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ULTRA-SONIC WET GAS MEASUREMENT - DAWN GAS METERING A "REAL WORLD" SYSTEM

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1 INTRODUCTION

In 1995 Phillips Petroleum Co UK Ltd decided to exploit the Dawn reserves in the Southern North Sea via a subsea well and existing facilities on the Hewett 48/29C platform. Following the resolution of the Ultraflow Wet Gas JIP [1] it was decided to use the prototype JIP Ultrasonic Meters as the production meters for Dawn.

A short meter skid was designed to incorporate the two 6 inch USM's and NEL (Spearman) flow conditioners and was flow tested at the British Gas facility at Bishop Auckland. The results of these tests demonstrated the performance of the meters and the flow conditioners and may be found in Reference [2].

In brief the metering skid enables Dawn gas to be metered following primary liquid separation via one or two 6 inch Daniel Ultrasonic meters. The skid can be configured to meter the gas in a simplex, duplex serial or parallel meter mode. See Figures 1 and 2 for further information.

The design of the meters is also covered in Reference [1] and consisted of reduced size acoustic transducers housed in large ports so that liquid build up does not cause an acoustic link between the transducers and the body of the meter.

This paper details our experiences with wet gas measurement and the results from these specialised meters when used in liquid saturated gases in harsh process conditions.

2 PRE-COMMISSIONING

Following the flow testing at Bishop Auckland the meter skid was shipped offshore for installation. Once all the installation had been completed pre-commissioning and commissioning took place.

i. In pre-commissioning we set up the skid with nitrogen at 10 to 15 bar g to test the USM transducers and found that the signals from otherwise previously perfect transducers were not particularly good. Following some investigative work we found that the meters had been hydro-tested complete with the transducers. We were assured that the pressure had been let down "slowly" ... but we reckoned that the pressure let down had detached the 0.005" shim from the USM transducers.

The shim seals the epoxy face from the "nasties" we often find in the gaseous products ... methanol, H2S etc.

The shim is part of the transducer and is acoustically bonded, but the pressurising and depressurising allowed the shim to detach and thus break the acoustic bond.

As there was no H2S in this case we were able to grind off the shims and rescue most of these transducers and get on with the commissioning after only a few days delay.

ii. Whilst we were setting up the meters we found that the lower chord transducers would fail on a regular basis. Each time we removed the transducer pair we found that liquids had accumulated in the bottom of the meter which was a low point in the process pipework ... a design failure on our part, but one of those things that happen when retrofitting a skid to existing facilities ... which in any new design we would certainly design out ... we hope.

We were at a loss to find out where the water was coming from, but we are convinced now that it was hydrotest water from both upstream and downstream of the process.

Our "low point" design certainly cost us time with these problems, and has probably affected us since in normal operation.

3 IN OPERATION

3.1 Flow Conditions

ISO 5167 states that good flow conditions exist when the flow profile is <±5% of the 100D flow profile and swirl is less than two degrees. Experience shows that the swirl figures are difficult to achieve and have a considerable effect on the meters' performance.

In the last decade interest was generated by work done in Europe and the USA when people began to realise that plate conditioners being developed by Laws and NEL in the UK, K-lab in Norway, Gallagher in the USA and others have all been shown to work to varying degrees. All the rules that apply to dry gas with respect to developed flow profiles and swirl are equally applicable to wet gas.

The Dawn installation is a short metering skid with Ultrasonic Gas flow meters and upstream flow conditioners. We took the skid to BG's test site at Bishop Auckland for flow testing with and without the conditioners to demonstrate that the conditioners developed a good flow profile.

The results were reported in Reference [2].

However once we got to site, we found that the picture was somewhat different ... some interesting flow profiles were observed ... most were fully developed and a few were skewed. Figure 3 shows a normal and a skewed profile. When the conditioner was removed it was found that some of the perforations were fully or partially blocked with hydrates, giving rise to the unusual profile.

We knew later that the DP across the conditioner was about 10 psi with an operating pressure of 300 psig, which is well within the hydrate range so the presence of hydrates should have been expected.

It is not advocated that flow conditioners be installed in a wet gas environment ... unless it is absolutely sure that hydrates cannot be formed or hydrate inhibitors are to be used as a matter of course.

3.2 Hydrates

Hydrocarbon gases containing free water can at certain pressures and temperatures form "ice" plugs - hydrates. This problem can be suppressed or removed by one or a combination of the following ... but remember that its always easier to engineer the problem out at the start rather than try to retrofit solutions afterwards.

1. Operate above the hydrate point on the pressure/temperature curve for the gas. From Figure 4, which is a typical hydrocarbon hydrate curve, it is seen that the most efficient suppression process is to raise the temperature.

   For many reasons it may be impossible to raise either parameter. Temperature is often governed by external factors - sea temperature, pipeline length, flow rates etc.

2. Remove the water ... a difficult solution for wet gas measurement!

3. Hydrate suppression with methanol or glycol. If this is considered always arrange for the installation of the injection points before start up. In the case of subsea metering, retrofitting could well be impossible, and the additional costs for the umbilical to transmit inhibitors may well be prohibitive.

4. Heat tracing is sometimes an effective process and should always be considered in the design.

3.3 Pipework Configuration

Pipework design has always been recognised as important. With wet gas it is probably more so: all the dry gas rules apply plus a few new ones too! It doesn't help to install the meter at a low point - makes sense doesn't it?

Now consider some of the meter layouts out there in the field.

- Lowered to grade for operator access ... OK for dry gas but then the Design mentality sticks and we do the same for a wet gas installation creating a low point in the meter tubes for all those liquids to accumulate.
- Pipework slope: sloping the pipework away from the meter may help, provided that the liquid is effectively drained and not held up so that it will slug towards the meter.
- Piping orientation: horizontal or vertical, and if vertical is the flow up or down?

The Ultrasonic Meter Bi Phase JIP has conducted tests with wet gas in vertical pipework for both up and down flow. t was expected that down flow, with gravity, would be self draining and easier than up flow. However, preliminary results show that errors are less with up flow, demonstrating once again the complexity of multiphase flows.

3.4 Liquid Slugs

With wet gas metering there is the risk of liquids accumulating somewhere in the pipework and being moved towards the meter by the flowing conditions.

Typically liquids slugs accumulate in:

- production tubing during well shutdowns.

  On resuming production a subsea meter may be presented with several hundred feet of liquid in the production tubing (say 75 cubic feet/2 M3 of liquids).

- subsea pipelines laid on the seafloor.

  The seafloor is neither smooth nor flat and pipelines have a series of high-low points in which liquids accumulate, and are driven towards the pipeline riser.

Liquid removal is also subject to the performance of the separator. For any number of reasons these may not be as efficient as the Process Engineer would wish especially when redundant equipment is being reused.

3.5 Gas Composition

Regardless of the meter it is important to know the fluid composition through the meter. This will be required to determine base and line density and for energy determination. How the gas is sampled is dependent on the system design and the location of an accessible sample point.

In cases where a number of fields are tied into a single pipeline the ability to purge the line to get a representative gas sample may be impossible. The minimal size of the development may preclude the CAPEX and OPEX of a chromatograph, not that running wet gas through a chromatograph would do (it) much good.

3.6 Meter Recovery

Having established that the meter is likely to be subject to hydrates and liquids, it is also likely to be in a remote spot - either subsea or on an unmanned platform. Knowing this, it is also essential to establish the failure and recovery mode. Figure 5 shows the recovery of a wet gas ultrasonic multiphase meter after flooding as tested in the Ultraflow Wet Gas JIP. In one of the Dawn meters we extracted a failed transducer, which was fractured as a result of hydrates, but the meter continued working.

When all 4 chords are working the meter stirs the velocity profile and uses that information to make substitutions when chords fail.

In service we have seen these meters fail and recover many times in a day, with minimal effect on the overall outcome.

3.7 Noise

With conventional meters noise from valves is not a problem ... but it really is with an ultrasonic meter, so resist the temptation to put one near a choke valve or pressure control station ... experience shows that the USM signals collapse with loss of measurement when exposed to large pressure drops across a device.

Many of the commercial USM's have filtering, stacking and other sophisticated digital signal processing that can help improve the signal to noise. However they cannot totally eradicate noise and loss of signal is often the common result.

It is preferable to place the meter upstream of the noise generator and pipework, fittings, bends, blind tees between the meter and noise source all help to attenuate the noise. Sharing the pressure drop across two valves can considerably reduce noise problems, and it is often much easier to solve these problems in the design stage than by retrofit engineering.

3.8 Metering Results

In late 1995 we commenced gas production and sales. It became apparent that there were problems being experienced by the Operations staff.

However, we were not convinced that the problems were all with the meters.

- Having been through the problems with liquids it was determined that corrections needed to be made to the vertical separator packing trays and a liquid drain tube. Correcting this removed some of the liquid carry over.
- The low temperature (approx. 5 to 10 Celsius) at the meters was addressed by insulating/heat tracing the hydrocarbon feed line/meter skid.
- The local drain line upstream of the skid was converted into a chemical injection point for additional hydrate suppression.

These modifications improved the meter performance, but failures were still evident and we could no longer hide any defects behind any apparent process problems as we had done all we could to improve or eradicate these.

Monitoring the two meters during late 1995/1996 & early 1997 we found that there were a significant number of failures in both meters.

3.8.1 1995/1996/1997 Flow measurement results

The first series of data in late 1995, 1996 and 1997 indicate that whilst the meters were tracking each other quite well, it was evident that they were failing and recovering.

At this point in time the flow test results from the meters appeared to look good, even promising and an initial set of results from July 1996 are shown in Figure 6.

However once the process was settled down we had to start looking at the meter reports and what came back was not so reassuring.

A thirty day period in July 1996 was logged and can be seen in Figures 7 and 8. The spread looks like +/- 10% with outliers in the +/- 15% range. A form of histogram (Figure 8) shows that about 90% of the measurements are within the +/- 6% range.

During the production period of 1997 the word coming back was that there were large numbers of "**Warning** – Chord Failures" and "**Fatal** - Chord Failures". "Warning" was to announce a single chord failure, not in itself a calamitous event as the signal processing is able to cater for this until the chord recovers. "Fatal" was to announce that all 4 chords had failed, which is far more serious and could lead to exceptional errors. D-Chord failures are not all bad, as they indicate the presence of liquids.

Figure 9 shows the chord failures recorded during a 20 day period in February 1997 attributed to the two meters. Meter 2 appeared to be worse with significantly more failures than meter 1.

Once Meter 2 was modified (see Section 4) chord failures reduced significantly. Figure 10 shows the chord failures recorded in a similar period in February 1998 and Figure 11 is Figures 9 and 10 superimposed. The reduction is from an average of 10 per day to less than 4 chord failures per day.

4 MODIFICATIONS

Following discussions with the Operating Group and Daniels it was agreed that the "Bad" meter (2) would be modified during the zero nomination period (summer) of 1997 ready for 1998.

The original British Gas Ultrasonic Meter was designed for clean dry sales gas. The main practical feature of the design to fail in wet gas was the small clearance between the transducer (1 1/8" Dia.) and port (1 ¼" Dia.). This 1/16" (1.6 mm) radial clearance is very easily bridged by liquids, which causes acoustic coupling to the steel meter body and noise to appear in the received signals.

It is quite easy to cure the problem by increasing the clearance to ¼", making the port Dia. = 1 1/8 + ½ = 1 5/8". Unfortunately, this is not possible with 6" and 8" meters because the ports on the outer chords break through the pipe bore and leave a trap that fills with liquid. The only possibility with these small meters is to reduce the transducer size. Keeping a ¼" clearance from the 1 ¼" port gives a 1 ¼ - ½ = ¾" (19 mm) diameter transducer.

The Ultraflow specification for the ¾" transducer was:

Pressure	10 to 180 bar
Temperature	-10 to 150°C
Liquid	< 1% volume fraction
Corrosion	< 2% H_2S

This proved very difficult to achieve and in hindsight was over ambitious! We probably threw out some good ideas because they did not meet all our criteria. To meet the severe corrosion conditions, the transducer was built into a sealed Hasteloy can. This led to two other major problems:

1. It is difficult to manufacture.
2. It is prone to acoustic coupling with the steel body.

Eventually a compromise was reached, see Figure 15:

- a PEEK acoustic isolator was used to connect the transducer to the flange
- 'O' rings were used to seal against corrosive gases
- the epoxy matching layer was protected with a thin metal shim

The small wet gas transducer used a 10 mm Dia. Piezoelectric crystal compared with the standard 20 mm crystal, leading to considerable losses:

- treating the crystal as a piston, it has ¼ of the area and ¼ of the power
- with a speed of sound = 400 m/s and a frequency = 120 kHz, the wave length in gas is about 3.3 mm. The beam from the 20 mm crystal will spread with an half angle of 10° while the 10 mm crystal will spread at 20°, further dispersing the energy.
- the shim is yet another interface between crystal, epoxy and gas, incurring more transmission losses
- the possibility of the shim delaminating is a potential hazard, which would lead to complete loss of signal.

Many of these shortcomings were unfortunately realised during the field trials, hence the decision to revert to standard transducers, with a few changes:

- the acoustic isolation between transducer and flange was improved, to make it harder to couple the transducer to the body
- the system improvements reduced the liquid content of the gas
- most liquid problems were with the bottom D-chord in the horizontal layout
- loss of the D-chord did not cause significant errors, due to the substitution algorithm
- the D-chord recovers after flooding

On the basis of these considerations, the bad Dawn meter (2) was upgraded to the almost standard transducers. It has showed considerable improvement in performance, and meter (1) has been upgraded this summer and is ready for use offshore.

5 POST MODIFICATION RESULTS (1998)

Figures 12 and 13 show the flow test results for a 20 day period in February 1998. This is with the old "bad" meter (2) replaced with "standard" transducers and the old "good" meter (1). The plots show the discrepancy in percent terms between the two meters and Figure 14 is a histogram of the discrepancies.

As can be seen from Figure 12, the hourly data over 20 days is very tight around +/- 1% with only a few outliers. There is one at +15% which accounts for the day when 11 chord failures occurred. On the daily data comparison (Figure13) the error between the two meters does not exceeds +/- 1%.

In addition the histogram of all hourly data shows 91.2% of all measurements are within +/-1%.

6 CONCLUSIONS

The modifications put in place in the process improved the primary metering results. The 1998 results are much improved from a band of +/- 6%, to +/- 1% which is very satisfactory for a wet gas meter.

The 1996 hourly data (390 points in total) has a flat histogram with around 90% of the results within +/- 6%, whilst the 1998 hourly data (460 points in total) has a normal histogram and shows that 91.2% is within +/- 1%.

However it must be stressed that the transducer alone did not effect a cure, good system design is essential:

- avoid low points for the meter
- ensure self draining, by gravity
- do not make flow and gravity fight one another
- avoid hydrate formation

It is expected that the modifications installed for 1998/1999 will improve matters even further.

Remember to think wet gas at the design stage and avoid expensive corrective action in the field.

If you have to go wet gas metering ... read the Standards ... but do not follow them slavishly. Use your brain ... its as good as anyone else's .... especially those of the guys who write the Standards!!

REFERENCES

[1] Wilson, M., Ultraflow Wet Gas Development Report: Restricted BP Report ESR.96.ER.016, BP job Number 115-4213

[2] Zanker, K., Stobie, G., Ultrasonic Meter: In-Situ Skid Mounted Flow Testing. North Sea Flow measurement Workshop, Lillehammmer, Norway. Norwegian Society of Chartered Engineers, 1995

ACKNOWLEDGEMENTS

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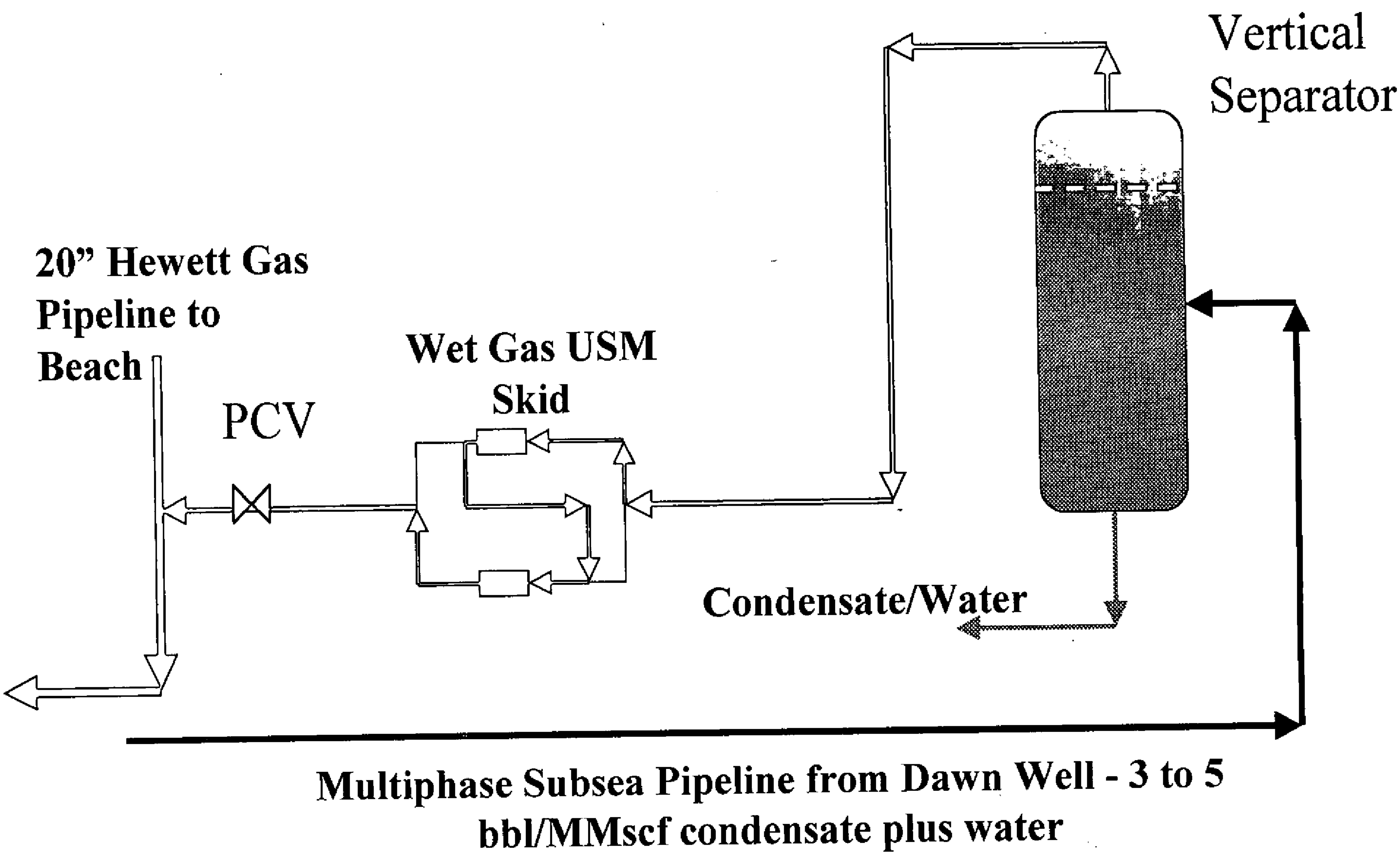

Vertical
Separator
20" Hewett Gas
Pipeline to
Beach
PCV
Wet Gas USM
Skid
Condensate/Water
Multiphase Subsea Pipeline from Dawn Well - 3 to 5
bbl/MMscf condensate plus water

Figure 1

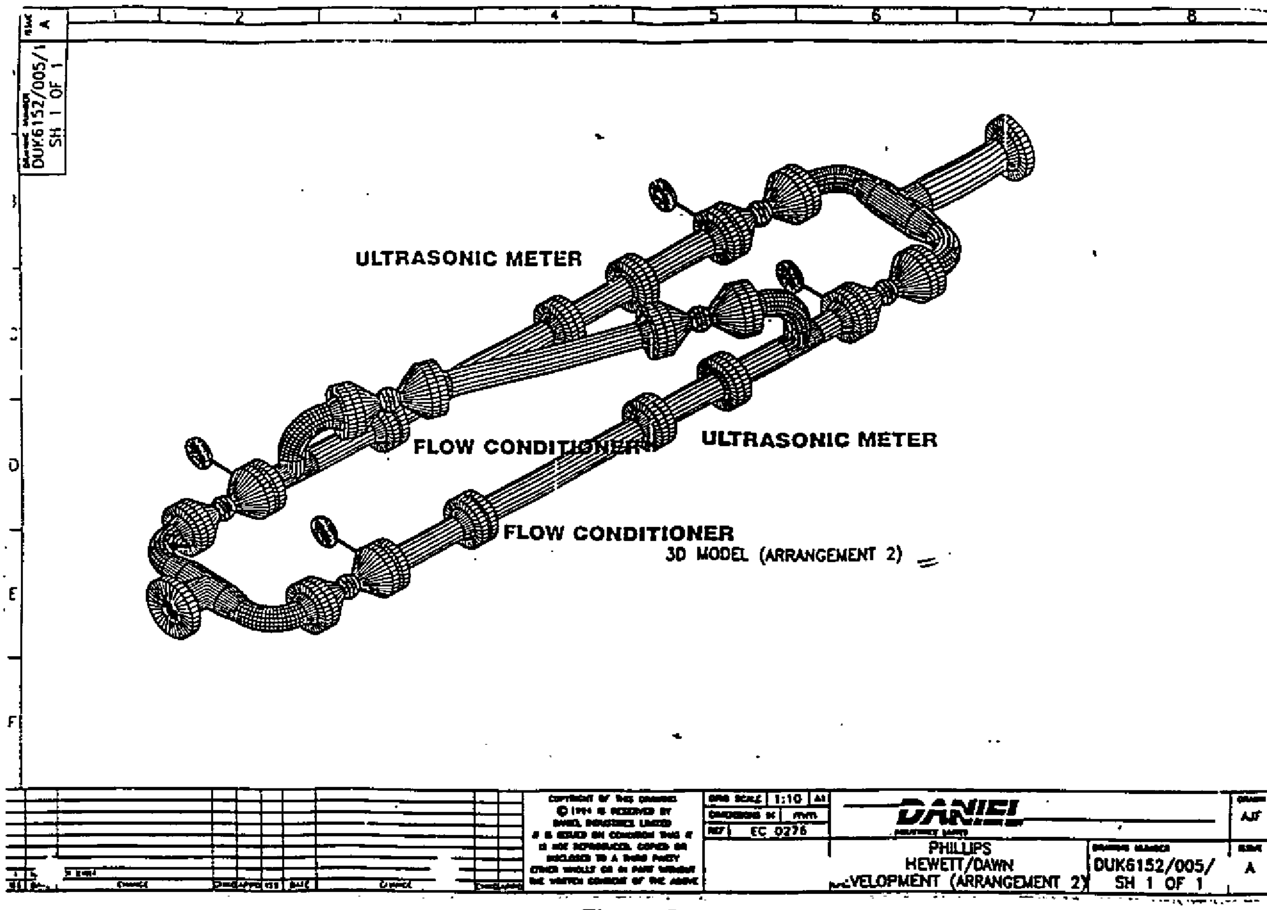


Figure 2

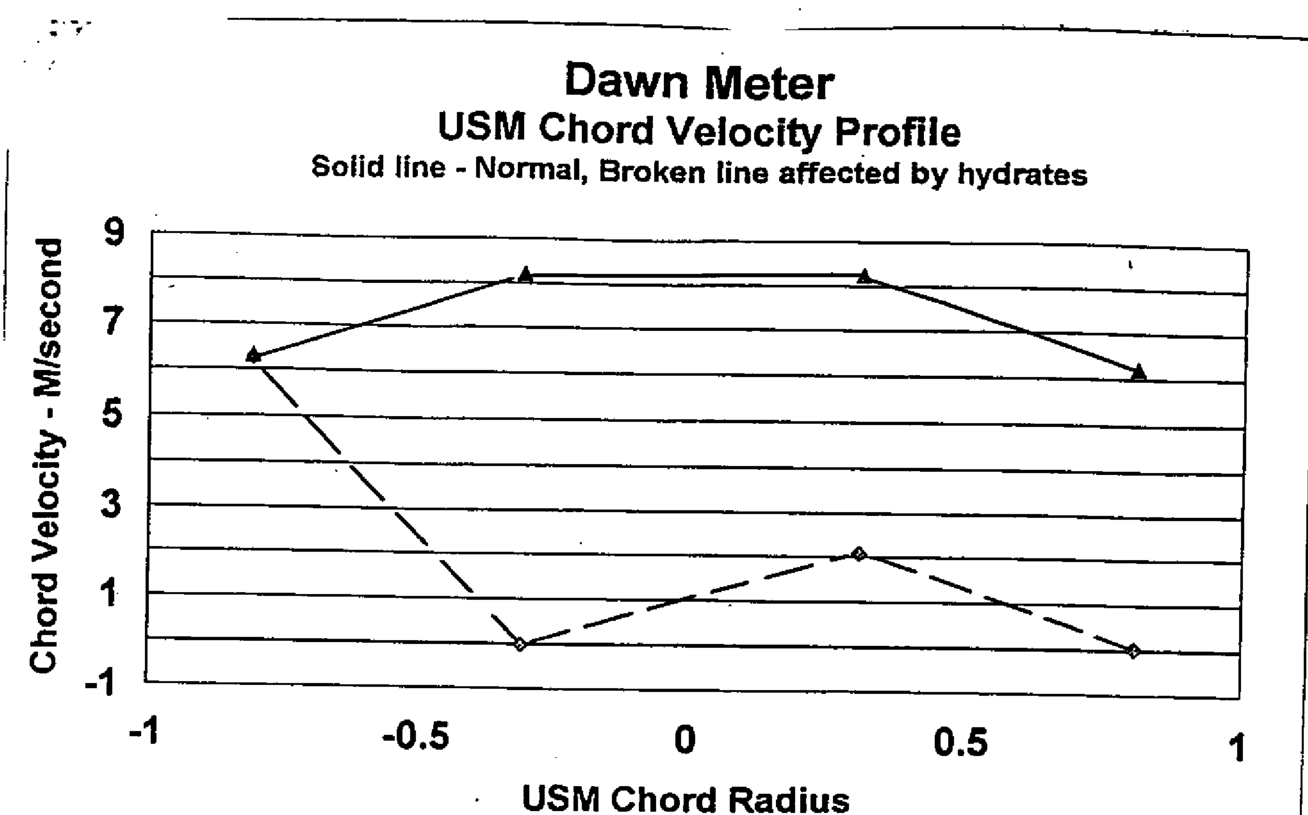


Figure 3

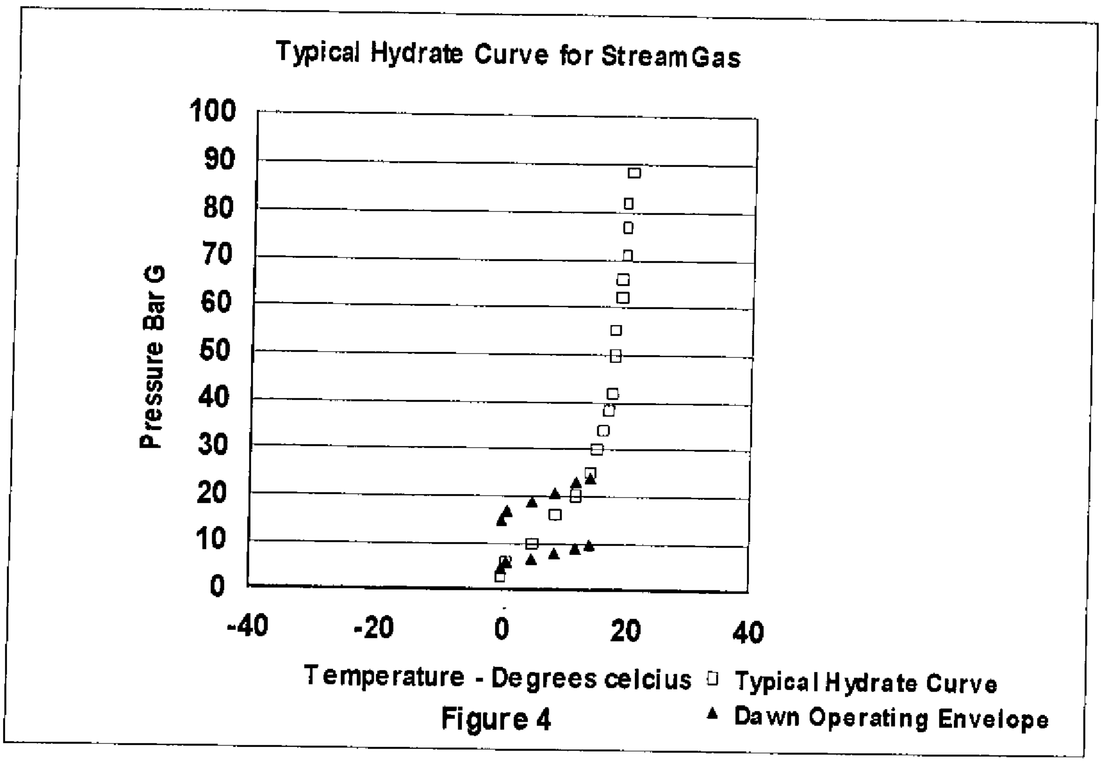


Figure 4

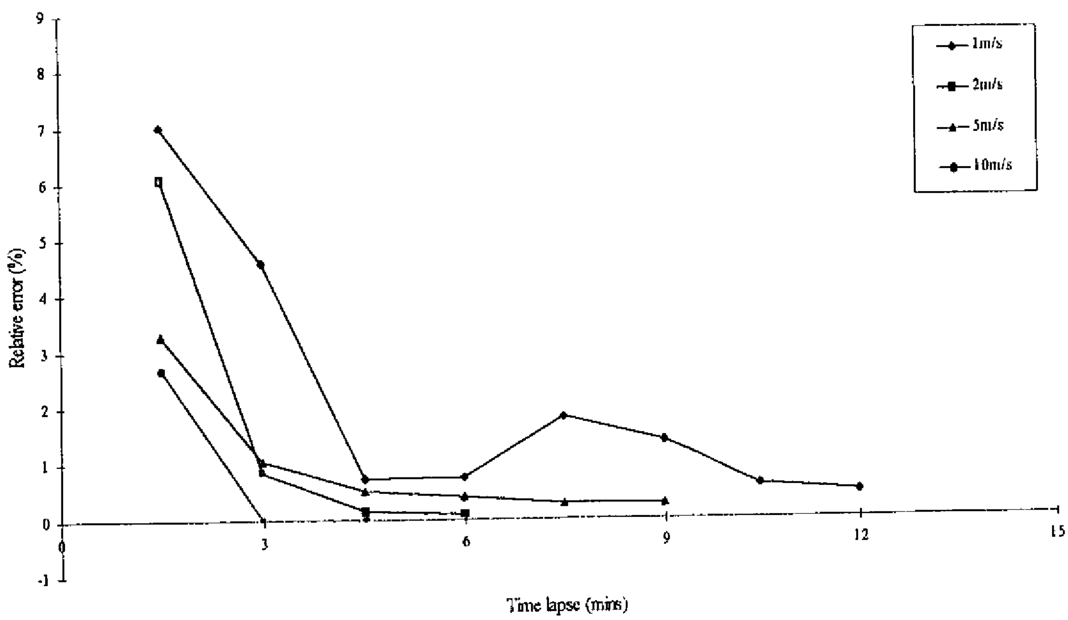


Figure 5

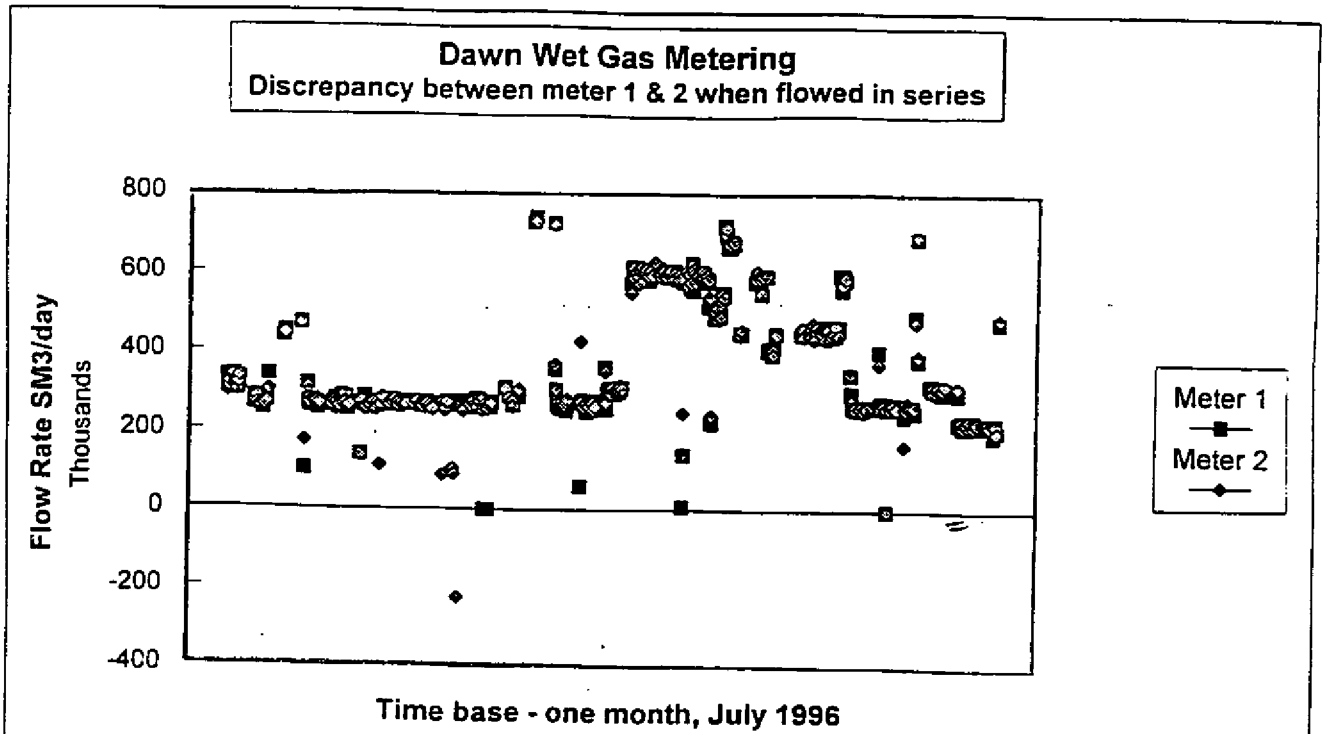


Figure 6

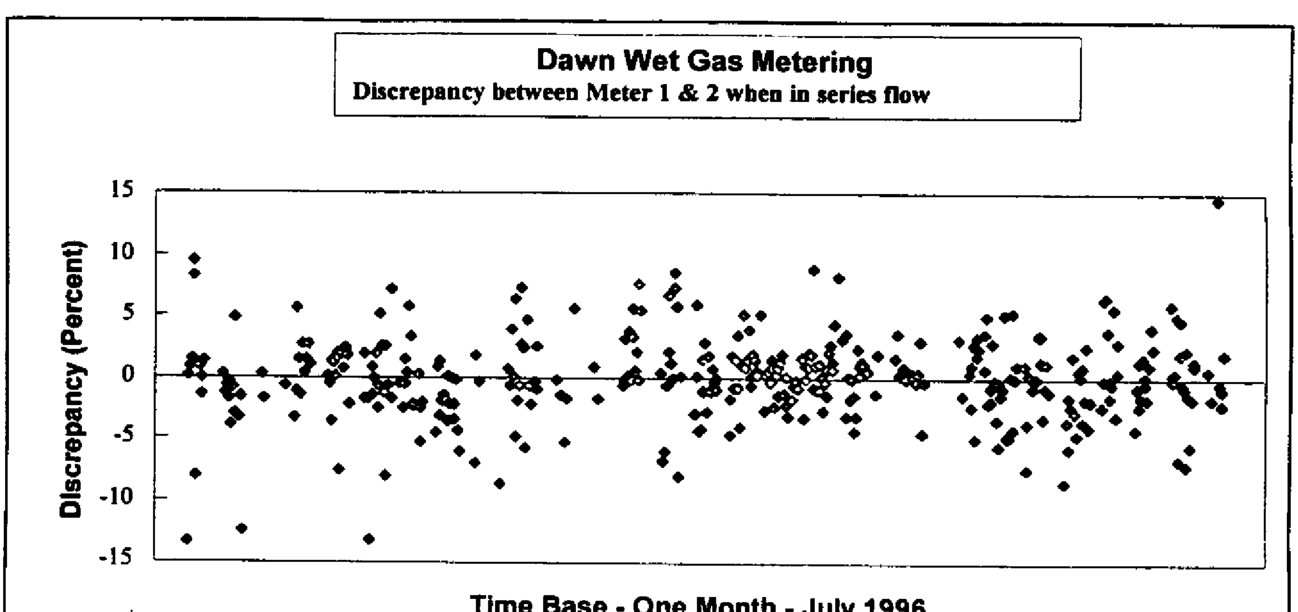
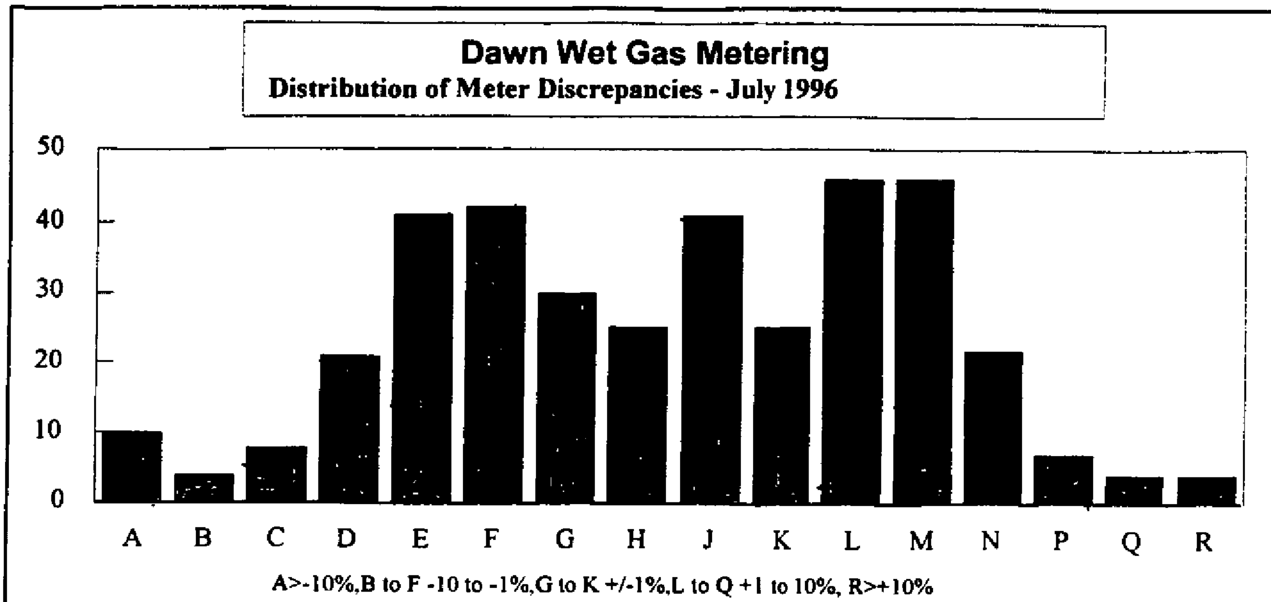


Figure 7



D to N represents a spread of +/-6% which is 90.1% of all measurements
Hourly Measurement data, total measurements = 376points
Figure 8

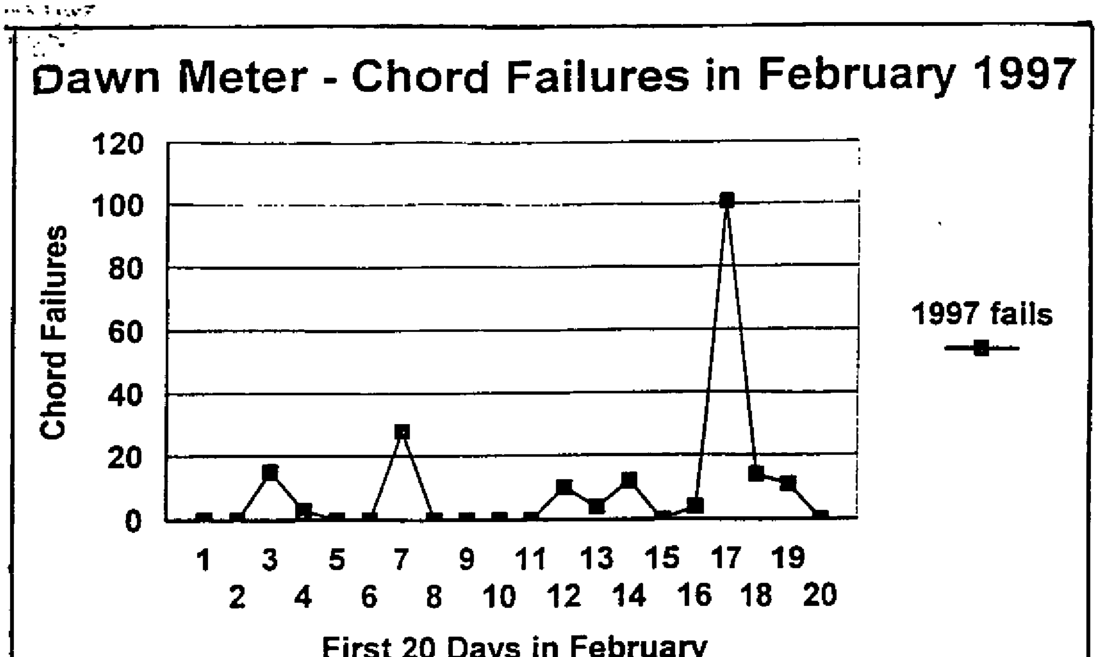


Figure 9

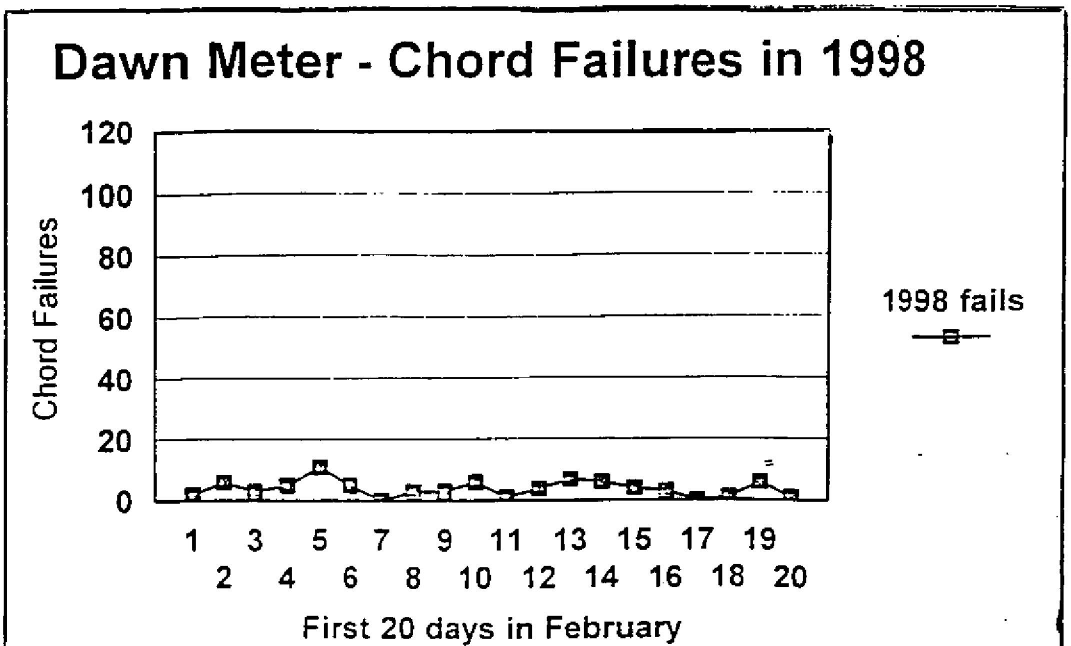


Figure 10

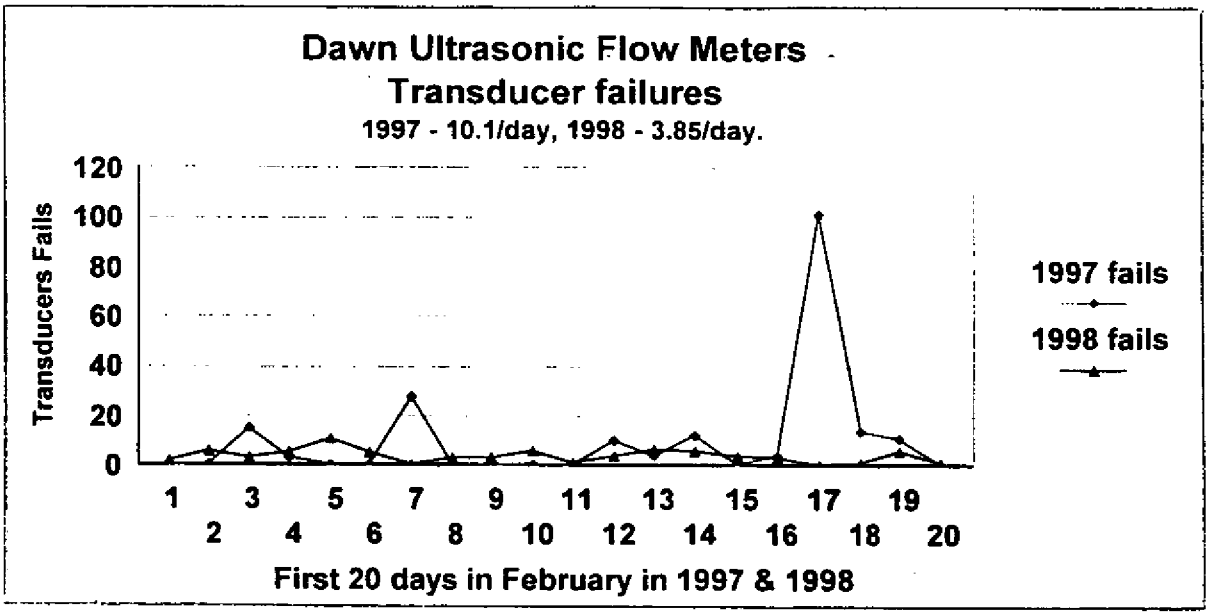


Figure 11

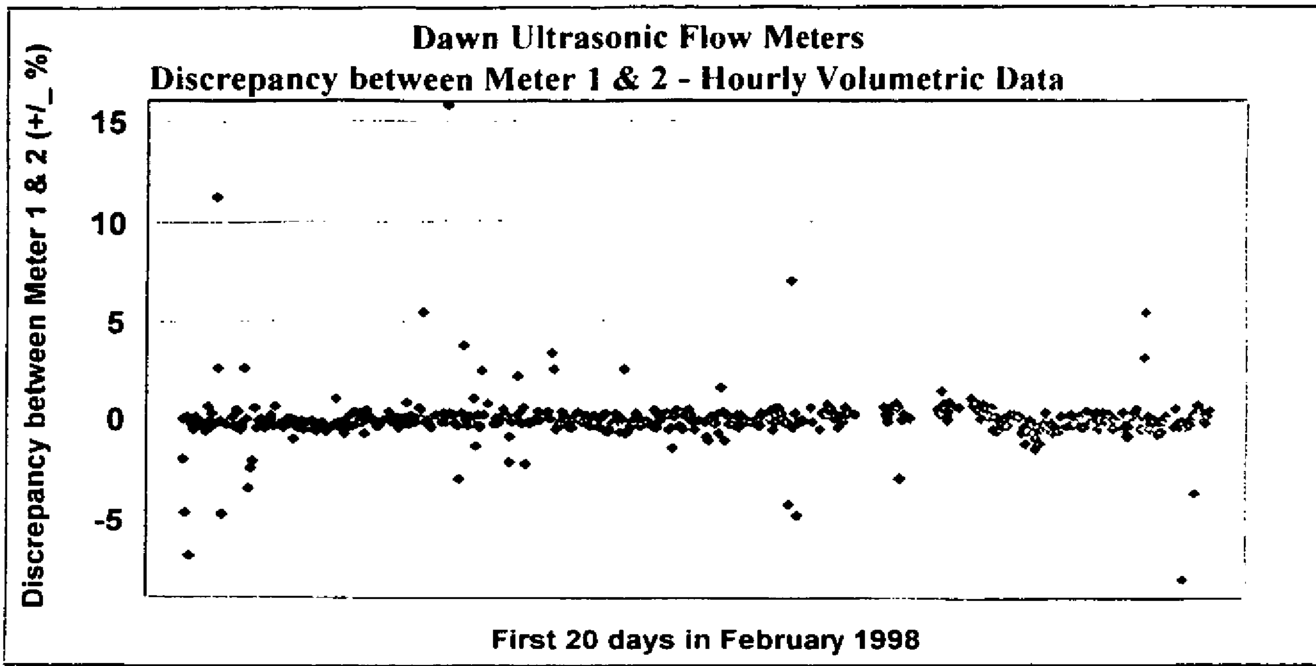


Figure 12

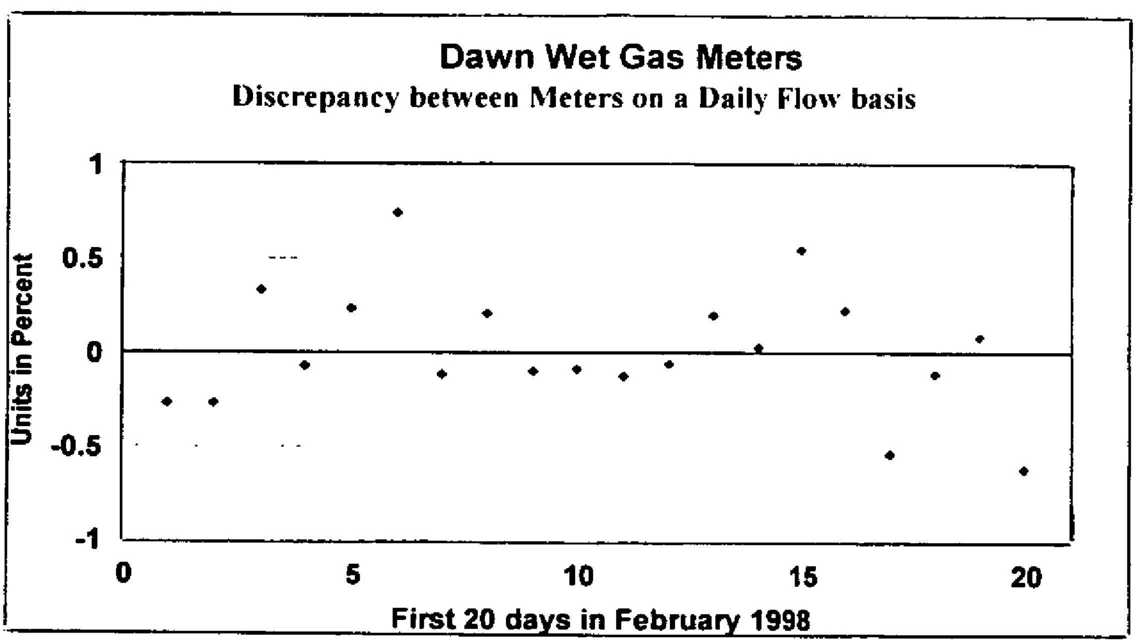


Figure 13

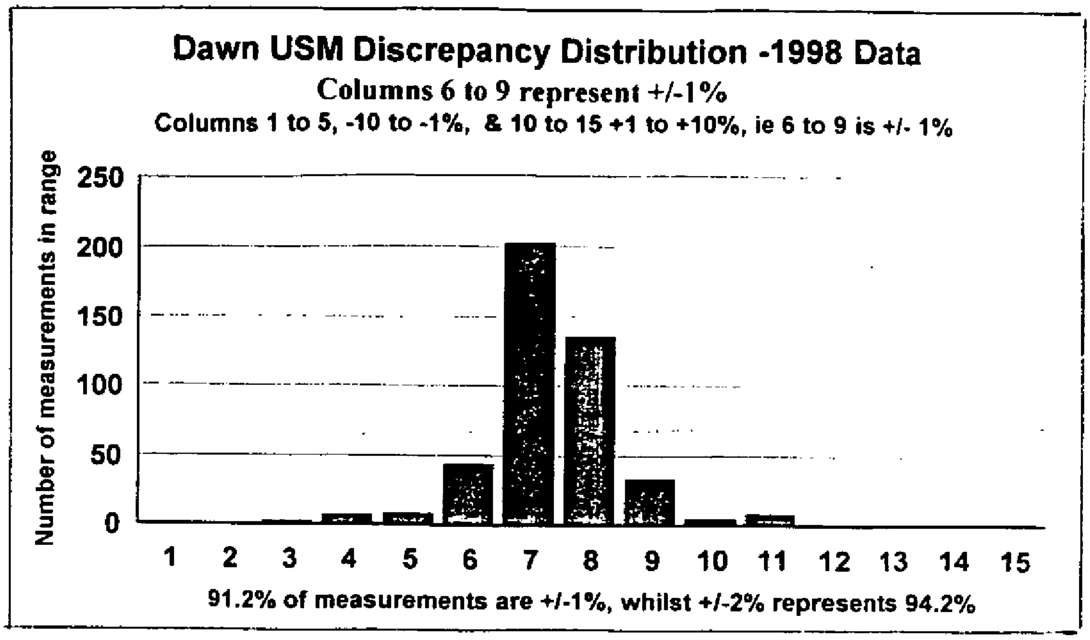
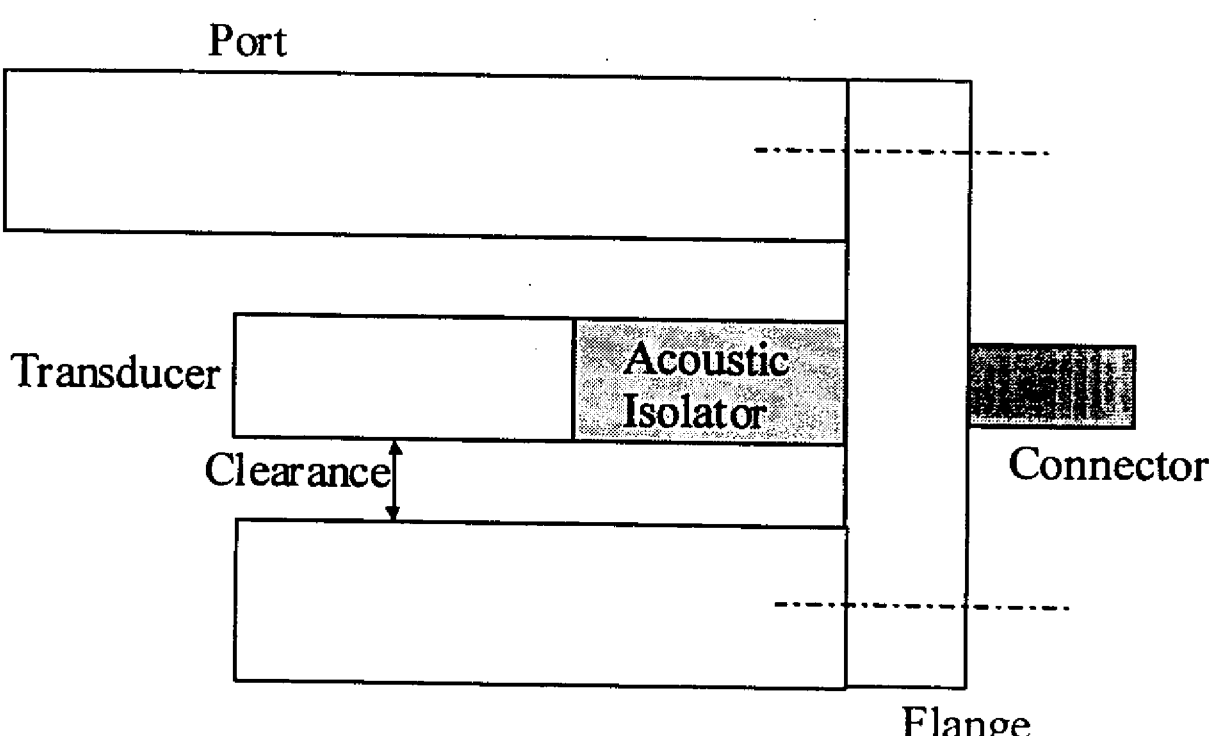


Figure 14

Wet Gas USM Metering



Wet Gas Transducer Design
Figure 15