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ULTRASONIC METER: IN-SITU SKID MOUNTED FLOW TESTING

5.1

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ULTRASONIC METERS

In-Situ Skid Mounted Flow Testing

ABSTRACT

This paper is a continuation of the work and results presented last year by Klaus Zanker (Ref 1) and Karen Van Bloemendall (Ref 2) at the North Sea Flow Measurement Workshop, Peebles; Scotland, on behalf of the Ultrasonic Meter (USM) "Ultraflow" Consortia projects and the developments presented by Michael Reader-Harris (Ref 3) at San Antonio earlier this year at the AGA Flow Symposium on behalf of the Flow Headers Consortium.

These projects covered the development of :

i. a wet gas multipath ultrasonic meter using a modified dry gas meter;

ii. an investigation into the installation effects of the meter;

and iii. an investigation into the flow properties downstream of a variety of flow conditioners when inserted in meter tubes downstream of a flow header.

Using the results from these projects and two prototype six inch meters a compact metering skid has been designed, built and flow tested which will be used on 'wet' process gas. This skid will be installed on Phillips Petroleum Co UK Limited's Hewett 18/29C platform in the UK sector of the North Sea to meter gas from the Dawn subsea development.
The results of the flow testing on dry gas under different flow conditions are reviewed in this paper.

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CONTENTS

1.0 DAWN DEVELOPMENT

1.1 INTRODUCTION

Dawn is a single subsea gas satellite located some 6 miles from Phillips' unmanned Hewett Charlie platform in the Southern sector of the North Sea. It will be produced onto the Hewett, free liquids (condensate and water at 5-10 bbl/mmscfd) will be separated out, and the gas metered and commingled into the Hewett gas. The Hewett gas is committed under contract, so there is a need to meter the Dawn gas in order to allocate it on arrival at the Bacton processing plant where it will be sold to another customer. The gas on Hewett is not dehydrated or metered and it is necessary to meter the Dawn gas in the 'wet' state.

1.2 METERING OPTIONS

As the project commenced it was evident that only two or three options were available for metering the produced gas. These were :-

1.2.1 Conventional gas processing and drying prior to metering with orifice meters. However, due to the weight and cost constraints and the additional risk to personnel because of increased maintenance, it was disregarded.

1.2.2 Wet gas metering utilising a Venturi and the Jamieson modified Chisholm equation as part of the flow algorithm. The limitations are the Venturi turndown ratio - which is significantly less than the ultrasonic meter - and the need to know the liquid content in the gas (from regular well tests). As a result this method was not pursued further.

1.2.3 Wet gas metering using the newly developed and tested wet gas ultrasonic meters. Based on the results produced in testing and the availability of the prototype test meters, this option was selected.

In attempting to meter 'wet' gas, it is essential to remember that there are two types of meter currently available - momentum meters (which measure DP,ρv^2) and velocity meters. Wet gas which has say, 1% by volume of liquid at 60 barg, will have a mass difference of around 10% - and it is this difference which creates large errors when using a DP device in measuring 'wet' gas.

1.3 METERING APPROVALS

The UK's Department of Trade and Industry, Oil and Gas Office provide guidance and approval for systems used for allocating UK petroleum revenue taxes. In general, provided "good oilfield practice" is used there are few problems. When approached with new technology or dramatic changes to established practises, the Department requires the Operator to establish a period in which the technology can be evaluated and a fall back position which can be utilised if the technology is unsuccessful.

1.0 DAWN DEVELOPMENT

1.3 METERING APPROVALS (CONTINUED)

In this respect, the wet gas ultrasonic meters have been accepted for evaluation with a programme to monitor the meters' performance using a dry gas calibration of the skid, a data acquisition package for long term monitoring and the ability to place the meters in a series mode of operation (see Figures 1 and 2), in order to carry out checks on the individual meters' performance, during the evaluation period.

1.4 SKID DESIGN

To flow the required rates (60 mmscfd) in the initial production period at the pressures available for entry into the Hewett systems, two 6 inch meters are required. These have been provided by utilising the two prototype meters manufactured for the Wet Gas Consortium. The meters are installed in a parallel configuration , (see Figures 1 and 2), with an optional 'transfer' line between the output of one meter to the inlet of the second.

In considering the skid 'footprint' available, it was certain that the available meter tube lengths would be short, and with the use of the 'transfer' line to flow in series, the flow profiles would probably be unacceptabe. To overcome the additional uncertainties due to installation effects presented by K.Van Bloemendall (Ref 2) the results of the "Flow Header" consortium work (Ref 3) were reviewed. The optimum design from the Flow Header project work would have been to install a plate conditioner 4D downstream of the header, with the meter 10D downstream of the conditioner and a 3D for USM (5D for an orifice) discharge pipe to the outlet header. This would have given a 17D overall meter tube length. However, the need to install a 'transfer' line to facilitate operation of the meters in series required a slightly-larger skid footprint. As designed, an NEL flow conditioner is installed, with the meter installed 10D downstream of the flow conditioner. The results from the Header Consortium indicates that a near optimum flow profile and acceptable swirl stability will exist in these conditions to ensure zero additional uncertainty due to installation effects (Ref 2).

1.5 FLOW TESTING

As part of the acceptance procedure for the meters and the skid design, a dry gas calibration was requested by the Department of Trade and Industry, Oil and Gas Office. This was carried out at the British Gas Bishop Auckland site against a master turbine meter in June 1995, and the results are presented here.

1.0 DAWN DEVELOPMENT

1.5 FLOW TESTING (CONTINUED)

The skid was flowed at four flows (10%, 25%, 50% and 100% of full scale) for the following combinations :-

- Flow through Meter 1.
- Flow through Meter 2.
- Flow through Meters 1 and 2 in parallel.
- Flow through Meters 1 and 2 in series.
- Flow through Meter 2, with its conditioner removed.
- Flow through Meters 1 and 2 in series with conditioner (#2) removed.
- Flow through Meters 1 and 2 at a reduced pressure of 38 bar.

See Figure 4.

Test Pressure : Maximum available on site : nominally 58 bar gauge (840 psig).
Test Temperature : Ambient : nominally 5 to 10°C.
Test Gas : Natural Gas : nominally 88% Methane.

Test Procedure : The metering skid was installed downstream of the site reference turbine meters. British Gas provided the secondary instrumentation to measure pressure and temperature at the ultrasonic skid and pressure, temperature and frequency output at the reference turbine meters.
The test line was pressurised to the maximum pressure available. The site flow control valve position was adjusted to produce the minimum flow required, 10% of 21 meters per second. When conditions steadied, six test points were collected.
Each comprised :-

1. Five sets of readings of all pressures and temperatures.
2. A one hundred second count of reference turbine meter output.

Item 1. above was collected for use with data averaged during Item 2.
The above procedure was repeated for 3 other flows up to the maximum velocity of 21 metres per second.

Calculations : The data from the reference turbine was converted, using the analysis of gas samples taken during the test, into a volume flow rate through the system. This together with the pressure and temperature at the turbine meter was corrected for the conditions prevailing at the ultrasonic skid.

The test installation allowed the meters to be calibrated independently, to test the efficiency of the header flow conditioner system in the parallel mode and provide a base line for the series tests for the meter to be used to track each other once the skid is placed into operation.

1.5 FLOW TESTING (CONTINUED)

It was anticipated that the tests with the meters in parallel and series operations with and without one conditioner will provide valuable data in respect of the validity of using flow conditioners in high pressure gas flow.

1.5.1 Test Result Traceability and Uncertainty

The flow meters are traceable to a Dutch standard (NMI) via a 4" Instromet turbine meter. The reference volumetric flows have an uncertainty of ±0.29%. The pressures are traceable to National standards via the dead weight tester used to calibrate the pressure transmitters. The uncertainty on pressure measurement was ±0.1%.

The differential pressure measured across the turbine meters and the skid discharge is traceable to National standards via the dead weight tester used to calibrate the DP transducer. The uncertainty on differential pressure measurement was ±0.25%.

The temperature circuit was calibrated using a traceable decade resistance box. The resistance probes had been individually calibrated. This produced an uncertainty of ±0.1% on temperature.

The overall Test Centre uncertainty for flow rate measurement is stated as ±0.4%.

1.5.2 Test Set Up

The test set up is shown in the schematic on Figure 3. The various flow configuration through the skid are shown on Figure 4. Due to constraints at the site and the physical size of the ultrasonic skid it was impossible to locate the skid close to the reference meters, and the need to use both an 8" and 12" reference meter to cover the total flow range, made it difficult to move these next to the skid. Furthermore the skid was mounted in a 24" line. These problems resulted in a large volume being present between the skid and the reference turbine meters. The volume was measured as 61 cubic metres which when compared to the 100 second calibration volumes was large. At 10% flow rate, the volume measured was 4m^3 and at 100%, 40m^3. In conditions of stable pressure and temperature this volume has no effect on the uncertainty of the experiment. However any change in these variables during each 100 second test point represented a net increase or decrease in density in the volume between the meters and this may have introduced a difference between the reference and test flows. Where applicable, these are represented by an estimated range of 'line pack errors' on the relevant figures and were provided by Bishop Auckland.

2.0 TEST RESULTS

2.1 INTRODUCTION AND TEST PROCEDURE

Flow Testing - what is it and why do we do it?

Flow testing is often purchased just as if we were buying widgits. Experience has shown that we rarely specify the performance envelope or all the details we want to see - or for that matter the installation under which the unit will be tested. We neither ask for (nor receive) details on the test site operations / areas which might affect the tests - and in some cases this can affect both the stability of the results and the time taken.

With respect to our testing at Bishop Auckland, we had stated the tests we wanted to carry out and been given a (fixed) price for a time slot. We had not agreed an installation location, reference meter location or discussed plant stability - this resulted in the situation described in 1.5.2. In retrospect, we should have located a single 8" meter just upstream of our skid and accepted the flow rate limitation - which would have limited the flow rate through one test point only - the 100% flow through two meters in parallel.

Another operational aspect to affect us, was British Gas pigging supply lines around Bishop Auckland. This meant for some days a loss of gas flow. Blending of gas supplies is thought to have ocurred to control calorific value resulting in changes in gas composition between the commencement and finalisation of the flow tests.

One aspect of the flow testing which surprised us all was the stability of some of the flow tests. Certain aspects were not as good as we had perceived, but that begs the question - is our perception that good?

2.2 FLOW ERROR RESULTS

i. Figure 5 compares the performance of Meter 1 and Meter 2 when being flowed independently with flow conditioners.
Meter 2 exhibits a 'dogleg' error vs flow rate. The error reported is in a band of -0.4% to +0.5% except at 10% flow. In general this meter lies within the claimed range for uncertainty.
Meter 1 exhibits a range of errors between +0.7% to -1.2% and if the span were adjusted would be within the claimed range of uncertainty.

ii. Figure 6 demonstrates the performance of the meter skid with both meters operating in parallel. What is not shown on this figure is the imbalance in flow through the two meters, which is less than 1%.
It could be argued that the very small imbalance is due to the dominant pressure

loss presented by the conditioners.
The error / flow rate curve is extremely flat and well within the errors claimed for the meters, and bodes well for the high rate (high value) flow metering when placed in operation.

iii. Figure 7 and 8 indicates the discrepancy of the meters when operated in series. Two sets of results are shown - Meter 1 and Meter 2 with conditioners (Figure 7) and Meter 1 with and Meter 2 without conditioners (Figure 8).
It should be noted that when conditioners are installed in both the meters in series, there was a high differential pressure across the skid and a pressure correction has been made for Meter 1, the upstream meter. At full flow the ΔP through both meters with conditioners was 21 psig. When one meter is operated on its own, with a flow conditioner the ΔP was approximately 9 - 10 psig. As a result, when in series with conditioners at full flow, there was a base line error for Meter 1 when compared with Meter 2.
This was estimated as :

$$\frac{10}{840} \times 100\% \quad = 1.2\%$$

and at half flow rate, it is assumed to be 1.2% x 0.25 = 0.3%. Errors were ignored below half flow rate.

Figure 7 indicates that both meters are within its claimed range of uncertainty, Meter 2 being in the range ±0.5% and approximately 0.5% above Meter 1.

Figure 8 indicates that Meter 1 (with a flow conditioner) and Meter 2 (without a flow conditioner have at the higher flow rates a similar performance.

iv. Figure 9 is a continuation of the Figure 7 data and compares Meter 2 installation with and without a flow conditioner. This demonstrates a clear half percent shift in metering error in the two installations. It is of interest that the 'dog' leg on this meter is present in both installations, and that the meter with the most acceptable error curve is the one tested with the conditioner.
This error shift corresponds to the work presented by the Installation Consortia (Ref 2), where the additional uncertainty recommended for a 6" meter with a 180° bend 10D upstream of the meter is ±0.5%.

v. Figure 10 provides an insight into the individual meters with flow conditioners operating a the lower operating pressure (of 38 bar). Both meters perform within their claimed performance envelope, however the need to pre-heat and reduce pressure in the system has added to the line pack and pressure control problem thus increasing error scatter.
This figure is the result of at least 4 different tests and this may be the reason for the apparent drift between results, but there does appear to be some repeatability.

2.3 VELOCITY OF SOUND

Velocity of sound (VOS) which is a property of a gas at a given pressure and temperature is an excellent "diagnostic tool" in reviewing data from the meter. It uses the same geometry and time measurements that are required to determine line / chord velocity.

Measurements of velocity of sound of the flowing gas are made at each chord. It was observed that the interchord VOS agreement was good (ie better than 1 in 400, ie <0.25%). This was to be expected - a six inch meter is small with few dead areas for temperature gradients to form. The fact that velocity of sound errors were small confirms that the individual chord geometry and timing is good.

In series and in parallel meter installations had good correlations for VOS. This was expected as the same gas passes through both meters.

However, it was noted that there were changes in VOS between the beginning and the end of the tests. A review of the gas sample component analysis after the test showed that there was a clear shift in gas analysis from a relatively 'lean' gas to a more 'richer' mixture. See Table 1 below.

Component	Sample Number 492	Sample Number 495
Methane	91.29	86.946
Ethane	4.66	6.989
Propane	1.37	2.430
N-Butane	0.26	0.450
Iso Butane	0.12	0.207
Pentanes	0.07	0.146
N-Hexane	0.02	0.063
Carbon Dioxide	1.39	2.113
Nitrogen	0.80	0.654
Mol Wt.	17.78	18.77

Table 1

Figure 11 indicates the range of VOS seen throughout the test and compares the measurements made between the meters. The agreement in the VOS corresponds to the agreement in calibration between the meters. A 1% error in velocity corresponds to 0.5% error in VOS. Work after the tests revealed that the major change in VOS is due to composition (15 m/sec). Changes in process temperature resulted in a change of around 4m/sec. The VOS ranged between 376 and 392 m/sec..

2.4 FLOW PROFILES

The ultrasonic meter has the ability to provide a large range of data. Amongst this data is the flowing velocity through each of the four measuring chords and the weighted average of the 4 chords. This data can be used to observe elements of the flow profile effects caused by the pipe work through the meter in the following installations:-

- Meter 1 and Meter 2 (with flow conditioners)
- Meter 2, with and without flow conditioners

and - Meter 2 with and without the flow conditioner in series with Meter 1.

However, it should be noted that the flow profiles presented show only 4 points for each profile and are non dimensional average velocity profiles (not centre line velocity profiles) and possibly do not provide as much data on the performance of the flow conditioner (swirl etc) as is necessary to give conclusive data on its performance.

The Pipe Reynolds numbers for full and half rate flow are 9.0×10^6 and 4.4×10^6 respectively.

i. Figure 12, comparing Meter 1 and Meter 2, with flow conditioners indicates that the flow profile for Meter 1 is somewhat more symmetrical than that observed in Meter 2. For all tests, Meter 1 always had a flow conditioner, and whilst not shown elsewhere was always symmetrical and very close to a fully developed flow profile.

ii. Figure 13 compares Meter 2 with and without the flow conditioners. The figure indicates that the flow profile is asymmetrical and marginally better (more symmetrical) without the conditioner.

iii. Figure 14 compares Meter 2 with and without the conditioner in series with Meter 1. We considered that this was a severe flow with 2 radiused bends and two sharp bends through piping tee's within a confined space but a subsequent review of this data - indicates that the configuration may not be as severe as first thought. It is however probably more akin to a 180° bend upstream of the meter. It would appear from this data that the flow conditioner in this installation provides no advantage which is not backed up by the data from Figure 9 which compares the 0.5% difference between installations with and without the flow conditioner. This 0.5% shift corresponds to the data provided form the Installation Consortia (Ref 2).

2.5 STANDARD DEVIATION OF DELTA TIME

The delta time (DLTT) is the difference in the time for the ultrasound to travel from the downstream transducer of a chord pair to the upstream (T1) and the upstream transducer to the downstream transducer (T2), delta rime = (T1 - T2).

Typically a batch of 20 times are used to calculate velocity and provide statistical analysis. These batches are analysed and the standard deviation of the delta time is calculated. Large shifts of standard deviation of delta time can be caused by swirl, turbulence and liquids or solids in the flow. In essence it is a measure of the disturbed nature of the flow. Figure 15 plots the standard deviation against flow for three installations.

- Meter 2 alone, no flow conditioner.
- Meter 2 in series with a flow conditioner.
- Meter 2 in series with no flow conditioner.

It was considered that these three installations would provide the best "installation effect" comparison. The first two installations had almost identical standard deviations. This indicates that the flow state in a normal flow route without a conditioner is very similar to that when in the complex series flow mode but treated with a flow conditioner.

The last installation, series flow, no conditioner has a distinct shift (upwards) in standard deviation. When looked at on its own, this may be considered significant. However, experience from other installations where two out of plane elbows have been installed with a half plate orifice upstream of the USM standard deviation shifts in the order of 5 or 6 times the base value have been experienced. Compared with this prior installation knowledge it could be said that the test flow conditions were good.

2.6 PLANT STABILITY

During the tests, it appeared that the flow facility had a problem with plant stability at high flow rates.
Measurements were taken by the facility over 100 second windows every 10 seconds, and an average flow over the 100 seconds was computed and compared with the USM. These flow tests were repeated up to 5 times.Our concern was that at each repeat the average flow would change and in most cases it would drop continously
Stability and line pack were also judged by these 10 second measurements..
Figure 16 demonstrates the drop in flow (at high flow rates) through the reference meter and the response from the USM in a variety of installations.
The plots of pressure and temperature are shown in Figure 16. They should be read as the time base starting at the right hand side (near flow rate at 1449) and trend as a drop in pressure and temperature over the test. Whilst the test facility recorded these changes over 10 second intervals we were left with an uneasy feeling about the repeat tests.

We perceived this apparent lack of stability as another potential source of errors - but are our perceptions correct?

3.0 DISCUSSION

Earlier discussions have commented on the Bishop Auckland Test Facility uncertainty. The overall uncertainty claimed is ±0.4%. The configuration utilised for testing was not ideal and this has been recognised . Notwithstanding the above, the results derived exhibit a high degree of repeatability which bodes well for confidence in the skid design and the meters.

It was surprising not to see greater differences in velocity profiles in the various installations. However, profile configurations are not merely a function of local velocity but of swirl also, and it is swirl which causes great interest, especially in orifice installations. The chord velocities as measured by the USM are functions of axial velocities and swirl (in a plus or minus sense), and represent a single line average value for each chord. As a result, we were probably expecting too much in this area. By observation of the standard deviation of DLTT we are able to comment on the installation (of Meter 2) with and without flow conditioners. We observed a discrepancy at high flow rates of standard deviation in the order of 10%. Knowing that a really severe flow disturbance will cause this figure to change by a factor of 6 or so, these observations are probably understandable.

The error, flow profile and standard deviation all indicate that the series pipework with no flow conditioner is a qiute mild flow disturbance.This configuration is more like a 180 degree bend rather than two 90 degree offset bends, as in fact the bends are only 20 degrees offset and are not close coupled. The error shift of 0.5% agrees with the Ultraflow work for a 180 degree bend 10D upstream of the meter.
Meter 2 with no flow conditioner has a more symmetric flow profile, approaching that of Meter 1 with a flow conditioner and the error curves are also similar.

At reduced flow rates, the line packing errors, meter geometry and meter timing errors all increase and leads to a wider uncertainty band, and this was clearly demonstrated.

4.0 CONCLUSIONS

- Meter Skid

  - The tests clearly demonstrated that high performance compact meter skids are now achievable.

- Meter Error

  - Under all conditions, the meters were within the claimed ±1% of a factory dry calibrated meter.

  - In the parallel flow mode, the 'meter' skid uncertainty is better than ±0.5% - a real confidence boost for high flow (high risk) production.

- Velocity of Sound

  - The agreement of velocity of sound between interchord and inter-meter measuremnts corresponds to the meter errors. Interchord VOS agrees to 0.1% and inter-meter VOS to 0.5% and is consistent with the meter error above.

- Flow Profiles and Flow Conditioners

  - The inability to measure flow profile in the classical manner left the question of flow improvement unanswered.

  - Meter 2, with a flow conditioner was more accurate with respect to the reference meter.

  - Meter 2 without a flow conditioner and Meter 1 (with a flow conditioner) had a similar performance.

  - The installation of the flow conditioner provided sufficient differential pressure to equalise flow around the skid in parallel mode operation.

- Standard Deviation

  - Standard deviation as a measure of disturbance showed that only small velocity profile effects occurred in the different skid arrangements.

ACKNOWLEDGEMENTS

1. The Wet Gas JIP (which consists of BP International, British Gas, Shell Expro, NAM, Phillips Petroleum, Amoco Europe, and Daniel Industries) sponsored the work on wet gas, and contributed to these dry gas calibrations and have generously allowed this publication. The DTI participated with the JIP and their input is gratefully acknowledged.

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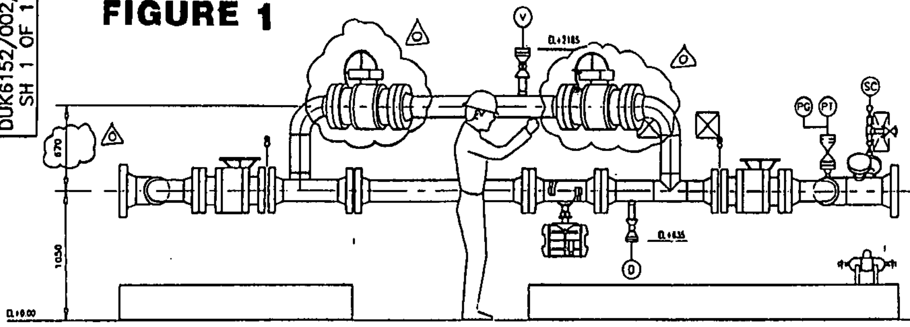
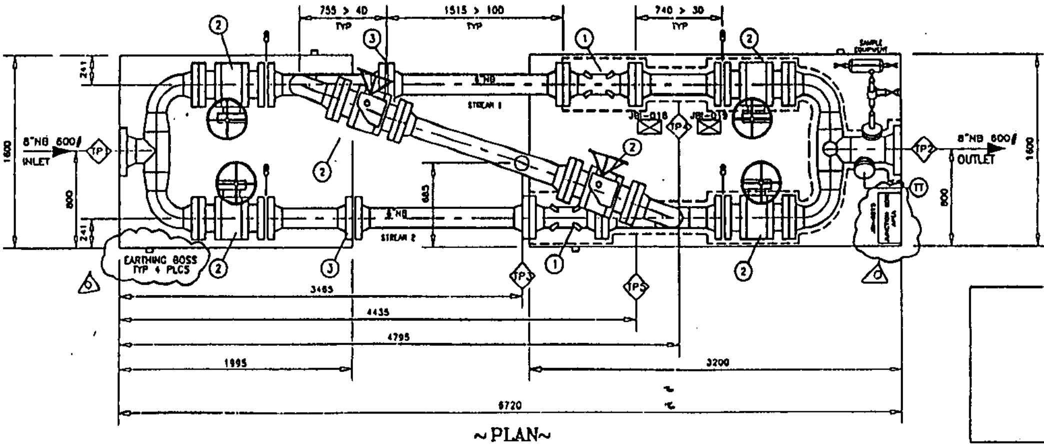
FIGURE 1



~ELEVATION~



~PLAN~

TERMINATION SCHEDULE

TP1	8" 600# RF INLET
TP2	8" 600# RF OUTLET
TP3	2" 600# RF VENT
TP4	1 1/2" 600# RF DRAIN (STREAM 1)
TP5	1 1/2" 600# RF DRAIN (STREAM 2)

MAJOR ITEMS

①	8" 600# WET GAS ULTRASONIC METER.(NOT INCLUDED)
②	8" 600# FULL BORE BALL VALVE.(MANUALLY OPERATED)
③	FLOW STRAIGHTENER

LEGEND

V	VENT
D	DRAIN
PT	PRESSURE TRANSMITTER
PG	PRESSURE INDICATOR
TT	TEMPERATURE TRANSMITTER
SC	SAMPLE CONNECTION (MANUAL)
-----	DENOTES INSULATION

00-001-001-8

PROJECT DAWN FIELD DEVELOPMENT

TITLE OVERALL FIELD LAYOUT

ISS	DATE	CHANGE	CHKD	APPD
	7/3/95	FOR MANUFACTURE (ECN2028/95)		
A	25.2.95	FOR APPROVAL	DB	SL

ORIG SCALE 1:15 A1
DIMENSIONS IN mm
REF S.O.4212

DANIEL INDUSTRIES LIMITED

PHILLIPS
DAWN
PROJECT

DRAWN D.Fisher

DRAWING NUMBER DUK6152/00
SH 1 OF 1

ISSUE 0

DRAWING NUMBER
DUK6152/005/1
SH 1 OF 1

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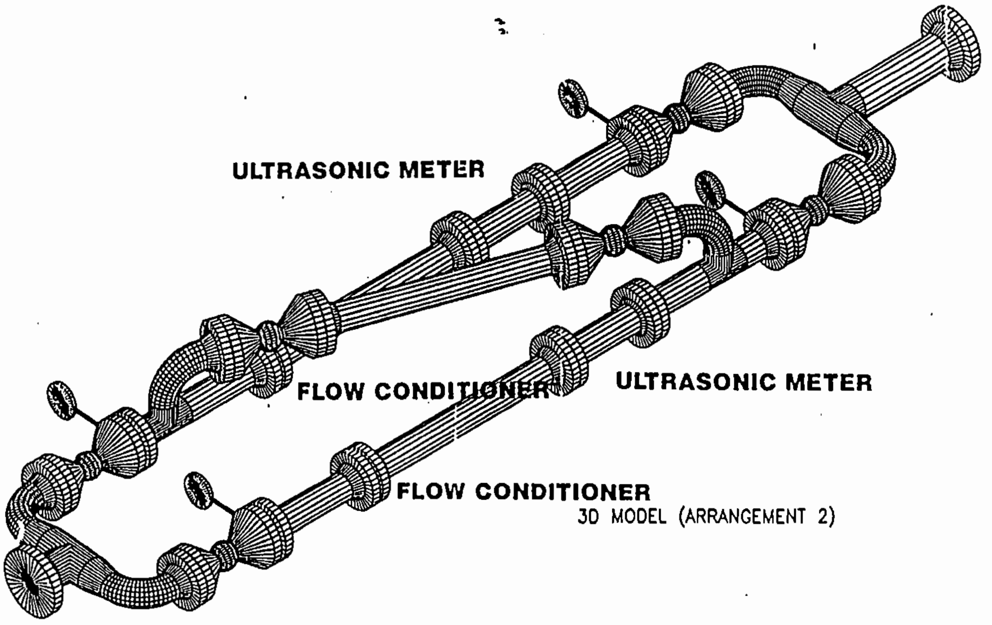
FIGURE 2



3D MODEL (ARRANGEMENT 2)

ISS	DATE	CHANGE	CHKD	APPD	ISS	DATE	CHANGE	CHKD	APPD
A	10.1.95	FOR TENDER							

ORIG SCALE 1:10 A1
DIMENSIONS IN mm
REF EC 0276

DANIEL
INDUSTRIES LIMITED

PHILLIPS
HEWETT/DAWN
DEVELOPMENT (ARRANGEMENT 2)

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SH 1 OF 1

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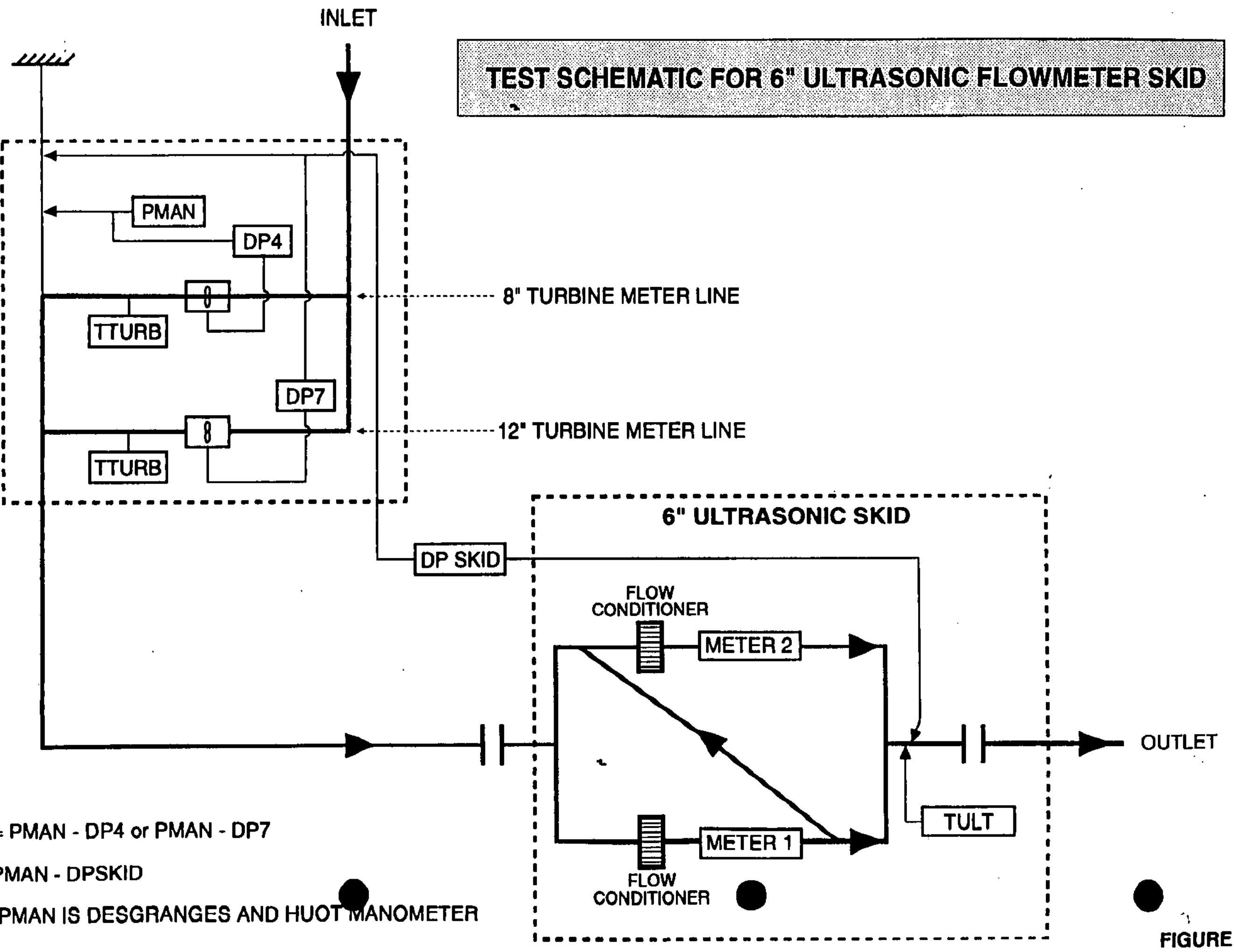
TEST SCHEMATIC FOR 6" ULTRASONIC FLOWMETER SKID



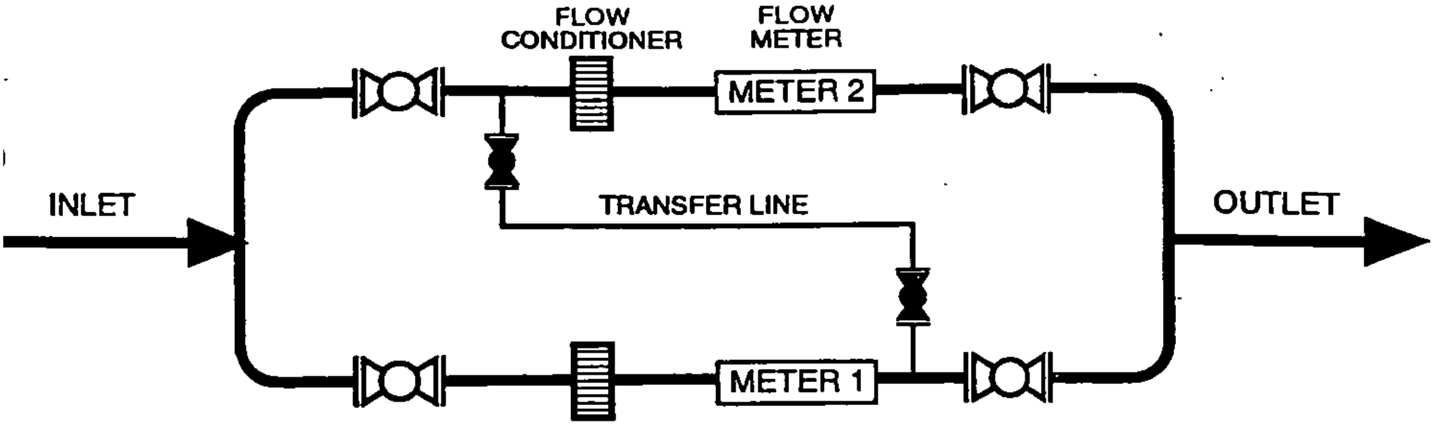
NOTES :

PTURB = PMAN - DP4 or PMAN - DP7

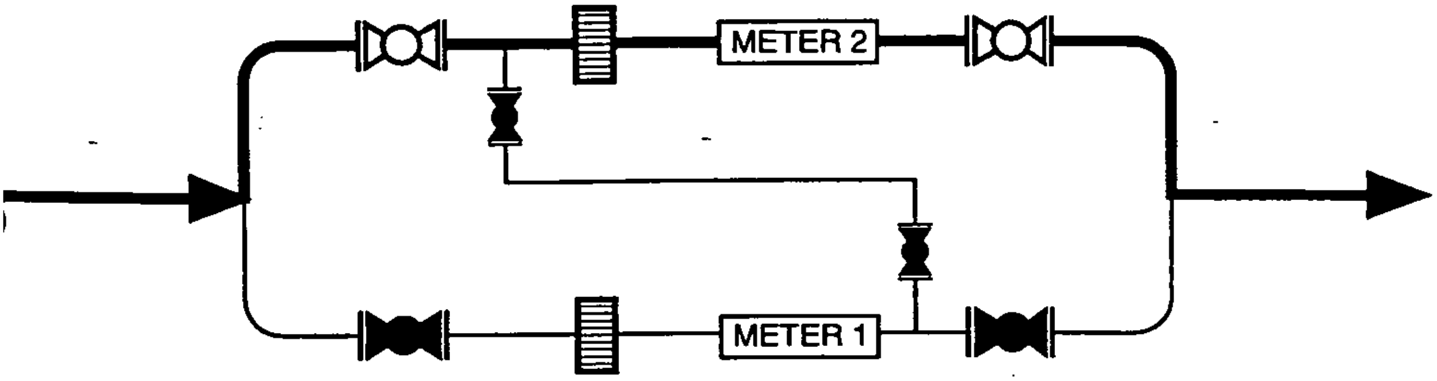
PULT = PMAN - DPSKID

WHERE PMAN IS DESGRANGES AND HUOT MANOMETER

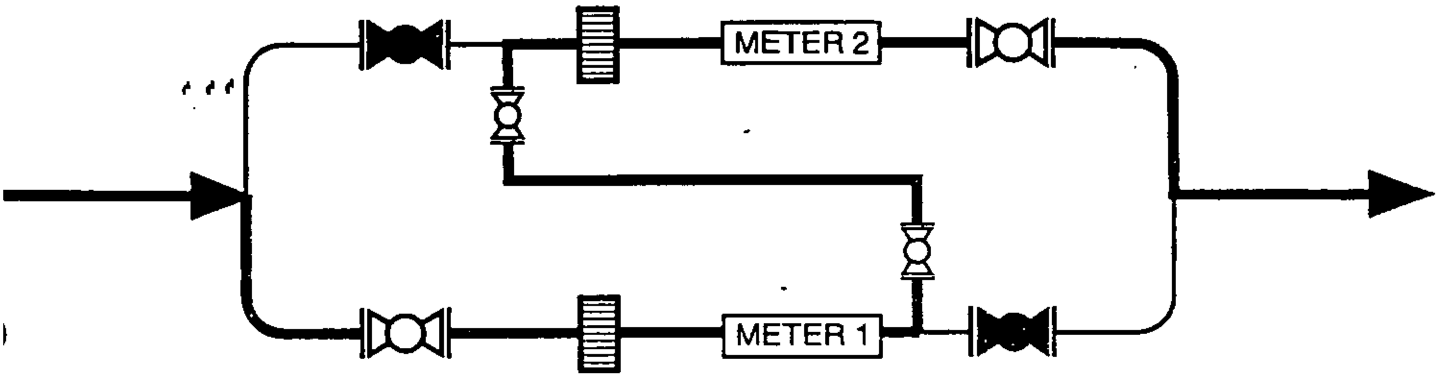
FIGURE 3.



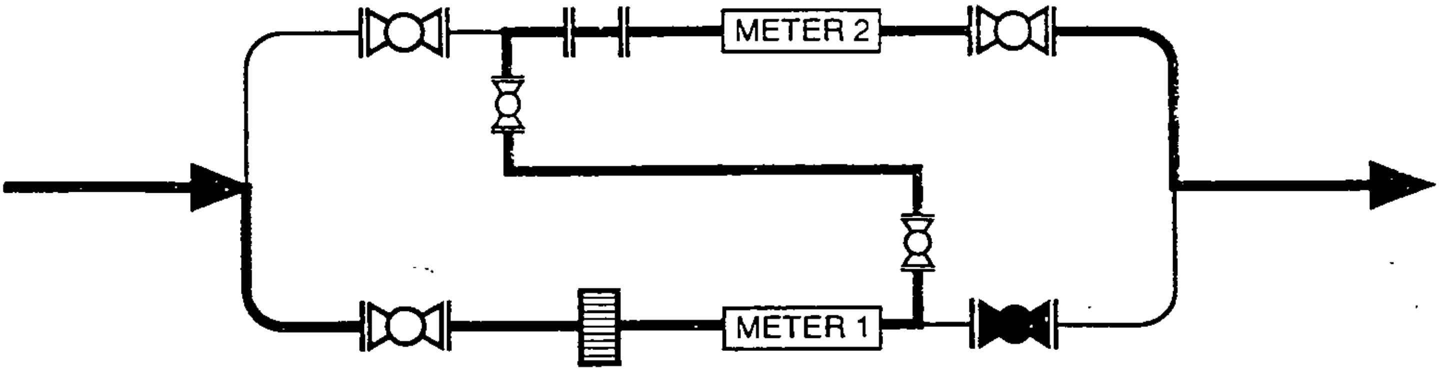
PARALLEL FLOW.



INDIVIDUAL FLOW.

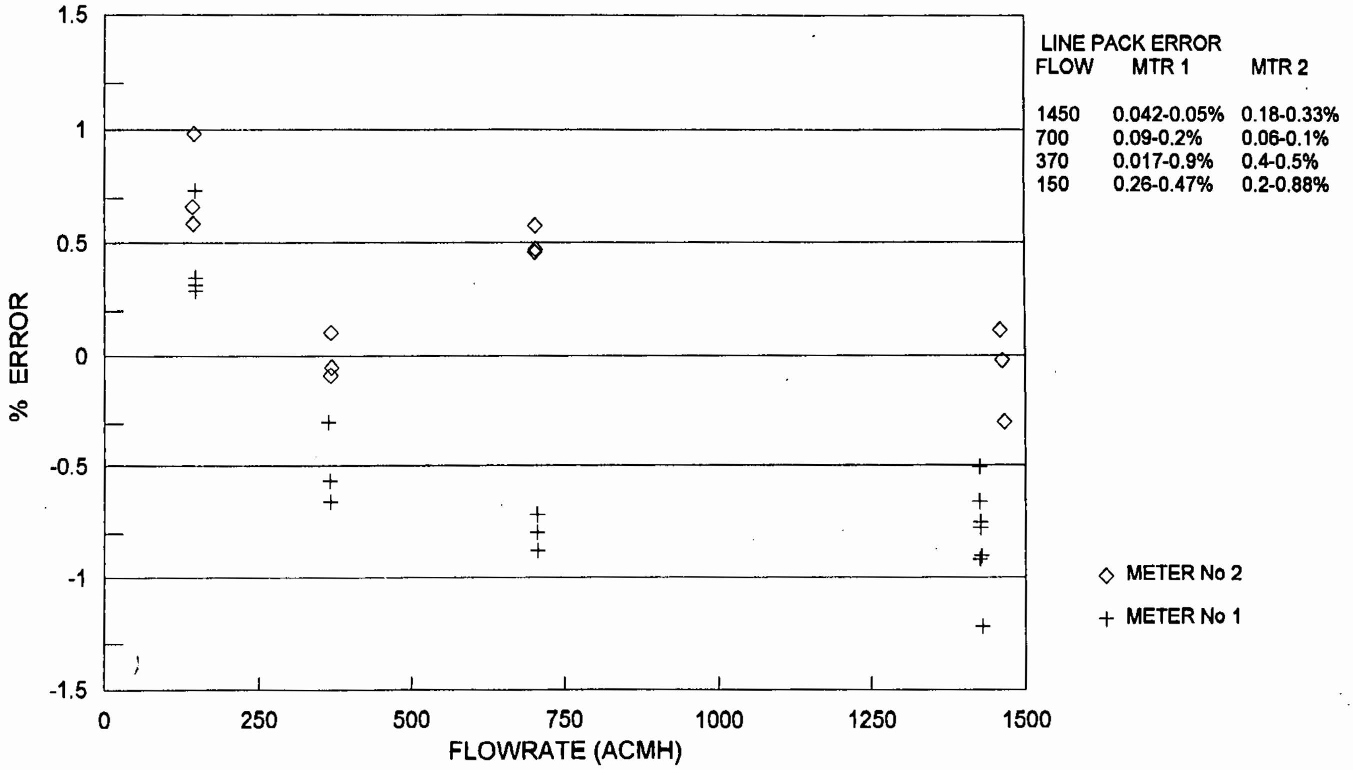


SERIES FLOW, WITH CONDITIONER.



SERIES FLOW, WITHOUT CONDITIONER.

FIGURE 4. - FLOW SCHEMATIC PERMUTATIONS



METERS 1 & 2 COMPARED

INDEPENDENT INSTALLATIONS WITH CONDITIONERS

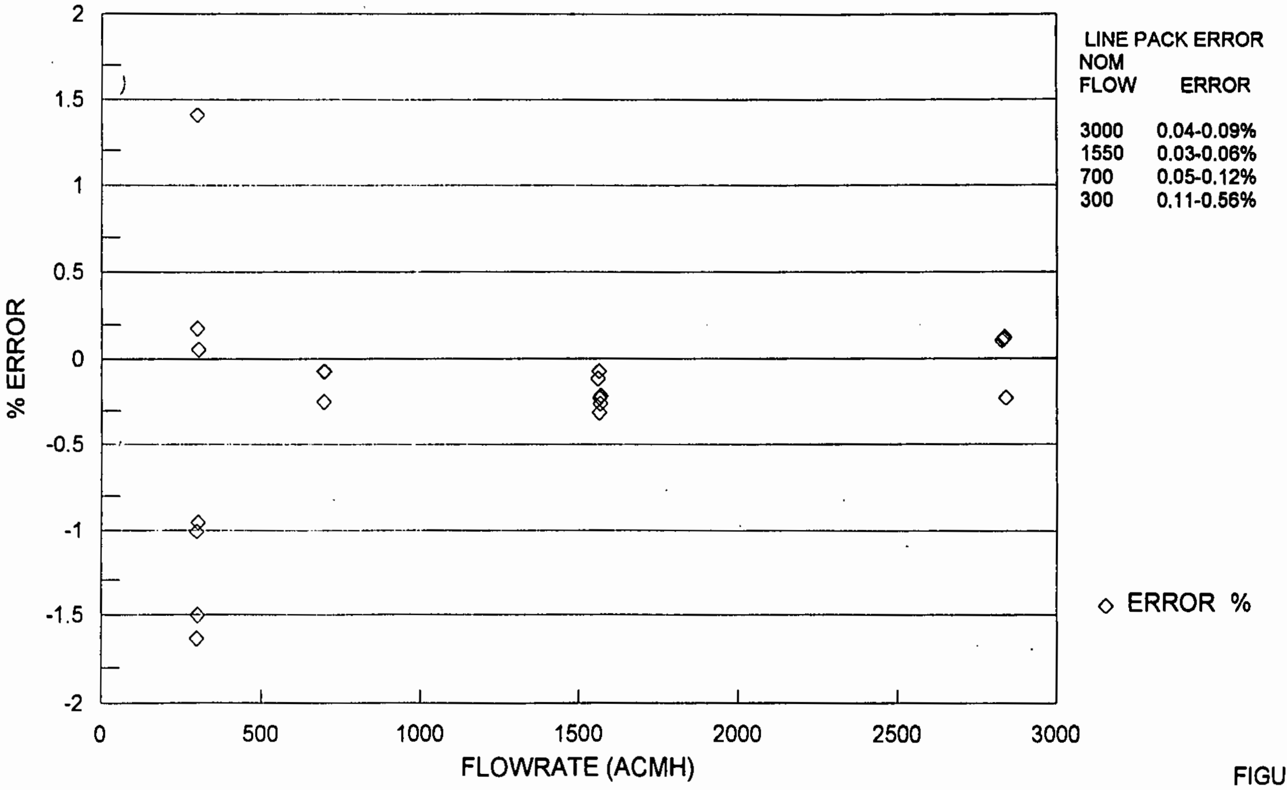
LINE PACK ERROR

FLOW	MTR 1	MTR 2
1450	0.042-0.05%	0.18-0.33%
700	0.09-0.2%	0.06-0.1%
370	0.017-0.9%	0.4-0.5%
150	0.26-0.47%	0.2-0.88%

FIGURE 5

METERS IN PARALLEL

ERROR % Vs FLOWRATE(ACMH)



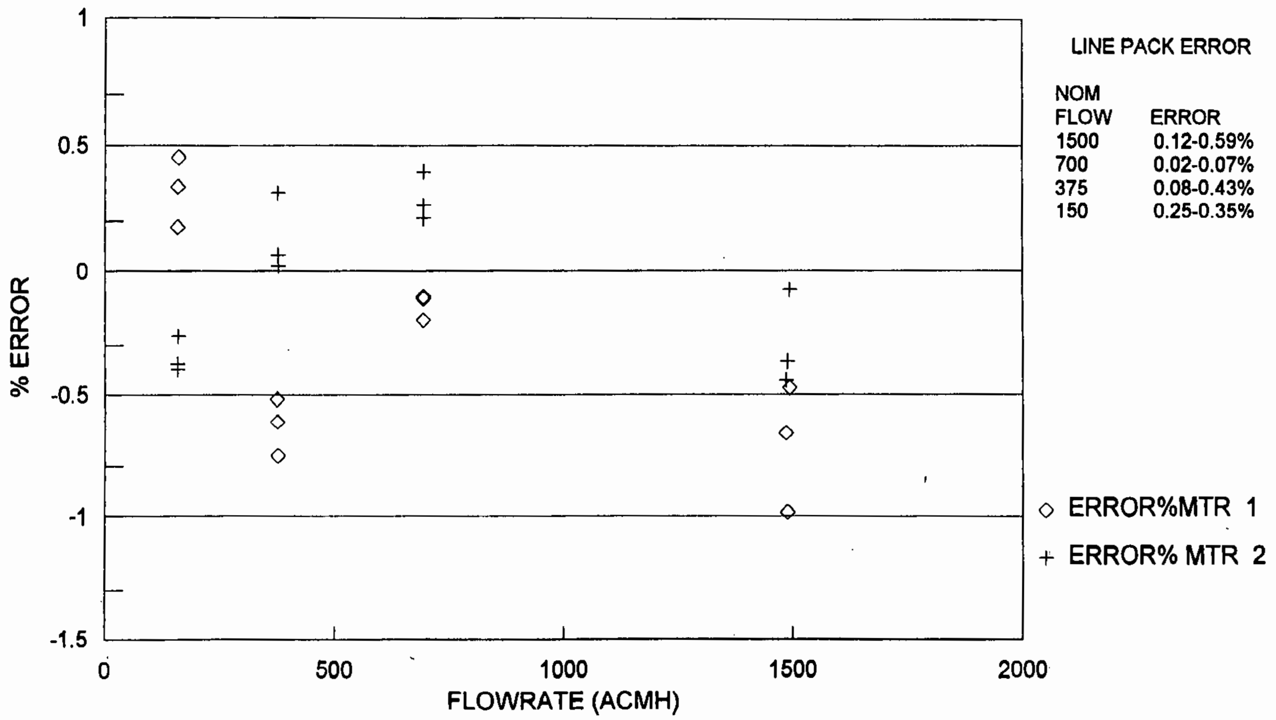
LINE PACK ERROR

NOM FLOW	ERROR
3000	0.04-0.09%
1550	0.03-0.06%
700	0.05-0.12%
300	0.11-0.56%

FIGURE 6

METERS No 1 & 2 IN SERIES

C/W FLOW CONDITIONERS



LINE PACK ERROR

NOM FLOW	ERROR
1500	0.12-0.59%
700	0.02-0.07%
375	0.08-0.43%
150	0.25-0.35%

PRESSURE CORRECTIONS MADE FOR HIGH AND MEDIAN FLOWS

FIGURE 7

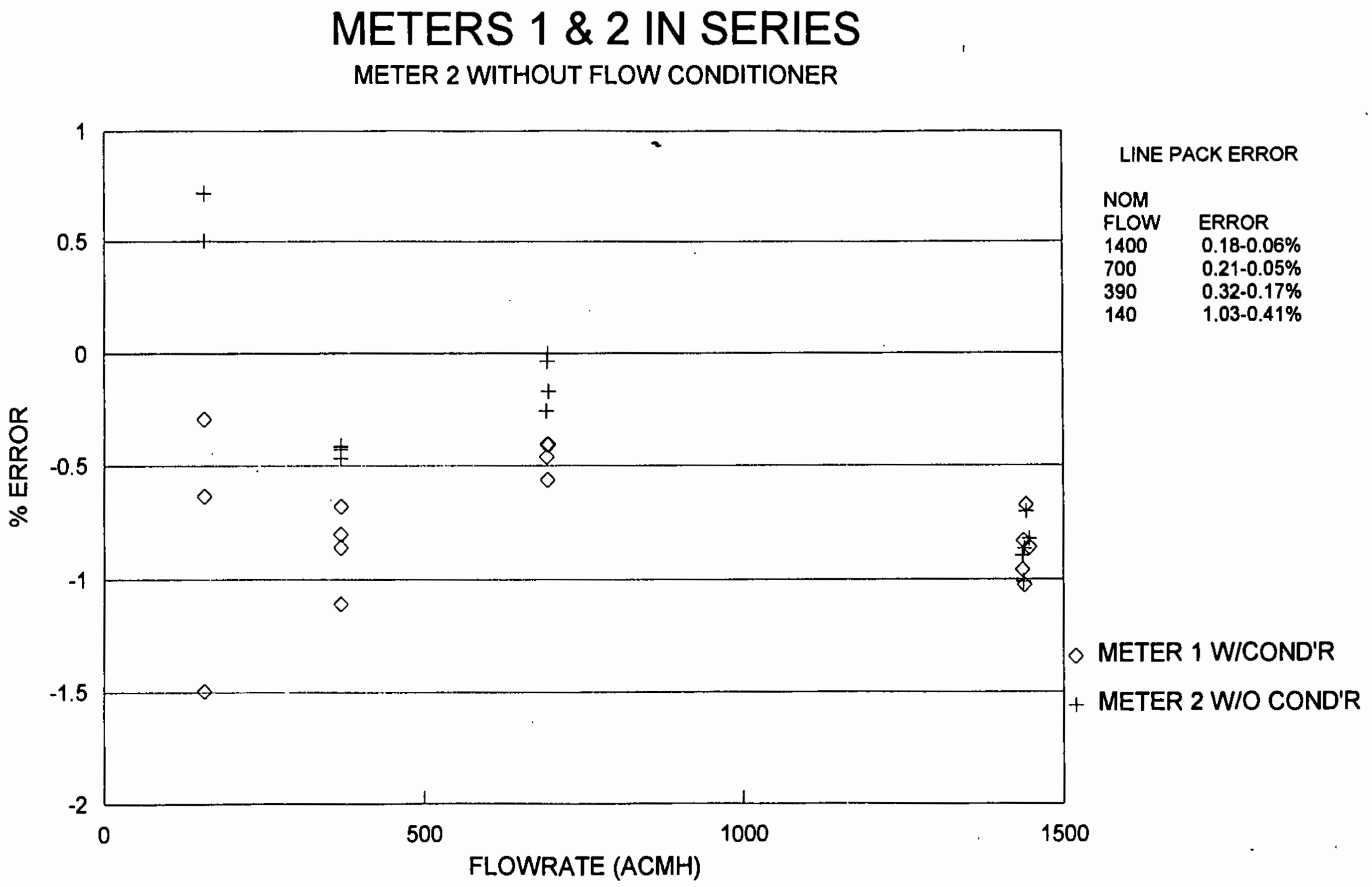
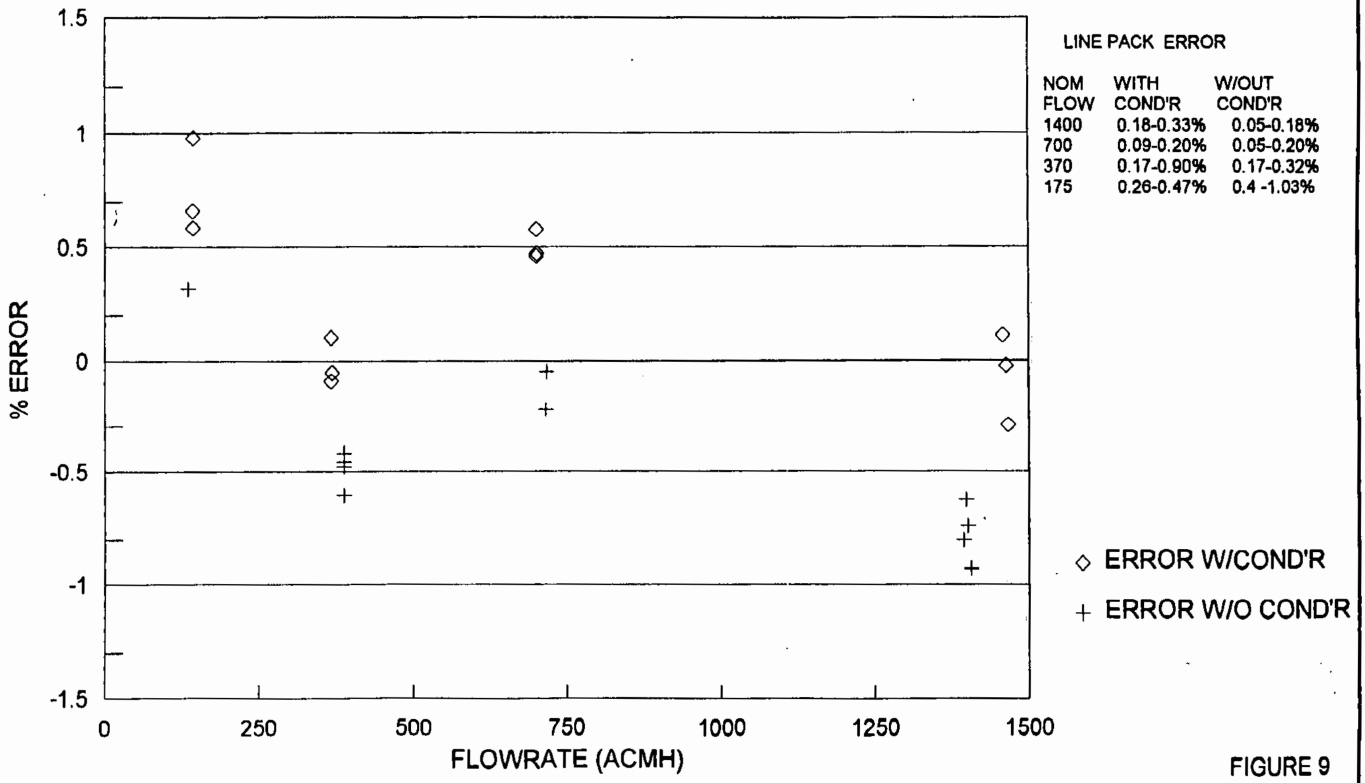

METERS 1 & 2 IN SERIES
METER 2 WITHOUT FLOW CONDITIONER
% ERROR
1
0.5
0
-0.5
-1
-1.5
-2
0
500
1000
1500
FLOWRATE (ACMH)
LINE PACK ERROR
NOM FLOW
ERROR
1400 0.18-0.06%
700 0.21-0.05%
390 0.32-0.17%
140 1.03-0.41%
◇ METER 1 W/COND'R
+ METER 2 W/O COND'R

FIGURE 8

METER No 2

WITH AND WITHOUT FLOW CONDITIONER



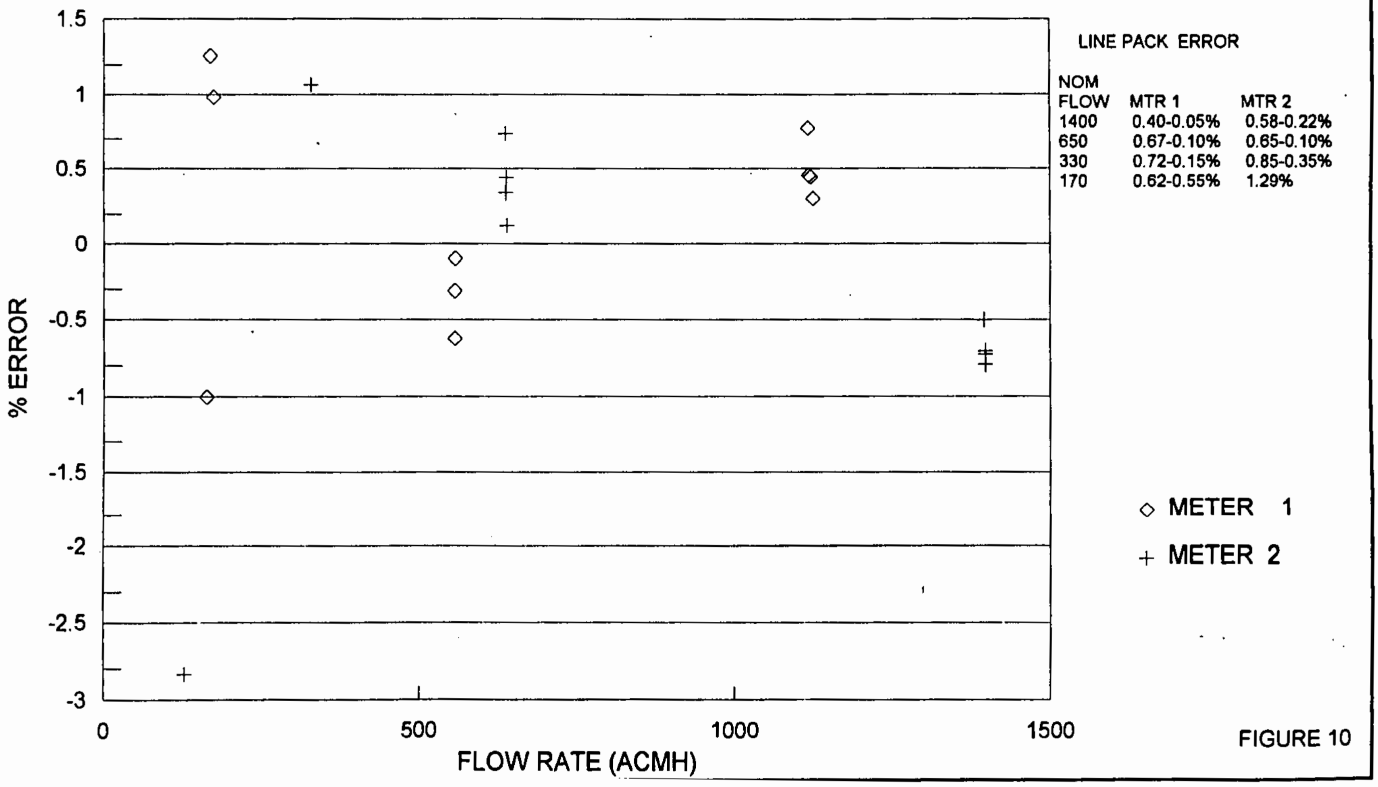
LINE PACK ERROR

NOM FLOW	WITH COND'R	W/OUT COND'R
1400	0.18-0.33%	0.05-0.18%
700	0.09-0.20%	0.05-0.20%
370	0.17-0.90%	0.17-0.32%
175	0.26-0.47%	0.4 -1.03%

FIGURE 9

METERS 1 & 2

LOW PRESSURE FLOW (38Bar)



LINE PACK ERROR

NOM FLOW	MTR 1	MTR 2
1400	0.40-0.05%	0.58-0.22%
650	0.67-0.10%	0.65-0.10%
330	0.72-0.15%	0.85-0.35%
170	0.62-0.55%	1.29%

FIGURE 10

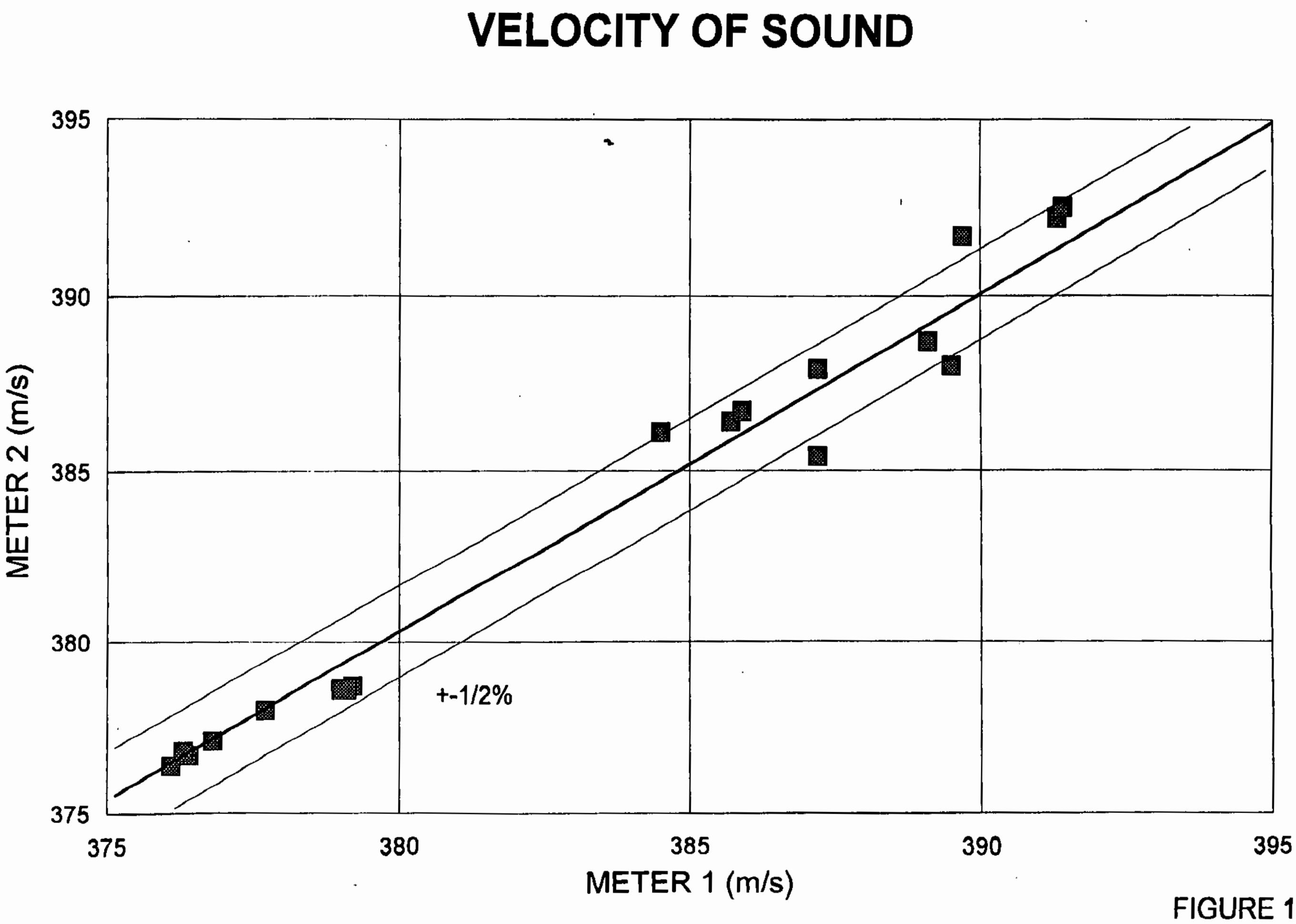

VELOCITY OF SOUND
395
390
385
380
375
METER 2 (m/s)
375
380
385
390
395
METER 1 (m/s)
+-1/2%

FIGURE 11

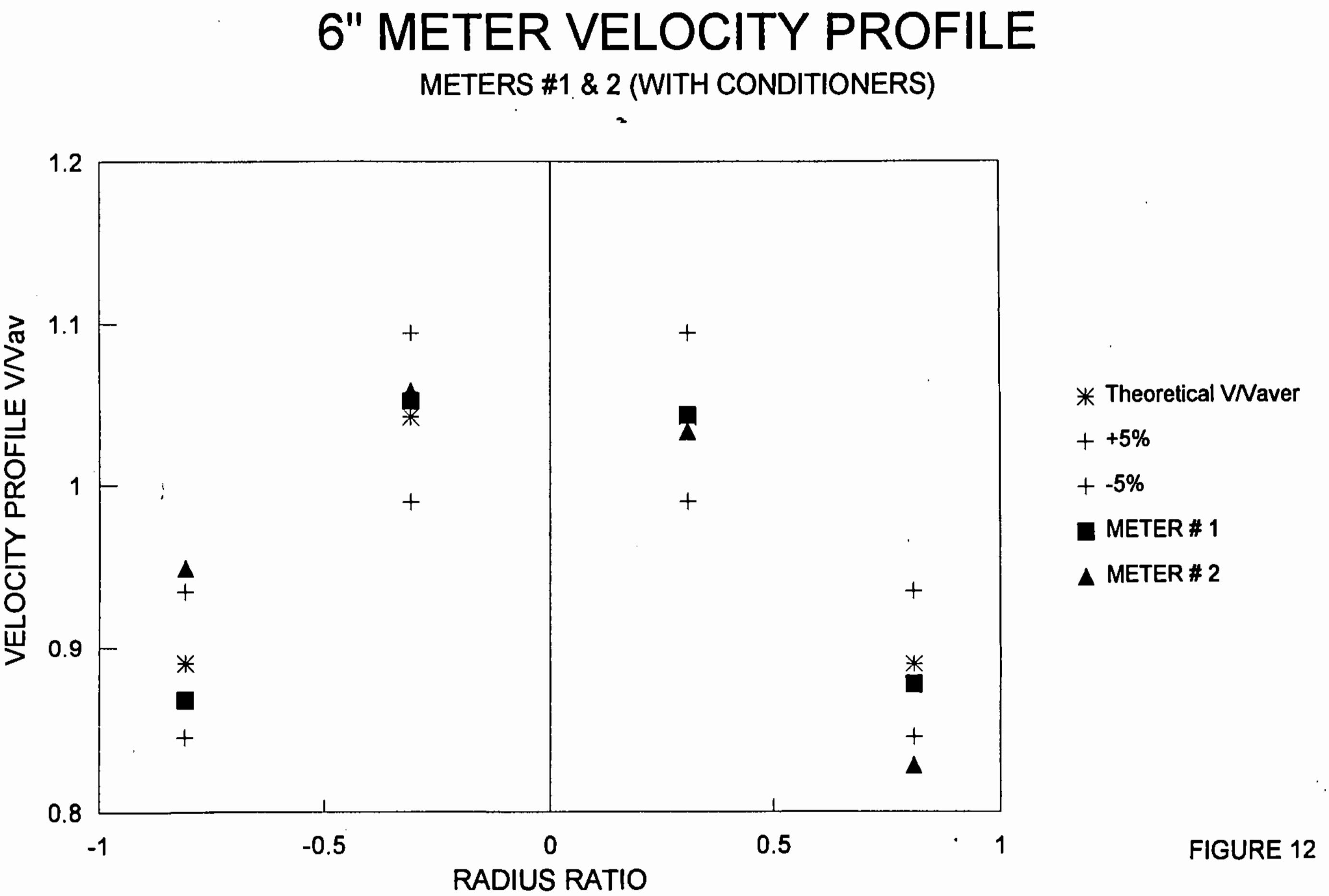

6" METER VELOCITY PROFILE
METERS #1 & 2 (WITH CONDITIONERS)
1.2
1.1
1
0.9
0.8
VELOCITY PROFILE V/Vav
-1
-0.5
0
0.5
1
RADIUS RATIO
✳ Theoretical V/Vaver
+ +5%
+ -5%
■ METER # 1
▲ METER # 2

FIGURE 12

6" METER VELOCITY PROFILE

METER # 2 WITH & WITHOUT FLOW CONDITIONER

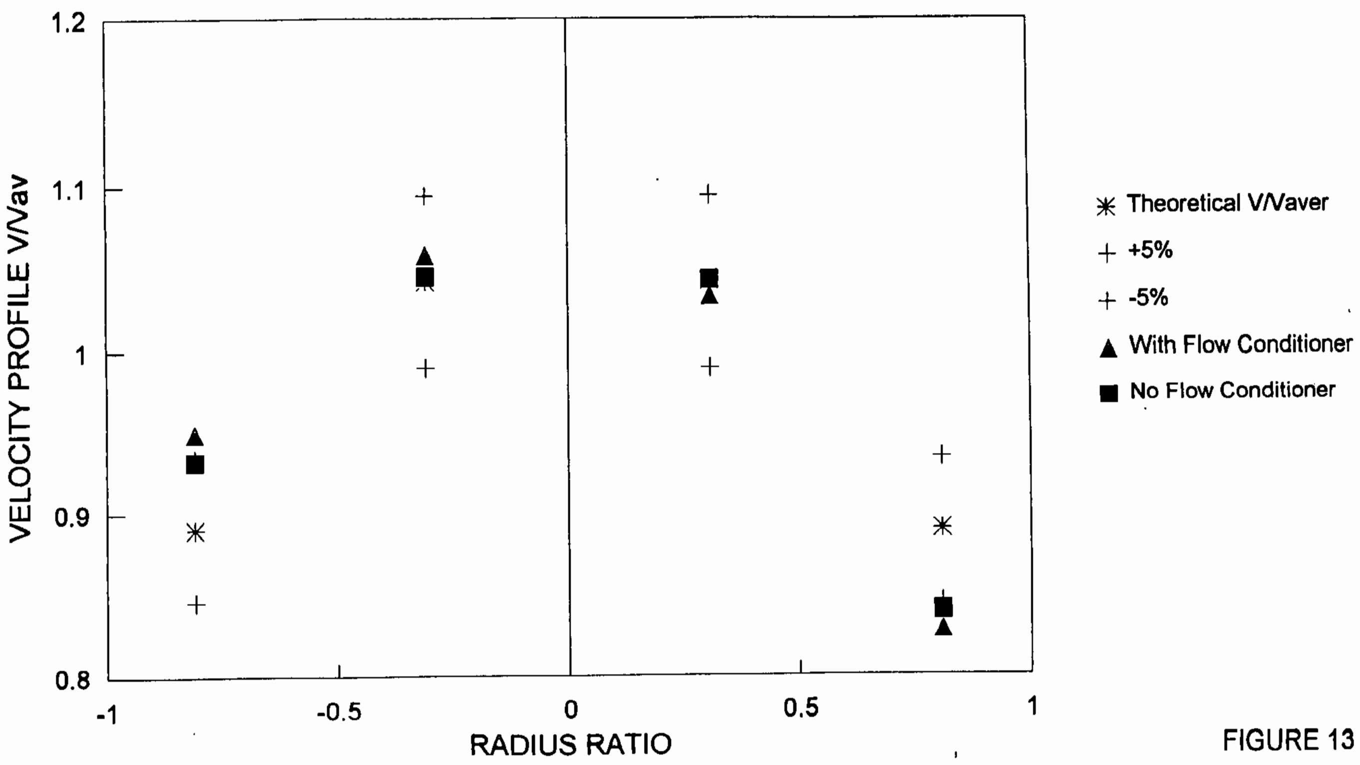


FIGURE 13

6" METER VELOCITY PROFILE

METER #2 IN SERIES WITH & WITHOUT CONDITIONER

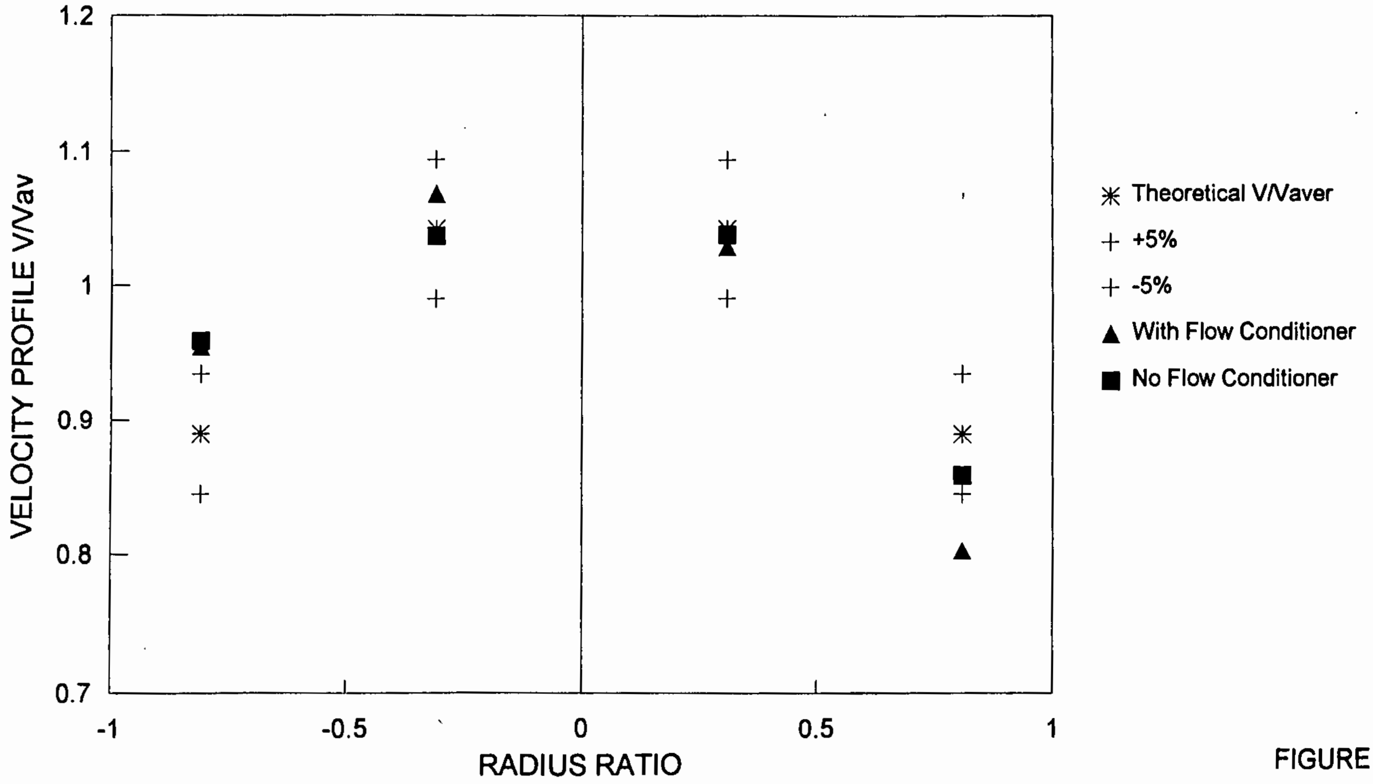


FIGURE 14

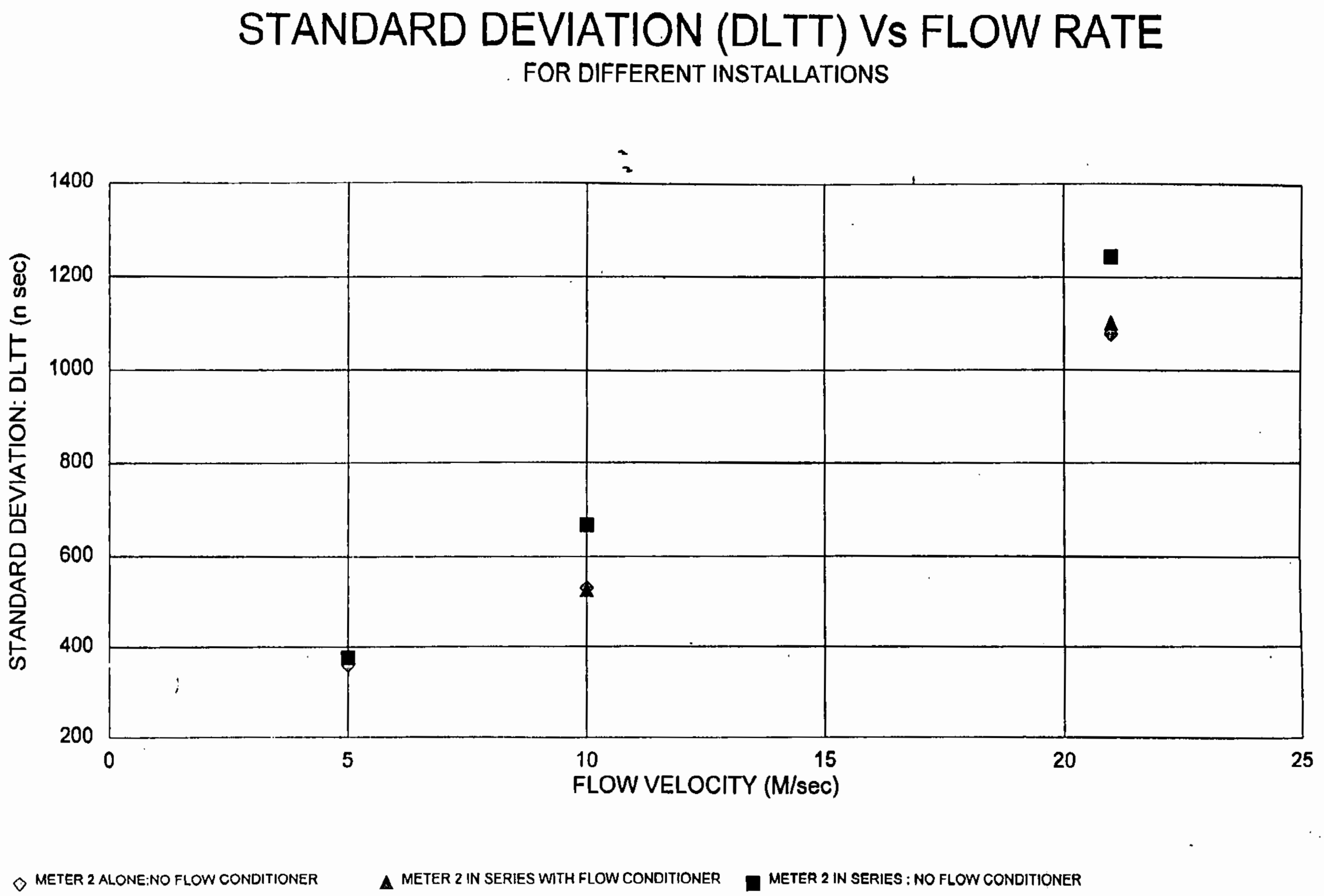
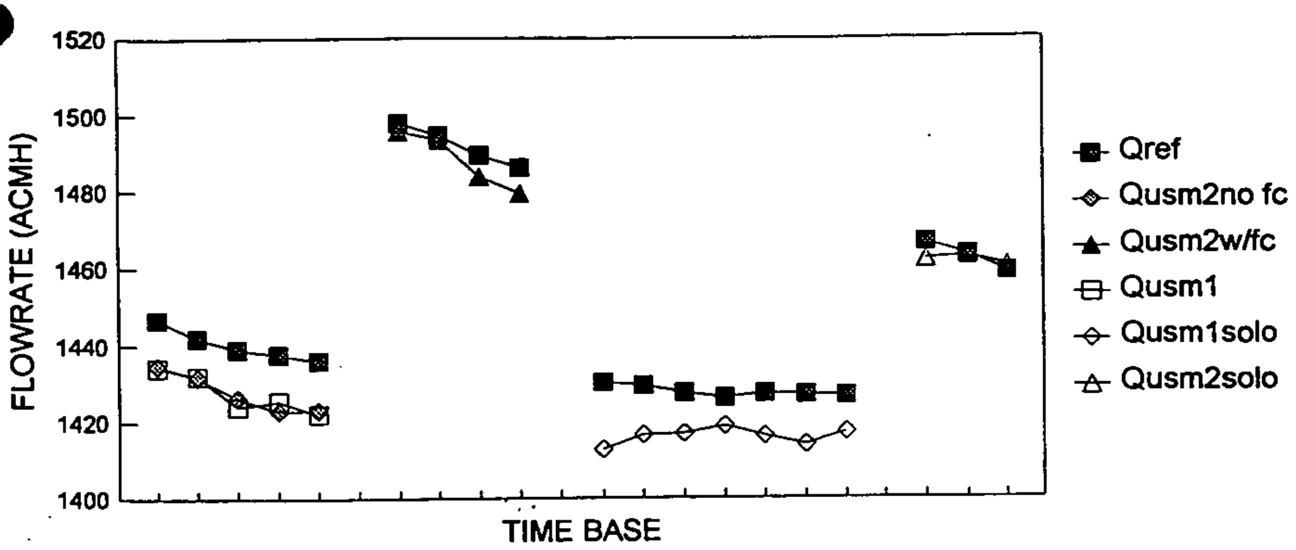
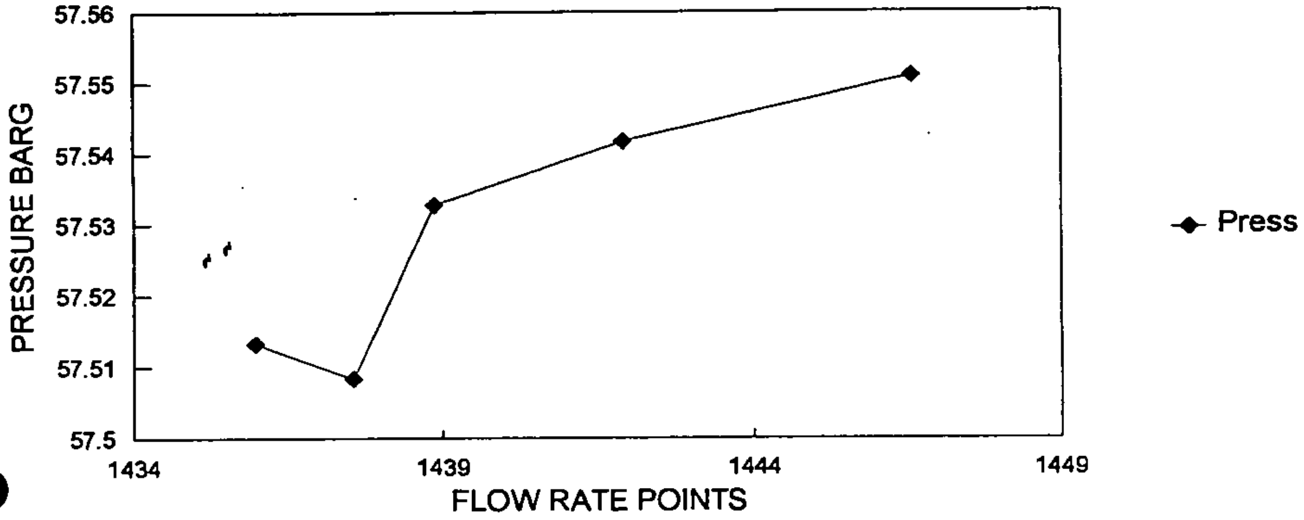

STANDARD DEVIATION (DLTT) Vs FLOW RATE
FOR DIFFERENT INSTALLATIONS
STANDARD DEVIATION: DLTT (n sec)
1400
1200
1000
800
600
400
200
0
5
10
15
20
25
FLOW VELOCITY (M/sec)
◇ METER 2 ALONE:NO FLOW CONDITIONER
▲ METER 2 IN SERIES WITH FLOW CONDITIONER
■ METER 2 IN SERIES : NO FLOW CONDITIONER

FIGURE 15

METER COMPARISON: Qref Vs Qusm



PRESSURE VARIATIONS



TEMPERATURE VARIATIONS

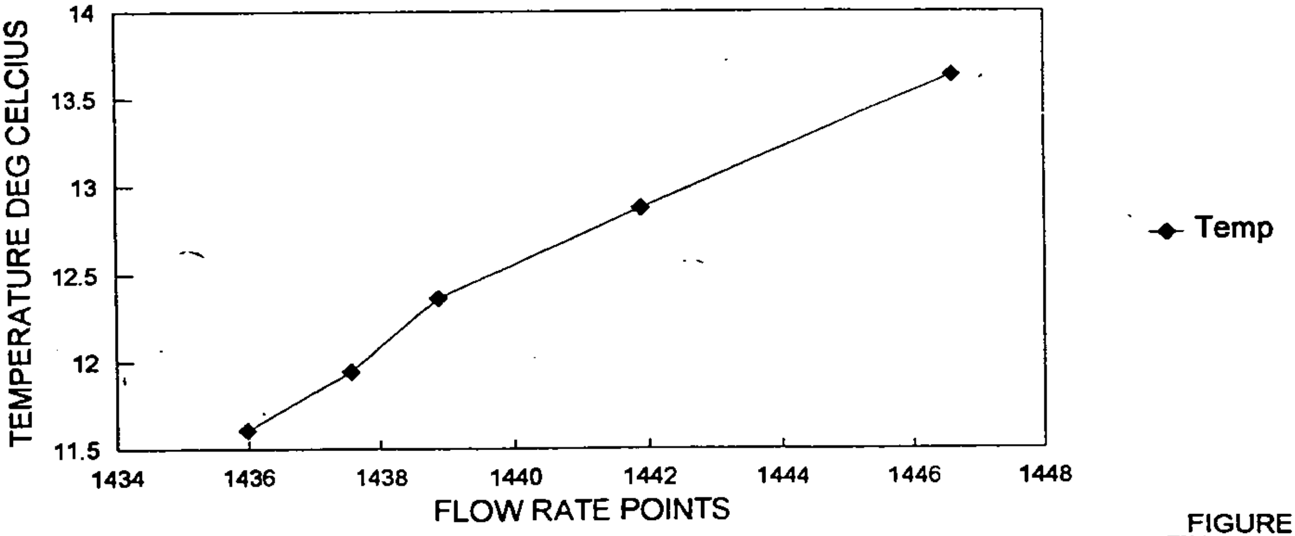


FIGURE 16