# CHALLENGES FOR ULTRASONIC FLOW METERS IN WET GAS APPLICATIONS

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#### 1 ABSTRACT

Accurate flow measurement of wet gas flows in real life applications is an important driver in the marketplace today, encompassing a wide range of users from upstream separator measurements to underground gas storage and natural gas wells. Clamp-on ultrasonic technology allows this measurement to be performed non-intrusively with the additional benefit of being able to install the instruments without shutting down the process.

This paper addresses the specific measurement challenges involved in wet gas operations such as the amount and changes in gas wetness, wide variations in gas pressure, pipe wall thickness, short straight pipe runs and acoustic disturbances caused by valve noise or low flow velocities.

The effects of gas wetness on accuracy and reliability were investigated in a measurement series conducted at the Colorado Experiment Engineering Station Inc. (CEESI) wet gas test facility in Colorado. The paper will report on the objectives of this test as well as on the procedures and results. The findings of other gas laboratory tests will be presented to show the effects of insufficient straight pipe runs or low flow velocities on accuracy. The effects of changing gas pressures will be explained based on ultra-sound theory and actual field measurement results will be presented.

#### 2 INTRODUCTION

Gas flow measurement has always been a key parameter in oil and gas operations and the requirement for meters with better accuracy and reliability is growing.

The measurement of wet gas does not normally fit with the 'better accuracy' statement, as by nature, these types of measurement have their accuracy impacted by the wetness of the gas, the flow regime and the piping arrangement.

This paper will examine the effects of the wetness of the gas and the flow regime (as dictated by the flow velocity and liquid content) has on an ultrasonic clamp-on flow meter. The piping under test was horizontal, therefore no data is available for metering on vertical or inclined pipes.

The amount of liquid in a gas depends on many factors including the pressure and temperature of the gas in the pipe. The liquid carried in the gas stream can be in form of droplets or in the form of a vapour. Any gas flow meter must therefore be able to deal with wet gas.

A clamp-on USFM does not restrict the pipe, nor is it in contact with the gas. It therefore does not liberate more condensation (caused by a pressure drop) into the gas than is already present.

Years of practical clamp-on gas measurement experience proved the ability of clamp-on USFM's to measure wet gas environments, without being able to quantify the limits of measurement in terms of liquid content. In order to answer these questions, a test series was conducted at the CEESI wet gas test facility in Colorado to investigate the capabilities and limits of clamp-on USFM technology with regard to wet gas.

#### 3 PRINCIPLE OF MEASUREMENT

#### 3.1 Meter Formula

The transit time ultrasonic flow meter measures the transit times  $t_{up}$  and  $t_{down}$  of an ultrasonic signal travelling upstream and downstream respectively. The difference  $\Delta t$  between the transit times is directly proportional to the mean flow velocity  $v_l$  on the sound path.

$$v_l = K_{\alpha} \frac{\Delta t}{2t_{fl}} \tag{1}$$

 $K_{\alpha}$  is the acoustical calibration factor and  $t_{fl}$  is the transit time within the fluid. The volume flow Q is the product of the average flow velocity  $v_A$  over the cross section of the pipe multiplied by the area A of the cross section.

$$Q = v_A \cdot A \tag{2}$$



Fig. 1 Ultrasonic Clamp-On Measurement

If the flow profile v is known, the area average  $v_A$  of the flow velocity can be calculated from the path velocity  $v_l$  measured by the flow meter. The meter calculates the fluid dynamical calibration factor  $K_{re}$ .

$$K_{re} = \frac{v_A}{v_l} \tag{3}$$

Thus the meter formula is

$$Q = K_{\rm Re} \cdot A \cdot K_{\alpha} \frac{\Delta t}{2t_{\rm fl}} \tag{4}$$

The meter assumes the flow profile to be fully developed. This requires a sufficiently long distance of the measurement location from disturbances like bends and Tees. In that case the fluid dynamical calibration factor  $K_{re}$  depends on the kinematic viscosity of the fluid and the roughness of the pipe wall only.

If the flow profile can not be assumed to be fully developed, a deviation of the fluid mechanical calibration factor  $K_{re}$  has to be applied. Usually, this deviation is nearly independent of the flow velocity, as long as the Reynolds number is well above 10000. This permits accounting for such conditions by means of a constant correction factor if the magnitude of the influence is known. In some cases, empirical data can be used as many investigations have been carried out on 90° elbows for instance. The most reliable way of determining the necessary correction factor is to measure it on site by a calibration against a reference if such a reference is available. If neither method is available, a numerical simulation of the flow profile can help. This approach is described i.e. in [1].

# 3.2 Path Configurations

The fact that the flow profile is not always ideal is often addressed by using multiple sound paths. Fig. 2 shows a reflecting configuration in two planes. The advantage of a reflecting path is that non-axial flow components are compensated for. This is because the effect of the non-axial component (cross flow) on the two components of the reflecting path is the same in magnitude but opposite in sign. The use of sound paths in two planes reduces the impact of non-symmetry in the flow profiles caused by disturbances like bends or t-branches.

It is not always possible to use reflecting paths. In such cases the compensation for cross flow can be achieved by using two direct paths as shown in Fig. 3.





Fig. 2 - Reflecting Paths in Two Planes

Fig. 3 - Two Direct Paths

#### 3.3 Sound Transmission

The clamp on technology requires that a sufficient amount of the sound energy can be transmitted from the transducer on the outside via the pipe wall into the flowing fluid. The angles under which the sound waves propagate through the pipe wall and the fluid are given by Snell's law as expressed by formula (5).

$$\frac{\sin\alpha}{c_{\alpha}} = \frac{\sin\beta}{c_{\beta}} = \frac{\sin\gamma}{c_{\gamma}}$$
(5)

The main difficulty with clamp-on gas measurement is the strong mismatch between the density of the pipe wall and the fluid.

Two different modes of propagation are used with clamp-on measurement on steel pipes, the shear or transverse mode and the Lamb mode. The advantage of the shear waves is that the sound absorption within the pipe wall is negligible and nearly independent of the transducer frequency. So there is practically no upper limit in pipe wall thickness and the choice of the transducer frequency is not restricted by the pipe wall. This makes them suitable for high pressure applications as shown in Fig. 4. Lamb waves travel in parallel to the pipe wall boundary thereby producing a broad sound beam within the fluid. The effect can be seen as an impedance transformation reducing the strong mismatch between the high density pipe wall and the low density gas thus increasing the efficiency of the sound transmission through the pipe wall as shown in Fig. 5. However, the frequency needs to be matched to the pipe wall thickness.



# 4 APPLICATION RANGE REGARDING FLUID PRESSURE AND SOUND ABSORPTION

The total loss the sound wave suffers on its way from the transmitter to the receiver consists of the loss associated with the transmission thorough the pipe wall (insertion loss) and the attenuation caused by the sound absorption in the fluid (propagation loss). The insertion loss mainly depends on the difference between the acoustic impedance of the pipe wall and the fluid. The acoustic impedance Z is the product of sound velocity and density.

$$Z = C \cdot \rho \tag{6}$$

This means that the acoustic impedance of the gas is approximately proportional to the pressure. In [1] it is shown that the insertion loss  $D_I$  is approximately proportional to the acoustic impedance of the fluid.



Fig. 6 - Signal Gain in Dependence of Pressure

$$D_I \Box \frac{1}{Z_F};$$
  $Z_F \Box Z_R;$   $Z_R = konst.$  (7)

As a result, the signal loss increases with decreasing pressure. Formula (7) provides a means to check the tolerable decrease in pressure for a meter that is installed at a given pressure. From (7) it follows that, as the density and, thus the impedance, is proportional to the pressure, the insertion loss increases by 20dB per decade of pressure decrease.





If the pressure dependency of the sound absorption in the gas is not negligible the propagation loss has also to be taken into account, the propagation loss  $D_T$  is given by

$$D_T = e^{\alpha \cdot l}, \tag{8}$$

With the absorption factor  $\alpha\,$  and the path length l , the total signal loss  $\,D\,$  is thus expressed by

$$D \Box \frac{e^{-\alpha \cdot l}}{Z_F}; \qquad Z_F \Box \quad Z_R; \qquad Z_R = konst$$
(9)

Fig. 7 shows the gain versus pressure measured in pipes filled with compressed air. Fig. 7 shows the insertion loss calculated from those results by subtracting the propagation loss. The 20dB decrease in gain per pressure decade is clearly visible.

# 5 EFFECT OF MOISTURE IN THE GAS

The ability of the clamp-on meter to tolerate moisture in the gas flow was tested at the CEESI wet gas test facility in Colorado. The definition of wet gas flow is based on the Lockhart-Martinelli parameter  $X_{LM}$ . With an  $X_{LM} < 0.3$  the flow is defined as a wet gas flow. With an  $X_{LM} > 0.3$  it is considered to be a two phase flow [2]. Although typical applications a clamp-on ultrasonic flow meter is used in have a liquid content much lower, all tests were performed up to this  $X_{LM}$  limit of 0.3, or up to a Liquid Volume Fraction (LVF) of 5%. The aim of the testing program was not to verify the application of the meter for wet gas flow measurement, but to show that the LVF present in typical applications do not affect the meter.

The CEESI wet gas test facility in Colorado can provide gas flow with a liquid loading of water or kerosene substitute (Exxsol D80) or both. The tests undertaken used natural gas with the kerosene substitute.

The main results recorded during these tests for further analysis were the meter error, signal attenuation, flow velocity, pressure and liquid loading. The flow conditions within the pipe are documented by 10 second video segments at each test point.

#### 5.1 Definition of Terms

The way in which liquid content is carried within the gas flow can be very complex and depends on various factors. At low flow velocities in horizontal pipes the liquid is likely to flow on the bottom of the pipe. This is one form of the so called stratified flow state where the velocity of the liquid flow is usually smaller than that of the gas flow. The ratio of the liquid and gas velocities is called slip.

The level the liquid reaches at the bottom of the pipe depends on, amongst others, the liquid content, velocity and density of the fluids and the pressure. At high velocities, the liquid content is more likely to be carried in form of a mist at the same speed as the gas (annular mist flow). Various other flow patterns are possible.

The Lockhart-Martinelli parameter can be expressed in terms of the Liquid Volume Fraction.

$$X_{LM} \approx LVF \sqrt{\frac{\rho_l}{\rho_g}}$$
(10)

The LVF is the ratio of the liquid flow rate to the total liquid and gas flow rate, which can be expressed as follows:

$$LVF = \frac{\dot{Q}_l}{\dot{Q}_g + \dot{Q}_l} \tag{11}$$

Where QI and Qg are the actual liquid and gas volume flows respectively. It needs to be considered that the velocity of the liquid flow can be much smaller than that of the gas flow. Therefore, the ratio of the liquid to gas volume in the pipe can be much bigger than the LVF.

# 5.2 Set Up and Test Plan

The test utilised two ultrasonic clamp-on flow meters on 4" pipe sections (see Fig. 8). To test all configurations, one meter was set up in dual channel reflect mode using Lamb wave transducers as shown in Fig. 2. The other was set up in dual channel direct V mode with shear wave transducers as shown in Fig. 3. In addition to this testing, a third meter was tested in parallel by CEESI engineers on a 6" pipe section. This meter was set up with one horizontal path and one perpendicular path with the idea of using the perpendicular path to sense the liquid level. The test parameters are listed in Table 1.

The following tests where done at 30bar and at 75bar, respectively: -

- Vary the LVF from 0% to 5% at a constant velocity of 30ft/s
- Vary the LVF from 0% to 5% at a constant velocity of 60ft/s
- Vary the velocity at a constant LVF of 1%



Fig. 8 - GRK Transducers (500KHz Lamb Wave) in Dual Channel Reflect Mode on the 4" Pipe

	Location 1	Location 2	Location 3	
Serial Number	G6010836	G6010837	G6010285	
Transducer	GRK - Reflect	GDK - Direct	GRH - Reflect	
Pipe material	Carbon Steel	Carbon Steel	Carbon Steel	
Outer diameter	4.5"	4.5"	6.63"	
Wall thickness	0.224"	0.224"	0.413"	
Inflow length to next flange	25D	18D		

# Table 1 - Parameters of the test locations

#### 5.3 Test Results

#### 5.3.1 Signal Quality and Attenuation Depending on the Liquid Load

Both transducer types under test, shear and Lamb wave, are used in situations with high moisture content. The testing of both shear and Lamb wave transducers in parallel had several advantages. The shear wave transducers were mounted in double direct mode (see Fig. 3) and the Lamb wave transducers were installed in reflect mode.

The path length of the Lamb wave transducers is double the path length of the shear wave transducers. By using the same frequency it is possible to estimate the attenuation related to the moisture content by comparing the gain of both meters.

During the initial set up of the flow meters, the two sets of the Lamb wave transducers were set up at  $\pm 45^{\circ}$  on the pipe circumference as per normal installation practice (see Fig. 2) After the initial test runs it became apparent that such a configuration is not recommended with high liquid content. When the liquid level reaches the reflection point (diametrically opposite the transducers at 135° with respect to the top of the pipe) the measurement fails. As this occurred at an LVF of 2%, the transducers were moved to a more horizontal position.

Fig. 9 shows the gain and the SCNR at 75bar with a flow velocity of 60ft/s plotted against the LVF. The SCNR is the ratio of the signal amplitude to the amplitude of coherent noise. Coherent noise is acoustic signals travelling around the pipe wall from the transmitter to the receiver. These signals (also referred to as "pipe signals") carry no information about the flow velocity and are thus a disturbance. Assuming that the coherent noise level is independent of the LVF, the SCNR should decrease by the same amount the gain increases. The gain of the reflect mode setup (2-path) should increase with double the slope of the direct mode setup (1-path). The gain shown in the diagram is linearly proportional to the LVF increasing by 10dB / %LVF with the 2-path setup and by 5dB / %LVF with the 1-path setup. Comparing the gain of the two setups at the highest LVF, the attenuation caused by the sound absorption with a transducer frequency of 500kHz can be estimated: -

$$\alpha_{500kHz} \left[ dB, LVF = 3\% \right] = \frac{gain(2L) - gain(L)}{L} = \frac{110dB - 90dB}{0.2m} = 100dB / m \quad (12)$$

The attenuation depending on the LVF in the annular mist state of flow is then: -

$$\alpha_{500kHz} \left[ dB / \% LVF \right] = 33 dB / m / \% LVF$$
(13)

As another example, the results at 30ft/s are shown in Fig. 10 Here with an LVF up to 2% there is nearly no effect as the flow is in the stratified state and most of the liquid is moving on the bottom of the pipe. The gas at this point does not contain much liquid, so, as long as the liquid level does not reach the sound path location, the signal is not affected. As the LVF rises above this, the gain increases as the flow turns into the mist state and the attenuation increases with the liquid load.







Fig. 10 - Signal Parameters at V=30ft/s and P=75bar

# 5.3.2 Measurement Error Depending on the Liquid Load

The error versus flow velocity with a constant liquid load at 30bar and 75bar respectively are shown in Fig. 11 and Fig. 12. The dependency of the error on the velocity is caused by the change of the flow pattern. At low velocities a stratified flow pattern is present causing a "slip" with the velocity to occur. The liquid flows at the bottom of the pipe thus reducing the pipe area which theoretically leads to an error that is proportional to this reduction.

The liquid level depends on the ratio of the gas flow velocity to the liquid flow velocity which is also called the "slip ratio". The higher the slip ratio is (with the LVF kept constant) the higher the liquid level becomes.

Fig. 11 and Fig. 12 show an error increasing from the lowest velocity to a maximum and then decreasing again as the velocity continues to increase. This corresponds to a slip rate increasing with the flow velocity up to the point where the flow pattern changes into the annular mist state. With the slip the liquid level on the bottom of the pipe increases. This causes a cross sectional error in the calculation of flow rate. When the flow achieves a mist state the liquid is travelling in droplets with the gas. This confirms the results reported in the ASME report which states that 'at low flow with slip the error must increase due to the reduction of the cross sectional area' [2].

The result of this is that the flow meter should measure the sum of both the liquid flow and the gas flow resulting in an error that is identical to the LVF. The maximum error at 30bar is slightly bigger than that at 75bar and the velocity at which the maximum is located is lower at 75bar than at 30bar.



Fig. 11 - Error versus Velocity with Constant LVF at 30bar



Fig. 12 - Error versus Velocity with Constant LVF at 75bar

#### 6 EFFECT OF UPSTREAM FLOW CONDITIONS

The inflow conditions are not always ideal so it is useful to know what error is introduced by insufficient straight inflow length. Various tests and Computational Fluid Dynamics (CFD) analysis have been done to investigate the affect of upstream flow conditions on the accuracy of Clamp-on flow meters.



Fig. 13 - Measurement Errors for Various Inflow Conditions

As gases and liquids are physically both fluids, the results achieved with water can, to a certain degree, be transferred to gas flow as long as the Reynolds number in both cases are identical. Fig. 13 shows the measurement error to be expected after three different disturbances, a 90° bend, a double bend out of plane and a reducer.

The curves are calculated based on flow profiles measured by a Laser Doppler Anemometer (LDA) on water flow. Additionally, a CFD based curve is shown for the double bend out of plane. In all cases the effect of the disturbances is a negative error. This is typical and due to the fact that most disturbances cause the flow profile to be flatter than the ideal fully developed turbulent flow profile.

The curves of the double bend show an oscillation caused by the swirl it produces. The CFD result does not show exactly the same shape but approximately the same magnitude of error as the result based on the LDA measurement.



Fig. 14 - Piping for Test after 90° Bends

It can be seen that for both the reducer and the 90° elbow after 10D the error is below 3%. With the double bend out of plane 20D is required.

Also various tests in gas flow calibration labs have been performed to investigate Clamp-on flow meters. KEMA (Gasunie Engineering & Technology before 01 July 2009) has carried out a test program of an ultrasonic clamp-on flow meter (manufacturer FLEXIM) in April 2009 at the request of Gasunie, in order to investigate if this meter is suitable for process purposes (not for fiscal metering) in high pressure gas transport systems.



Fig. 15 - Effect of Swirl

Part of that program was to test the meters performance under non ideal inflow conditions. The results are published in [3].

A very common disturbance is a 90° bend, or two or more bends in succession. This situation was provided by the setup shown in Fig. 14. A first bend was followed by a second bend in the same plane at 18D after the first bend. A calibration was done at 10D after the first bend and at 10D after the second bend. The results are shown in Fig. 16 compared to the results at a reference position with 17D of straight run. The transducers where set up in a reflecting configuration as shown in Fig. 2.

Two pairs of transducers where used, but the results were recorded separately to see the advantage of using two pairs versus only one pair. The results after the first bend are 1 to 2% below the results at the reference location. After the second bend the results are about 1% higher than at the reference location. A single 90° bend typically causes the meter to under read. The over reading after the second bend may be an effect of the combination of the two bends.



Fig. 16 - Effect of 90° Bends

A double bend out of plane is known to produce swirl, therefore a swirl generator was used to simulate this effect. The swirl is produced by means of two plates in which the mutual angle can be adjusted in the range of 0° to 25°. The maximum angle of 25° is considered extreme and would not normally occur in practice. The tests where carried out at 17D and 18D, two locations close to each other because flow profile with swirl changes rapidly along the pipe. The results are shown in Fig. 15.

The impact of the swirl is just 1%, even with extreme swirl angles. This shows that the main effect of the swirl is non axial flow, the impact of which on the measurement is compensated for by the reflecting path configuration.

# 7 EFFECT OF PRESSURE REDUCER (VALVE NOISE)

The meter was tested in a configuration where the transducers were mounted 12 diameters downstream of a 'silent' Baai pressure regulator (type R100), which reduced the pressure of the gas from 40 bar to 9 bar(a). As a consequence of the (audible) silent operation, noise frequencies are shifted into the ultrasonic range, which (at this relatively high reduction in pressure) might disturb the proper working of an ultrasonic flow meter (known from practical experience with this pressure regulator at the KEMA flow laboratory, Groningen).



Fig. 17 - Pressure Regulator in front of Clamp-on Flow Meter

The Baai pressure regulator is shown in Fig. 17 and the test results shown in Fig. 18.



Fig. 18 - Valve Noise Results

The clamp-on ultrasonic meter performed well during these tests which may be as a result of the transducers working in the 500kHz range. The red and orange lines are from the reference metering locations with the blue trace showing the response of one pair of transducers and the purple with two pairs working in a dual path operation.

The single pair of transducers exhibited a 1% downwards shift, but it should be noted that the Baai regulator can be considered a large disturbance in flow and with the metering location only 12D from the valve, flow profile effects are expected to be seen. The performance of the two path arrangement was <0.6%. A typical valve noise distribution curve is shown in Fig. 19.





# 8 WET GAS METERING FIELD TRIAL

Field trials for wet gas metering took place offshore in the North Sea. All test locations had approximately the following parameters: -

- Pipe Size: 4 inch
- Material: DUPLEX steel
- Wall thickness: 13.5mm
- Temperature: 45°C
- Medium: Natural gas
- Pressure: 102bar
- Velocity: 6.5m/s
- Liquid flow: 583l/hr
- Gas flow: 190m3/hr
- LVF: 0.3%

Test measurement point 1 can be seen in Fig 20 which has a choke valve controlling the gas flow. Immediately after exiting the valve the flow goes through one  $90^{\circ}$  bend and two  $45^{\circ}$  bends which can be seen directly in front of the metering point.



# Fig 20: Platform under test in North Sea

Test results show that the degree of turbulence created by the various disturbances was so high that the ultrasonic clamp-on gas meter was unable to perform continuously.



Fig 21: Test results from metering point 1

The blue trace in Fig 21shows the flow rate in  $m^3$ /hr which shows a high standard deviation due to the high degree of turbulence. The high turbulence is also visible in the high amplitude variation, the black trace, which is about 13%. The green and grey traces in Fig 21 are the two Signal to Noise ratios SCNR and SNR (see Table 2), which are low at 20dB 10dB, respectively.



Fig 22: Test results from metering point 2

Test measurement point 2 in Fig 22 is now 10 metres downstream of the choke valve. The piping arrangement is somewhat more favourable with one  $90^{\circ}$  bend, six  $45^{\circ}$  bends and a final  $90^{\circ}$  bend about 10D before the measurement location.



Fig 23: Test results from metering point 2

The results recorded at metering point 2 are shown in Fig 23 and indicate that the meter is working well. The SCNR remains comfortably above 20dB with a mean of 27dB and as such enables the meter to perform correctly. The standard deviation of the volume flow rate is much lower than at metering point 1 (see Table 1).

	Metering Point 1		Metering Point 2	
Parameter	Mean	Std. Dev	Mean	Std. Dev
Flow Rate (m <sup>3</sup> /hr)	183.13	7.6	211.16	0.51
SCNR (dB)	20	0.8	27	0.9
SNR (dB)	9	0.6	21	0.6
Amplitude variation[%]	12.7	0.6	7.1	0.26

 Table 2 - Parameters of the metering locations

SCNR (dB) - Signal to Correlated Noise Ratio (FLEXIM Specific) - The noise here (the pipe signal) is correlated to the signal because both signal and noise are generated by the same source. This noise cannot be filtered and can only be reduced by acoustical means. The use of damping materials and transducer design are used to reduce this noise including matching the transducers to the pipe (selecting the right transducers).

SNR (dB) - Signal to Noise Ratio - The noise in this context is random with respect to the signal. It can be filtered and further reduced by signal processing (as long as the remaining noise is not so strong that the signal cannot be detected) and does not affect the long term average of the measurement result. The only effect is an increased standard deviation. Potential random noise sources are electrical sources like variable frequency drives and acoustical sources like regulating valves.

### 9 CONCLUSIONS

The clamp-on USFM of today has been designed to meet the demands of wet gas measurement by utilising state-of-the-art technology and having an understanding of the needs of operators. They are easy to install and troubleshoot because they are mounted on the outside of a pipe, but they also address the technical challenges of wet gas measurement.

Increasing pipe wall sizes to accommodate increases in pressures has to be met by the instrumentation industry. The clamp-on USFM can utilise two modes of transducers, these being shear and Lamb wave. Each has its own advantages, but it allows the flow meter to work with a virtually limitless upper pipe wall thickness.

The wet gas testing showed that the meters were able to measure throughout the whole range of LVF up to 5%. The tests also showed that a substantial amount of liquid can gather at the bottom of the pipe even at an LVF below 5% due to the fact that the liquid usually flows much slower than the gas at low flows.

Signal loss can be avoided by using a horizontal path configuration to ensure that the ultrasound paths are not interrupted by the higher liquid levels.

Through these test results it was possible to quantify the signal attenuation at the mist state of flow which occurs at high flow velocities. This can be used to estimate the application range of the meter in terms of moisture content.

The effect of pressure change on the clamp-on meter can be calculated from the acoustic impedance of the gas. This makes it possible to verify the application range regarding pressure after the meter has been installed.

The testing on upstream disturbances shows that USFM meters are capable of maintaining accuracy as long as good installation practices are followed. Single and double bends, both in and out of plane can have their effects reduced to errors under -2 to -3%.

The effect of valve noise can be significantly reduced by the selection of higher frequency transducers which take the USFM away from the frequency range generated by the valve. To eliminate flow errors caused by the valves influence on the flow profile, the straight run lengths and distance from the valve should be considered.

In real world installations, careful consideration needs to be given to the installation location of the ultrasonic meter because the degree of turbulence can be so high that the signal quality is decreased below an acceptable level. The diagnostics can be used to ensure that the SCNR is sufficiently high to ensure that the USFM is located in the best installation location possible.

The question of reliability has had to be addressed, and clamp-on USFM's have had to adapt to meet this demand. The use of solid transducer to pipe coupling material has not only made these devices almost maintenance free, but has made them a reliable and dependable alternative to wetted systems.

# 10 LITERATURE

- B. Funck. Ultraschall Clamp-on-Gasdurchflussmessung in der Nähe der Einsatzgrenzen. 5. KÖTTER Workshop Gasmengenmessung, Rheine, Germany, März 2010
- [2] ASME technical report MFC-19G-2008, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, New York, New York.
- [3] G. J. van Essen. Testing the performance of an ultrasonic clamp-on flow meter. 9th South East Asia Hydrocarbon Flow Measurement Workshop, March 2010