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WET GAS EXPERIENCE WITH A SINGLE PATH ULTRASONIC FLOW METER

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SUMMARY:

Ultrasonic gas flow meters are gaining popularity every year and they are also being introduced to more and more different applications. FMC developed a 3 path version of the MPU 1200 6 path fully fiscal ultrasonic meter which was tested with wet gas at CEESI, Colorado in 1999 [1].

In 2002 FMC was encouraged by a Russian client to develop a single path ultrasonic meter based on the MPU technology for single well monitoring directly on the gas well header of wet gas producing fields in Russia.

FMC then manufactured a 4" single path ultrasonic meter called the MPU 200. This meter was first flow calibrated at the Advantica facility in October 2002. It was then shipped to the gas field in Siberia. The meter was installed and commissioned directly on the gas well header in March 2003 and remained there for a 3 month test period. During this period it was tested under very varying conditions including extreme cold ambient conditions, semi dry gas at a wide flow range and wet gas with several different percentages of liquid content.

This paper will describe the meter, show the results from the flow calibration in England, some of the most interesting results and experiences from the installation in Siberia and some enhancements in the design as a result of the experiences.

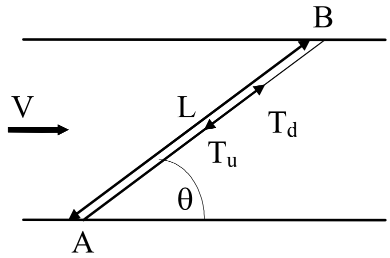
The conclusion will try to demonstrate that a single path ultrasonic gas flow meter can be a very good device for measuring wet gas even as close to the well as is the case here.

ABBREVIATIONS AND SYMBOL LIST:

AGA	American Gas Association
MPU	MultiPath Ultrasonic
USM	UltraSonic Meter
MPU 200	FMC Kongsberg Metering ultrasonic gas flow meter with 1 path
MPU 1200	FMC Kongsberg Metering ultrasonic gas flow meter with 6 paths
CMR	Christian Michelsen Research AS

1. INTRODUCTION

All ultrasonic meters are based on the well known transit-time principle where an ultrasonic signal travels a known distance (L) at a known angle to the pipe (θ). By then measuring the travel time of the signal in both directions (T_u and T_d) the velocity (V) of the gas can be calculated. This is shown in the figure below.



By trigonometry we get the two equations for the travel times in both directions, T_u and T_d:

$$T_d = \frac{L}{c + v\cos(\theta)} \qquad T_u = \frac{L}{c - v\cos(\theta)}$$

By combining the two we can calculate the gas velocity (*v*) and the velocity of sound (*c*) as follows:

$$v = \frac{L}{2\cos(\theta)} \cdot \frac{T_u - T_d}{T_u T_d} \qquad c = \frac{L}{2} \cdot \frac{T_u + T_d}{T_u T_d}$$

Since this is a single straight path meter the integration from the single path gas velocity to the actual gas volume flow rate (Q) is a simple multiplication of the velocity, the cross sectional area (*A*) and a weight factor or K-factor (*K*):

$Q = A * v * K$

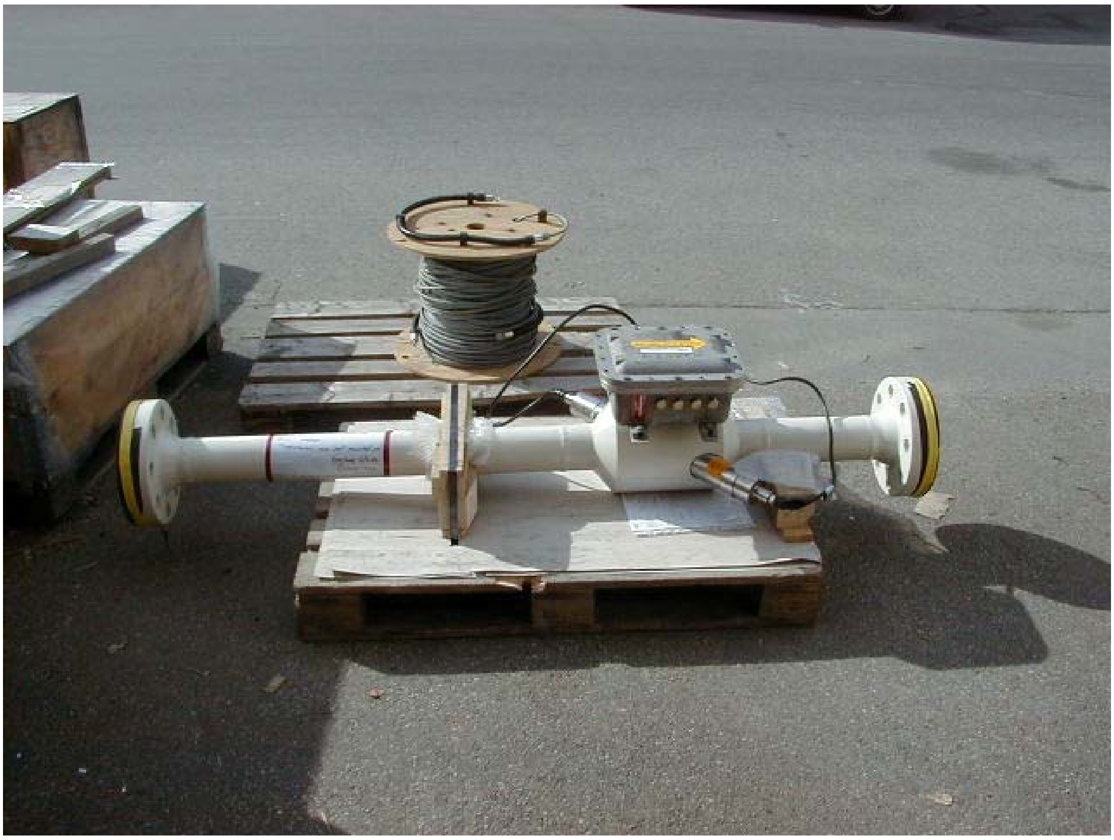
2. MPU 200 DESIGN

The 4" MPU 200 was designed with one straight path located at the centre of the pipe with an angle of 50°.

The straight path design was chosen to avoid any of the known problems with reflective path designs when liquids or contaminants are present in the flow. The straight path design is then only affected by the disturbances when they are passing directly in front of the transducers.

The nozzle design around the transducers have been made with an increased ID of 30 mm which creates very good drainage for liquids and minimizes the possibility for continued acoustic short circuits between the 20 mm OD transducer and the nozzle. Such an acoustic short circuit will completely destroy the measurement as much of the ultrasonic energy is absorbed by the spool piece and is not transmitted into the gas.

It was chosen to place the path in the centre of the pipe to get as long a path as possible. This was done to optimize the accuracy with the MPU timing resolution and to get the best possible results at lower velocities. As we found out later these items were not as critical as we originally thought and after completing a study with CMR [2] this has been changed.



As can be seen on the above picture the meter was to be installed with the AGA-9 [3] recommended 10D upstream and 3D downstream pipe with same inner diameter as the meter itself. We chose to make that whole section in one piece with flanges mounted on each end to minimize installation time in the hostile Siberian environment.

The MPU 200 is a wet gas meter in the sense that it can still measure gas in the presence of a certain amount of liquid but it will not measure the amount of liquid. The meter is set up with a liquid hold-up factor which can be manually set to adjust for the expected amount of liquid, as this is often known to a certain degree.

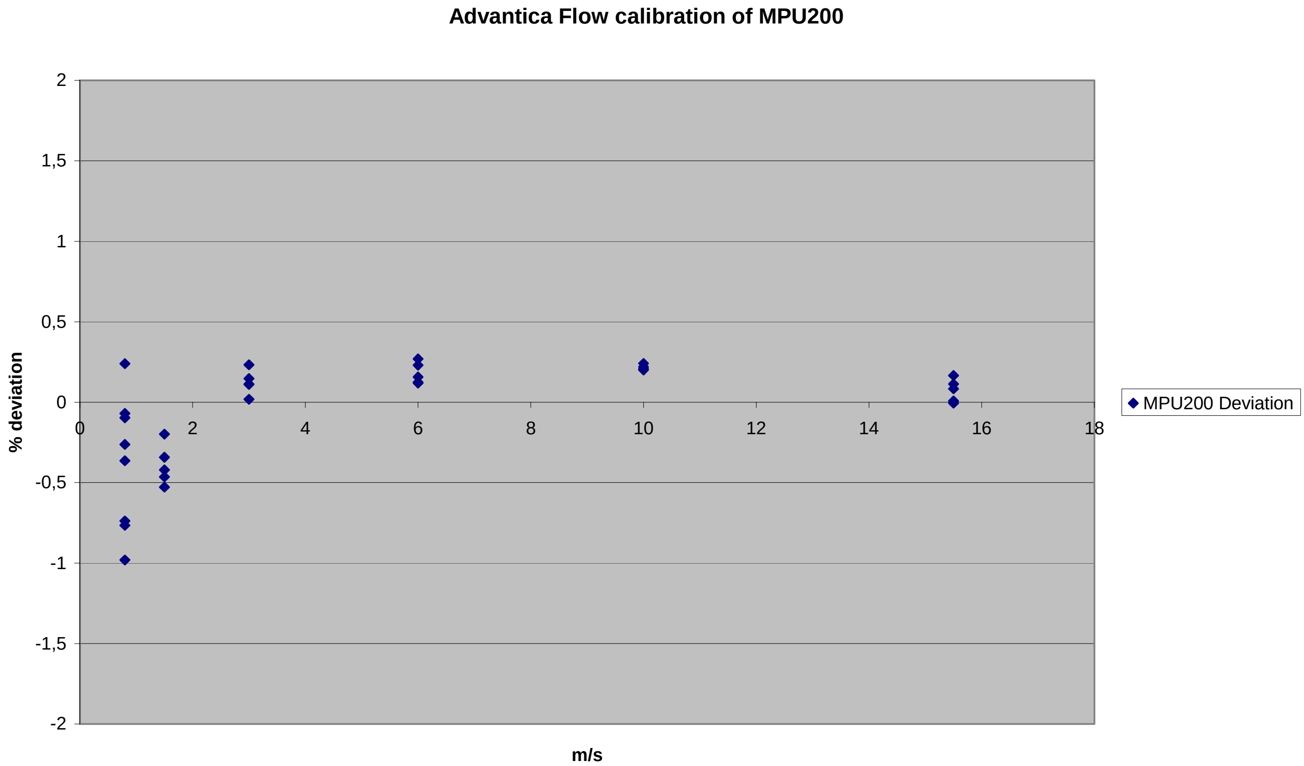
3. FLOW TEST AT ADVANTICA

The meter was flow calibrated on dry gas only at the Advantica Flow Calibration facility in Bishop Auckland, UK during September 2002. The calibration had 3 main purposes:

1. Calibrate the meter to get an error curve over the expected flow rate range.
2. Test the meter to the limit of its performance at the high end
3. Test the meter's performance without the transducer coupling layer

3.1. FLOW CALIBRATION

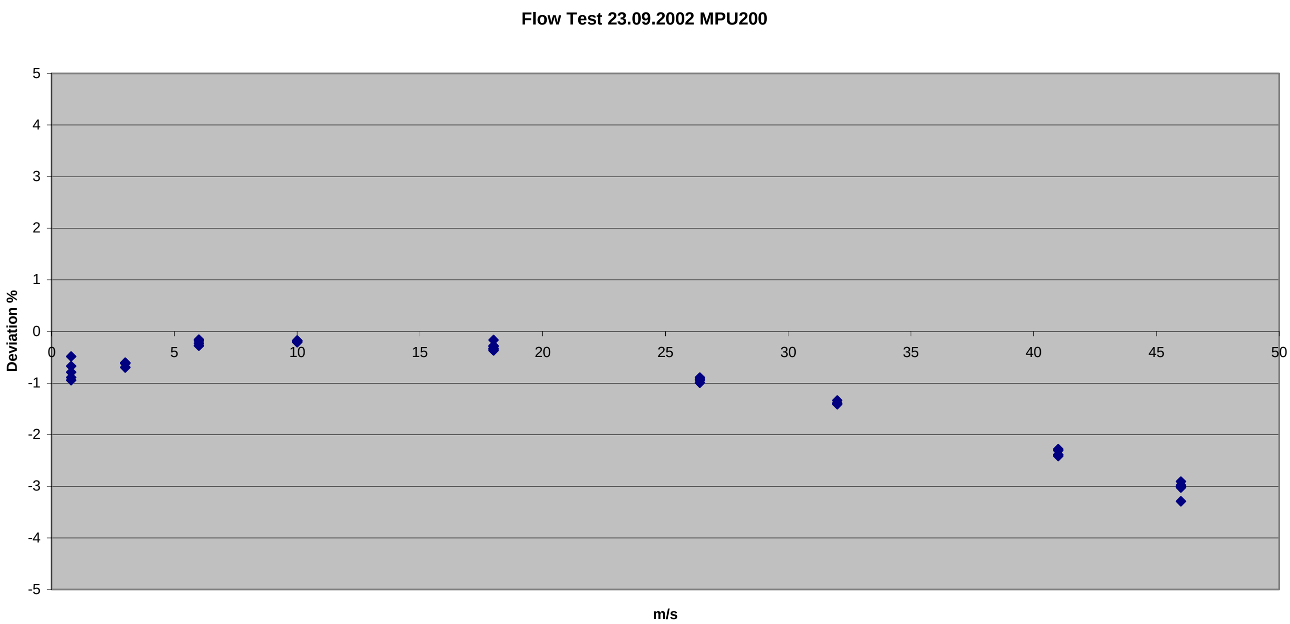
The flow calibration was performed in the 4" line at Advantica in the same building which houses all their reference turbine meters and it was witnessed by several of our end users. The calibration curve is shown below.



As can be seen above the expected flow range of the meter on site in Siberia is from 0,8 to 15,5 m/s. The above data show that a single path ultrasonic meter can give very good, and actually within fiscal requirements for multipath meters [3], results when used with well developed flow profiles. This can be achieved either with generous upstream lengths, as in this case where we had more than 35D, or with the use of flow conditioners.

3.2. HIGH END TEST

The high end test was performed to determine the real capacity of the meter and to see the shape of the performance curve as the velocities increased.



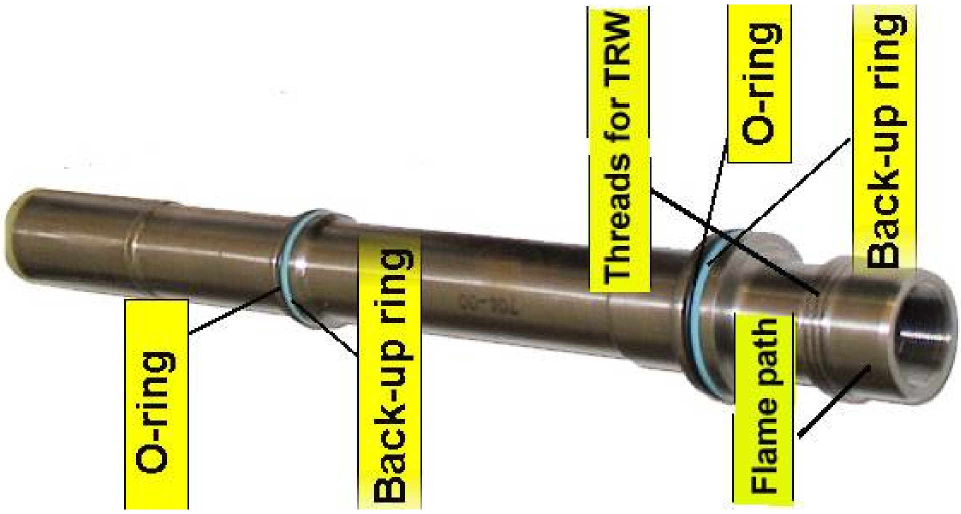
The meter performed remarkably well all the way up to 46 m/s which seemed to be the absolute limit. It still gave good performance for a single path meter at approximately -3% at 46 m/s but at 47 m/s the signal processing breaks down completely as the signals are completely unrecognizable.

The explanation for the straight line decrease in accuracy has several factors but the most important one is probably the Reynolds number as this meter has no Reynolds number correction functionality.

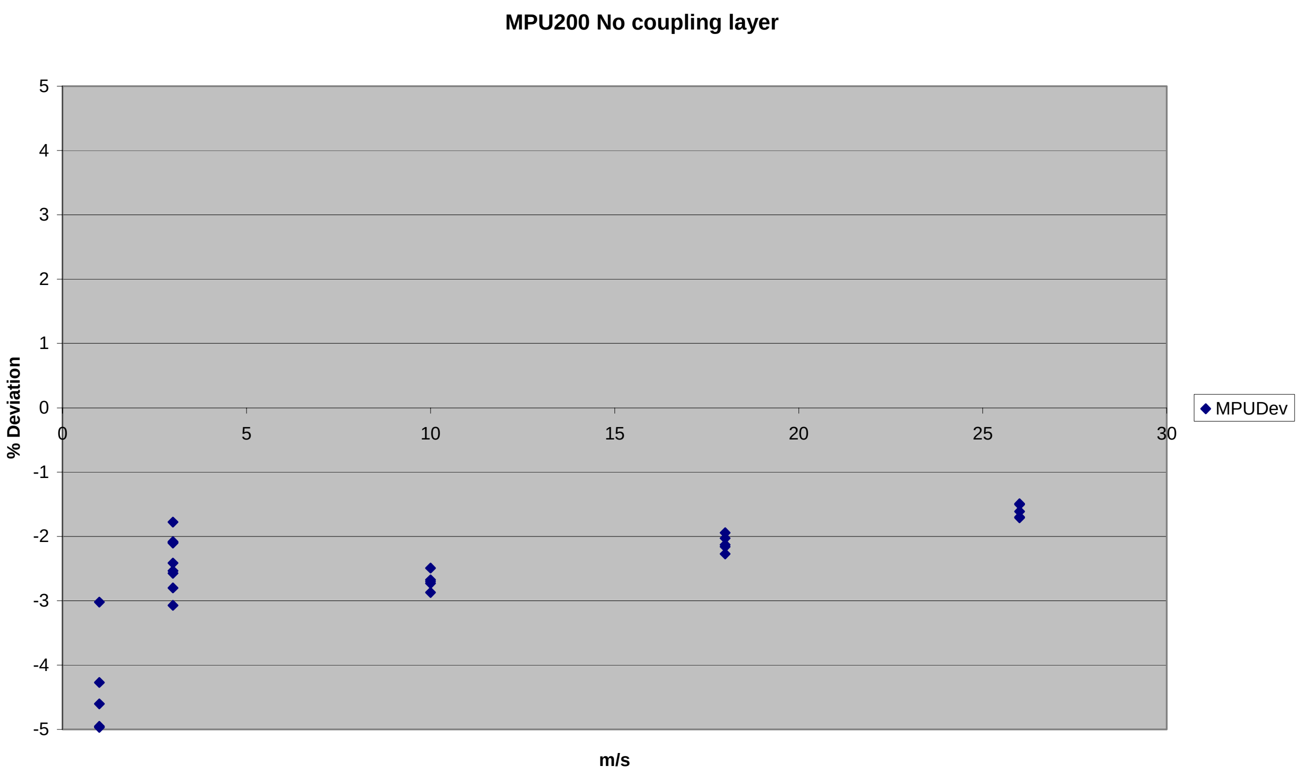
3.3. NO COUPLING LAYER

The third and last purpose was to test the performance of the MPU 200 without the coupling layer on the transducers.

The transducers used in the MPU 200 are the exact same as the ones used in our fully fiscal six path MPU 1200 and three path MPU 600 meters. The transducers consist of a piezo electric element which is fully encapsulated in a titanium housing. The front end of the titanium housing has a coupling layer of epoxy which is there to reduce the acoustic reflection of the ultrasonic energy moving from the titanium media into the pressurized natural gas. This epoxy layer can be seen all the way to the left on the picture below.



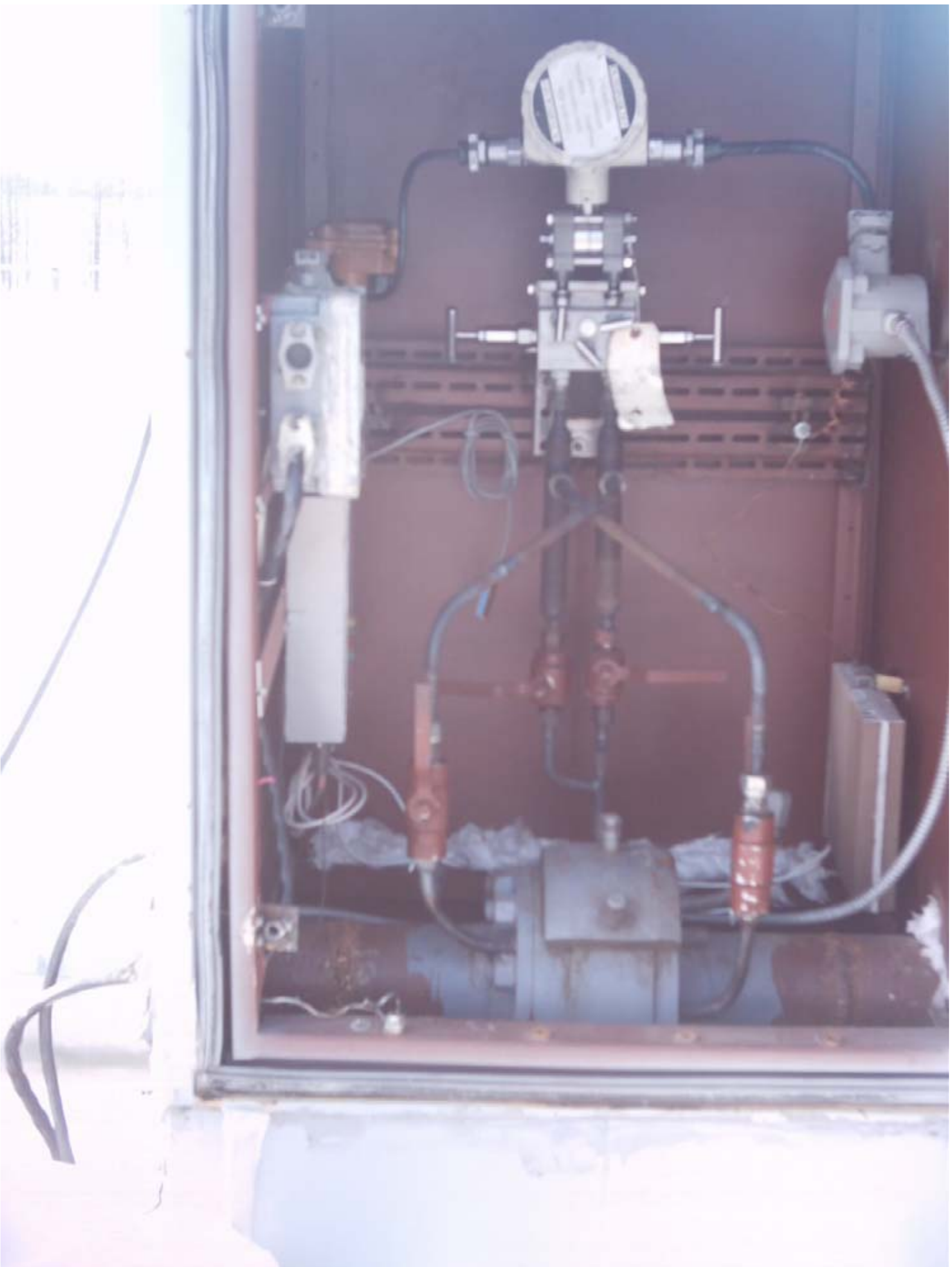
The epoxy does not have the same abilities as the titanium to withstand corrosive chemicals, such as H_2S, which can be present when locating a meter close to the well head. An option could then be to use the transducers without the epoxy matching layer if the performance would be acceptable. We therefore mounted the meter with two transducers without the coupling layer and ran another flow test run.



The performance of the 4” MPU 200 was absolutely encouraging and demonstrated that the meter can well be used without the coupling layer. The performance was not as good as with the coupling layer and the meter was unable to measure beyond 27-28 m/s.

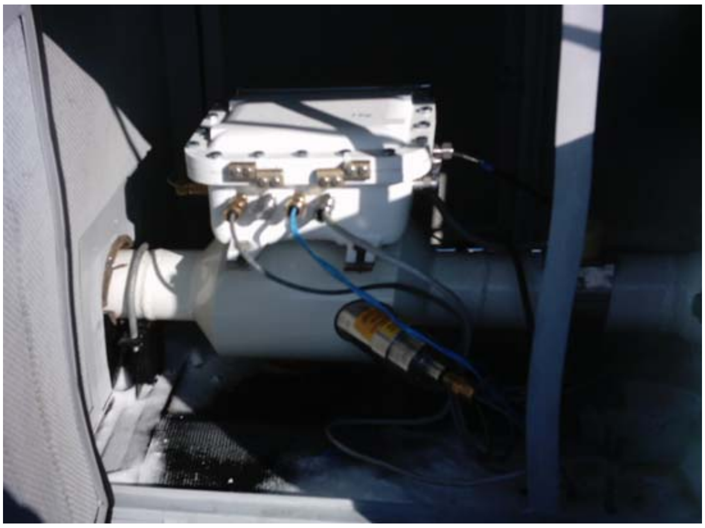
4. ON SITE IN SIBERIA

The 4" MPU 200 was installed at the gas field on a well pad. Testing was done in the cold Siberian climate directly on gas from the well during the period from mid March thru May. Measurements were compared against orifice meter measurements already located on the well. This orifice meter was of Russian origin and the client assumed a +/- 3 % performance. The below is a picture of the orifice meter and the associated transmitters.



The gas from the wells are actually pretty dry here, the client didn't provide us with an accurate number but estimated somewhere around 0,1-0,5 % liquid volume. Therefore, in order to thoroughly investigate the wet gas flow performance, wet gas was generated by injecting different amounts of methanol into the pipe from a tanker truck.

The meter was installed with an enclosure around as can be seen on the right here. This is to protect the meter from snow and ice as the winds are never ending in Siberia and snow tend to get into everywhere. In addition, they want to protect all their equipment as the snow ploughs often ruin equipment buried in snow.



All computer work when confirming communication and adjusting flow rates etc. was done from inside the car that is parked alongside the meter. The car can be seen behind the frozen technicians below where Mr. Atle Abrahamsen can be seen in to the left. The ambient temperature during the week when the meter was started up ranged from -30°C to -47°C with crystal clear skies and a constant wind.

We observed upon arriving on site that the box and the boards were covered in snow because of the strong wind. When opening the box to make connections etc. we were not really prepared for the constant wind and snow drift which in minutes filled portions of the box with snow when it was opened. The boards were taken out of the box and the snow was removed from the board and from the box. The heater in the car was used to dry the boards. When everything was mounted back in the box and all connectors were plugged in the meter came up and was running immediately.

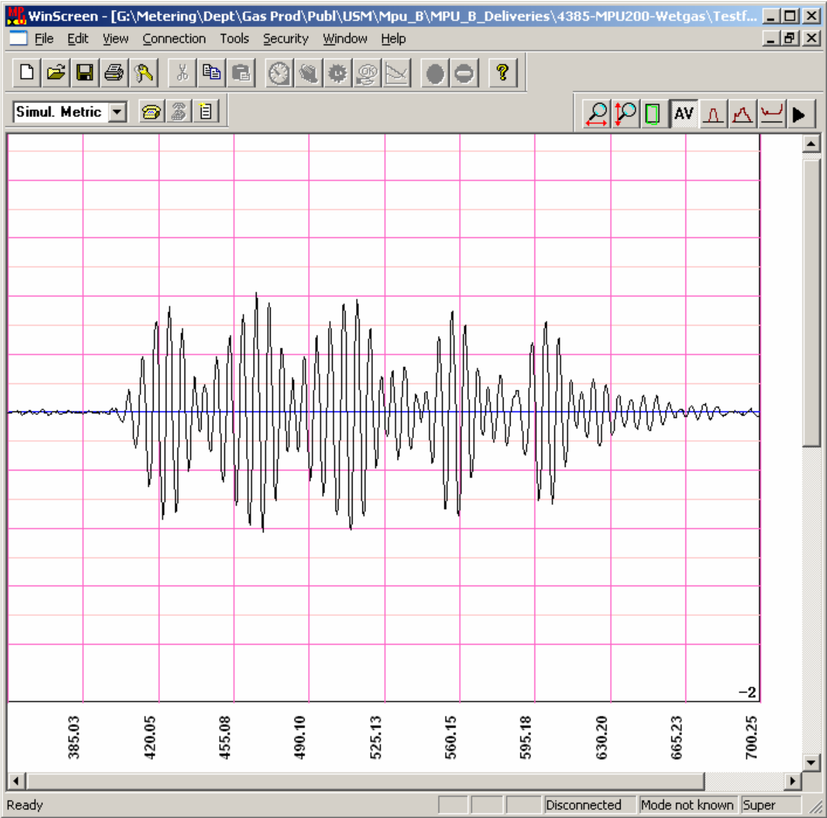
The pressure and temperature was taken from the orifice meter which was located 4-5 meters away from the MPU.

4.1. DYNAMIC TESTS

A high number of different flow rates were tested within the capable range of the well and as can be seen in the graphs below the MPU followed the flow very nicely from minimum to maximum flow.

The flow was changed in small steps to collect data from many different flow rates both on the MPU and from the orifice. The MPU logged all the data to a file during this period and the same was done for the orifice meter.

On lower flow rates the temperature dropped and hydration started which lead to clogging of the pipe and meters. The dP transmitter of the orifice meter stops working because of this, and this is one of the main reasons why the client are looking for another method of measurement as this is causing major problems for them. No problems were detected at the MPU because of hydration, it continued to work over the entire flow range. It was observed that the gain values increased, but all the signals still looked good as can be seen in the screen below.

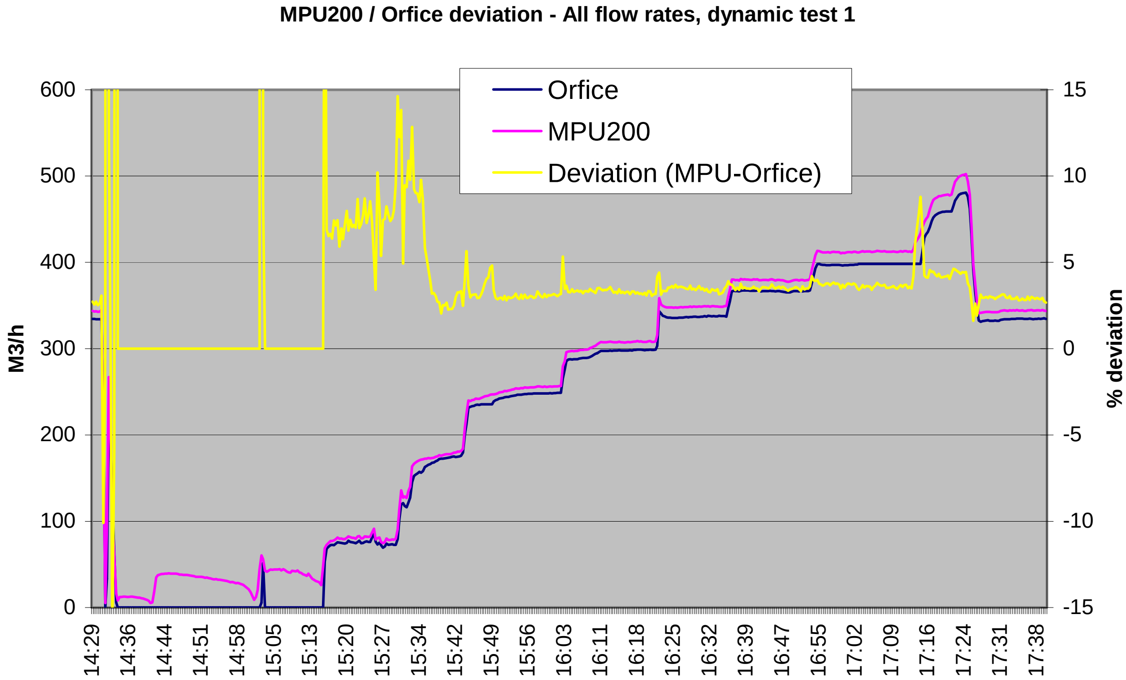


At high flow rates the well produced more liquid in the gas but this did not seem to influence the MPU, the ultrasonic signals were all undistorted.

Below are 3 graphs displaying the results during the different dynamic tests which were performed and there are comments below each graph.

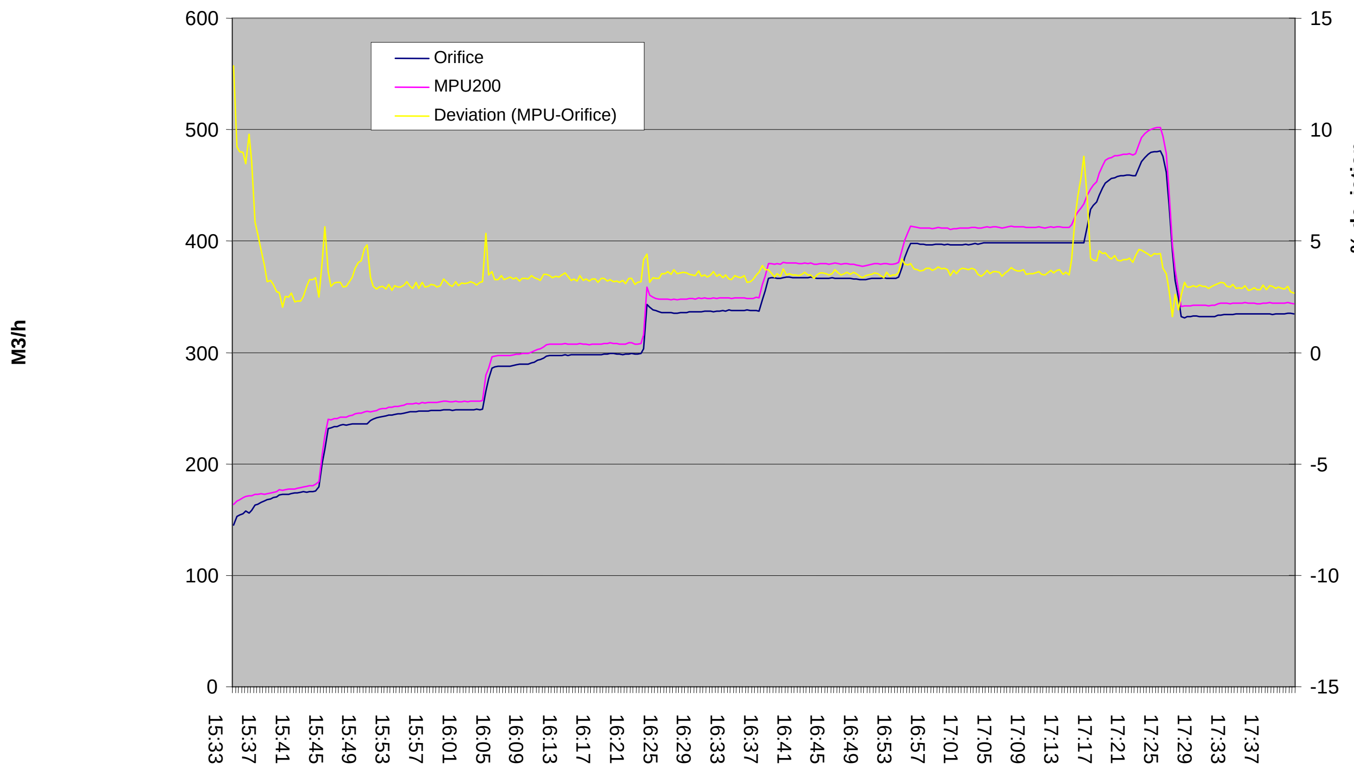
It is important to note that the files from the control system were all in SM3/h while the files from meter were in AM3/h. The files from the control system were then calculated back to actual conditions using pressure, temperature and compressibility supplied by the client. However, these parameters later proved to be wrong. Pressure was measured in kg/cm2 instead of in bar. This resulted in that the calculated curves for the orifice is approx 2% lower than what is correct compared to the MPU 200. In addition the wrong compressibility was used and this biased the results another 1% approximately in the same direction.
This then results in that all the deviation curves between the MPU and the orifice, where the orifice was used as the reference, should be about 3% lower. All these results could have been recalculated afterwards but we have chosen to present all the data uncorrected since this is the way all the data has been presented in the official test report between the client and FMC.

Please note that on low flow rates the orifice was not producing any measurements. It was not possible then to compare the MPU 200 against anything.



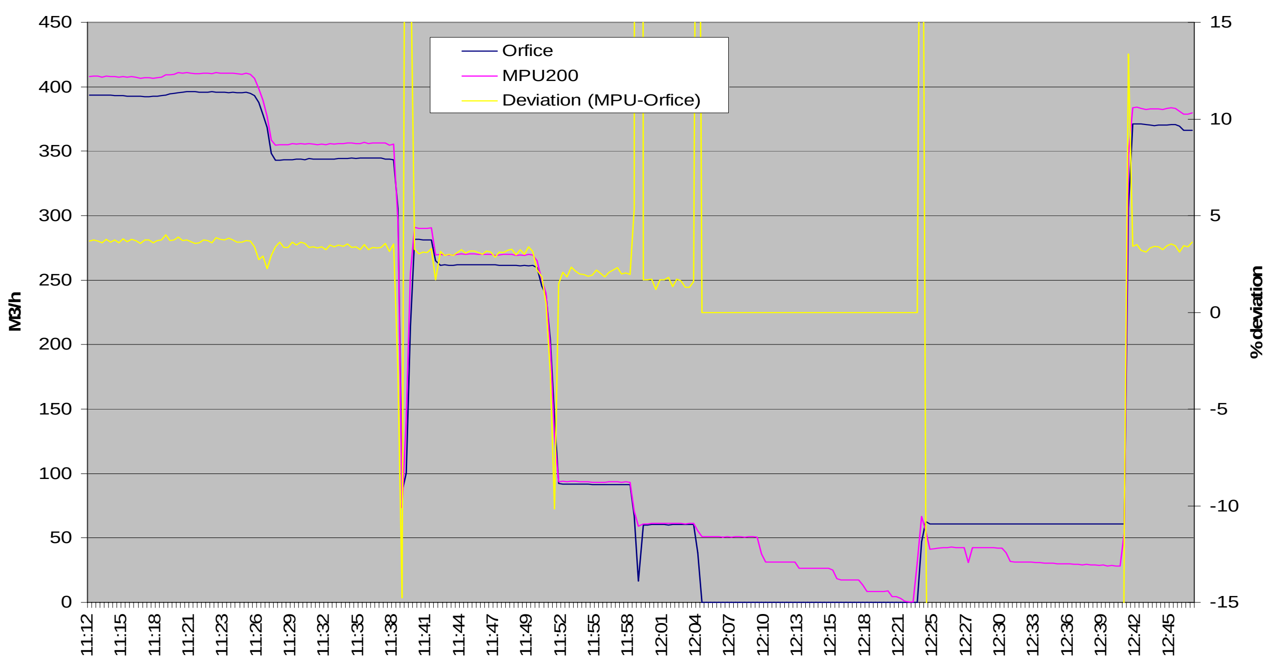
The above figure shows that the MPU and the orifice meter follow each other very well for all flow rates above approximately 220 m³/h. The deviation of the MPU from the orifice is stable at approximately 3-3,5% which then really is 1-1,5%, in the range where the orifice provides good results. When the flow dips below 100 m³/h the orifice is unable to measure but the MPU continues to provide stable readings all the way down to approx. 10 m³/h.

MPU200 / Orifice deviation - Orifice working conditions – Dynamic test 1



The above graph shows the same results as on the previous page but here it only displays the results within the working range of the orifice meter.

MPU200 / Orfice deviation - All flow rates - 30.03.2003 Appendix F



The above graph shows another cycle where the flow rates were changed from high flow down to zero and back up again with shorter intervals. The most interesting observations here is to see that the orifice meter was capable of measuring down to approximately 60 m³/h but it did show unstable performance as the flow was changing (easily seen at 11:58). It was also demonstrated here that the MPU 200 follows the flow variations very well all the way down to zero flow without showing any abnormal behavior even with the hydration and clogging/icing which occurred. This can be seen in the continuous stepping down in flow at 11:55 to 12:25.

4.2. FLOW TEST

In addition to the dynamic tests we also performed a flow test in the same manner as a normal flow calibration. In this case we ran 4 points at each flow rate and we did 10 flow rates from 12 m³/h up to 500 m³/h. All the results are given in the three tables below.

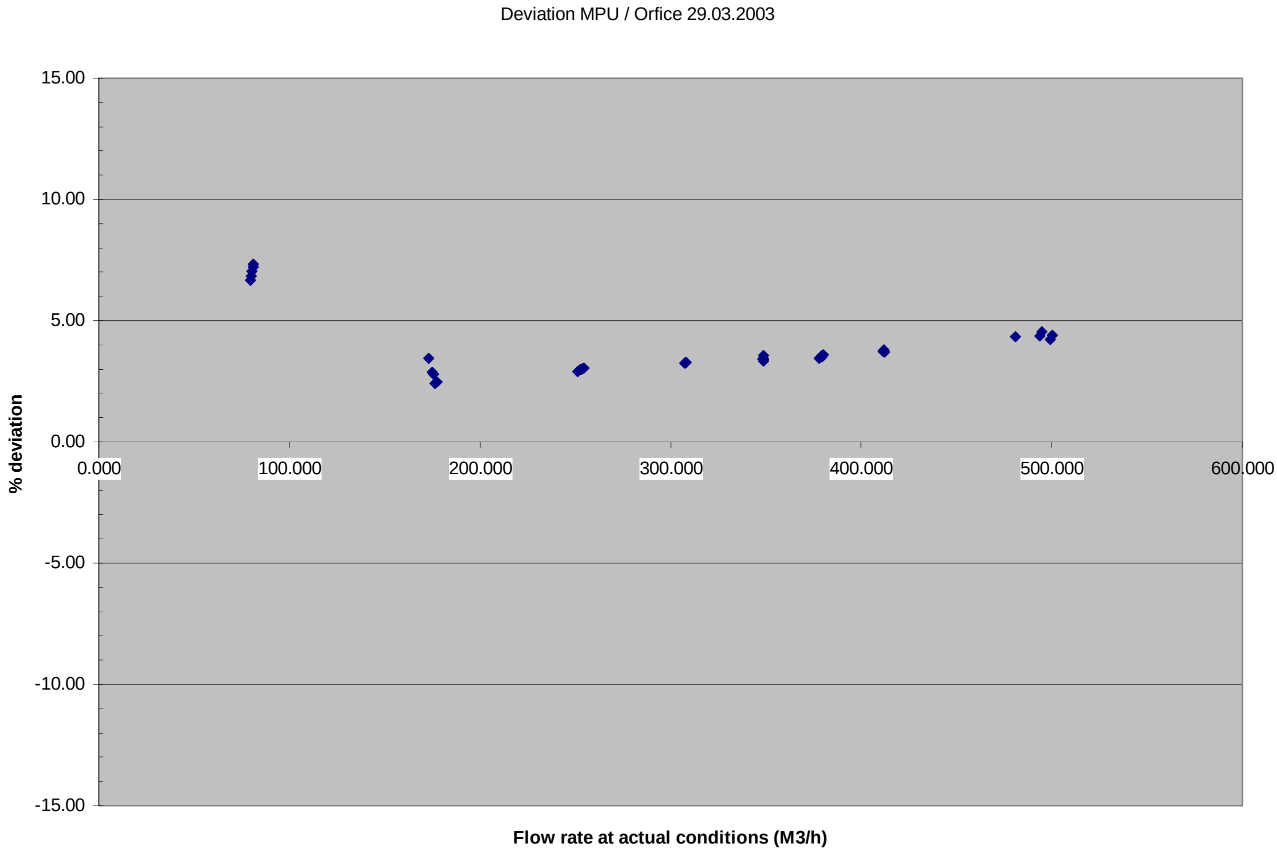
NM = No measurement

	Flowrate Orifice	**Flowrate MPU**	**Pressure**	**Temperature**	**delta P**	**VOS**	**Deviation**
	(m3/h)	*(m3/h)*	*Bar*	*DegC*	*Bar*	*m/s*	*%*
Run 1	NM	12.318					NA
Run 2	NM	12.433					NA
Run 3	NM	12.484					NA
Run 4	NM	11.995					NA
Average	**NM**	**12.296**	**109.12**	**15.23**	**NM**	**438.77**	**NA**
Run 1	NM	39.454					NA
Run 2	NM	39.399					NA
Run 3	NM	39.061					NA
Run 4	NM	37.958					NA
Average	**NM**	**38.634**	**109.20**	**13.01**	**NM**	**436.85**	**NA**
Run 1	74.859	79.973					6.83
Run 2	74.634	79.602					6.66
Run 3	75.396	80.923					7.33
Run 4	75.519	80.974					7.22
Average	**75.144**	**80.438**	**109.46**	**11.47**	**0.018**	**436.37**	**7.04**

	Flowrate Orifice *(m3/h)*	Flowrate MPU *(m3/h)*	Pressure *Bar*	Temperature *DegC*	delta P *Bar*	VOS *m/s*	Deviation *%*
Run 1	167.500	173.252					3.43
Run 2	169.961	174.858					2.88
Run 3	172.361	176.517					2.41
Run 4	173.261	177.545					2.47
Average	**170.844**	**175.605**	**110.13**	**12.45**	**0.092**	**439.21**	**2.79**
Run 1	244.292	251.398					2.91
Run 2	245.412	252.732					2.98
Run 3	246.445	253.847					3.00
Run 4	247.050	254.582					3.05
Average	**245.835**	**253.177**	**110.73**	**13.69**	**0.190**	**440.90**	**2.99**
Run 1	297.905112	307.702669					3.29
Run 2	297.6511815	307.3367855					3.25
Run 3	297.8362333	307.49335					3.24
Run 4	298.2735863	308.043001					3.28
Average	**297.941**	**307.672**	**111.22**	**14.83**	**0.281**	**442.25**	**3.27**
Run 1	336.954152	348.514248					3.43
Run 2	336.6921565	348.680002					3.56
Run 3	337.3630687	348.911214					3.42
Run 4	337.613347	348.878097					3.34
Average	**337.198**	**348.752**	**111.60**	**15.37**	**0.361**	**442.90**	**3.43**

	Flowrate Orifice	Flowrate MPU	Pressure	Temperature	delta P	VOS	Deviation
	(m3/h)	*(m3/h)*	*Bar*	*DegC*	*Bar*	*m/s*	*%*
Run 1	366.791585	380.0077957					3.60
Run 2	366.448642	379.2953865					3.51
Run 3	366.2995653	379.345719					3.56
Run 4	365.358561	377.9105653					3.44
Average	**366.204**	**379.126**	**111.93**	**15.76**	**0.426**	**443.39**	**3.53**
Run 1	397.547665	412.2857677					3.71
Run 2	396.803951	411.631102					3.74
Run 3	396.805358	411.6134893					3.73
Run 4	396.984951	412.011239					3.79
Average	**397.057**	**411.909**	**112.28**	**16.00**	**0.503**	**443.76**	**3.74**
Run 1	461.0368647	481.0470237					4.34
Run 2	473.201245	494.7077445					4.54
Run 3	479.1349397	500.180399					4.39
Run 4	479.0661323	499.2390877					4.21
Average	**473.101**	**493.710**	**111.30**	**16.07**	**0.710**	**443.25**	**4.36**

All the deviation results within the orifice meter's operating range have been plotted in the below graph. Again one must remember that the true deviation curve is approximately 3% lower than the one in the graph, which means that the deviation between the two again is quite linear at 0-0,5%.

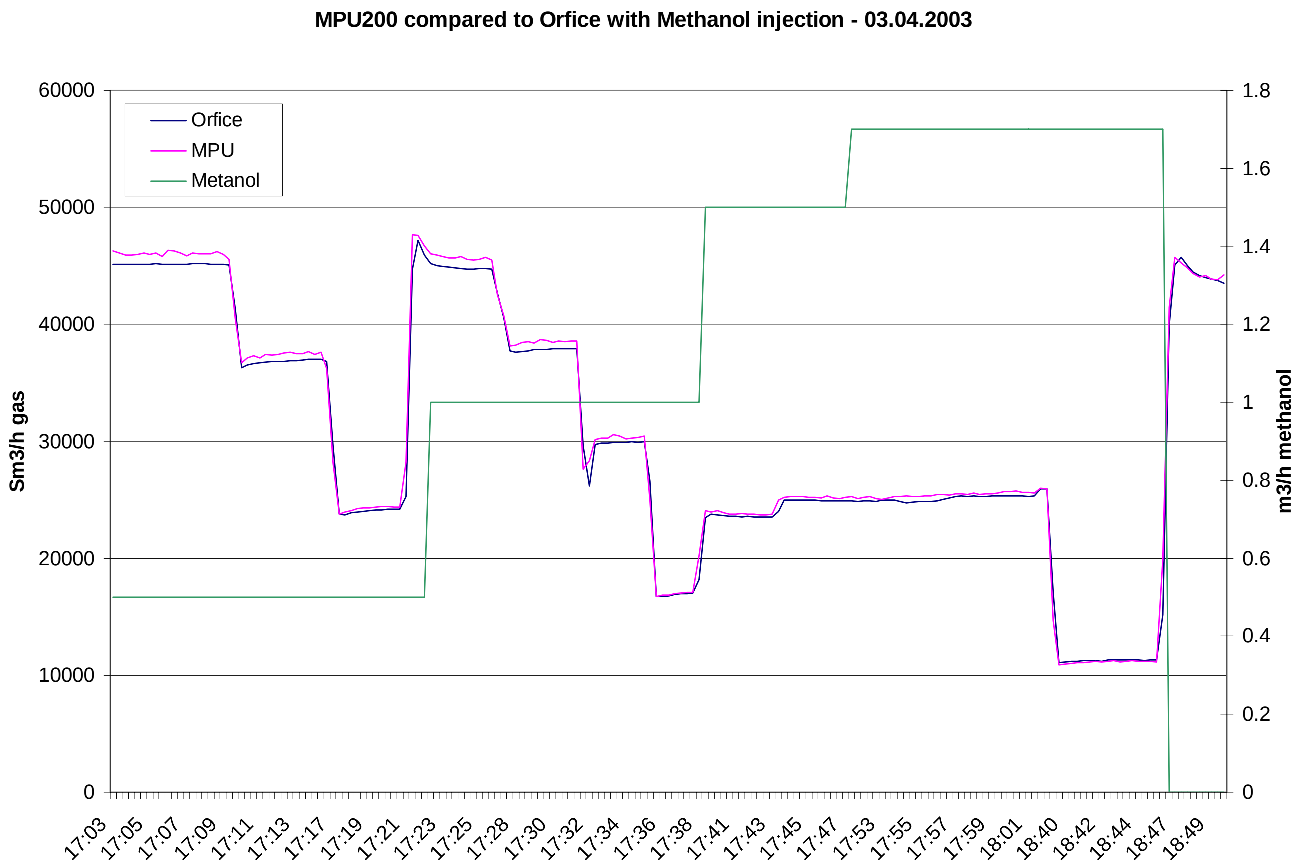


4.3. WET GAS TESTING

As explained above the proper wet gas testing had to be performed by injecting methanol from a tank truck directly into the pipe just 5-6 meters upstream of the MPU. This then arrived at the meter, which was placed at the well head, almost immediately.

Testing started with 0.5m3/h of methanol injected into the pipe in addition to the amount normally produced by the well, and several different flow rates were tested. The methanol flow rate was increased in steps up to 1.7m3/h of methanol with different flow rates of gas which represented more than 2% methanol in addition to the natural wetness in the gas. Again no major influences on the signals could be observed. The results are plotted in the two graphs below.

One interesting observation both our clients and we made was that the orifice meter still seemed capable of measuring with the wet gas, but one can see that as the liquid content increases the orifice meter is "over" reading compared to the MPU. The second graph below shows this clearly. However, neither meter was able to measure the amount of liquid.


MPU200 compared to Orfice with Methanol injection - 03.04.2003
Orfice
MPU
Metanol
Sm3/h gas
m3/h methanol
60000
50000
40000
30000
20000
10000
0
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
17:03
17:05
17:07
17:09
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17:21
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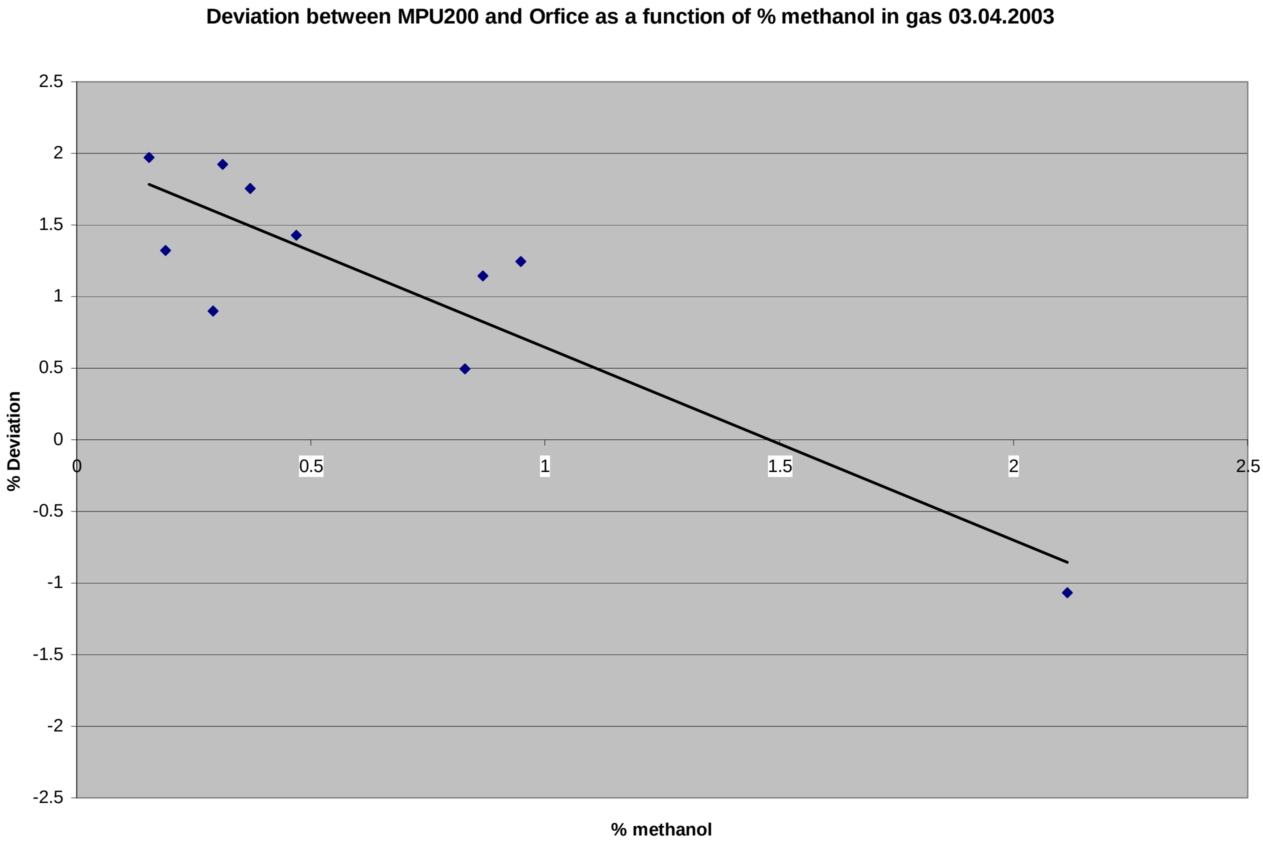


5. CONCLUSIONS

The overall impression of the MPU 200 was that it does deliverer high accuracy and high repeatability over the complete range of flow compared to the orifice meter, which they were currently using for this purpose. The meter is also capable of handling wet gas without problems and provides much more linear results than the orifice meter which clearly starts to over read as the liquid content increases.

The tests were concluded with summarizing the following advantages of the single path ultrasonic meter over the orifice meter:

- High reliability at all flow rates.
- No problems with hydration at low flow rates.
- No problems with liquid in the gas for the volumes tested which was up to 2% liquid content.
- Huge flow rate range compared to the orifice. Flow measurements from almost zero (< 0.2m/s) up to well above 30 m/s flow velocity.
- Additional measurements (gain and burst %) will possibly give more information about the flow. For example, high liquid content will change the gain and burst %.
- Use gain changes to detect hydration at lower velocities.
- Fast response to changes in the flow rate.

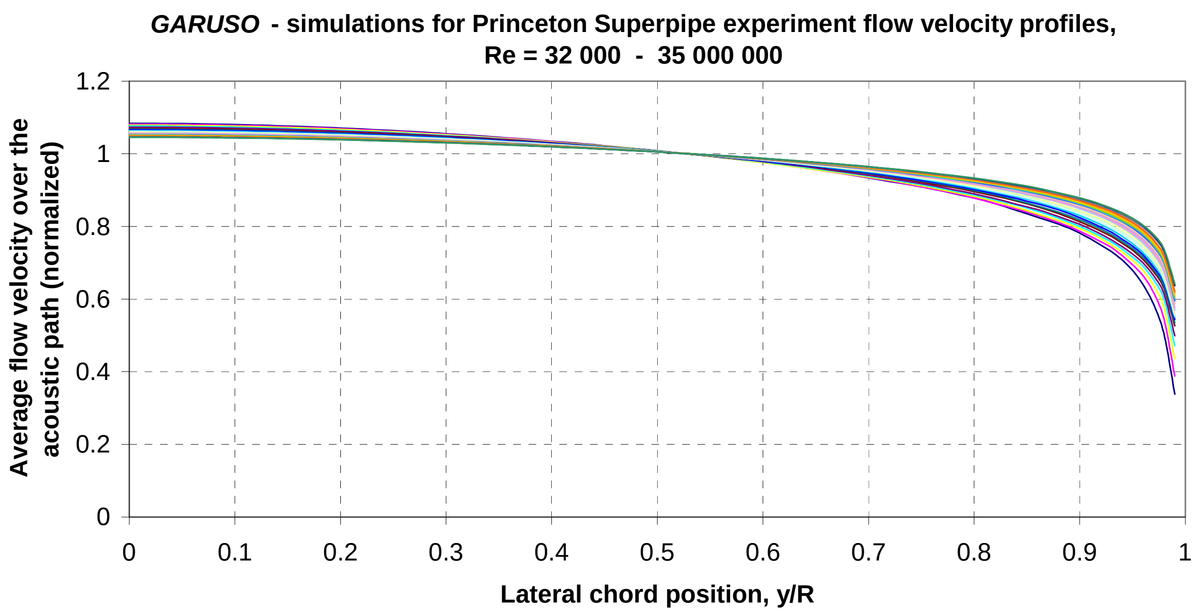
The client internally concluded that the single path ultrasonic meter was now the recommended technology for these types of applications.

6. POST TESTING WORK

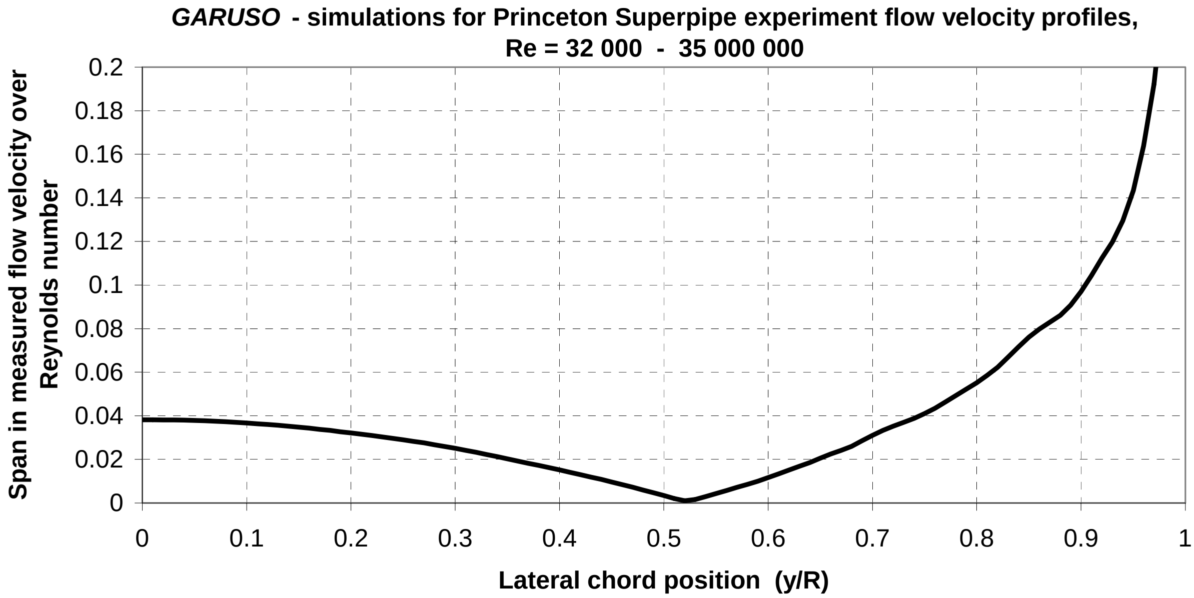
After the test program was completed FMC in cooperation with CMR did a small project to evaluate how we could further optimize the design of the MPU 200. This work was summarized in a technical note from CMR [2]. What was done was to use CMR's GARUSO – model for identification of an optimal acoustic path location to minimize the Reynolds number dependency over the Reynolds number range of relevance.

The data plotted below is taken from an experiment at Princeton (Superpipe)[4] where flow profiles have been measured for 26 different Reynolds numbers in the range from 32 000 to 35 000 000. This covers most of the range we foresee the MPU 200 to be exposed to.

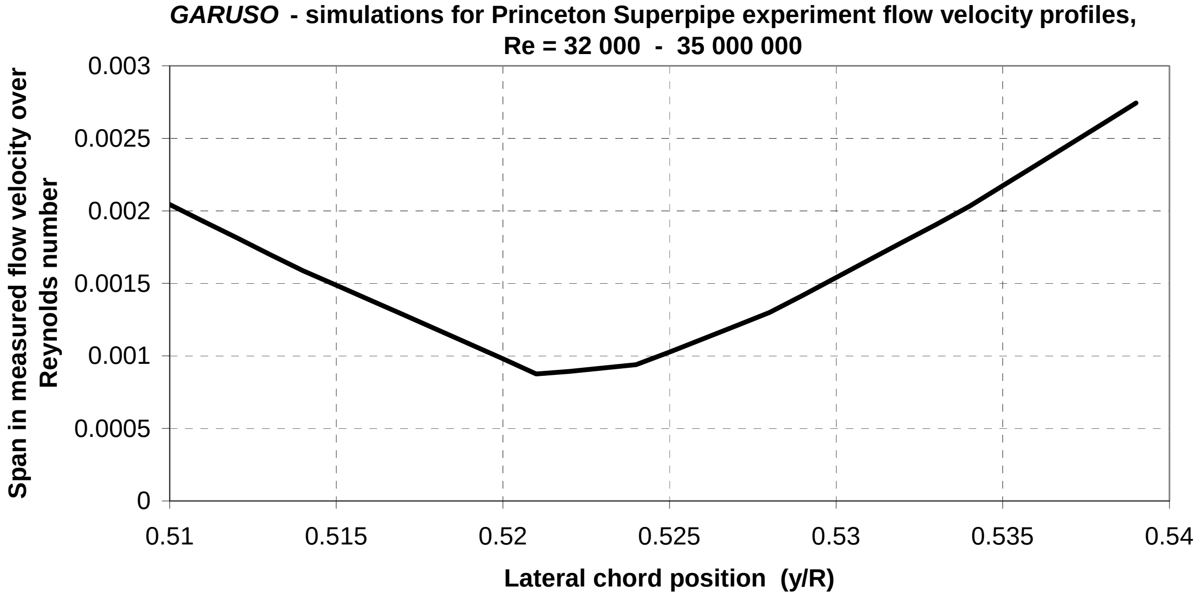
The first graph shows all the average axial flow velocities across the acoustic paths as calculated by GARUSO and plotted for the lateral positions from 0, which is at the centre of the pipe as was the case with the 4" MPU 200 tested above, to 1, which is at the pipe wall.



The below graph shows the spread of the 26 curves plotted as a function of the lateral positions and clearly shows that the spread is at a minimum, and very close to zero, at a lateral position just above 0,5.



In the below graph the same data is plotted but now focused around the points just around the minimum point to better determine the actual minimum. The minimum spread, and hence the minimum Reynolds number dependency, was found to be at a lateral position then slightly above 0,5..


GARUSO - simulations for Princeton Superpipe experiment flow velocity profiles,
Re = 32 000 - 35 000 000
Span in measured flow velocity over Reynolds number
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0.51
0.515
0.52
0.525
0.53
0.535
0.54
Lateral chord position (y/R)

7. CONCLUSIONS

The above discussions and results show that a single path ultrasonic meter can produce very good results on dry gas installations over a wide flow range with well developed flow profiles.

The technology has also been proven to provide excellent results when used on a wet gas well head and compared to an orifice meter. Among the advantages of the MPU the following has been mentioned:

- High reliability at all flow rates.
- No problems with hydration at low flow rates.
- No problems with liquid in the gas for the volumes tested which was up to 2% liquid content.
- Huge flow rate range compared to the orifice. Flow measurements from almost zero (< 0.2m/s) up to well above 30 m/s flow velocity.
- Additional measurements (gain and burst %) will possibly give more information about the flow. For example, high liquid content will change the gain and burst %.
- Use gain changes to detect hydration at lower velocities.
- Fast response to changes in the flow rate.

All the above mentioned tests were done with a 4” MPU 200 with the path at the centre of the pipe, at lateral position equaling 0. As the work done by CMR [4] shows, some of the nonlinearity seen during the flow calibration of the 4” meter, especially at the higher velocities, should be minimized by choosing a less Reynolds number affected lateral position. This optimum position was found to be just above 0,5 for fully developed flow profiles.

8. ACKNOWLEDGEMENTS

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Igor Marmylev, FMC Measurement Solutions
Tom Heistad, FMC Kongsberg Metering AS

9. REFERENCES

[1] **P. Lunde, K .E. Frøysa, J. B. Fossdal & T. Heistad:** *"Functional Enhancements Within Ultrasonic Gas Flow Measurement"*, North Sea Flow Measurement Workshop, Oslo, 25-28 October, 1999.

[2] **K. E. Frøysa:** *"MPU 200 single path ultrasonic flow meter, reduction of Reynolds number dependency by acoustic path location"*, CMR Technical Note CMR-TN03-F10013, Bergen, September 2003.

[3] **AGA-9:** *"Measurement of Gas by Multipath Ultrasonic Meters"*, Transmission Measurement Committee Report No. 9, American Gas Association (AGA), June 1998.

[4] **M. V. Zagarola & A. J. Smiths:** *"Experiments in high Reynolds number turbulent pipe flow"*, Phys. Rev. Lett. 78, 1997.