Flare Gas Metering: Minimizing Surprises

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Introduction

Flow measurement of flare gases is a challenging task and the collected data from the installed flow meters frequently surprises the users. The unexpected results stimulate investigations on the influence of flow profile and conclusions on applicability of some flow metering methods versus the others. Today, small flaring operations sacrifice performance and quality, to the convenience and lower prices when it comes to meter selection.

During a presentation at the 2013 Gas Processing Association's Annual Convention (GPA), it was questioned whether or not the conventional transit-time single path ultrasonic gas flow meters are suitable for flare gas measurement[1]. It was concluded that they were highly inaccurate in bent pipes and multi-point pitot tube systems were suggested to be more suitable for the flare gas metering. That unexpected conclusion can leave users without the technology which underwent detailed scrutinies unlike any other flow measuring techniques (pipe roughness effect, deposition on transducers, etc..), even though all of the commercially available ultrasonic flow meters have been studied for installation effects right at the beginning of their development. Nonetheless, the technology, since its inception, has been considered as the best methodology for flare metering[2,3].

Other swings in flare metering techniques are the growing promotions of the thermal dispersion flow meters to be particularly advantageous for flare and vent gas measurements[4,5]. Almost as inexpensive as the pitot tube, the thermal probe just needs to be inserted in the pipe through a single port to get the accurate flow recording of the flaring gas. As simple as it may appear, however, the probe will render surprising results as soon composition of the flare gas is changes.

This article presents our experimental results on applicability of low-cost flow meters for flare gas measurement. In addition, we also review the limitations of the conventional ultrasonic transit-time flow meters which are currently used for flare metering applications. In parallel, we present information on performance of ultrasonic transit-phase flow meters by providing our collected experimental data.

1. Attributes of Flare Gas

Being a 40-billion dollar annual energy waste flare gas measurement became a necessity, in turn, giving rise to certain specific attributes associated with flare gas meters. They are:

Low gas velocity (under normal operation) – flare gas is a waste and waste needs to be minimized as much as possible. Canadian regulations require continuous measurement of flare gas at production and processing facilities where annual average total flared and vented volumes per facility exceed 500m3/day. This flow rate translates into gas velocity of 0.08m/s for a flare pipe of 12" diameter.

Very high gas velocity (under abnormal conditions) – during an emergency or a blow down event, some flare systems are designed to handle gas flow above 130m/s in order to pass flows of several MMSCFD.

Varying transition state– may jump from normal to abnormal, with periods as short as a few minutes.

Minimum or no Flow Obstruction – to secure high flow rates during the blow down bursts.

Low pressure - typically atmospheric (slightly negative to slightly positive).

Varying chemical composition - depending on flow regime, the flare gas may periodically include the liquid carry over from knock out drums, vapour, etc.

This leaves very little opportunity for pitot tube meters due to their limited turndown ratio, of less than 10:1, and their sensitivity to liquids and dirt.

2. Thermal Dispersion Flow Meters

2.1. Gas Composition Effect

Thermal dispersion mass flow meters are produced in large quantities by a number of producers and gained a good reputation for measurement of clean gases. Their applicability for flare and vent gas metering, however, is not as straightforward as it is frequently thought to be. The basis of the thermal dispersion mass metering, the "hot wire anemometry" includes, besides velocity, a thermal property of the moving media. This is the fundamental birthmark of thermal mass flow meters similarly to other flow metering techniques. The pressure drop in differential pressure (DP) flow meters, for instance, besides velocities, depends on the size of the orifice and the density of the fluid. Increasing the number of temperature sensors does not actually introduce a new paradigm to this technology. It is equivalent to the splitting of a large orifice in the DP flow meter into a number of small ones but without knowing its actual size. Evidently this does not solve the gas composition effect problem without having to perform a recalibration in the correct medium.

One of the thermal mass flow meter producers has recently acknowledged this fundamental drawback in a patent application.[6] A test carried on by the manufacturer showed that adding only 1.6% of water mist to the air flow caused the flow meter to read 14 times too high. Such an error of 1400% is a "no go" for measurement of flare gases by dispersion thermal mass flow meters since gas wetness can be changed unpredictably due to moisture, carry-over from knock out drums, emergency blow out and many other factors. Adding a swirler in front of the heated contact to dry out the gas by centrifuging the moisture may look like an attractive idea, however, its practical merit is questionable. The swirler will add another uncertainty to the measurement caused by the local flow disturbance which will be dependent on gas velocity, pipe diameter, size of droplets, etc. Fig.1 shows the effect of water mist content in the air on reading of the thermal mass flow. The experimental setup included a 6" horizontal pipe, a blower and a reference meter (set for air velocity of 2.5m/s). The mist was generated by two ultrasonic atomizers, one to produce an average particle size of 2µ and another 40µm.

The water mass flow fraction was 1.1%. The test was set to indicate the difference in readings based on the size of the water droplets. The difference in total readings increased 9.6 times for smaller particles and 7.2 times for larger particles. There are two possible reasons for this to have had occurred, due to the low speeds and perhaps the gravitation effect.

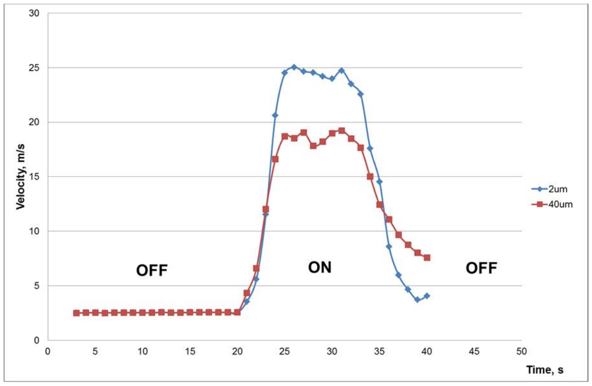

Fig.1. Thermal mass meter output in dry air (water mist OFF) and wet air (water mist ON, average diameter of droplets 2µm and 40µm, water mass flow rate 1.1%).

2.2. Fouling Effect

The heat transfer to and from a thermal mass flow meter senor is influenced by the interface between the sensor’s contact area and the moving gas. Covering the contact area with liquid hydrocarbons and soot reduces the heat transfer and changes the reading of the thermal mass flow meter; something that the meter manufacturers are reluctant to mention in their specifications.

A manual authorized by the founder of one of the thermal mass flow meter manufacturer teaches that users will be experiencing the fouling effect and in order to minimize the error they are advised to wait for one or two weeks until the coating will finally built up and the readings are stabilized.[7] This, however, does not resolve the problem as it is not known at which point the coating has stopped, i.e. there is no data on real flow measurement as the meter was calibrated prior to be coated with the coal dust, oil, etc. Also, the advised term of “the slight amount of residue coating” is fairly undefined value and is highly site specific.

To investigate the influence of the coating on thermal mass meter , we performed the following fouling effect test. A clean thermal mass meter was placed at the center of 7.5m long 6” diameter pipe. The upstream and downstream distances were 30D and 20D, respectively. The air flow was provided by the blower and the flow rate was set to 1.0 m/s using a calibrated orifice meter. The test was conducted in normal lab conditions (temperature +18.5C, humidity 75%). The data was recorded every second for one hour.

The test with the clean probe showed a steady offset of approximately 1.5% which was within the manufacturers specifications of the device.

The same meter covered with a thin layer of the synthetic motor oil (10W30) behaved very differently (Fig.2). The measurements showed an offset of 55% higher at the start of the test; the offset then dropped to approximately 37% after 15 min and remained unchanged afterwards. One may expect that the visible change in readings were due to reduced coating thickness as a result of gravity and/or the initial oil drying. The above experimental results show that the sensitivity of the thermal mass flow meter is highly dependent on the liquid substances within the flare lines.

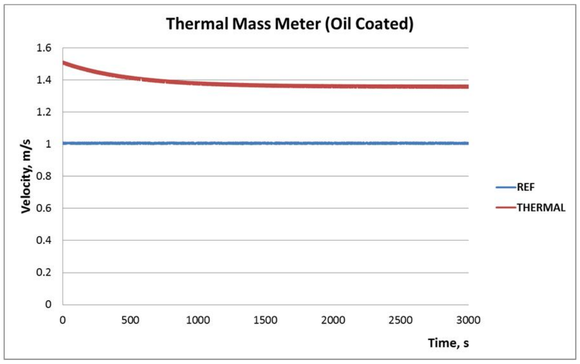

Fig.2. Test 1: Reading from thermal mass meter coated with synthetic motor oil

During our second fouling effect test, we used black grease (see below) and did not utilize the thermal mass meter, as it showed a fault at zero air velocity and the shift was unresolvable by the regular zeroing procedure.

3. Conventional Ultrasonic Gas Flow Meters

3.1. Low Velocity Operation

Conventional transit-time ultrasonic gas flow meters (UFGM) have established themselves as meters of choice for flare gas measurement. None of the other flow metering technologies (except, perhaps, optical meters[8]) can offer a turn down ratio in excess of 2000:1. The minimum gas velocity for ultrasonic gas flow meters is claimed to be 0.03m/s or 0.1ft/s which complies with the emission control regulations for refinery flares first adopted in California in 1998.

All three most active ultrasonic flare gas meter manufacturers advertise their meters' accuracy as being ±2.5% to ±5.0% over the entire velocity range. However, non-commercial presentations disclose that this has not been achieved yet for low velocities.[9] In particular, the ultrasonic flow meter at zero flow recorded velocity ranging from -0.3 to 0.3m/s in a 60" low pressure flare line.

This effect is induced by cross flow / vertical eddies due to thermal convection in large pipes (Fig.3).

This thermal gradient in the pipe introduces the gas convection. In addition to the axial gas flow with velocity V_{gas}, the gas is getting a vertical convection velocity component V_{conv} which rises with the increase in pipe diameter and the temperature difference between the top and bottom of the pipe.

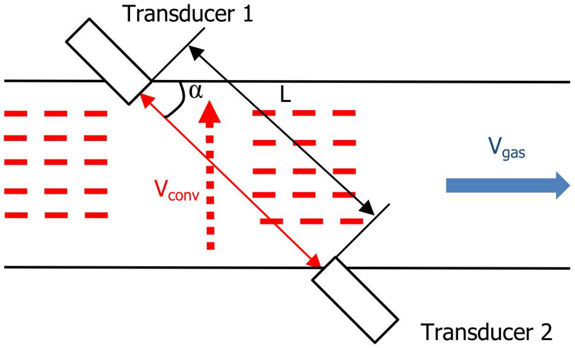

Fig.3. Illustration of thermal convection effect at low velocity measurement

The vertical components contributes to the measured time difference along and against the gas flow due to effect of the velocity projection on the path L:

$$V_{conv}\sin(\propto)$$

where α is the angle between the ultrasonic path and the pipe.

Axial placement of the transducers eliminates the influence of the cross flow. Also, this will allow increase in axial distance L between the transducers without being limited by pipe diameter (Fig.4). The distance L actually contributes directly to minimum velocity level in transit-time ultrasonic flow meters. However, while this solution may be helpful at low gas velocities, it will limit the high velocity V_{max} due to additional turbulence generated at the transducer holders (Fig.4).[10]

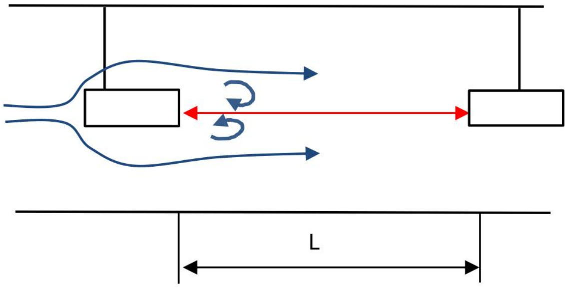

Fig.4. Axial location of transducers improves V_{min} but reduces V_{max} due to additional turbulence

3.2. High Velocity Operation

During the blow-out event, velocity of the flaring gas may exceed 100 m/s. Some operators in British Columbia and Alberta require a maximum velocity measurement up to 150m/s based on P&ID calculations.

High gas velocity influences the conventional UFGM in a variety of ways. The sound coming from the emitter is blown away thus reducing the signal strength on the receiver (Fig.5).

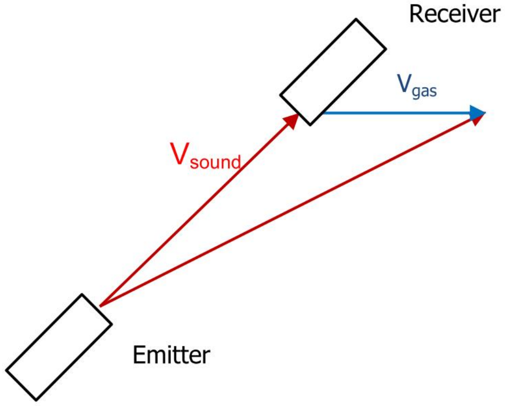

Fig.5. Sound blown away at high gas velocity V_{gas} reducing signal level at the receiver

Using transducers with a broader diaphragm can mitigate this effect. However, emitting the sound at a wider angle proportionally reduces the signal strength.

Alternatively, transducers can be oriented against the gas flow as illustrated in Fig.6.

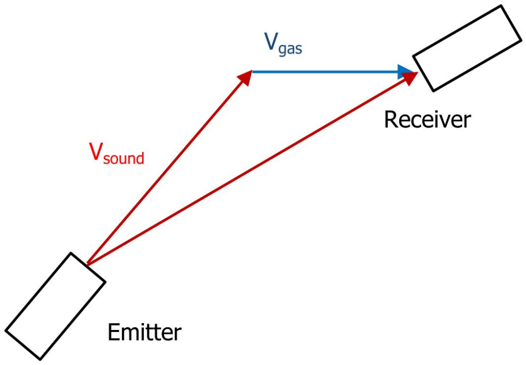

Fig.6. Orientation of transducers against the gas flow to minimize the blow away effect

Such arrangement, however, will sacrifice the V_{min} at low gas velocity due to reduced signal-to-noise level.

Turbulence induces the cross-flow velocity in the pipe as described by Rans[11] (Fig.8). This sporadically changes the upstream and downstream timing intervals and increases the measurement error.

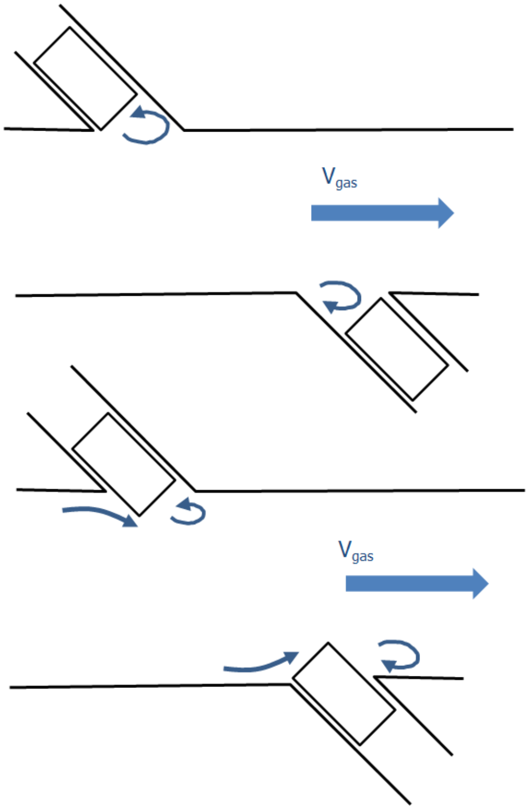

Fig.7. Turbulence caused by angular placement of transducers in transit-time method

The effect is further enhanced by increasing the path length and changing the ultrasonic ray trace path.[12,13]

Orientating transducers at an angle α, in the transit-time method, introduces pockets or protrusions in the pipe which become a source for additional turbulence at gas velocities exceeding 20 m/s (Fig.7)

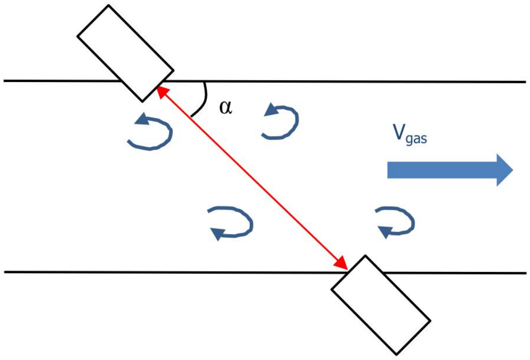

Fig.8. Cross flow caused by turbulence

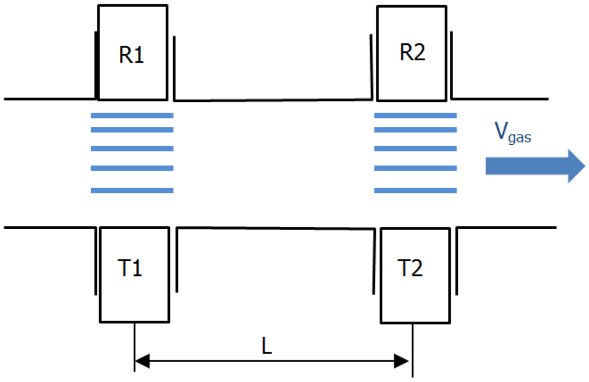

Fig.9. Schematic of transit-phase ultrasonic flow meter

4. Lauris Technologies Inc. Solutions

Lauris Technologies Inc. is focused on non-fiscal gas flow measurements which have proven to be a challenge for conventional ultrasonic and other flow metering techniques. Applications include flow measurements of:

- Flare gas in small to large flare pipes, diameters from 0.15 m to 1.0 m (6” to 40”);
- Flue gas in medium and large flare stacks, diameters from 0.9 m to 15.0 m (3 to 45ft) ;
- Associated gas in separators and production pipes, diameters from 50 mm to 150 mm (2” to 6”);
- Vent gas and casing gas, pipe diameters from 15 mm to 50mm (0.5” to 2.0”);
- Shale gas while drilling and well completion, pipe diameters from 100 mm to 200mm (4” to 8”).

4.1. Transit-Phase Measurement

Lauris Technologies Inc. flare gas flow meters, for small to large flare pipes, are based on transit-phase measurement as illustrated in Fig.9.

The transit-phase UGFM includes at least two pairs of ultrasonic transducers located at the opposite sides of the pipe wall and are displaced from each other at a distance L. Each pair consists of a transmitter (T) and a receiver (R). Transmitters and receivers are mounted flush with the pipe wall and transilluminate the pipe perpendicularly to the gas flow. The phase shift between signals in two pairs is recorded by the signal processing module and is proportional to flow velocity V_{gas}.

Transmitters and receivers can face each other (Fig.10, a) or be arranged in a reflective mode (Fig.10, b) which increases the ultrasonic beam path and, therefore, the accumulated phase.

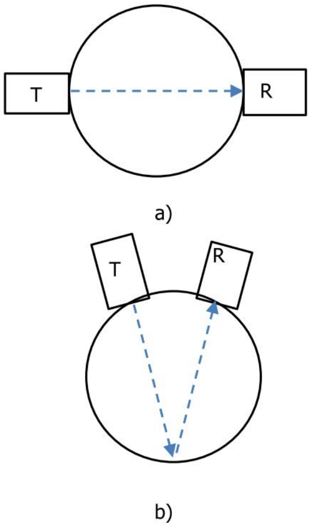

Fig.10. Transducer location: direct (a), mirror (b)

The reflective or mirror arrangement is sometimes beneficial in pipes with smaller ID. This design, however, may limit the maximum velocity V_{max} as transducers cannot be placed exactly flush with the pipe wall.

Fig.11. Flow meter FC1221-6

Fig.11 shows the picture of the flanged version of the transit-phase flow meter, model FC1221-6 with 6” bore to fit into Schedule 40 piping and ANSI #150 flanges.

4.2. Minimum Velocity

The minimum velocity V_{min} provided by the transit-phase method is not influenced by the presence of the uncontrolled eddies and cross-flows but by the lack of phase changes in the ultrasonic pulse. An ideal laminar flow provides no changes to the phase of the ultrasound signal and, therefore, cannot be measured by this method. The value of V_{min} can be calculated through Reynolds number at the border of the laminar flow regime (Re=2000) as

$$V_{min} = \frac{\mu\, 2000}{D\rho}$$

where μ is the dynamic viscosity of the gas; D is the pipe diameter, and ρ is the gas density.

The real value of the minimum velocity is lower than the calculated one due to pipe roughness, turbulence generation on flanges and weldolets, pipe vibration, etc. Eddies and cross-flows in large pipes also positively contribute to minimizing the V_{min}. We found that the actual value of V_{min} in a straight long pipe is about 25% lower than the calculated one. Pipe bends, joints, elbows and other attributes of the real piping system further reduce the V_{min}. For instance, the minimum air velocity is lowered from 0.18 m/s to 0.05 m/s in a 6” pipe if the flow meter is installed at a distance of 10D after the 90-degree elbow.

The V_{min} can be further reduced by inducing a turbulent flow using mechanical or thermal turbulators. This way, the V_{min} can be lowered to 1cm/s in a pipe with a diameter of only few inches. One should note though, that mechanical turbulators will limit the maximum velocity due to the increased flow resistance and creation of periodic density oscillations based on the Karman effect. The latter introduces signal ambiguity, thus, making an exact phase measurement difficult.

4.3. Maximum Velocity

The above V_{max} limiting factors, in transit-time UGFM, are not applicable to flow meters based on a transit-phase method. The method actually operates on the opposite principle, “the higher the flow abnormality, the better the signal”. The blow-away effect is also minimal as ultrasonic beams are directed perpendicularly to the flow making the exact value of V_{max} very difficult to determine. These values have to be established experimentally. This becomes quite challenging due to the large amount of flow required for pipes above 12” in diameter and velocities above 100 m/s. The following initial test for verifying the upper velocity limit was carried out at our facility (Fig.11).

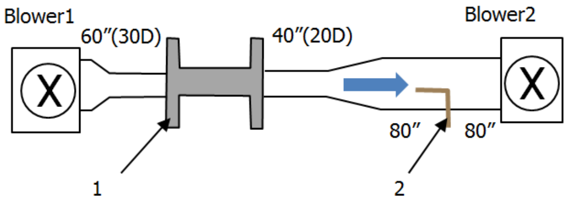

Fig.11. Schematic of 2” setup for testing FC1221 at maximum velocity.
1- flow meter FC1221-2; 2- pitot tube

A small pipe flow meter, FC1221-2 (ID 2”, beam spacing 30mm) was installed in a 2” air blowing setup which included a 30D upstream and 20D downstream piping, and an upstream blower (Blower 1). Using a 20” long pipe expansion, 2” piping was expanded in to a 4” pipe. The 4” pipe was 160” long, and a pitot tube installed in the middle thus providing 20D upstream and 20D downstream for the reference flow metering. A second blower (Blower 2) was installed at the end of the 4” piping. The conversion factor of four (x4) was used for calculating velocity through the FC1221-2 meter section of the pipe, ignoring the air compressibility since the pressure change across the 2” section was low. The signal averaging was set to a fixed value of 1s, as the FC1221 normally automatically reduces the velocity averaging.

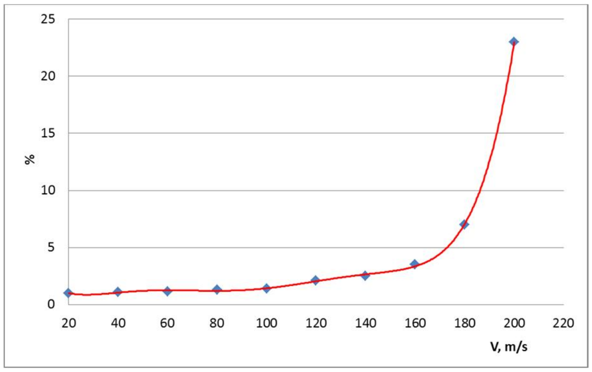

Fig.12. Velocity uncertainty (2σ) as function of velocity

Data presented in Fig.12 indicates that from the error limit of 5%, the FC1221-2 was able to measure air flow up to 170 m/s. The 10% limit allowed for measurement of flow up to 190 m/s.

If required, the V_{max} can be further increased by signal filtering and flow straightening using longer pipes and smoothening the joints.. Positioning of the transducers in the pipe further influences the velocity uncertainty at speeds of above 120 m/s. A slight protrusion of the transducer in to the pipe, reduces the V_{max} due to phase change in the close proximity to the transducer. Furthermore, in a 2” pipe, the axial displacement of the transducer of 1 mm increases the velocity uncertainty by a factor of three (3), thus further reducing the V_{max} below 100 m/s; this effect is reduced with the increase in pipe’s OD.

4.4. Installation Effects

The effects from a bent pipe were tested in the 6” PVC SCH 40 pipe, which included a 22D upstream section and a 20D downstream section. For this test we used our FH1223-6 meter (ANSI 150 flange, 500 mm meter body, 120 mm beam spacing) operating in a transit-phase mode. A set of three orifice meters was used for reference velocity measurement covering the velocity range from 0.2 to 25 m/s.

Six tests were carried out with a single 90-degree elbow at three locations, 10D, 4D and 2D and in two orientations, in plane with ultrasonic paths and perpendicular to ultrasonic paths. The straight spool of the pipe before the elbow was 12D. In addition, we also carried out three tests with two 90-degree elbows out of plane with location of the first elbow at 10D, 4D and 2D and the distance between elbows of 4D. First elbow was oriented in plane with the ultrasonic wave path. The straight pipe before the second elbow was 12D.

The velocity offset, straight pipe vs. bent pipe, was then recorded. The test data is presented in Fig.13 to Fig.16

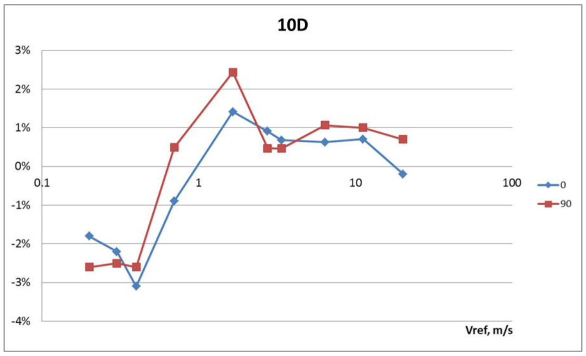

Fig.13. Single elbow placed at 10D, (0 – in plane with beams, 90 – perpendicular to beams)

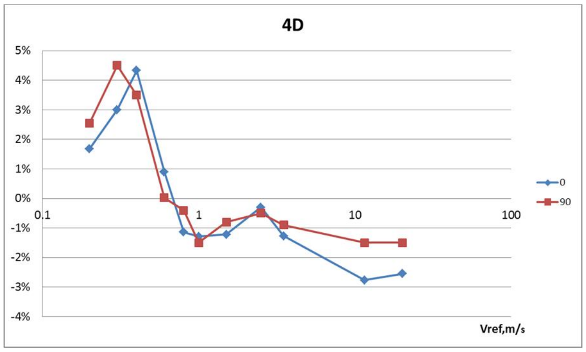

Fig.14. Single elbow placed at 4D, (0 – in plane with beams, 90 – perpendicular to beams)

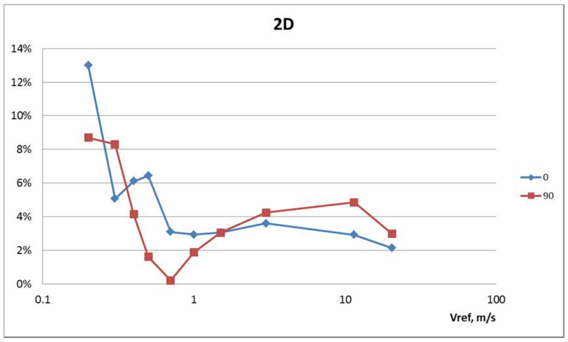

Fig.15. Single elbow placed at 2D, (0 – in plane with beams, 90 – perpendicular to beams)

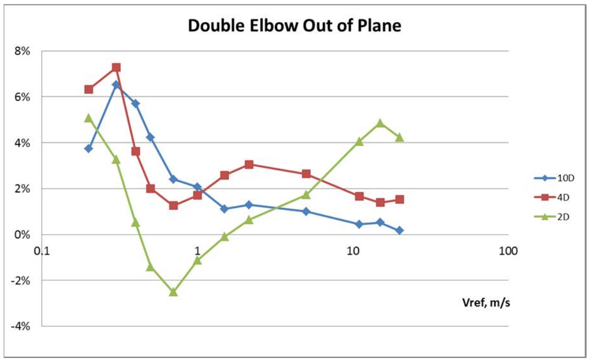

Fig.16. Two elbows out of plane. Locations of first elbow: 10D; 4D and 2D, distance between elbows 4D, straight pipe upstream of second elbow 12D

The data above indicates:

1) The behavior of installation curves in transit-phase UGFM is different from transit-time UGFM
2) Installation of the meter up to 4D from a single 90-degree elbow does not introduce the offset exceeding 5%;
3) A very short upstream pipe (2D) may lead to offset exceeding 10% at low velocities below 0.5 m/s
4) In plane or perpendicular orientation of the elbow against the ultrasonic paths does not significantly influence the error;
5) Presence of the second elbow out of plane does not drastically change the offset, it is slightly creased at low velocities but acts similarly to a single elbow above 1 m/s

4.5. Fouling Effects

The fouling effect test was carried out in parallel to the thermal mass meter described above. The regular FC1223 meter, model FC1223-6 (ID of meter body 6”, spacing between transducers 120mm) was placed in the setup 10D upstream from the thermal mass meter.

During the first test, the meter body and the transducers were coated with synthetic oil from the inside. The air flow test was then performed similarly to that of the thermal mass meter. The FC1223 meter recorded no air velocity changes, before or after the coating.

During the second test, the flow meter body and the transducers were internally covered with the black Motor Master grease (Moly Extreme). The internal surface of the meter is shown in Fig.17 and Fig.18.

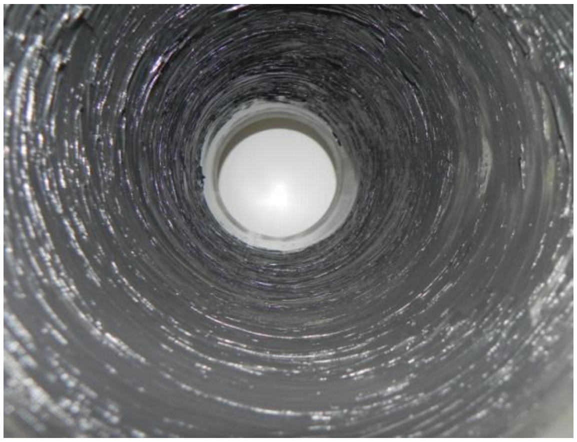

Fig.17. Meter body covered with black grease

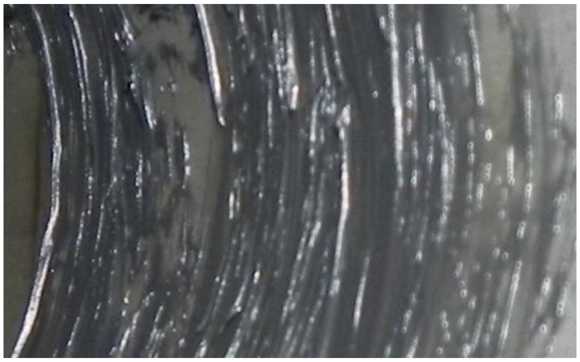

Fig.18. Closer view, transducers are fully covered with grease

The results showed that the 1mm thick layer of heavy grease did not inlfuence the performance of the FC1223-6 meter as can be seen on Fig.19.

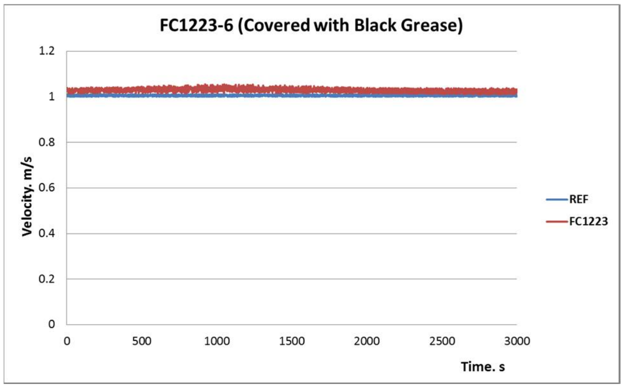

Fig.19. FC1223-6 meter with transducers covered with a heavy black grease

Signals levels measured in both channels during each of the tests and their mean velocities over one hour are presented in the table below:

	Signal, V		Mean Velocity, m/s	
	Channel 1	Channel 2	Reference	FC1223-6
Test 1, Dry	0.75	0.80	1.010	1.025
Test 2, Oil	0.78	0.79	1.015	1.020
Test 3, Grease	0.79	0.76	1.012	1.028

The data indicates that the fouling effect was not present and that the performance of the ultrasonic gas flow meter FC1223-6 was not decreased. Signal level in one of the channels reduced by 5%, while being covered in grease, while it increased by 5% in another channel.

The thermal mass meter was not functioning after being covered with the same layer of black grease. Most likely other flare metering techniques, including multi-point pitot tube, will not operate in such severe conditions such as in the one shown above in Fig.17.

5. Cost of ownership

5.1. Selling Price

For a long time now the high price of the ultrasonic gas flare meters has been the main obstacle for supporters of the substantially cheaper differential pressure and thermal mass meters. The price of the industrial thermal mass flow meters has dropped by more than a half over the last decade due to competition and they are offered for as low as $4,500 . However, manufacturers of ultrasonic flare gas flow meters kept their prices unchanged and currently such meters are about 10 times the cost of the thermal mass flow meters.

5.2. Installation Cost

Flare gas flow meters are commonly installed in a retractable form using ball valves which are mounted on to the flare pipes through NPT threadolets. Welding of the two threadolets for one pair of transit-time transducers represents an additional overhead cost, in comparison to a single port which is sufficient for the thermal mass meter. The labor (drilling the pipe and welding the threadolet) contributes mainly to the cost which may end up in several hundred dollars. Hot-tap installation could be a few times higher than that. The FC1223 flow meter has four transducers, consequently four ports are required.

5.3. Maintenance Cost

The maintenance cost varies, it depends on the operation type, the site location, the service organization, the local and national regulations etc. This aspect can be further investigated in details with the possible outcome of many thousands of dollars required annually for inspection and cleaning of the meters.

5.4. Cost of Meter Non-Performance

Small operations such as oil batteries in Alberta produce tens of thousands tons of CO_2 annually, gas processing plants in British Columbia (BC) emit from 50,000 to 100,000 tons of CO_2.[14] That is still a fraction from what any oil refinery is producing. A flare gas meter installed in the gas producing province of British Columbia which reports, for example, a 50% higher flow rate due to the presence of moisture in the flaring gas, costs its user more than $500,000 by over reading the flow (carbon tax in BC was $21 per one ton of CO_2 in 2012). That is why oil & gas processing facilities in BC are equipped with expensive yet performing flare gas flow meters. Cheap flare meters are prohibitively expensive to own.

The take away from the above:

1. There is no alternative to ultrasonic flow meters when it comes to for measuring flare gases. The transit-phase method minimizes the installation effect and allows flow measurement in short bended pipes.

2. Thermal mass meters, in general, are not suitable for flare gas metering due to fundamental effect of gas composition of probe contamination with deposits.

3. Pitot tubes have limited range; multipoint pitot tubes will present significant flow obstruction.

4. Users should make a decision on whether to save on buying cheap flare gas meters and get penalized by their maintenance and non-performance cost or to install ultrasonic flow meters which do the job.

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