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GAS WELL FLOWLINE MEASUREMENT BY ULTRASONIC FLOW METER

Authors:
J. B. Agricola,
Nederlandse Aardolie Maatschappij B.V. The Netherlands

Organiser:
Norwegian Society of Chartered Engineers
Norwegian Society for Oil and Gas Measurement
Co-organiser:
National Engineering Laboratory, UK

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J.B. Agricola

NEDERLANDSE AARDOLIE MAATSCHAPPIJ B.V., The Netherlands

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SUMMARY

In Underground Gas Storage plants the gas in the well flowlines flows bidirectional: from the well in production mode; to the well in injection mode.
Ultrasonic flow meters (UFM), bidirectional from origin, were therefore considered for this application.
However, no UFM had ever been designed for use in well gas flowlines.

This article emphasizes the design of an UFM for use in well gas flowlines and the starting problems that occurred during tests aimed at proving the reliability of the UFM. Some preliminary measurement results are given.

The prototype UFM has been installed and tested at NAM's Munnekezijl location and performs well.

A comprehensive report of field test results will be issued by NAM, Assen, The Netherlands, and Shell Exploration and Production Technology (EPT-OM), Rijswijk, The Netherlands.
Conclusions will be drawn and recommendations given.

1. INTRODUCTION

For the NAM Norg Underground Gas Storage (Norg-UGS) plant, fully operational by the end of 1997, flow meters had to be selected for measurement and control of bidirectional flow in the well flowlines (injection and production mode).

Conventional metering systems like orifices and venturis, normally in use in well flowlines, have the following drawbacks when used in bidirectional flow:

- no practical experience with the performance, reliability and uncertainty of orifices and venturis in bi-directional flow;
- necessity to use two sets of differential pressure (dP) transmitters to be switched with flow direction;
- doubts on the short- and longterm reliability and accuracy of the dP transmitters exposed to reverse dP's and
- limited rangeability.

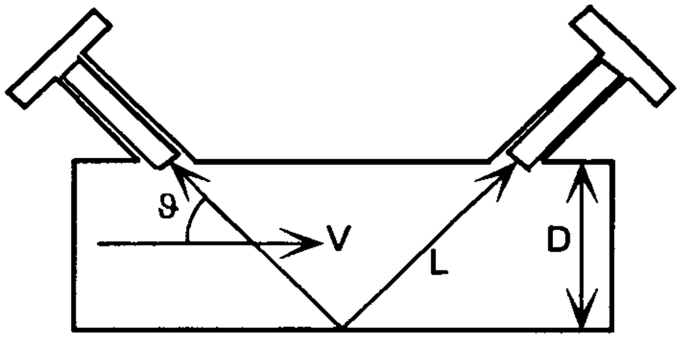
In view of the above it was preferred to use UFMs, since this type of flow meters have the following advantages over orifices and venturis:

- in principle bidirectional flow measurement devices;
- high rangeability and
- no pressure drop.

However no UFM had ever been designed for and tested in well gas flowlines.
No experience in terms of mechanical design and performance of such a meter in this application was available.
It was therefore decided to design and test such a meter.

2. ULTRASONE MEASUREMENT PRINCIPLE

Ultrasonic gas flowrate measurement is based on the time difference (time-of-flight) between acoustic pulses transmitted from and received by one or more sets of sensors. Single or multiple reflection against the pipe wall can be applied.
Both sensors transmit pulses at the same time and the time difference between receipt of these pulses is measured.



Drawing 1 Principle of operation

Gas flow velocity V_a, from which the flowrate can be established, is under ideal circumstances directly related to the time of flight and can be calculated from:

$$V_a = \frac{L}{2\cos\varphi} \times \left(\frac{1}{t_d} - \frac{1}{t_u}\right)$$

Measured down- and upstream times of flight t_d and t_u have the following relation to path length L, sensor angle φ, gas flow velocity V_a and the speed of sound in the gas C:

$$t_d = \frac{L}{C + V_a \cos\varphi} \quad \text{and} \quad t_u = \frac{L}{C - V_a \cos\varphi}$$

From above formulas it can be proven that ultrasonic flow measurement is basically independent of gas composition, pressure and temperature and that the impact of the speed of sound C is eliminated.

Flowrate Q at operational conditions is calculated from:
$Q = V \times A$ in which A is the cross sectional area of the pipe and $V = K \times V_a$.

K is a factor to correct for gas flow velocity profile and is established mathematically from the number of paths available, single or multiple pipe wall reflections, Reynolds nr., etc.
K-factor correction is based mainly on empirical data gathered during numerous tests at various test facilities all over the world.

Accurate positioning of the sensors is of extreme importance.
Angle and distance between the sensors form the basis for correct functioning of the meter and for achievable overall measurement accuracy.
The acoustical path length needs to be known as accurate as possible.

3. DESIGN AND INSTALLATION OF THE UFM

3.1 Basis of Design

The one pair sensor Psonic-1 UFM, drawing 1, from Instromet Ultrasonics, Dordrecht, The Netherlands, (IU, formerly Stork-Servex), was chosen as the basis of design.

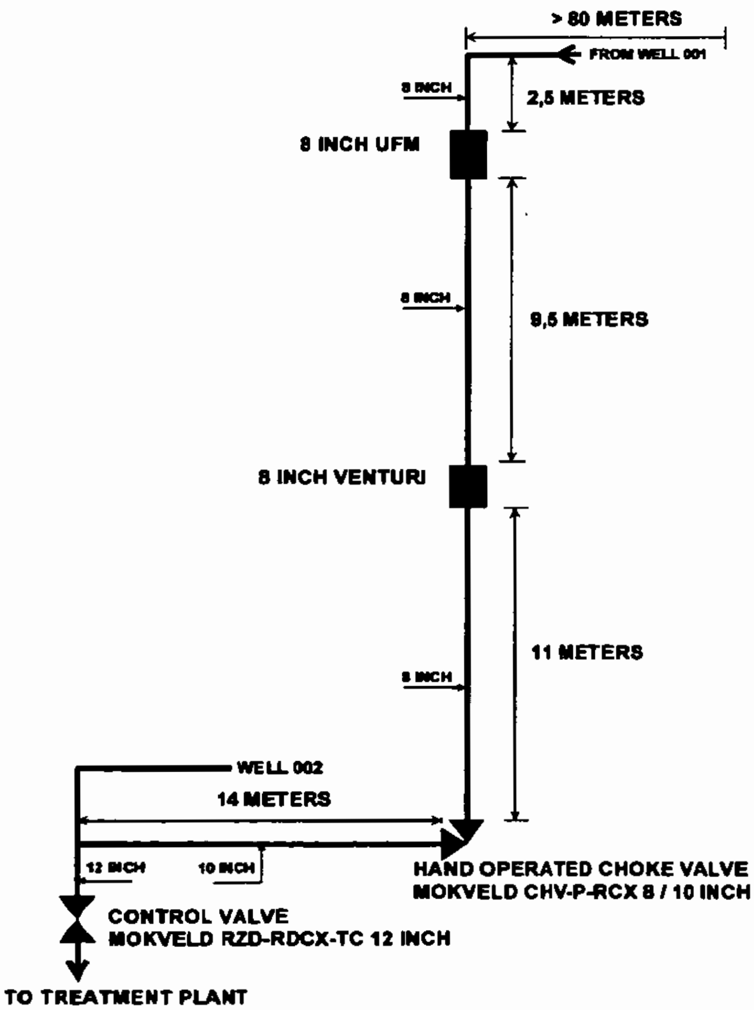
For application in high pressure and high temperature gas well flowlines the meter had to be re-engineered with respect to:

- spoolpiece;
- flanges;
- sensor legs;
- sensor mounting assemblies;
- sensors and
- sensor cable glands.

3.2 Test Location

As test location for the UFM the 8 inch 2500# flowline of well 001 of NAM location Munnekezijl (MKZ) was selected for the following reasons:

- gas pressure and temperature of about 240 Bar and 100 °C respectively at a flowrate of about 3×10^6 $m^3(n)/d$;
- the well produces some sand;
- a venturi, installed for flow control, could serve as a reference.



Drawing 2 Simplified plot Munnekezijl well area

MKZ gas was, at the time of the test, producing from two wells.
Produced gas is processed and brought on sales quality specifications in the Grijpskerk Depletion Facility (GDF), a silicagel drying plant.

3.3 Installation Requirements

Little knowledge and experience are available with manufacturers of UFM's on installation requirements for these meters in gas flowlines.

Necessary straight lengths, up- and downstream distance from potential sources of acoustical noise (chokes, thermowells, RTJ flanges, the venturi) are hardly known. Permitted (acoustical) noise levels and noise spectra are not defined.

Mechanical requirements of equipment for use at high pressures and high temperatures (type of flanges, gaskets, inspection, certification, etc.) are subjects the manufacturers of UFM's are not familiar with.

From discussions with the manufacturer, from publications and from company standards installation rules were defined.

3.4 Meter Sensors, Electronics, Meterbody and Sensor Legs

IU was responsible for the design of the sensors, (Ex) electronics, flowcalculations, data collection and data transmission.

Engineering of the meter was done by Tebodin, Hengelo, The Netherlands.

Veenstra, Coevorden, The Netherlands, manufactured the meter spoolpiece, ring type joint (RTJ) flanges, sensor legs and sensor leg flanges.

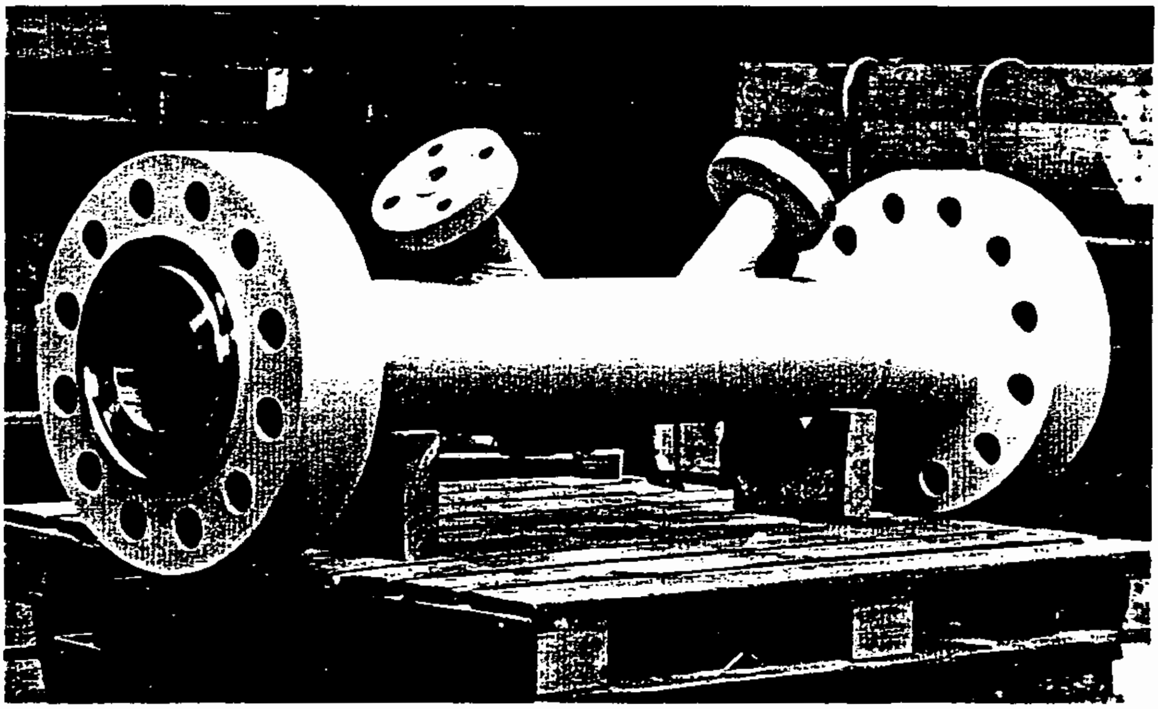


Photo 1 Manufacturing the UFM at Veenstra, Coevorden, The Netherlands

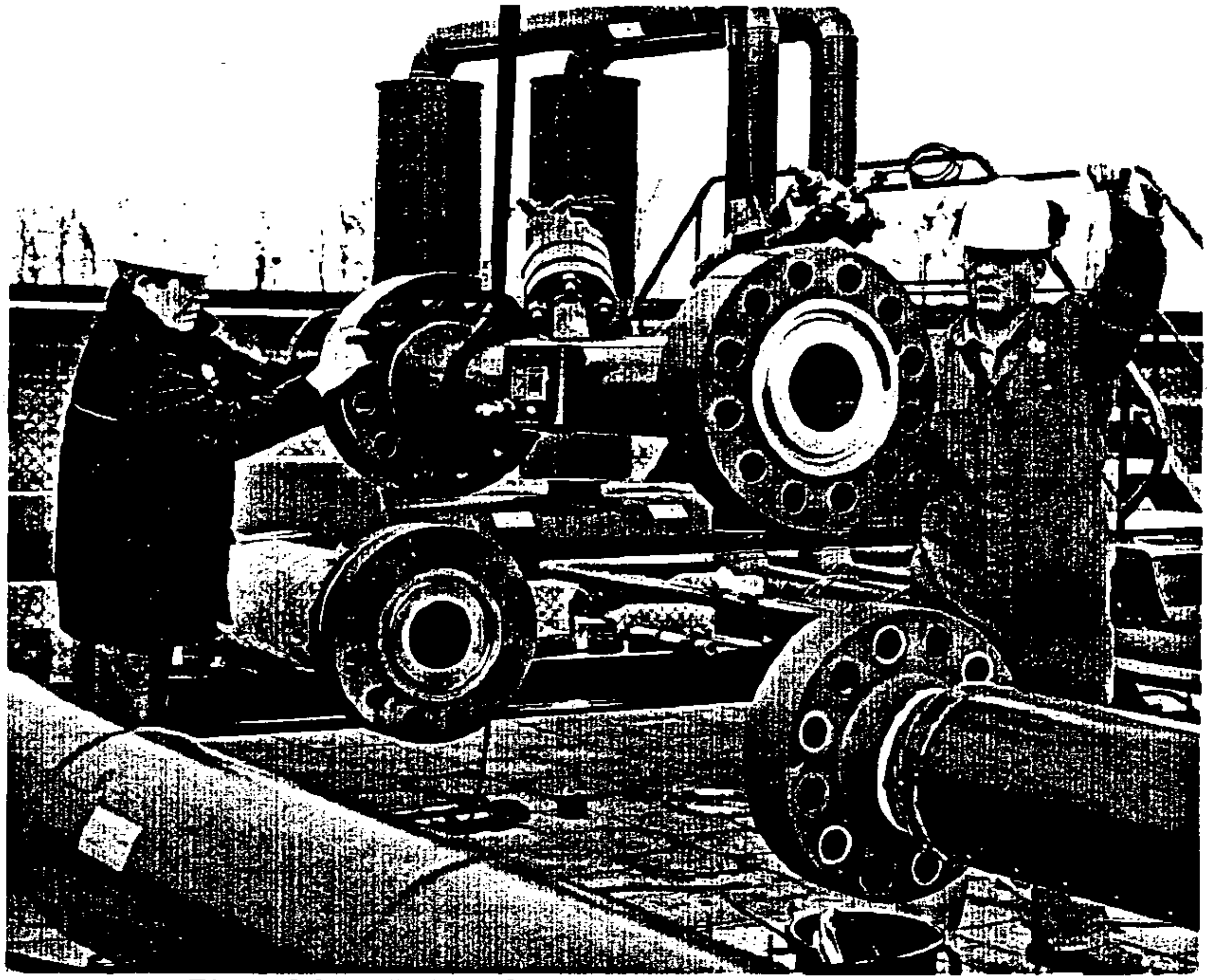


Photo 2 Installation of the UFM at NAM location Munnekezijl

Both IU and Veenstra were responsible for ensuring correct positioning in all planes of the sensor legs, in which the sensors are to be inserted, on the meter body.

All components were built together by Veenstra after which the meter was pressure tested for certification. Correct functioning of the sensors and electronics was executed by IU while the meter was pressurised at Veenstra's premises.

4. EXPERIENCED PROBLEMS

4.1 Sensors

The UFM was installed at the MKZ location in March 1995, see photo 2, and brought into operation by the end of that month.

Within 24 hours after becoming operational the performance of the meter fell down from 100 % to almost 0 %.
With performance is meant the percentage accepted sensor pulses for further processing in the meter electronics.

Checks on the electronics and observation of transmitted and received sensor pulses demonstrated that the sensors were not functioning properly.

After removing the sensors from the meter it turned out that the surface of the moulded synthetic sensor material of both sensors had gone spongy.

This resulted in a dramatically low transition of electrical into acoustical pulses and vice versa.

Investigations from IU and Shell Exploration and Production Technology, (SIEP EPT-IP, formerly KSEPL, Chemical Research), Rijswijk, The Netherlands, who were consulted for advise, made clear that the synthetic sensor material was sensitive to water in gas especially at the high MKZ operational gas temperature.
EPT-IP advised IU on new synthetic materials and moulding procedures.
A number of new sensors were produced, tested and installed in the meter.
Measurement results after this change were satisfactory, initially.

After a few weeks of operation however, new problems arose.
Slowly but surely the meter performance was decreasing again.

From investigations using X-ray techniques hairline cracks were discovered in the sensor material.
These cracks were caused by cohesive forces between the various types of synthetic material the sensor was made of.
Cohesive forces were found to result from depressurisation of the flow line.
Although depressurisation of a flowline is a controlled action the occurrence of inter-material forces in the UFM sensors could not be precluded.

Specialists on synthetic materials from the Dutch research organisation TNO, Delft, were approached for advise on possible solutions.
The problem was solved by using synthetic material and moulding techniques, commonly in use in spacecraft and satellite industry, neutralising internal forces due to depressurisation.

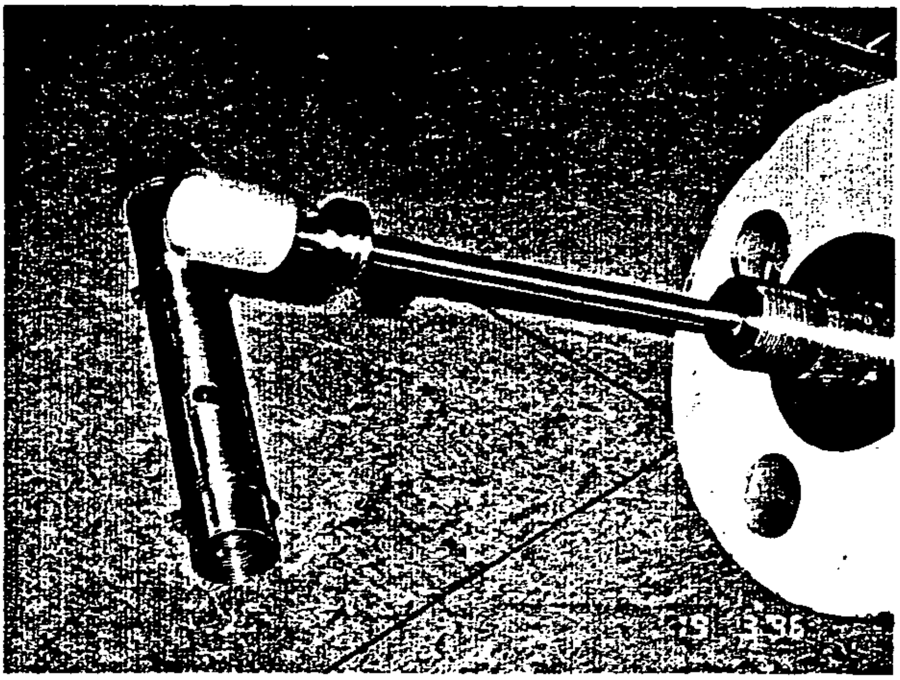


Photo 3 Final version of UFM sensors

The manufacturing and testing of prototype sensors turned out to be an extremely difficult task that, after a number of disappointments, led to a final version.

By the end of May 1996 sensors manufactured according to final laboratory test results were mounted in the UFM.
The meter has been performing without any problem since then.

Before these new sensors were installed an acoustical noise pattern survey was executed to measure noise levels and noise spectrum.
For this purpose a microphone was installed in one of the sensor legs of the UFM.
Data was collected under no-flow (flowline pressurised) and under operational flowing conditions.

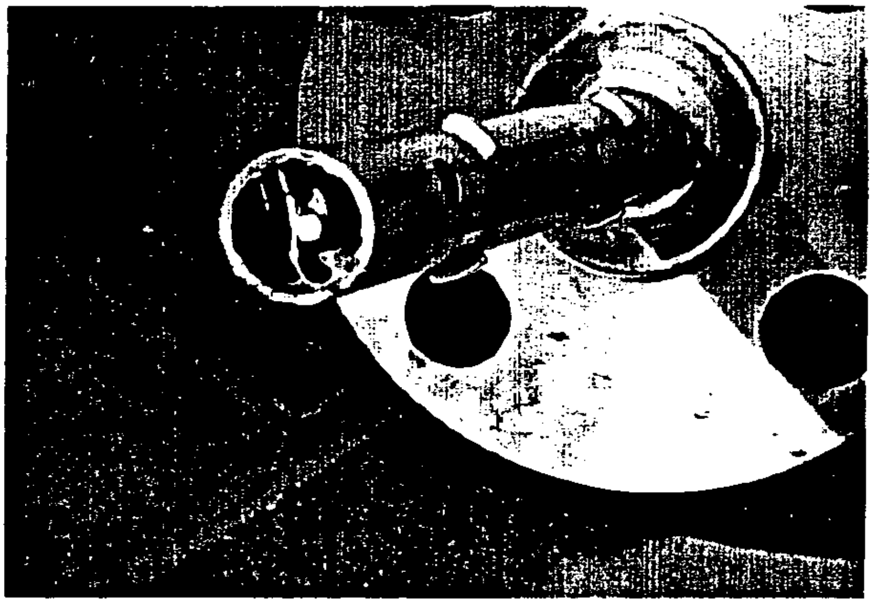


Photo 4 Microphone mounted in sensor assembly

From this data the signal-to-noise ratio could be established.
Noise spectrum measurements are of extreme importance in optimising UFM transmitter frequencies, for establishing required pulse energy and for defining acoustic noise filtering techniques.

4.2 Noise

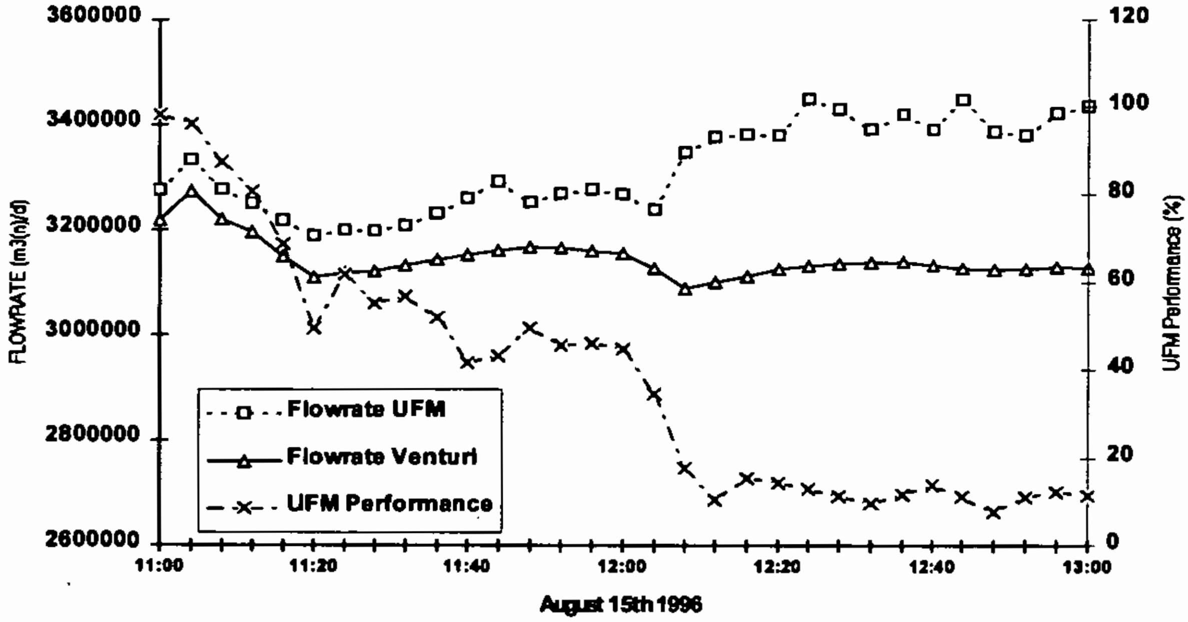
At August 15th, 1996, Operations had to balance the flow production between wells 001 and 002 for which the hand operated angle choke valve in the flowline of well 001 was adjusted from 70 % open to about 50 % open.
Results on UFM meter performance were dramatic, see graph 1.

This graph shows a fall in UFM performance from 100 % to 10 % while the UFM measured flowrate increases and suffered from instability.
From sensor pulse measurements it became clear that the signal-to-noise ratio had reached such a level that discrimination between noise and sensor pulses was hardly possible.

The flowing gas in the flowline was clearly audible and was undoubtedly caused by the angle choke valve but also by the impulse lines from the venturi.

Personal from Operations were not allowed to readjust the choke valve and, after discussions with IU, it was decided to raise the transmission output to the sensors as high as the electronics allowed for.

UFM meter performance recovered thereafter to an average of 90 % and the metered flowrate became more stable and more in line with the venturi flowrate again.



Graph 1 Influence of noise on UFM performance and measured flowrate

Although outside the scope of the test, a discussion was held with IU on observed rise of UFM measured flowrate during the period of low meter performance.
No clear explanation could be given as this phenomenon never occurred before.
A possible reason may be sought in received pulse detection philosophy and related electronic circuitry.

4.3 Other (minor) Problems

4.3.1 Power Supply

Power (24 V DC) for the meter was made available from the MKZ no-break set. For unknown reasons the fuse in the UFM-electronics blowed up randomly.
All possible causes were investigated (lightning, power dips from the mains, earth loops, shortage, etc.) but the real cause has never been found.
Power feed was finally established from a stabilised 220 V/24 V separate source and there haven't been any problems since.

4.3.2 Communication

Communication with the data logger for data collection and data readout was sometimes not possible due to a modem fault.
It was found by experiment that the modem fault occurred every time communication with the data logger was ended when using modem break signals.
By ending data transfer on data logger software level this fault never occurred anymore.

5 SET-UP OF FIELD INSTRUMENTATION

The venturi downstream of the UFM, engineered and designed fully in compliance with ISO 5167, served as a reference to the UFM.
Electronic instrumentation (P-, T- and dP-transmitters) was checked and calibrated regularly.

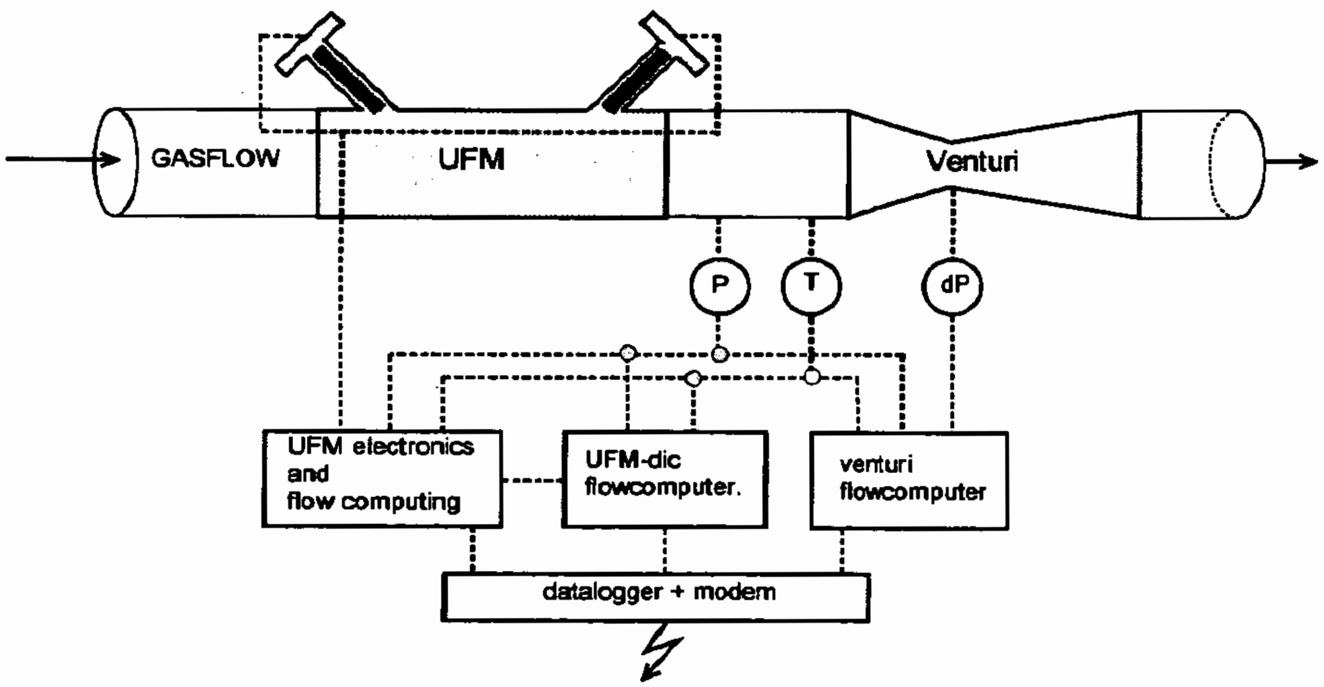
Venturi flowrate calculations, fully compensated for pressure and temperature to arrive at m3(n)/d [1]), are executed in a flowcomputer, make Digi Table, type DIC438, using AGA NX-19 for calculation of the compression factor.

The UFM flowrate (m3(n)/d) calculations are, according to IU, similar to these of the venturi.

To establish any possible differences from calculation routines between the venturi and the UFM a 2nd DIC438 flow computer was installed, see drawing 2.
This 2nd DIC438 received a frequency signal (F) from the UFM.
F is directly linear with UFM measured speed of the gas.

Compression factor calculation routines of this 2nd flowcomputer are exactly the same as these of the venturi flowcomputer.
Thermal expansion of the stainless steel UFM body is corrected for in the 2nd DIC438.

The calculated UFM flowrate from this 2nd flowcomputer, called UFM-dic, differed only slightly (0,5 % at the maximum) from the directly UFM measured flowrate.



Drawing 2 Set-up of field instrumentation

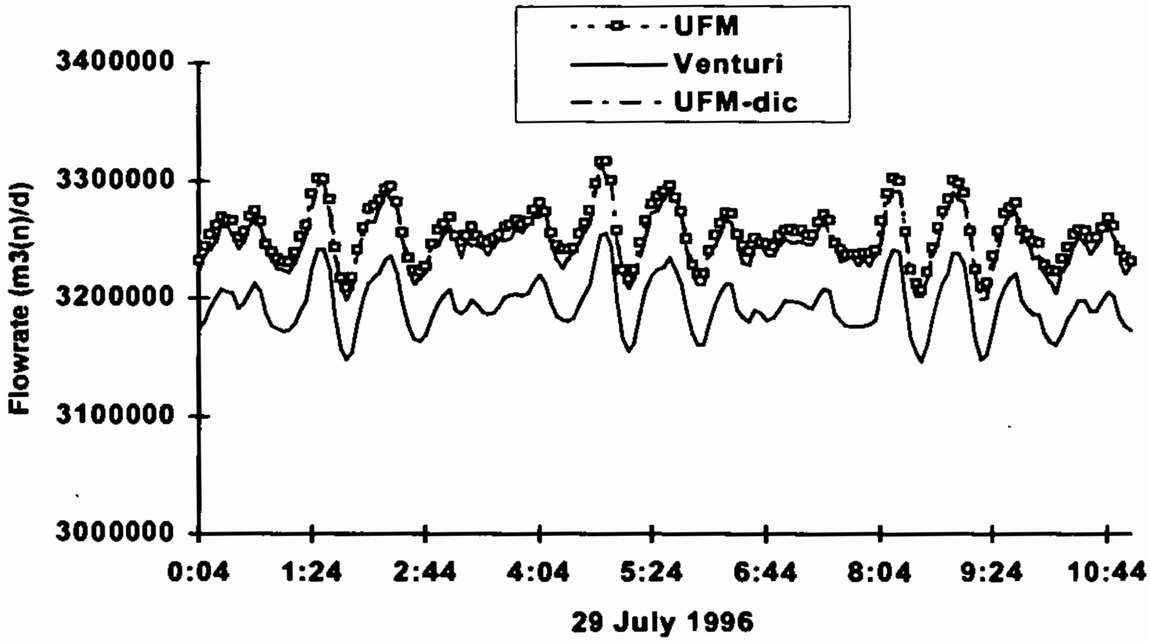
[1]) m3(n) = m3 at normal conditions i.e. at a temperature of 273.15 K and a pressure of 101.325 kPa

6. MEASUREMENT RESULTS

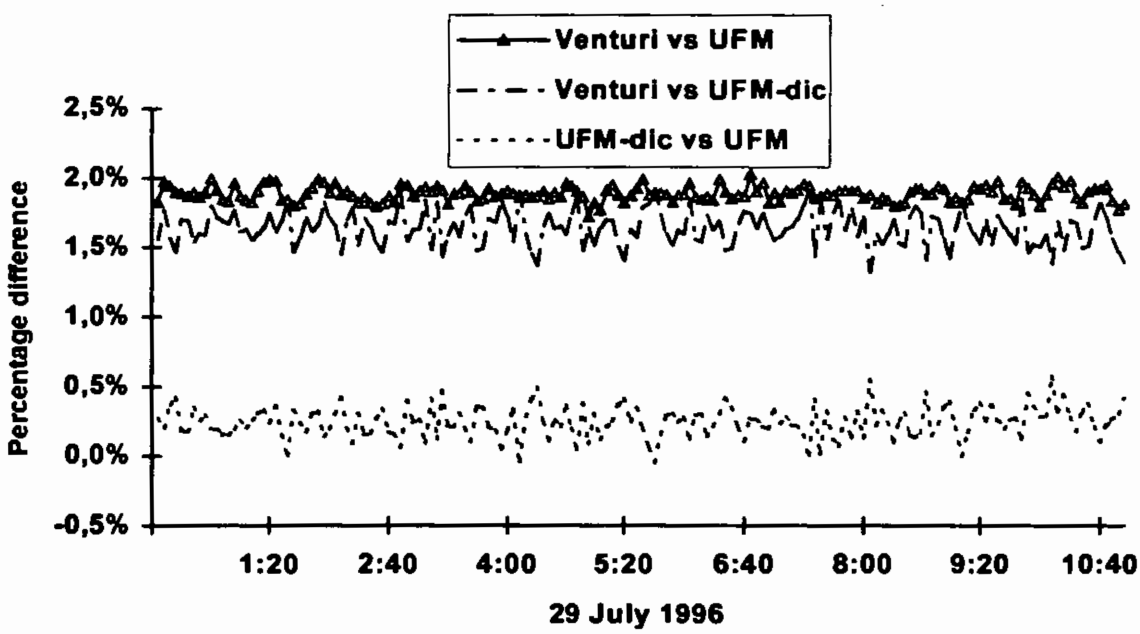
6.1 Preliminary results

Although results from the field test will be reported and discussed extensively in the NAM/Shell report, some preliminary results are given here.

Graphs 2 and 3 show UFM and venturi measured flowrates, UFM-dic calculated flowrate and mutual percentage differences at the same conditions.



Graph 2 Flowrate comparison



Graph 3 Percentage difference between flowrates

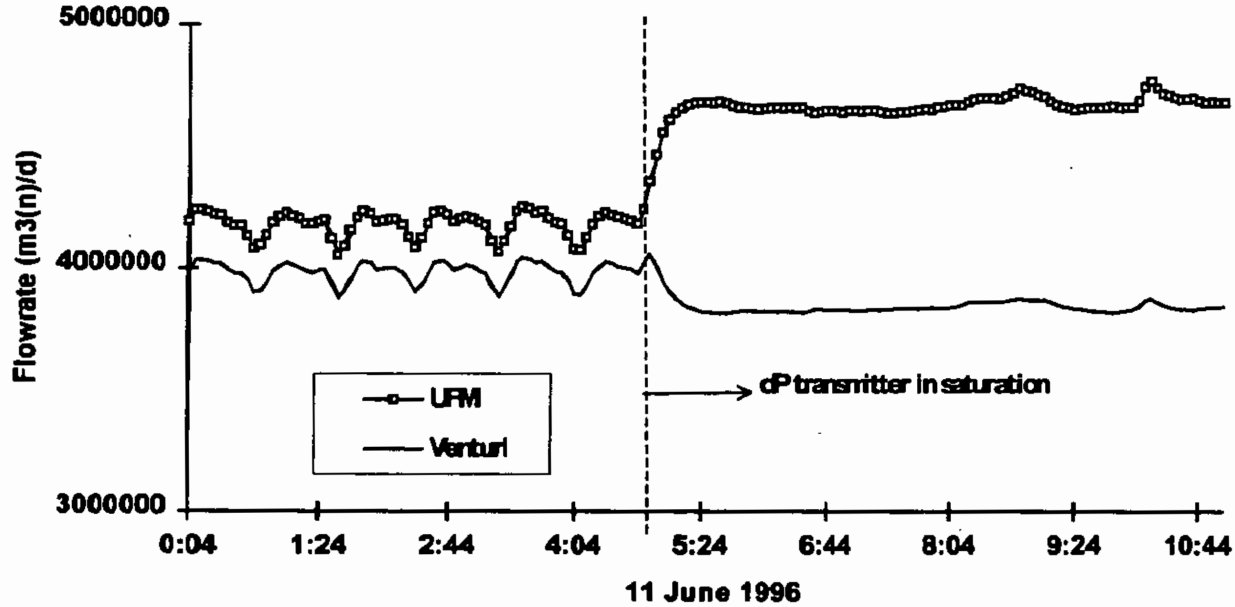
UFM measured flowrate is systematically positive compared to the venturi measured flowrate and to the UFM-dic calculated flowrate.

These differences can be quantified in detail only by executing a calibration run of each meter at a test facility.
The UFM was calibrated at the end of the test period, see paragraph 6.2.
Unfortunately the venturi could not be made available for such a calibration.

6.2 Rangeability

One of the main advantages of an UFM is its high rangeability.
An example of a typical venturi rangeability problem is given in graph 4.

A production raise to nearly 5×10^6 $m^3(n)/d$ causes saturation of the dP-high transmitter of the venturi resulting in a too low measured venturi flowrate.



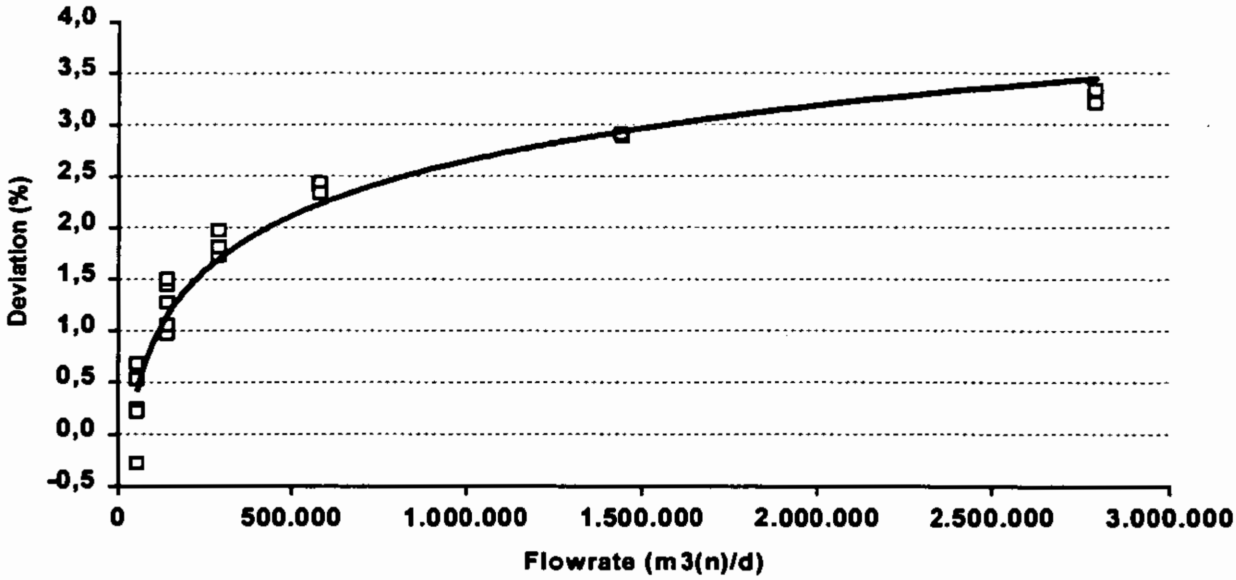
Graph 4 Example of limited venturi rangeability

6.3 Calibration

The UFM was calibrated at the end of the field test at the Ruhrgas (Pigsar) high pressure gas calibration facility in Dorsten, Germany.
Results are given in graph 5.

The calibration curve shows an UFM overreading of 2 to 3.5 % in the operational flowrate range as encountered during the test at MKZ.

Although this overreading is in line with observed difference between the venturi and UFM flowrates during the test, no strict comparison can be made as, for operational reasons, no calibration curve of the venturi could be made.



Graph 4 UFM Calibration results

The fact that the gas composition, operational temperature and pressure at the calibration facility (dry gas) are different compared to these parameters at MKZ introduces an extra, unknown, uncertainty.

Some data is available from a recent calibration of a venturi, in type and sizing comparable to the MKZ venturi, at the high pressure gas calibration facility of the Nederlands Meetinstituut (NMi), Bergum, The Netherlands.

From that calibration it may be concluded that the flowrate, measured with a standard venturi and using the ISO discharge coefficient of 0.995, is too low by 0.2 to 1.3 % over the flow range as encountered at MKZ.
This may imply that the difference between the UFM and venturi flowrates is smaller than the observed 2 % in practice.

7. COSTS

Cost price of an UFM may be split into the price of the sensors and related electronics and the body.
The price of a set of sensors and related electronics is more or less fixed.
The price of the body however depends on pressure class of the flowline, on material to be used (carbon, stainless or duplex steel) for the flowline and on (RTJ) flanges.
Body price may therefore be twice or more than that of sensors and electronics.

Overall costs of an UFM can be reduced significantly by not using flanges.
Price of such a meter is then comparable with that of a venturi of similar material.
The Norg-UGS UFM's do not have flanges.

8. THE USE OF FLOWLINE UFM'S IN THE FUTURE

Flowline measurements are necessary for flow control, for reservoir engineering and for product- and sales-allocations.

These applications, especially product- and sales-allocations, require reliable meters with reproducibilities and rangeabilities as high as reasonably possible.
Uncertainties are to be known.

Flowline UFM's are likely to meet with these demands.

Apart from the NAM Norg-UGS, flowline UFM's will be installed at the new NAM offshore production location L9, coming on stream early 1998.
Discussions to install these meters in the well flowlines of the Dutch Slochteren field are ongoing.

9. FURTHER INVESTIGATIONS

One of the goals of the NAM test was to proof the reliability of the UFM.
The test showed that the required reliability can be met.

However, further investigations are necessary and need to be undertaken the soonest.

Specifically the influence of (valve) noise, the wetness of gas and of sand particles on UFM measurement accuracy should be investigated, quantified and compensated for.

An on-line calibration or validation procedure need to be developed as dismantling of a flowline meter is normally not possible for operational reasons, apart from high costs and cumbersome logistics.

A complete different approach with respect to transmission frequency, filtering techniques and transmitted pulse characterisation may result from these investigations.
Mathematical components within the currently used K-factor formula may need to be revised or may have to become dynamic.

Funds, facilities and manpower of gas exploration and production companies need to be made available for these investigations.

10. ACKNOWLEDGEMENTS

Designing the UFM and bringing the instrument "to life" was made possible through contributions from many people.
It was a result of close co-operation between manufacturers, research institutes and NAM, the end user.

I would specifically thank Mr. Ghis Boerwinkel of NAM.
He did most of the work to get and keep all the instrumentation operational.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.