an analytical standpoint. With low rheology slurries the sample bottles would be completely filled making it difficult to rehomogenize in the lab. The absence of air in the vial made it difficult to "shake-up" the sample and if a spatula or stirring rod was inserted, some of the sample would spill over. This difficulty was reflected in that the standard deviation of the wt% solids analyses for the low rheology 15 ml samples was 10 times that for the low rheology dip samples where approximatley 100 ml were collected in 200 ml bottles.

The sample vials will be equipped with dual sceptum caps. As depicted in Figure 8, the outer most sceptum will have a circular hole which will allow tight sealing of the bottle when mounted on the needles. The inner sceptum will be slit to allow the needle to pass through however when the vial is removed this sceptum is expected to seal the bottle. One such sceptum was available for testing. In low rheology slurry no leaking was evident during sampling and sealing was complete when the bottle was removed. There was, however, a small residue of slurry on the outer surface of the inner sceptum after the vial was removed. Also a fairly large amount of force (>5#) was required to remove the vial from the needles.

The two design constraints for the sample device were that (1) there must be a means of containing the vial in case of rupture or shatter due to operating pressure and (2) to provide a positive hold on the vial so that it cannot be forced off the needle by line pressure. Item #1 was accomplished by providing a plexiglass shroud for the vial as detailed in Figure 12. The schroud totally encloses the vial except where the concentric needles enter. To accomplish Item 2, a "U" clamp was attached to the concentric needle device as indicated in Figures 10 and 11. A letter from M. A. McNeil to D. G. Kilpatrick dated 2-6-84 summarized all design constraints for the sampling device. Both the Hydraguard and the Fujikin valve configured as indicated above can meet essentially all requirements.

Testing

In all tests the concentric needle containerization device was used in conjunction with one of the candidate extraction devices. The 15 ml of material collected by the sampler was compared with a 100 ml reference sample and measurements of accuracy and precision were made. Accuracy and precision - as used in this report - is defined as indicated below:

$$A = \frac{\bar{x} - \bar{x}_R}{\bar{x}_R}$$

where:

A = accuracy

$\bar{x}$ = mean value of analyses of material from sampler

$\bar{x}_R$ = mean value of analyses of reference sample

$$P = \frac{SDEV}{\bar{x}}$$

where:

P = precision

$SDEV$ = standard deviation

$$\left[\frac{1}{n-1} \sum_{i=1}^{N} \left(x_i - \bar{x} \right)^2 \right]^{.5}$$

$\bar{x}$ = mean value of anlayses of material

In all cases, the samples were analyzed for weight percent (wt%) solids and density at three different flow rates. Due to previous discussions with DWPF Liaison members, primary consideration was given to weight percent solids analysis results. Actuation time for each of the units was typically 3-5 seconds.

The 677-T analysis lab makes two wt% solids measurements for any sample sent to the lab. In the results these are reported separately as "% solids 1" and "% solids 2". The first set of tests were done using the commercial Hydraguard valve only with low rheology slurry. (τ_y = 128, η= 13). In the second set, the manual and pneumatic Hydraguard valves and the Fujikin valve were tested using high rheology slurry (τ_y = 260, η = 19). Various differences between the low and high rheology test set-ups are indicated in their respective sections of this report. The summary of the test results in graphic and tabular form is included as Appendix C.

Low Rheology Tests:

The test set-up is as indicated in Figure 1. Ninety samples were drawn using the commercial Hydraguard valve in slurry with yield stress = 128 dynes/cm^2 and consistency = 13 cp. The pressure at the sampling device varied between 9 and 35 psig. To expedite the tests a nonprototypic arrangement was used which was worse than that recommended for the DWPF in terms of flow path, internal diameter, length, and irregularities. The location of the flush water was such that the concentric needle device could be flushed without flushing the hydraguard. This entire series of tests was conducted without routine flushing of the Hydraguard valve.

Test results show a strong correlation between the sampler's accuracy and precision measurements for wt% solids and the flow rate of the process stream. At .4 gpm flow rate the average mean accuracy = +1% at 2.2 gpm the accuracy = -1.5% and at 4.4 gpm the accuracy = -5%. For the same flowrates the precision measurement moves from 4.5% to 6.5% to 9.8%. In the DWPF slurry streams of this nature will flow at 3 fps. However the frit water stream may flow as fast as 10 gpm. Extrapolation of the available data indicates an error of -10% at this rate. The flow path into the sampler is perpendicular to the main flow. As the velocity in the process line increases it seems reasonable that fewer of the suspended particles can make the turn into the sampler. It may be possible to "tune" each sample pump using its variable speed drive and/or main stream restrictor to provide lower flow rates.

The accuracy and precision of the density measurement did not clearly correlate to the flow rate. For each of the 3 flowrates in increasing order the mean accuracy was +4.7%, -.9%, and -.8% and the mean precision was 5.4%, 3.6%, and 3.9%.

The weight % solids precision results for dip samples were an order of magnitude better than the same results from the Hydraguard samples. Two ml are extracted from a sample volume to do wt% solids analyses. With dip samples the sample consists of a half full 200 ml bottle which the technician shakes to homogenize the sample prior to taking the 2 ml for analysis. The 15 ml sampler vials are always completely filled with slurry making it difficult to homogenize by shaking. The precision of sampler samples seems to be affected by this inability to adequately reslurry the material in the vials. This problem could be solved by using a mechanical shaker or vibrator which does a better job of reslurrying than shaking by hand.

As several other potential solutions to this problem exists, it is not considered serious. To be sure that the disparity between the precision results actually was caused by the difficulty slurrying, both a large and a small - 15 ml - reference sample was taken for each sampler sample taken during the high rheology material tests.

High Rheology Tests:

The test set up is an indicated in Figure 5. Twenty samples were drawn from each of the sampling devices at each of three flow rates: .8 gpm, 1.4 gpm, and 3.2 gpm. Twenty large reference, samples were taken at each of the flow rates and, for reasons mentioned earlier, twenty 15 ml reference samples were also taken during each run. Accuracy was determined with respect to the large reference samples. The slurry being sampled had a yield stress of 260 dynes/cm^2 and a consistancy of 19 centipoise. The flow path of the material entering the sampler was very close to that recommended for the DWPF. The pressure at the sampler was varied between 13 and 40 psig.

The test results show no correlation between flow and sampler accuracy or precision for either weight percent solids or density analysis. In every instance for weight percent solids analysis the accuracy of the samples from the samplers was $\pm$2% and sampler precision stayed below 3%. The precision of the large reference sample was .5%. For density analysis the accuracy and precision of the samples was typically worse than for weight percent solids analysis. The Fujikin valve accuracy was the worst averaging +6.3%. This was probably due to its mounting design whch had the flow entering the branch of a tee and moving either up through the rest of the sample loop or down into the sampler. It is reasonable that some segregation may occur in this set-up with the more dense split moving downward. It would also seem that the weight percent solids would be affected in the same way, however this effect was not observed.

The % solids accuracy of the small reference samples during the series of tests run at 1.4 gpm averaged 4.5%. Because this deviates so markedly from the -2% and .6% accuracy from the other phases of the test is is assumed that the unusually hgih figures are the result of operator error.

The average absolute value of the pneumatic Hydraguard's accuracy was .3% while that for the manual Hydraguard was 1.3% for weight percent solids analysis. Since the only difference between these two samplers from the aspect of the process material is the location in the line this result indicates that location of the sampler with respect to up stream piping configuration will affect its performance.

Follow-up

The folloing additional testing is recommended to better predict and improve the accuracy and precision of the Hydraguard sampler.

- o Low rheology tests using a more prototypic arrangement.
- o Frit-water tests.
- o Tests to determine if actuation time or line pressure affects results.

The above tests would need to be conducted in a facility which nearly duplicates the in cell configuration of the sample piping. Such facilities will be available in the full scale mock-up of the SRAT/SME at TNX.

MAMcN:tks
Att

BY M.A. McNeil DATE 10-29-84 | SUBJECT DWPF SAMPLING DEVICE DEVELOPMENT | SHEET NO. 1 OF 1
CHKD. BY ______ DATE ________ | COMMERCIAL HYDRAGUARD INSTALLATION | JOB NO. DPST-850

FIGURE # 1

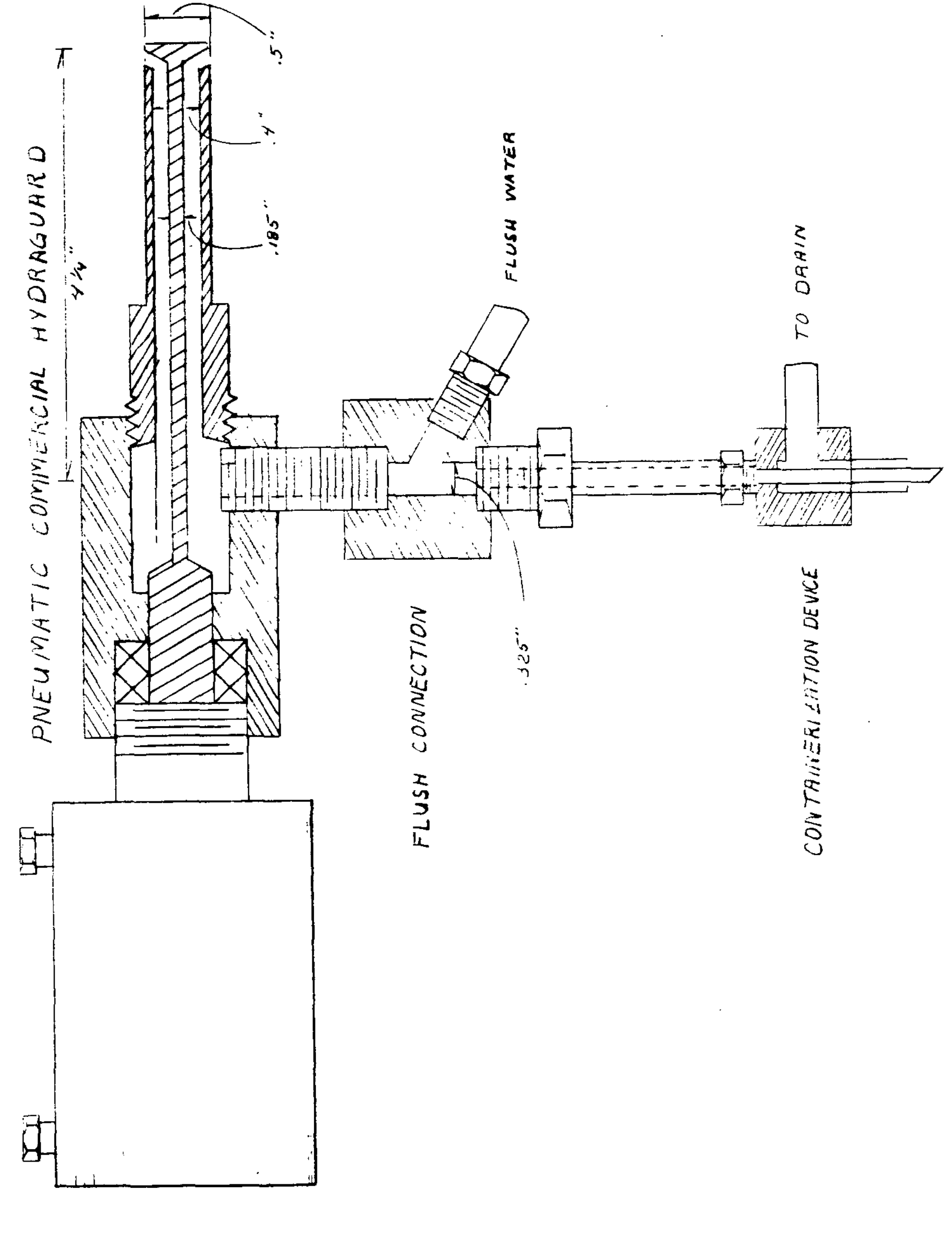


FIGURE 2

HINDS INTERNATIONAL, INC.
P. O. Box 4327
PORTLAND, OREGON 97208
(503) 234-7411

JOB CYLINDER - OPERATED PL-1; MODIFIED
SHEET NO 3.3-184 OF
CALCULATED BY DATE 2-13-84
CHECKED BY DATE
SCALE NONE

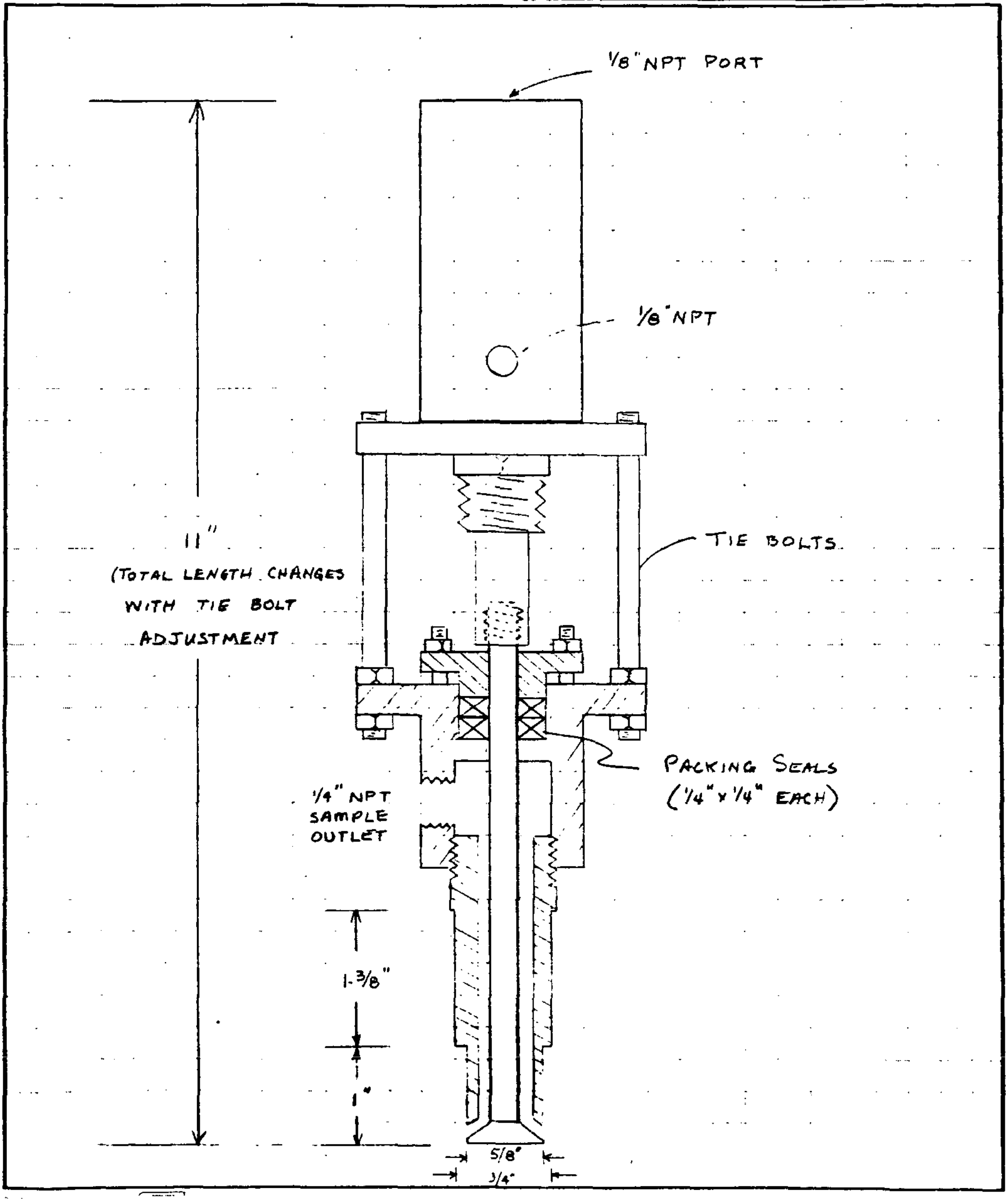
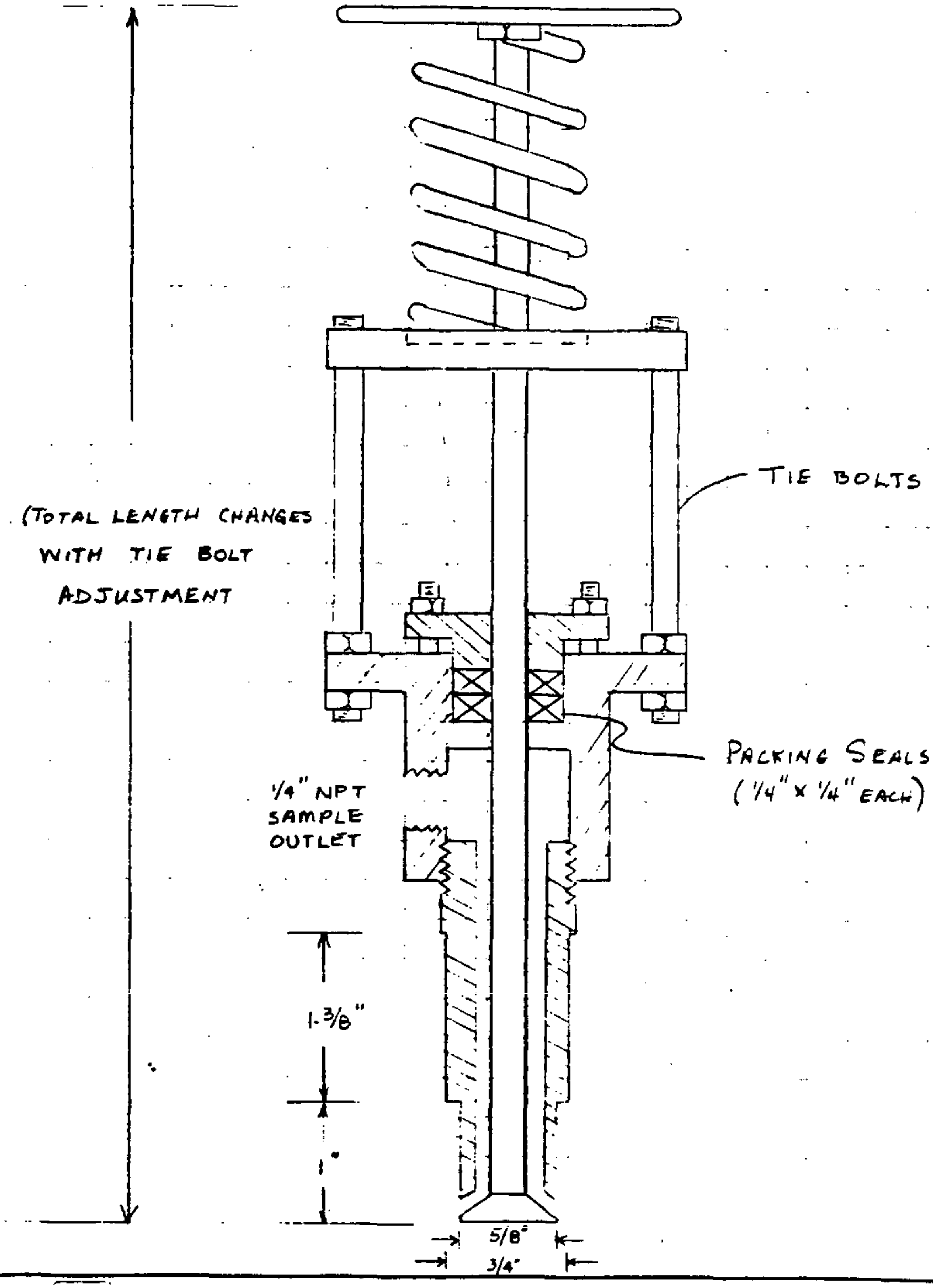


FIGURE 3

HINDS INTERNATIONAL, INC.
P. O. Box 4327
PORTLAND, OREGON 97208
(503) 234-7411

JOB MANUAL OPERATED PL-1; MODIFIED
SHEET NO 3.3-284 OF
CALCULATED BY DATE 2-13-84
CHECKED BY DATE
SCALE NONE



BY M.A. McNEIL DATE 10-26-88 SUBJECT DWPF SAMPLING DEVICE DEVELOPMENT SHEET NO. 1 OF 1

CHKD. BY ______ DATE ______ JOB NO. DPST-

FIGURE 4 RECOMMENDED SAMPLER CONFIGURATION

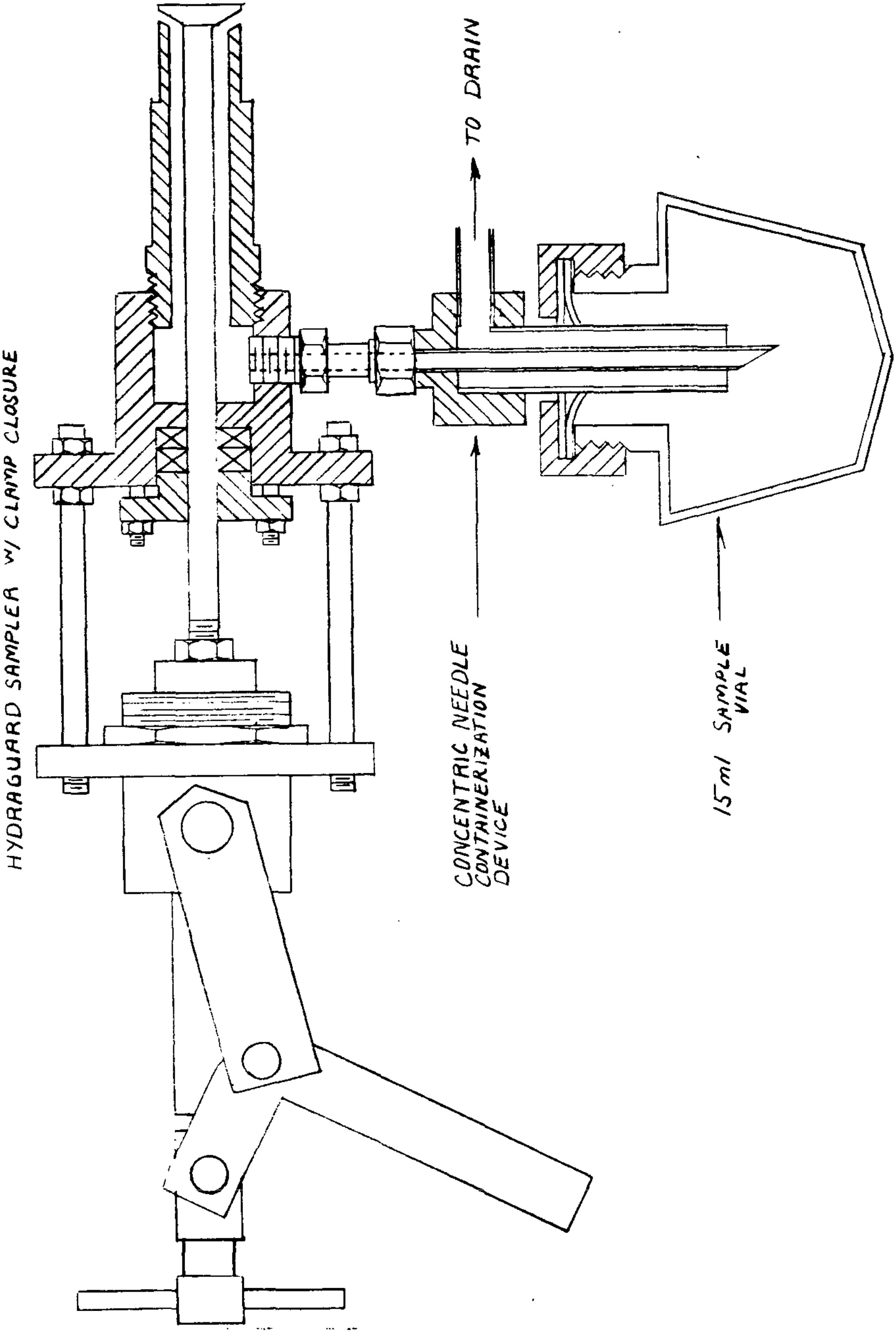


FIGURE 5

HIGH RHEOLOGY TEST INSTALLATION

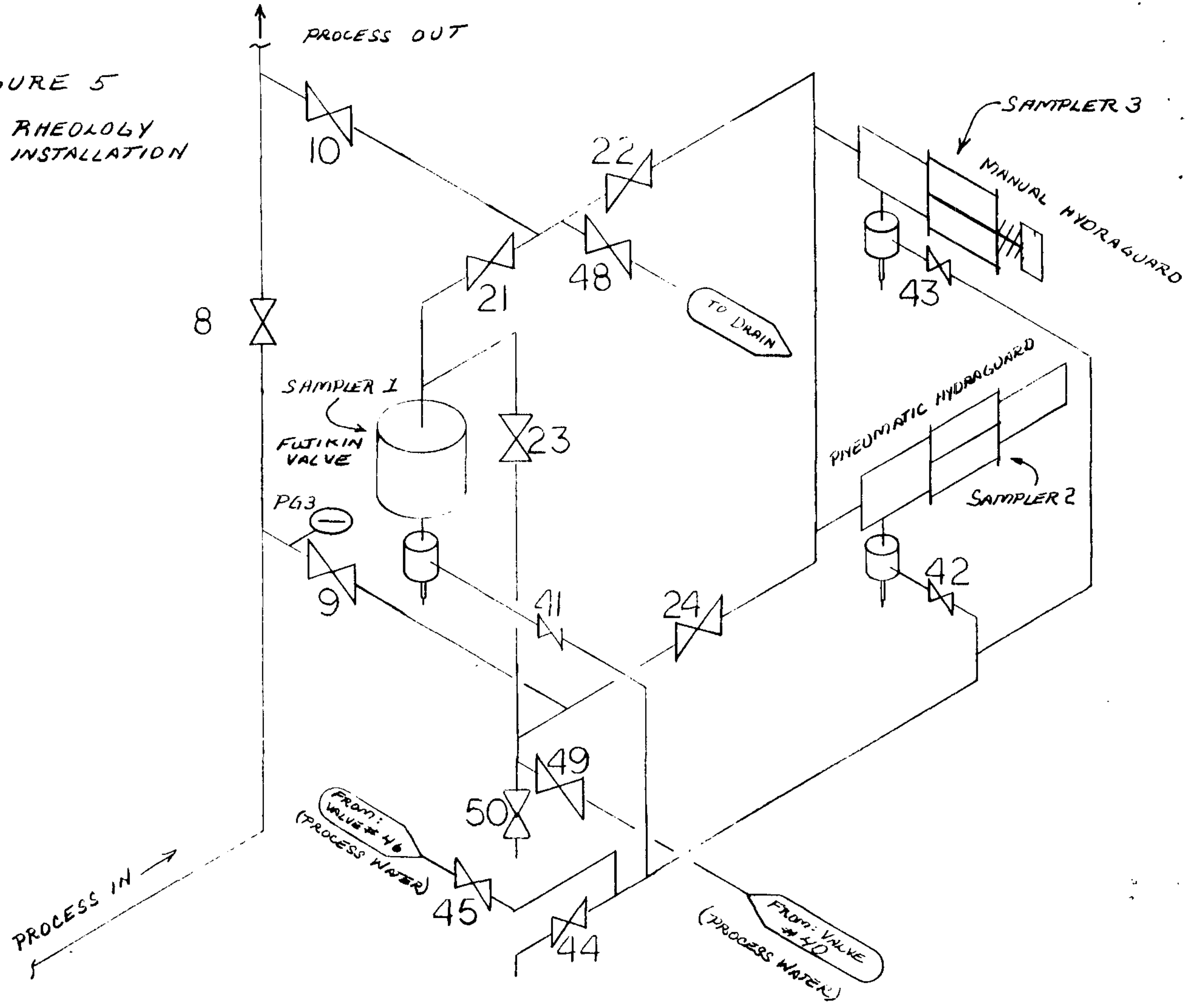
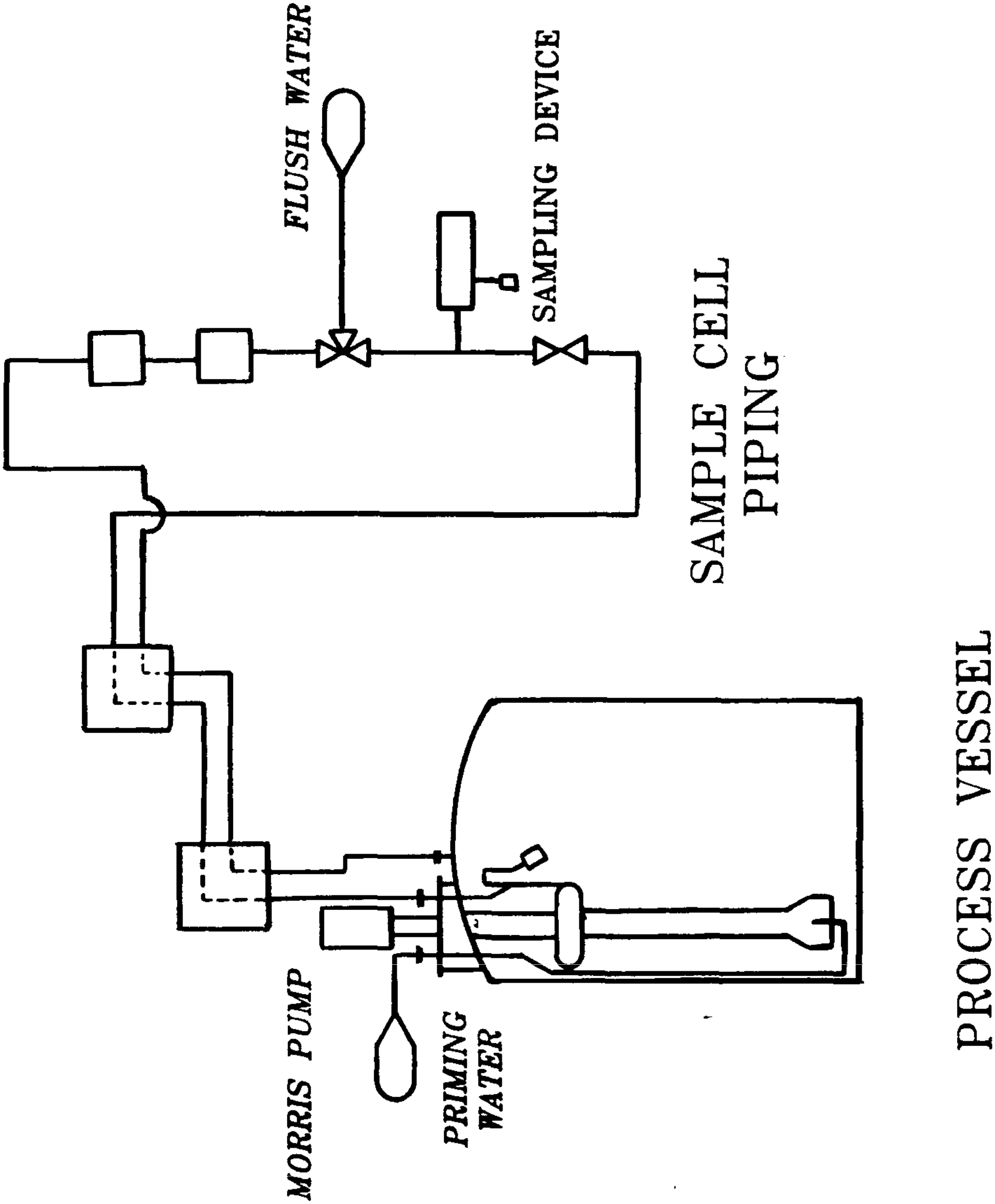
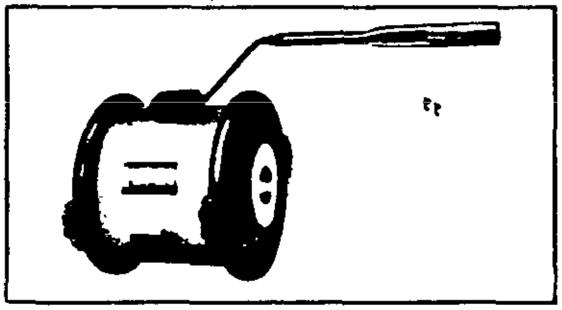


FIGURE 6

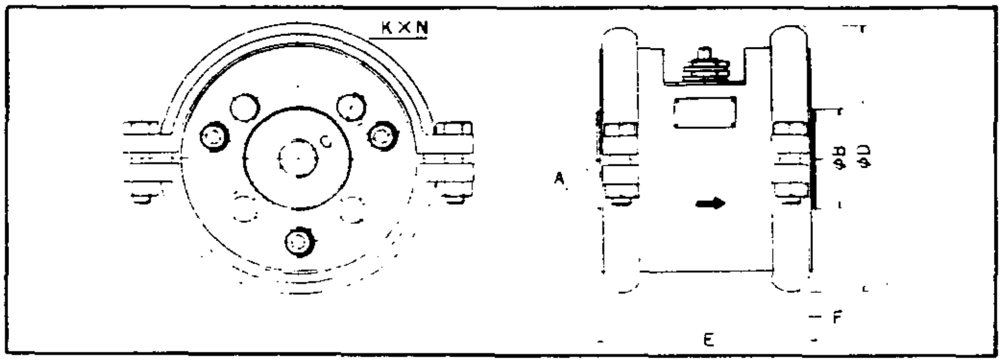

FLUSH WATER
SAMPLING DEVICE
SAMPLE CELL
PIPING
PROCESS VESSEL
MORRIS PUMP
PRIMING
WATER

FINE CERAMIC(ALUMINIUM OXIDE: Al_2O_3) BALL VALVES

Manual ON – OFF Operation



Size(Inch)	Allowable Torque
½ B	50 kg·cm



Remarks

1. *SUS 316 stainless steel stem is standard.*
2. Fine Ceramic stems are also available.
3. Torque to the Fine Ceramic stem should be lower than the allowable values given in the table above.
4. Fine Ceramic valve seat is standard.

Material Table

Part No.	Name of Parts	Material	Part No.	Name of Parts	Material
1	Socket (1)	Fine Ceramics	12	Teflon Seat	Teflon
2	Socket (2)	Fine Ceramics	13	Seat Packing	Carbon Teflon
3	Valve body	Fine Ceramics	14	Seat Packing	Teflon
4	Ball	Fine Ceramics	15	O-Ring	Teflon
5	Stem	SUS316	16	Packing Gland	Teflon
6	Cylinder	STPG	17	Gland Nut	SUS304
7	Inlet Flange	SS41	18	Lock Nut	SUS304
8	Outlet Flange	SS41	19	Clamping Ring	SCS13
9	Through Bolt	SUS304	20	Hex. Bolt	SUS304
10	Square Nut	SUS304	21	Hex. Bolt	SUS304
11	Disc	SUS304			

Dimensional Table (Applicable to all drawings)

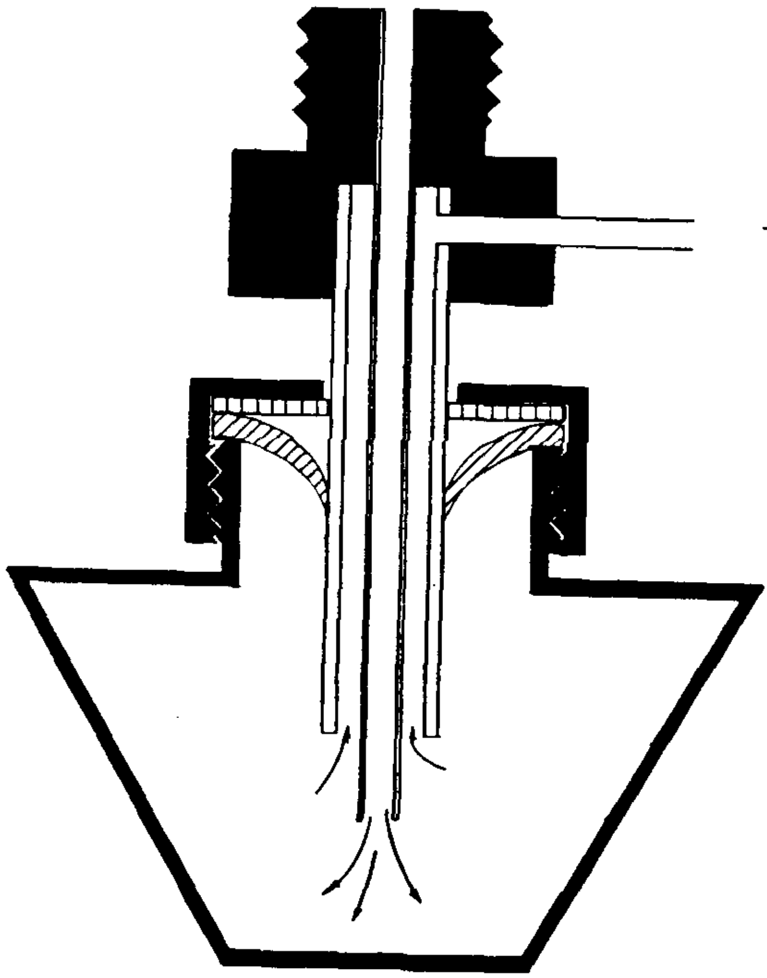
Dimensions / Size (Inch)	A Port	B	D	E	F	JIS 10K			ANSI(API)150			DIN 10K			Code No.	Weight (kg)
						C	K	N	C	K	N	C	K	N		
½ B	14	42	112	90	1.5	70	M12	4	60.5	W½	4	65	M12	4	CBV-2150D	3

*Dimension A is port diameter.

FIGURE 7

*Note: Due to technological improvements, material and dimensions

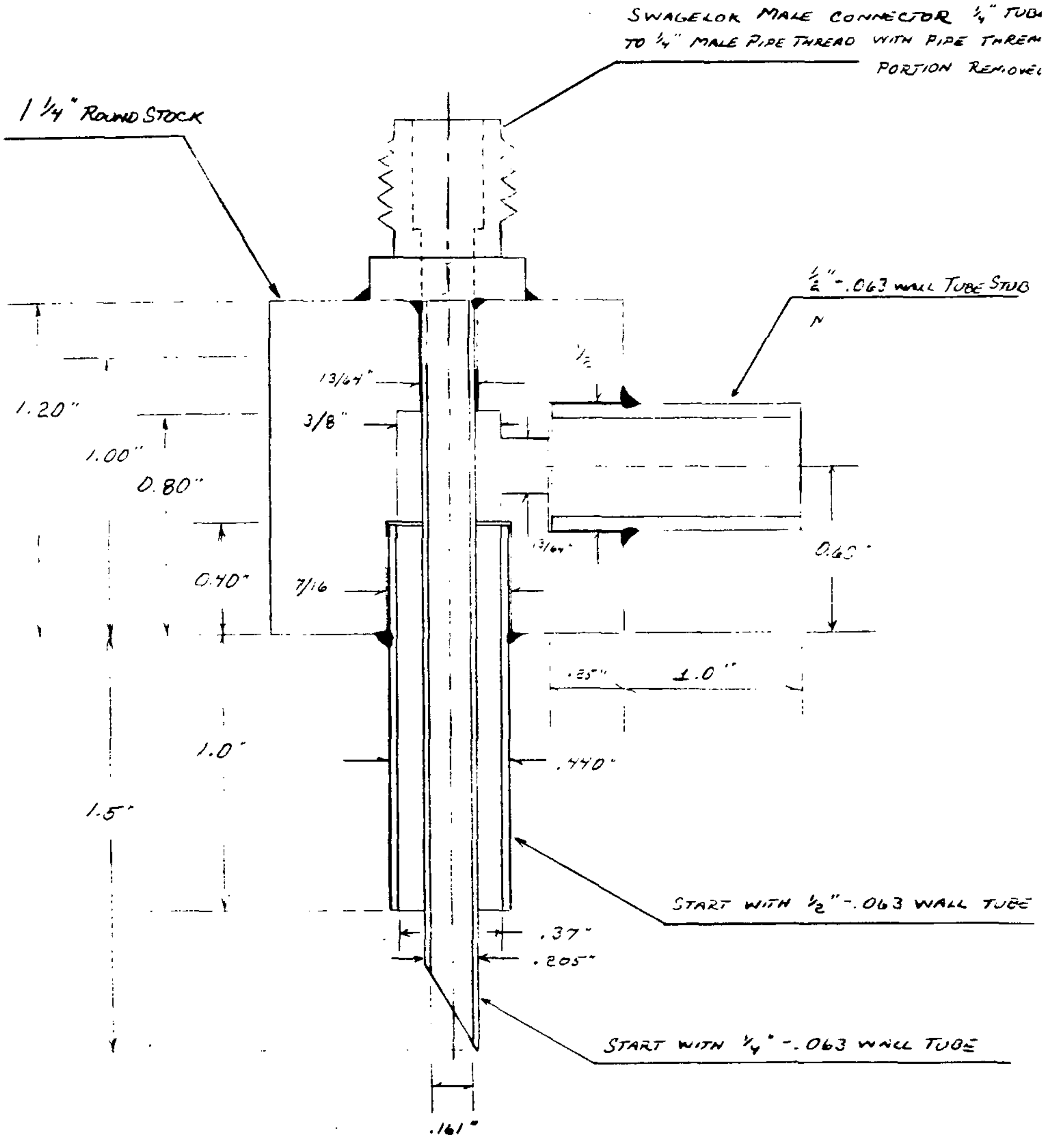
FIGURE 8



OAK RIDGE NATIONAL LABORATORY

CONTAINERIZATION DEVICE

FIGURE 9



SWAGELOK MALE CONNECTOR 1/4" TUBE TO 1/4" MALE PIPE THREAD WITH PIPE THREAD PORTION REMOVED
1 1/4" ROUND STOCK
1/2" -.063 WALL TUBE STUB
1/2
13/64"
3/8"
1.20"
1.00"
0.80"
0.40"
7/16
13/64"
0.65"
.25"
1.0"
1.0"
.440"
1.5"
START WITH 1/2" -.063 WALL TUBE
.37"
.205"
START WITH 1/4" -.063 WALL TUBE
.161"

FIGURE 10

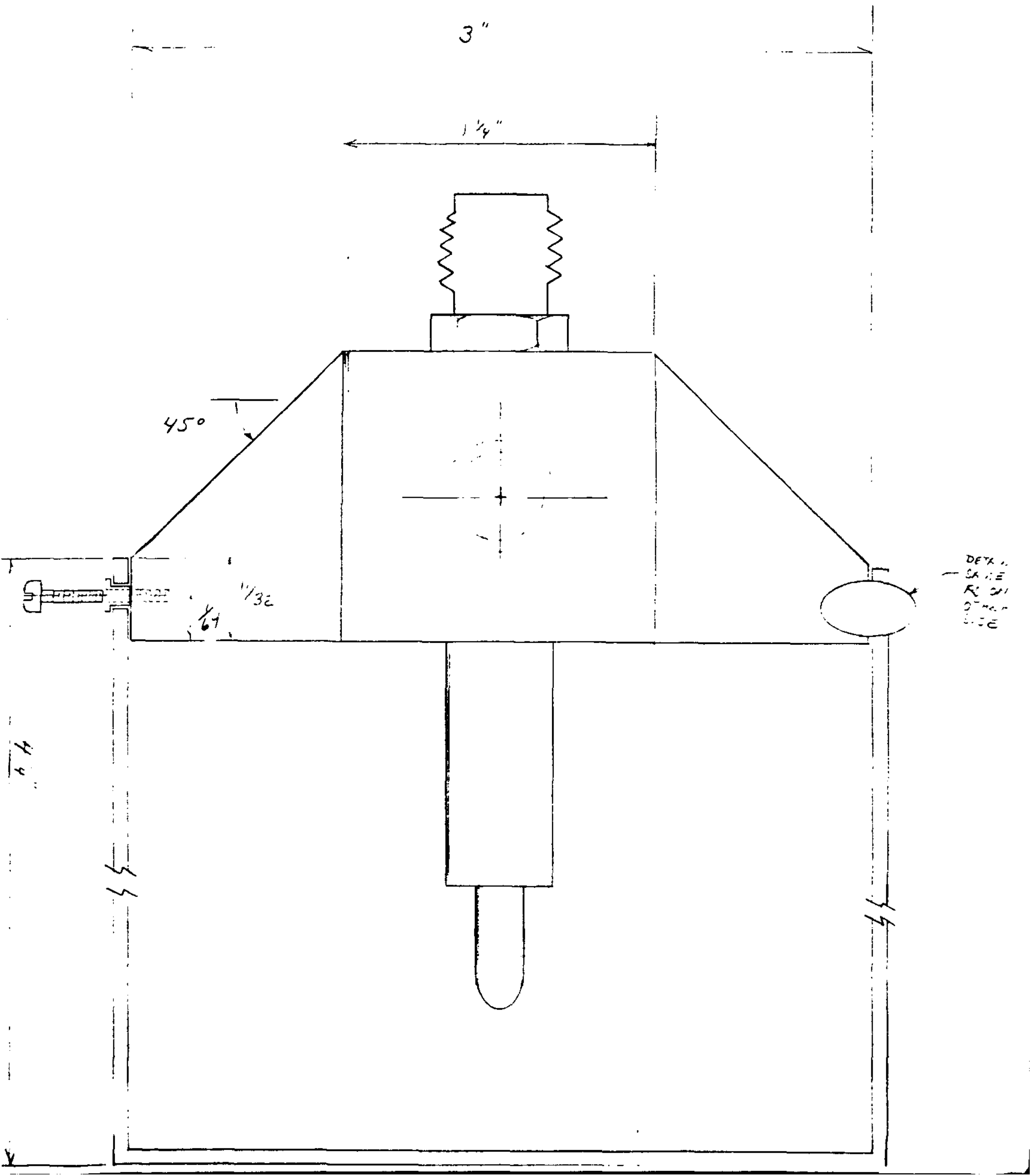


FIGURE 11

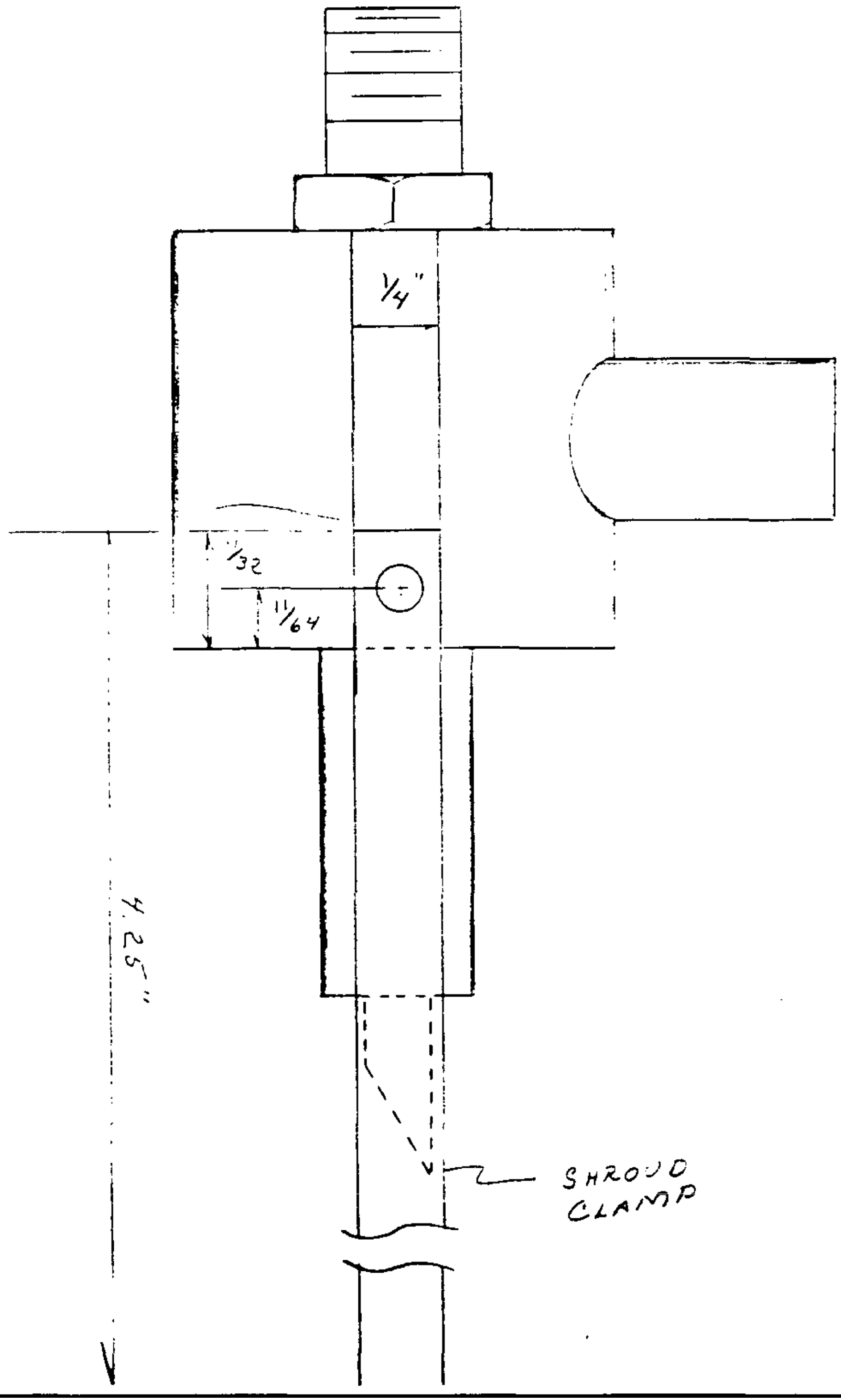
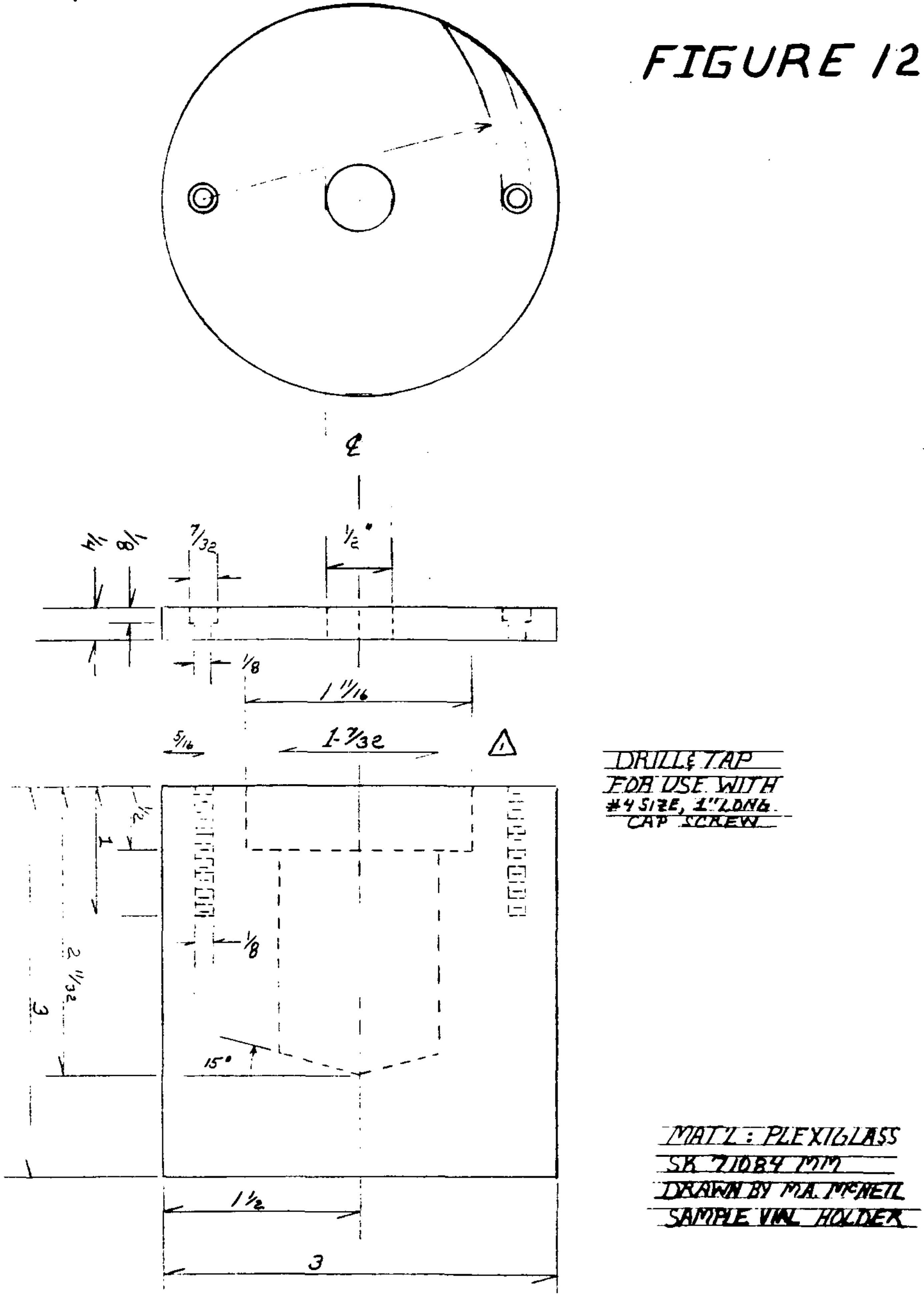


FIGURE 12



⚠ DIMENTION WAS 1-3/16

DWPF SAMPLING DEVICE DEVELOPMENT — DPST-850
SAMPLER DEVICE WEIGHTS — SRL-TNX
APPENDIX A — MA McNEIL — 10-28-84

EXTRACTION DEVICES

MANUAL HYDRAGUARD W/CLAMP

4 #

FUJIKIN VALVE

7 #

ALL METAL AIR CYLINDER
(FOR PNEUMATIC VERSION)

4.7 #

FLANGES & BOLTS REQ'D
FOR INSTALLATION

2.7 #

CONTAINERIZATION DEVICE

CONCENTRIC NEEDLE

.8 #

SHROUD

.9 #

VIAL W/ CAP

.1 #

ENTIRE ASSEMBLIES

MANUAL HYDRAGUARD W/CLAMP ASSEMBLY	5.8 #
PNEUMATIC HYDRAGUARD ASSEMBLY	9.5 #
FUJIKIN VALVE (MANUAL) ASSEMBLY	11.5 #

SAMPLE SENSE DEVELOPMENT [illegible]
FLOW CALCULATIONS [illegible]

APPENDIX B — M A McNEIL 8-1 84

DETERMINE VELOCITY AT FLOW RATES AND OTHER CONDITIONS LISTED.

TUBE SIZE $3/4''$ - 65 MILL WALL (.62" ID)
DENSITY (ρ) = 1.47 g/cc
FLOW = .8, 1.4, 3.2 GPM

[illegible]

$V = q/A$ WHERE: V = VELOCITY IN ft/s
q = FLOW RATE IN ft³/s
A = AREA IN ft²

$A = \pi d^2/4$ WHERE d = ID

$= \pi [(.62 \text{ in})(1 \text{ ft}/12 \text{ in})]^2 / 4$

$= 2.097 \times 10^{-3} \text{ ft}^2$

$q_1 = .8 \text{ GAL/min} (.13368 \text{ ft}^3/\text{GAL})(1 \text{ min}/60 \text{ s})$

$= 1.782 \times 10^{-3} \text{ ft}^3/\text{s}$

$q_2 = 1.4 \text{ GAL/min} (.13368 \text{ ft}^3/\text{GAL})(1 \text{ min}/60 \text{ s})$
$= 3.119 \times 10^{-3} \text{ ft}^3/\text{s}$

$q_3 = 3.2 \text{ GAL/min} (.13368 \text{ ft}^3/\text{GAL})(1 \text{ min}/60 \text{ s})$
$= 7.130 \times 10^{-3} \text{ ft}^3/\text{s}$

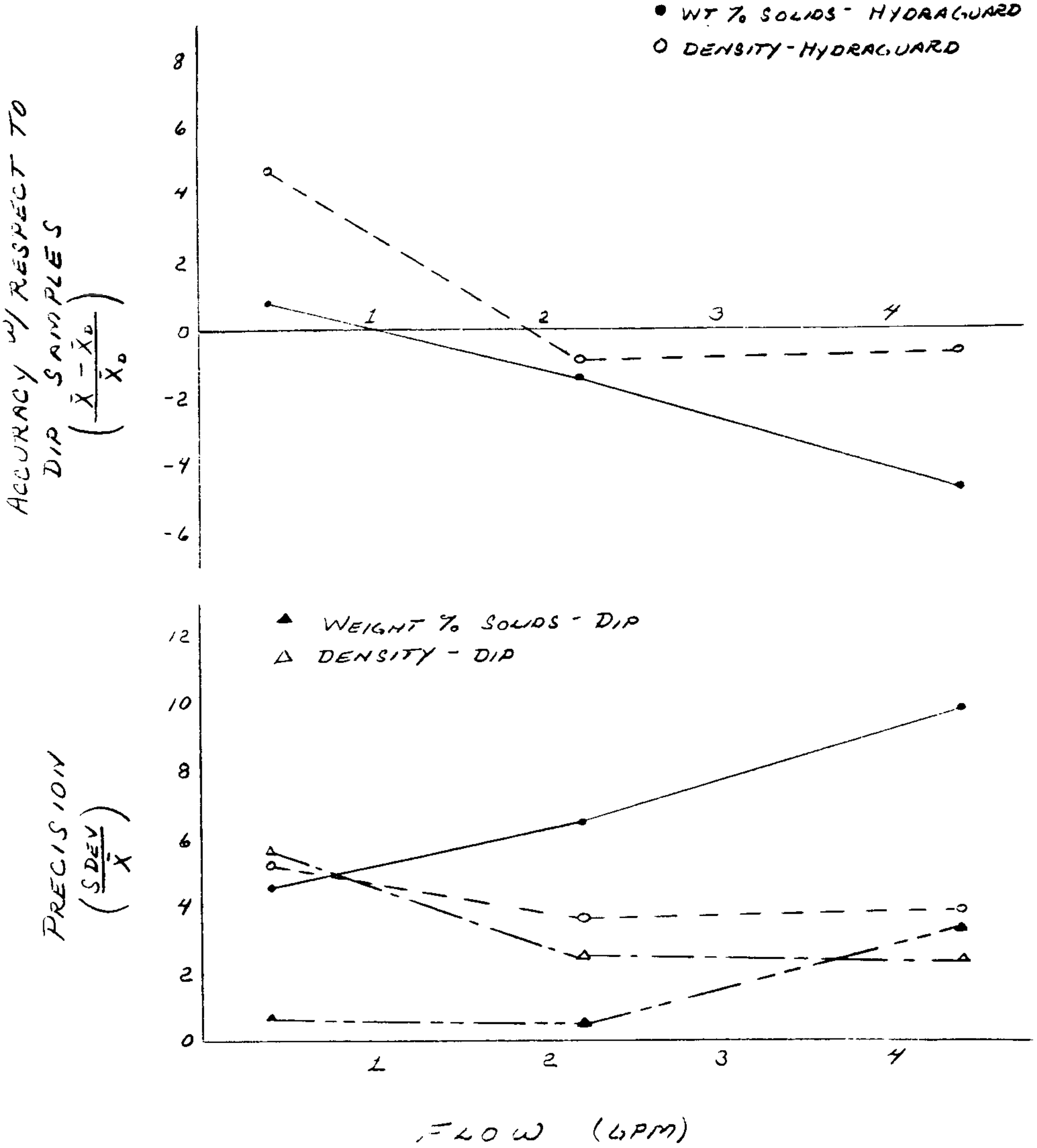
$V_1 = 1.782 \times 10^{-3} \text{ ft}^3/\text{s} / 2.097 \times 10^{-3} \text{ ft}^2$
$= .8498 \text{ ft/s}$

$V_2 = 3.119 \times 10^{-3} \text{ ft}^3/\text{s} / 2.097 \times 10^{-3} \text{ ft}^2$
$= 1.487 \text{ ft/s}$

$V_3 = 7.130 \times 10^{-3} \text{ ft}^3/\text{s} / 2.097 \times 10^{-3} \text{ ft}^2$
$= 3.400 \text{ ft/s}$

BY MA McNEIL DATE 10-28-84 SUBJECT DWPF SAMPLING DEVICE DEVELOPMENT SHEET NO. 1 OF 10
CHKD. BY ______ DATE ______ JOB NO. DPST-850

APPENDIX C — LOW RHEOLOGY TEST RESULTS — COMMERCIAL HYDRAGUARD

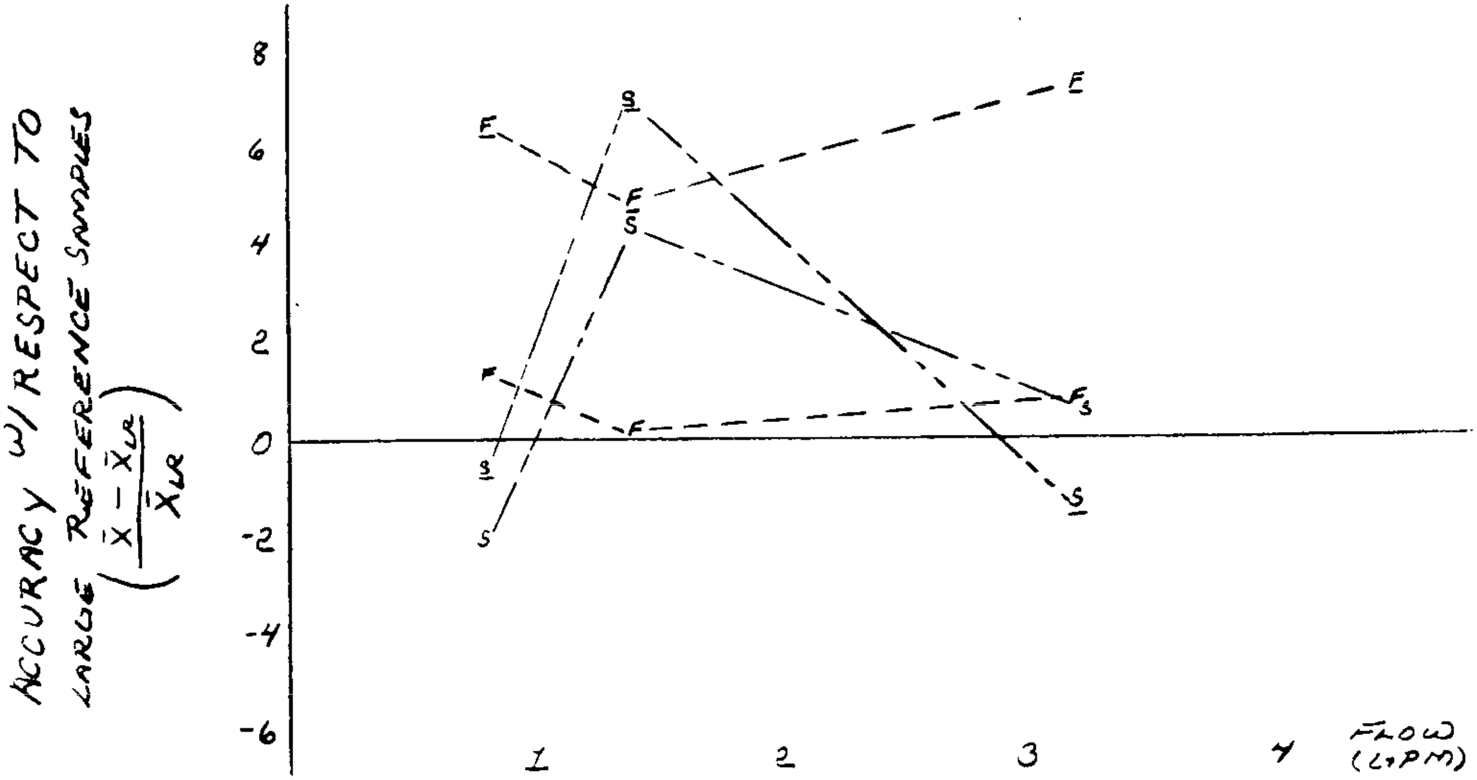


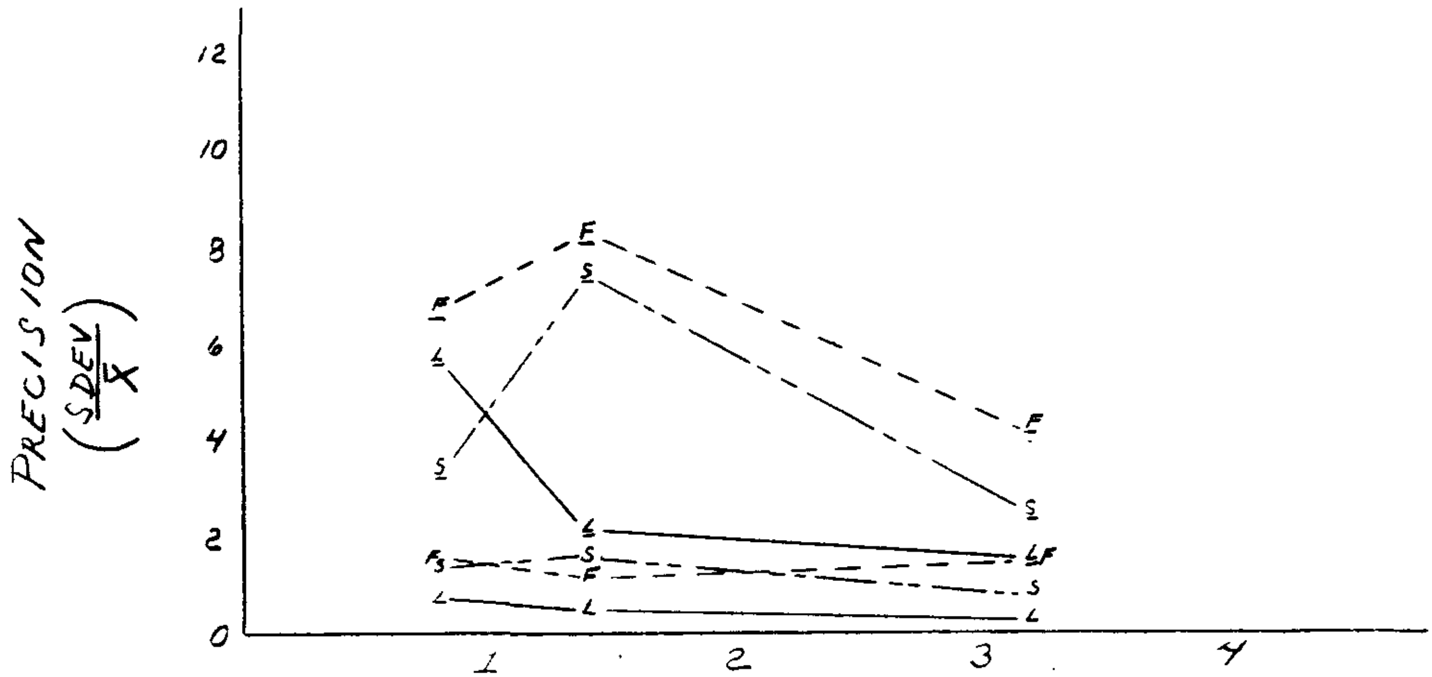
NOTE: DIP SAMPLES WERE NOT AFFECTED BY FLOW. THE POSITION ON THE GRAPH REPRESENTS THE AVERAGE VALUE OF THE SAMPLES TAKEN DURING WHICH TIME "X" GPM SAMPLES WERE TAKEN.

BY MA McNeil DATE 10-28-84 SUBJECT DWPF SAMPLING DEVICE DEVELOPMENT SHEET NO. 2 OF 10

CHKD. BY ______ DATE ______ JOB NO. DPST-850

APPENDIX C — HIGH RHEOLOGY TEST RESULTS — FUJIKIN VALVE





F - FUJIKIN VALVE, WT% SOLIDS

E - FUJIKIN VALVE, DENSITY FLOW (GPM)

S - SMALL REFERENCE, WT % SOLIDS

S̲ - SMALL REFERENCE, DENSITY

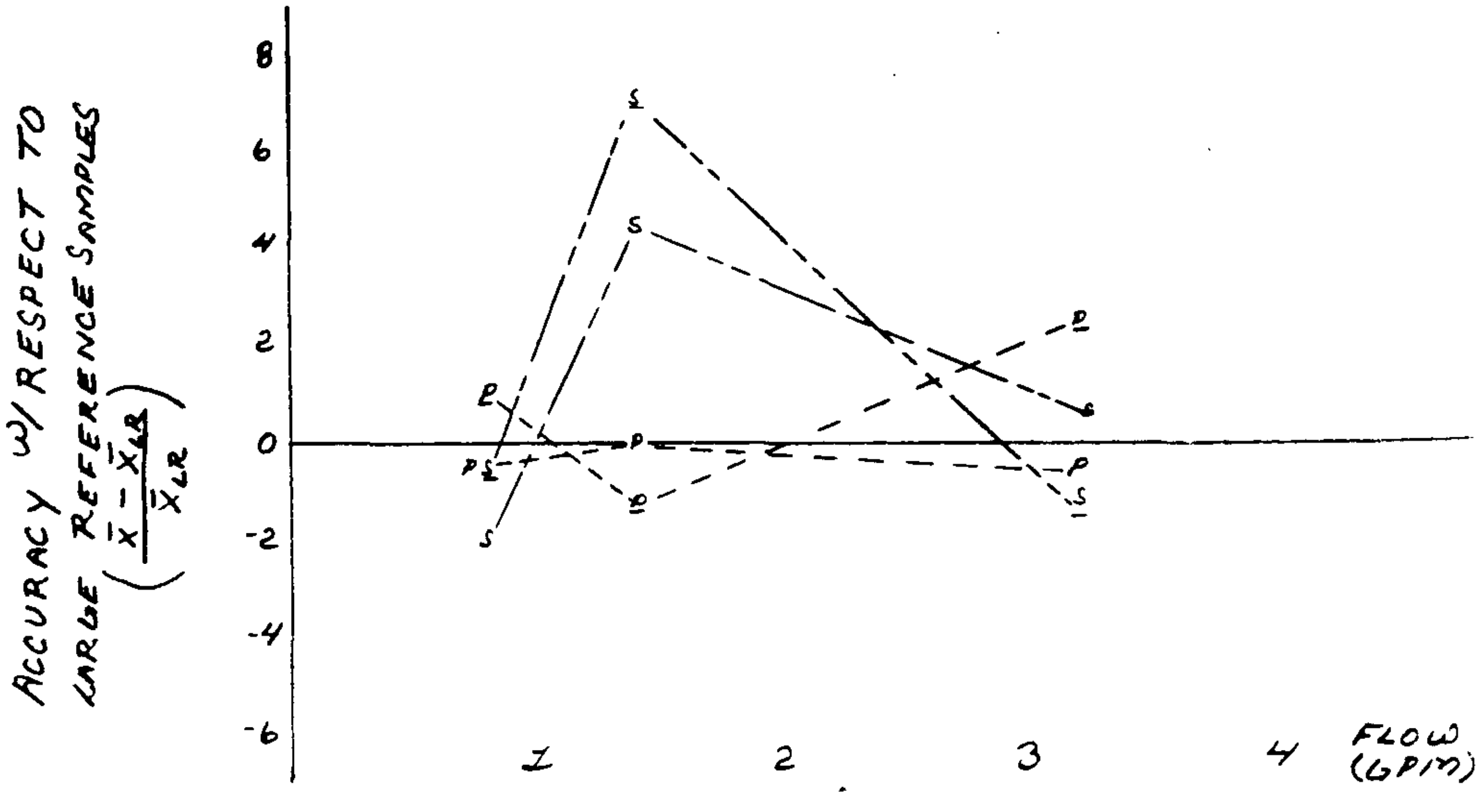
L - LARGE REFERENCE, WT% SOLIDS

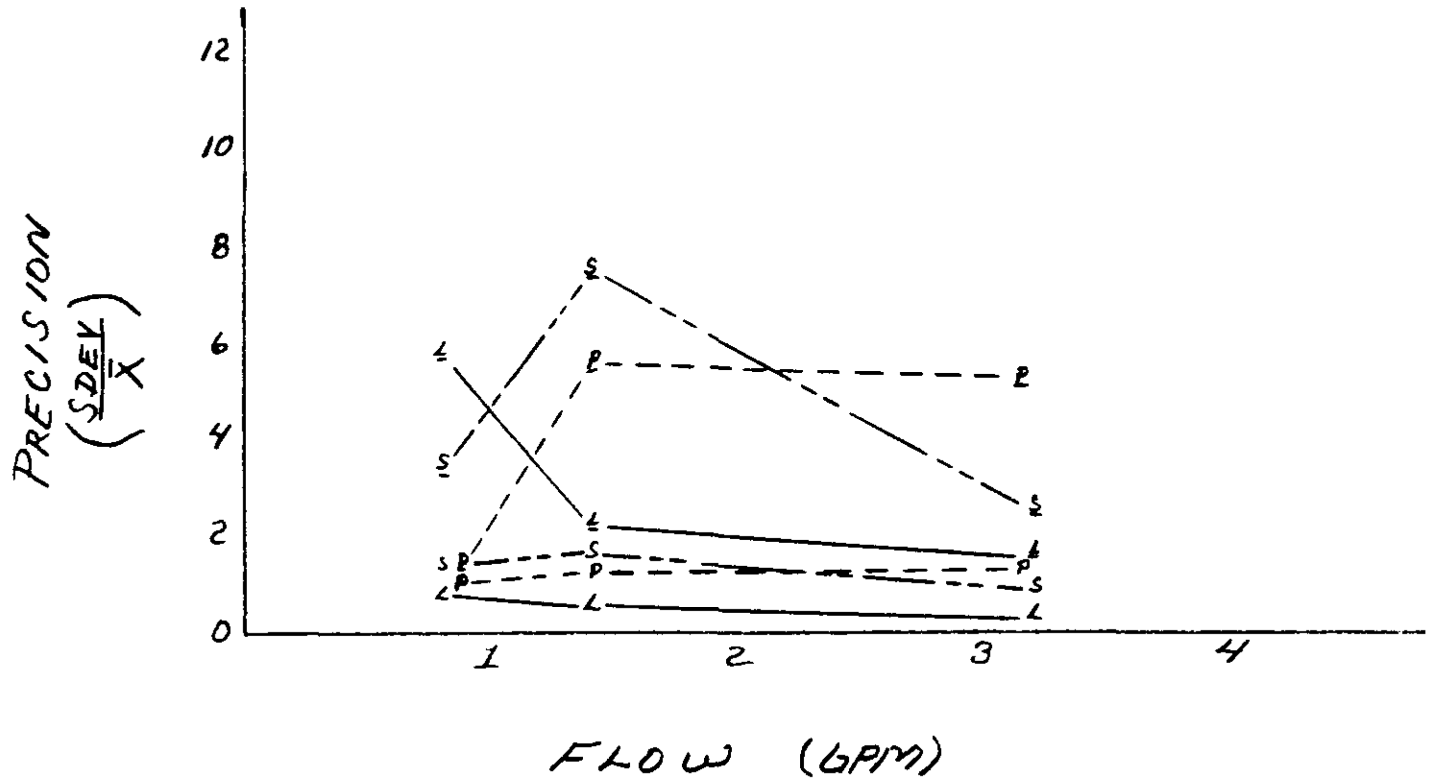
L̲ - LARGE REFERENCE, DENSITY

BY M.A. McNeil DATE 10-28-84 SUBJECT DWPF SAMPLING DEVICE DEVELOPMENT SHEET NO. 3 OF 10

CHKD. BY: ... DATE .... JOB NO. DPST 850

APPENDIX C — HIGH RHEOLOGY TEST RESULTS — PNEUMATIC HYDRAGUARD





P - PNEUMATIC HYDRAGUARD, WT % SOLIDS

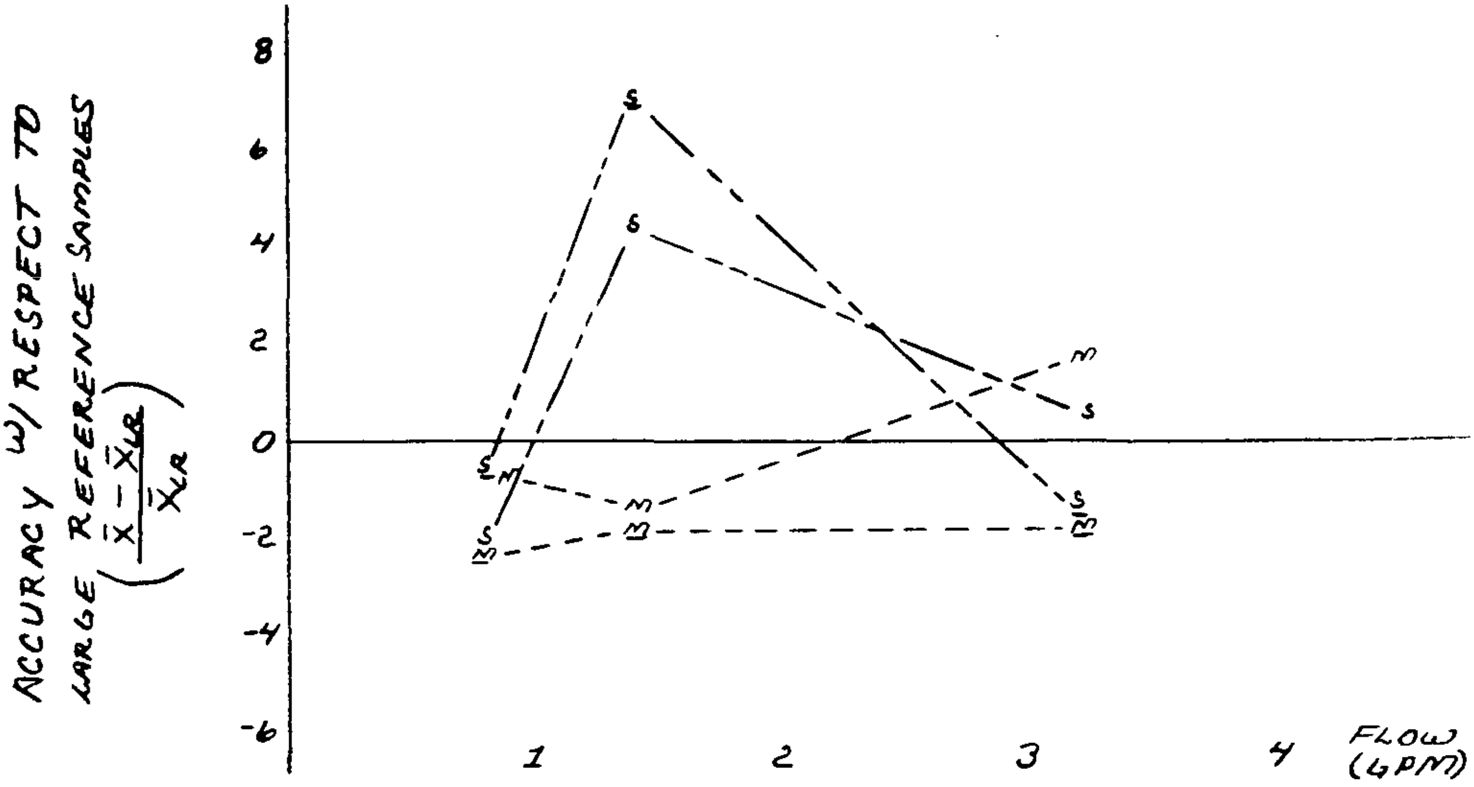
P̲ - PNEUMATIC HYDRAGUARD, DENSITY

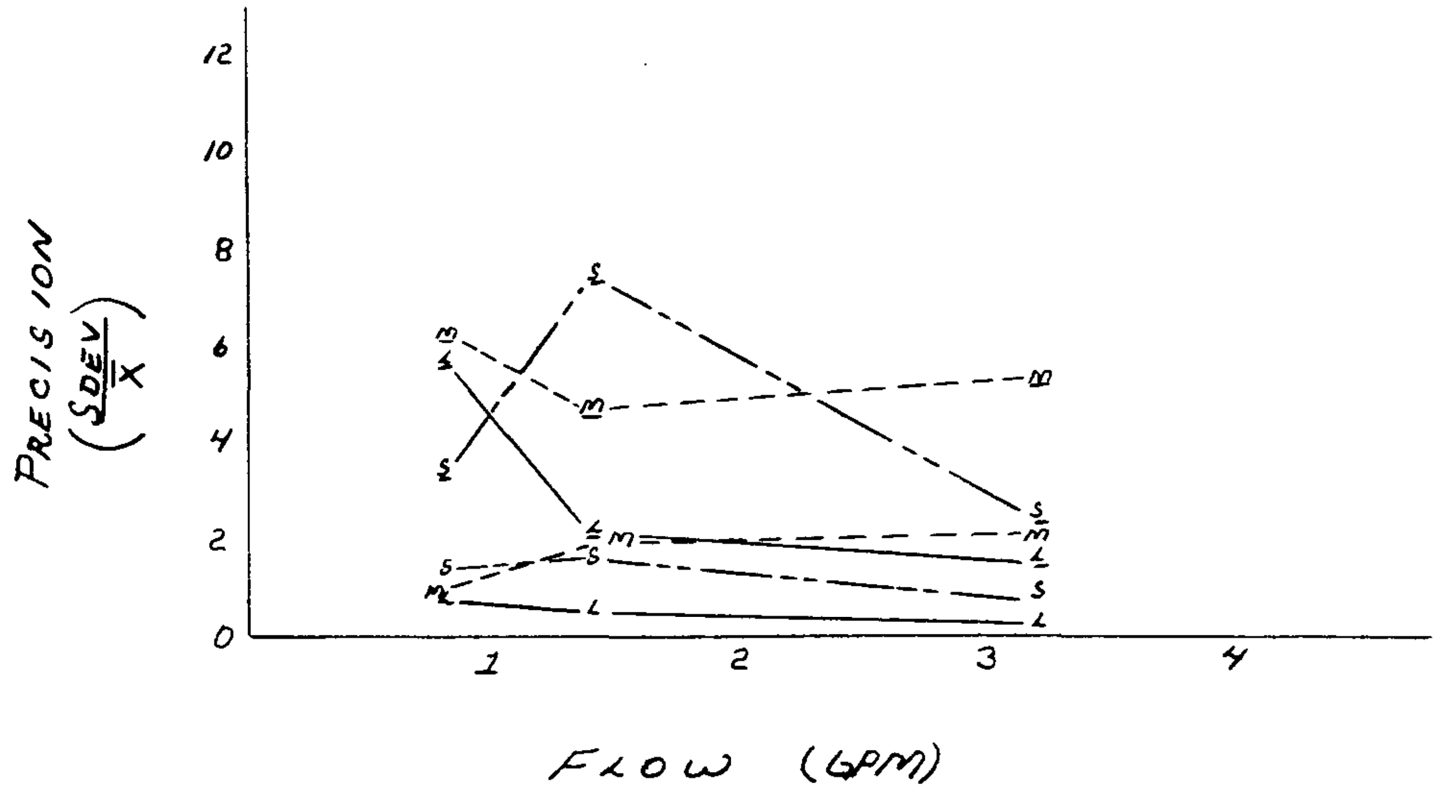
S - SMALL REFERENCE, WT % SOLIDS

S̲ - SMALL REFERENCE, DENSITY

L - LARGE REFERENCE, WT % SOLIDS

L̲ - LARGE REFERENCE, DENSITY





M - MANUAL HYDRAGUARD, WT% SOLIDS
M̲ - MANUAL HYDRAGUARD, DENSITY
S - SMALL REFERENCE, WT% SOLIDS
S̲ - SMALL REFERENCE, DENSITY
L - LARGE REFERENCE, WT% SOLIDS
L̲ - LARGE REFERENCE, DENSITY

LOW RHEOLOGY τ_y = 129 DYNES/cm² η = 14 cP

.4GPM

	COMMEREC, H. LIVARD	DIP
% SOLIDS 1		
$\bar{X}$	46.01	46.24
SDEV	2.18	.3099
n	31	31
$\bar{X} - \bar{X}_0 / \bar{X}_0$	-0.50%	—
SDEV/$\bar{X}$	4.74%	.67%
% SOLIDS 2		
$\bar{X}$	47.20	46.13
SDEV	2.061	.3378
n	31	31
$\bar{X} - \bar{X}_0 / \bar{X}_0$	2.32%	—
SDEV/$\bar{X}_0$	4.37%	.73%
DENSITY		
$\bar{X}$	1.442	1.377
SDEV	.0774	.0774
n	31	31
$\bar{X} - \bar{X}_0 / \bar{X}_0$	4.72%	—
SDEV/$\bar{X}$	5.37%	5.62%
% SOLIDS 1&2 (AVERAGED)		
$(\bar{X} - \bar{X}_0)/\bar{X}_0$	.91	
SDEV/$\bar{X}$	4.56%	.70

LOW RHEOLOGY $\tau_y = 129$ DYNES/cm^2 $\eta = 14$ cP

	COMMERC. H. GUARD	DIP
2.2 GPM		
% SOLIDS 1		
$\bar{X}$	45.71	46.57
SDEV	2.795	.2039
n	31	31 .14
$\bar{X}-\bar{X}_D / \bar{X}_D$	-1.85%	—
SDEV/$\bar{X}$	6.11%	0.44%
% SOLIDS 2		
$\bar{X}$	46.15	46.61
SDEV	3.062	.2949
n	31	31
$\bar{X}-\bar{X}_D / \bar{X}_D$	-0.99%	—
SDEV/$\bar{X}$	6.63%	0.63% .05
DENSITY		
$\bar{X}$	1.429	1.442
SDEV	.0511	.0366
n	31	31
$\bar{X}-\bar{X}_D / \bar{X}_D$	-0.90%	—
SDEV/$\bar{X}$	3.58%	2.54%
% SOLIDS 1 & 2 (AVERAGED)		
$(\bar{X}-\bar{X}_D) / \bar{X}_D$	-1.42	
SDEV/$\bar{X}$	6.37	.53

LOW RHEOLOGY τ_y = 124 DYNES/CM² η = 14 CP

	COMMERC. H. GUARD	DIP
4.4 GPM		
% SOLIDS 1		
$\bar{X}$	43.52	45.39
SDEV	3.646	2.680
n	30	30
$\bar{x} - \bar{x}_D / \bar{x}_D$	-4.12%	—
SDEV/$\bar{x}$	8.38%	5.90%
% SOLIDS 2		
$\bar{X}$	43.32	45.84
SDEV	4.885	.2397
n	30	30
$\bar{x} - \bar{x}_D / \bar{x}_D$	-5.50%	—
SDEV/$\bar{x}_D$	11.28%	.52%
DENSITY		
$\bar{X}$	1.419	1.431
SDEV	.0549	.0348
n	30	30
$\bar{x} - \bar{x}_D / \bar{x}_D$	-0.84%	—
SDEV/$\bar{x}_D$	3.87%	2.40%
% SOLIDS 1 & 2 (AVERAGED)		
$(\bar{X} - \bar{X}_D)/\bar{X}_D$	-4.81	
SDEV/$\bar{X}$	9.83	3.21

HIGH RHEOLOGY — TEST DATE 6-5-84

ρ = 1.47 g/cc τ_y = 260 DYNES/cm² η = 19 cP

	FLJIKIN	PN HGWARD	M. HGWARD	SMALL REF.	LARGE REF.
.8 GPM (.85 g/s)					
% SOLIDS 1					
$\bar{x}$	50.39	49.28	48.93	48.49	49.44
SDEV	.7172	.6005	.3557	.6895	.4271
n	20	21	21	21	21
$\frac{\bar{x}-\bar{x}_{LR}}{\bar{x}_{LR}}$	1.92%	-.32%	-1.03%	-1.92%	—
SDEV/$\bar{x}$	1.4%	1.2%	.727%	1.42%	.864%
% SOLIDS 2					
$\bar{x}$	49.90	49.24	49.24	48.51	49.49
SDEV	.9019	.4529	.5448	.6757	.3879
n	20	21	20	21	21
$\frac{\bar{x}-\bar{x}_{LR}}{\bar{x}_{LR}}$	.828%	-.505%	-.505%	-1.981%	—
SDEV/$\bar{x}$	1.807%	.920%	1.106%	1.393%	.784%
DENSITY					
$\bar{x}$	1.53	1.4514	1.403	1.429	1.437
SDEV	.1058	.01972	.08779	.05011	.08475
n	20	21	21	21	21
$\frac{\bar{x}-\bar{x}_{LR}}{\bar{x}_{LR}}$	6.472%	1.002%	-2.366%	-.557%	—
SDEV/$\bar{x}$	6.915%	1.359%	6.257%	3.507%	5.897%
% SOLIDS 1 & 2 (AVERAGED)					
$\bar{x}-\bar{x}_{LR}/\bar{x}_{LR}$	1.4	-.4	-.77	-1.95	
SDEV/$\bar{x}$	1.6	1.1	.92	1.41	.824

TEST DATE 6-4-84

HIGH RHEOLOGY

ρ = 1.47 g/cc τ_y = 260 DYNES/cm^2 η = 19 cp

	FUJIKIN	PN HOWARD	M. HOWARD	SMALL REF	LARGE REF
1.4 GPM (1.5 fps)					
% SOLIDS 1					
$\bar{x}$	49.63	49.60	49.09	52.08	49.69
SDEV	.6465	.5608	1.142	.8100	.2423
n	21	21	19	20	21
$(\bar{x}-\bar{x}_{LR})/\bar{x}_{LR}$	-.12%	-.18%	-1.2%	4.8%	—
SDEV/$\bar{x}$	1.30%	1.13%	2.33%	1.56%	.49%
% SOLIDS 2					
$\bar{x}$	49.61	49.84	48.93	51.81	49.75
SDEV	.6635	.6247	.8083	.9644	.2473
n	21	21	20	18	21
$(\bar{x}-\bar{x}_{LR})/\bar{x}_{LR}$	-.28%	.18%	-1.65%	4.1%	—
SDEV/$\bar{x}$	1.34%	1.25%	1.65%	1.86%	.50%
DENSITY					
$\bar{x}$	1.531	1.435	1.428	1.556	1.454
SDEV	.1279	.0796	.0677	.1190	.0306
n	21	21	19	20	21
$(\bar{x}-\bar{x}_{LR})/\bar{x}_{LR}$	5.03%	-1.31%	-1.79%	7.01%	—
SDEV/$\bar{x}$	8.35%	5.55%	4.74%	7.65%	2.11%
% SOLIDS 1 & 2 (AVERAGED)					
$\bar{x}-\bar{x}_{LR}/\bar{x}_{LR}$	.20	0	-1.43	4.45	
SDEV/$\bar{x}$	1.32	1.19	1.99	1.71	.50

TEST DATE 6-6-84

HIGH RHEOLOGY

ρ = 1.47 g/cc τ_y = 260 DYNES/cm² η = 19 cP

	FUNKIN	M. HOWARD	M. HOWARD	SMALL REF	LARGE REF
3.2 GPM (3.4 fps)					
% SOLIDS 1					
$\bar{X}$	49.88	49.26	50.35	49.72	49.50
SDEV	.7052	.5465	1.006	.4851	.1493
n	18	17	18	18	18
$(\bar{X}-\bar{X}_{LR})/\bar{X}_{LR}$	.77 %	-.48%	1.72 %	.44 %	—
SDEV/$\bar{X}$	1.41 %	1.1 %	2.0 %	.98 %	.30 %
% SOLIDS 2					
$\bar{X}$	49.96	49.32	50.37	49.92	49.55
SDEV	.8400	.6891	1.082	.3795	.1289
n	18	17	18	18	18
$(\bar{X}-\bar{X}_{LR})/\bar{X}_{LR}$	.83 %	-.46 %	1.65%	.75 %	—
SDEV/$\bar{X}$	1.68%	1.4 %	2.15%	.76 %	.26 %
DENSITY					
$\bar{X}$	1.563	1.493	1.430	1.438	1.456
SDEV	.0681	.0795	.0767	.0373	.0235
n	17	15	18	18	18
$(\bar{X}-\bar{X}_{LR})/\bar{X}_{LR}$	7.35%	2.54%	-1.79%	-1.24%	—
SDEV/$\bar{X}$	4.36 %	5.32%	5.36 %	2.59%	1.61 %
% SOLIDS 1 & 2 (AVERAGED)					
$\bar{X}-\bar{X}_{LR}/\bar{X}_{LR}$	.8	-.47	1.69	.60	
SDEV/$\bar{X}$	1.54	1.25	2.08	.87	.28