NUMERICAL INVESTIGATION OF FLARE GAS FLOW CONDITIONS AT METERING SECTION

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Abstract. *It is presented an early study aiming to investigate instalation effects in gas flow, especially those related to flare gas metering on offshore oil platforms. Velocities profiles are simulated by numerical techniques avalible at* CFX^{TM} *computational suite for a actual assembly and the results are commented. It is compared the velocity profiles considering two turbulence models: k-ε and RNG.*

Keywords: *ultrasonic flow meter, flare gas metering, installation effects*

1. INTRODUCTION

The motivation of present work appeared with publication of Portaria Conjunta ANP/INMETRO n^{o}. 1 (2000), a federal regulation which imposes new challenges for Brazilian companies and institutions which deals with flow metering, especially those users of new technologies, as ultrasonic flow meters – UFM´s. That regulatory mark described, for the first time in Brazil, the conditions and proceedings for operational and fiscal metering of hydrocarbons flows as well as included the utilization of ultrasonic flow meter as a legal and accredited technology for such measurements.

On the other side, the publication of American Gas Association – AGA report no. 9 (1998) diffused information about basic features of ultrasonic technology for gas flow measurement. On those times, AGA-9 text admitted that ultrasonic technology applied to flow metering was still in early stages and suggested that more studies were needed in order to define, with confidence, many features about UFM´s like installation effects, necessity of straight tubes, noise treatments, quality of the velocity profile at metering section, gas composition influence, etc.

Technological and scientific community answered this challenge with a large number of dedicated conferences and articles about such features effects, like were made by Eren (1998), Lansing (2000, 2002, 2004), Ruppel and Peters (2004) and Raisutis (2006) among others.

Due to such efforts, the utilization of ultrasonic flow meters for natural gas applications has grown significantly. Nowadays, virtually every oil company is using such technology, either for custody transfer or operational monitoring. Some benefits of this technology include the following:

- Accuracy: the meters can be calibrated to an uncertainty of less than 0.3%;
- Large turndown: typically more than 50:1 (orifice plates offer typical turndowns around 3:1 and turbines 20:1);
- Tolerant to wet gas;
- Non-intrusive: do not cause pressure drop;
- Low maintenance: there are no moving parts;
- Self-diagnostics: data for determine meter’s health is available.

Mylvaganan (1989) and Folkestad and Mylvaganan (1989, 1993) developed their works dedicated specifically to ultrasonic flow measurement developments applied to flare applications, including an extensive study about ultrasonic signals treatment in order to surpass noise problems due to turbulence at high velocities as well as high uncertainties at low flows.

2. ULTRASONIC METER BASICS

Ultrasonic meters are velocity meters by nature. That is, they measure the gas velocity within the meter body. By knowing the velocity and the cross-sectional area, volume flow can be computed.

The basic construction of an ultrasonic flow meter is relatively simple as shown in Fig. 1.

The fundamental of ultrasonic meter depends on precise knowledge of the transit time of an ultrasonic pulse traveling with the flow from transducer A to transducer B (t_{AB}). When this measurement is completed, a new pulse is launched from transducer B to A, now against the flow, and this traveling time can be determined (t_{BA}). The transit time of the signal traveling downstream is shorter than the upstream signal time.

Once the traveling times are known, downstream and upstream signal velocities (v_{AB} and v_{BA}, respectively) can be determined by Eqs. (1) and (2).

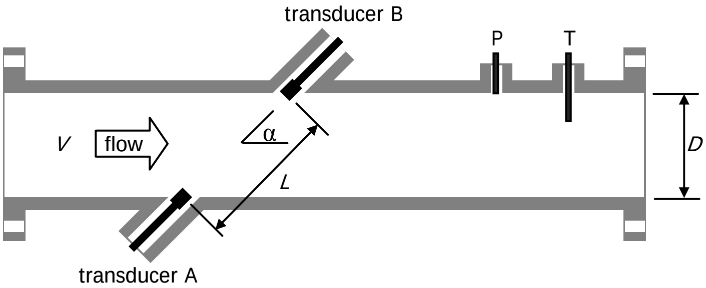


Figure 1. Ultrasonic meter scheme and basic dimensions

$$v_{AB} = \frac{L}{t_{AB}} = c + V\,cos\,\alpha \tag{1}$$

$$v_{BA} = \frac{L}{t_{BA}} = c - V\,cos\,\alpha \tag{2}$$

Where *L, α,* t_{AB} and t_{BA} are known; v_{AB} and v_{BA} are associated to the acoustic path through flow velocity and *c* is the gas speed of sound - *SOS.* The algebraic system composed by Eqs. (1) and (2) can be easily solved for the unknowns *c* and *V*, which gives:

$$v = \frac{D}{sin\,2\alpha}\,\frac{t_{AB} - t_{BA}}{t_{AB}\,.\,t_{BA}} \tag{3}$$

$$c = \frac{D}{2\,sin\,\alpha}\,\frac{t_{AB} + t_{BA}}{t_{AB}\,.\,t_{BA}} \tag{4}$$

By observation of Eqs. (3) and (4) it is possible to measure a variable associated to flow velocity *V*, as well as the speed of sound of flowing gas. Unfortunately, determining the correct flow rate within the meter is a bit more difficult task. The velocity *v* shown in Eq. (3) refers to the velocity on acoustic path. The velocity needed for computing flow rate, also known as bulk mean velocity, is the average gas velocity across meter´s area at metering section and it can be obtained multiplying *v* by a factor *k*, associated to the velocity profile at metering section as shown in Eq. (5).

$$V = k.v \tag{5}$$

Factor *k* represents the influence of the velocity profile on the ultrasonic acoustic path between transducer A and B. Usually, it is required a fully developed flow profile at metering section and this is considered an adequate condition for flow measurement (AGA-9, 1998, Hilgenstock and Ernst, 1996) which provides a characteristic formula to factor *k*.

Although it can be deduced from integration of the acoustic path over theoretical flow profiles, many manufactures have different methodologies for computing such factor. Some derive the answer by using proprietary algorithms. Others rely on a design that does not require “hidden” computations. Regardless of how the meter determines the bulk average velocity, Eq. (6) is used to compute uncorrected flow rate.

$$\dot{Q} = V.A \tag{6}$$

In Eq. (6), $\dot{Q}$ is volume flow rate and *A* is the cross section area at metering position.

On the other hand, it is usual to face situations with severe restrictions to install straight tubes long enough in order to reach a fully developed flow. Especially in flares tubing installed on offshore oil platforms. Characterized by large diameters, very turbulent flows, wet gas, large turndown range and low pressure, flare ducts remains a challenge to flow metering community.

3. NUMERICAL SIMULATION PARAMETERS

The so called installation effects in flow tubes are represented by the presence of different pieces and non-straight ducts usually found in tubing for industrial processes like: valves, curves, bends, expansions and contractions among others. Such pieces promote different effects on the flow, depending on the arrangement, which delays the formation of fully developed flow, necessary for measurement.

Actually, in some metering stations and depending on installation effects, fully developed flow is considered an idealized profile, since the tubing arrangements do not allow to reach this condition. So, effects like swirl and vortex have to be reduced in order to let flow profile be acceptable to measurement. It is not an easy task, especially where it is not possible to install straighteners or flow conditioners, as suggested by Schlüter and Merzkirch (1996) and Xiong *et al.* (2003), and where the metering section cannot have a straight tube long enough, like usually occurs in offshore flare ducts.

In such cases, it is proposed a new approach to factor k, which relates ultrasonic acoustic path to bulk average velocity. Such new factor k_{dis} has to take into account disturbances caused by installation effects which are estimated by using simulated profiles obtained numerically from commercial flow simulators. The error, in %, between the disturbed and undisturbed calibration factors is determined by Eq. (7), as pointed out by Hilgenstock and Ernst (1996).

$$e = \frac{(k - k_{dis})}{k} x100\% \tag{7}$$

At the moment, the scope of this early work is to simulate a flow disturbed by two bends installed at orthogonal planes upstream and downstream from metering section. The error caused by such disturbance on factor k will be subject of future analysis.

As an exemplification of such situation, it is shown in Fig. 2 a metering section of a flare gas line

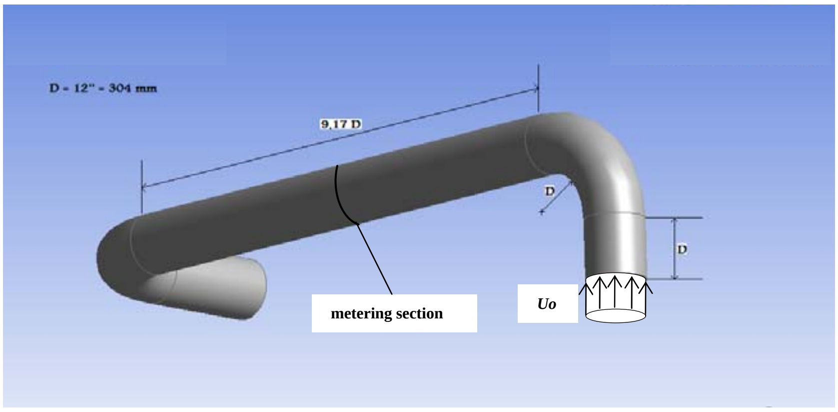


Figure 2. Arrangement and basic dimensions of an offshore flare metering section between two bends installed at orthogonal planes

Table 1. Parameters for numerical simulation

Parameter	Symbol	Value	Unit
Volumetric Flow	$\dot{Q}$	3,000	m^3/s
Diameter	D	0.304	m
Specific weight	ρ	1.185	kg/m^3
Mass flow	$\dot{m}$	0.9875	kg/s
Entrance velocity (uniform profile)	Uo	11.48	m/s
Dynamic viscosity	μ	1.83 E-05	kg/m.s
Reynolds number	Re	2.26 E05	-
Pressure	P	1	atm
Turbulence model: k-ε (medium intensity at entrance)			
Wall condition: No split			
Wall roughness: Smooth wall			
Flow regime: Steady state			

All numerical flow simulations were carried out using CFX™ (2007) software and parameters described in Tab. 1, which represents actual data from a flare installed on oil platform operating on Brazilian coast.

There is a large oil-gas separator vase installed upstream from the first vertical bend and the uniform velocity profile boundary condition at entrance was chosen since it seems to be the more verisimilar profile to occur at that position.

Convergence test was carried out for selected run with different numerical mesh for the conditions described at Tab. 1 and the results are synthesized at Tab. 2.

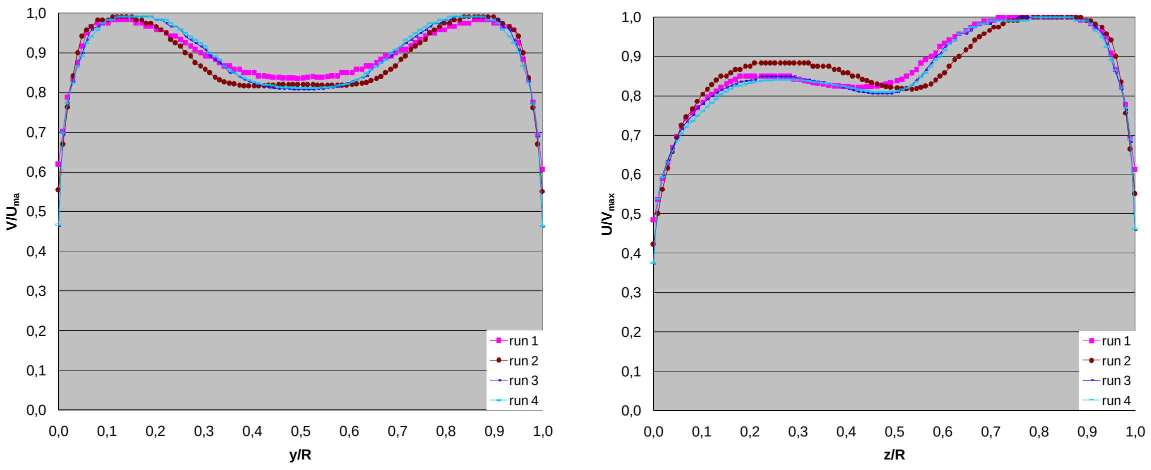
Table 2. Synthesis of numerical runs

Run(1)	**Node number**	**Tetrahedrons number**	**Elements number**	**CPU time**	**Interactions**	**Final residual RMS error**
1	278,161	1,067,754	1,230,354	01:36:24	85	9.8 E-05
2	670,309	2,897,307	3,194,499	03:02:49	79	9.8 E-05
3	1,663,252	5,333,668	6,743,188	04:52:24	73	9.7 E-05
4	1,843,037	4,339,924	6,449,286	13:32:05	200	6.3 E-05

(1) All runs were performed by a PC equipped with Quad Core processor 2.4 GHz, 4.0 Gb memory and 8 Mb cache

4. RESULTS AND CONCLUSION

The next results refer to run no. 4, considering the best mesh on Tab. 2. Such concept is defined when it is considered a convergence criterion based on velocity profiles in two orthogonal planes at measuring section, as shown in Fig. 3 in dimensionless form.



(a)

(b)

Figure 3. Convergence verification of dimensionless velocity at measuring section: (a) y-plane, (b) z-plane

As can be seen in Fig. 3, although the differences between runs 1 to 4 are not so significant, the curves for runs 3 and 4 collapse over each other in a very peculiar way.

Converged 3D velocity stream lines are plotted at Fig. 4, where metering section is detached as well as the velocity color scale.

As can be noted in Fig. 4, velocity stream lines are not parallel at metering section, which means that fully developed flow is not reached. Such behavior may be predictable since the total straight tube length since the first vertical bend is less than 10D, as indicated in Fig. 2, which is considered a very short development length for measurement aims, considering Reynolds number (Ruppel and Peters, 2004, Lansing, 2004).

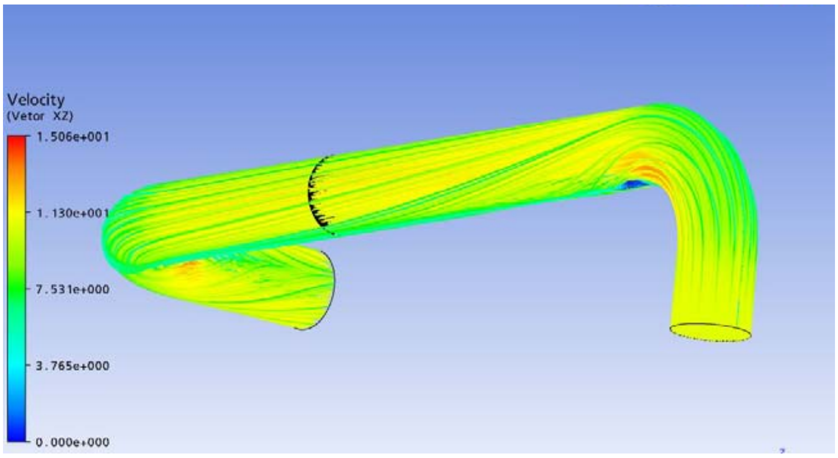


Figure 4. Converged 3D velocity stream lines

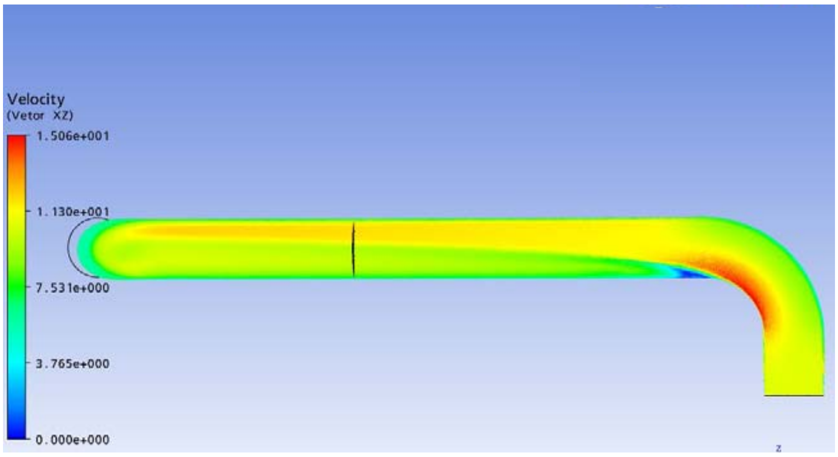


Figure 5. Converged 2D velocity vectors at duct middle plan

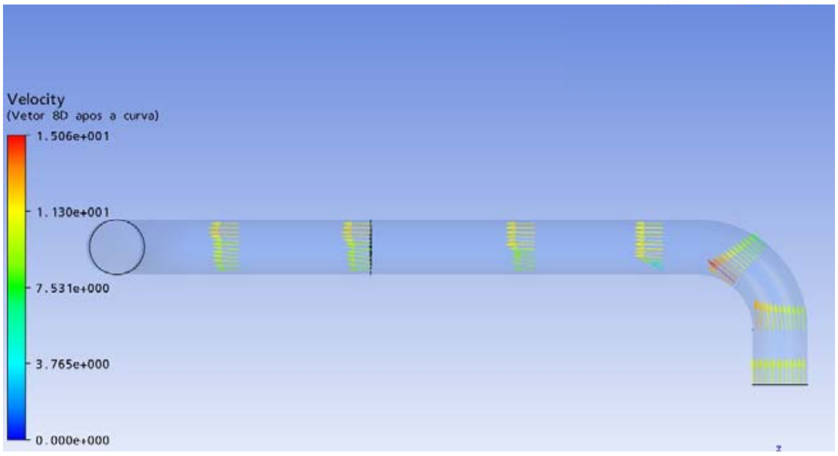


Figure 6. 2D velocity profiles at different duct sections

Figure 5 shows 2D velocity vectors at duct middle plan which confirm the observation at Fig. 4. As can be observed in Fig. 5, metering section present vectors of two predominant colors: yellow at top (11.30 m/s aprox.) and green (7.53 m/s, aprox.) at bottom. A fully developed flow may show a symmetrical color distribution, with highest velocities at centre tube.

Besides the short straight development length, fully developed flow is not reached because of the presence of the two bends, as can be seen in Fig. 4. It is visible in the figure the asymmetrical acceleration process that flow is submitted at vertical bend, just after tube uniform entrance. Such acceleration process may be seen at Fig. 6, but through 2D velocity vectors instead of 3D velocity stream lines.

Figure 7 detached the velocity contour plot at metering plan cross section, making explicit the asymmetrical nature of such flow conditions.

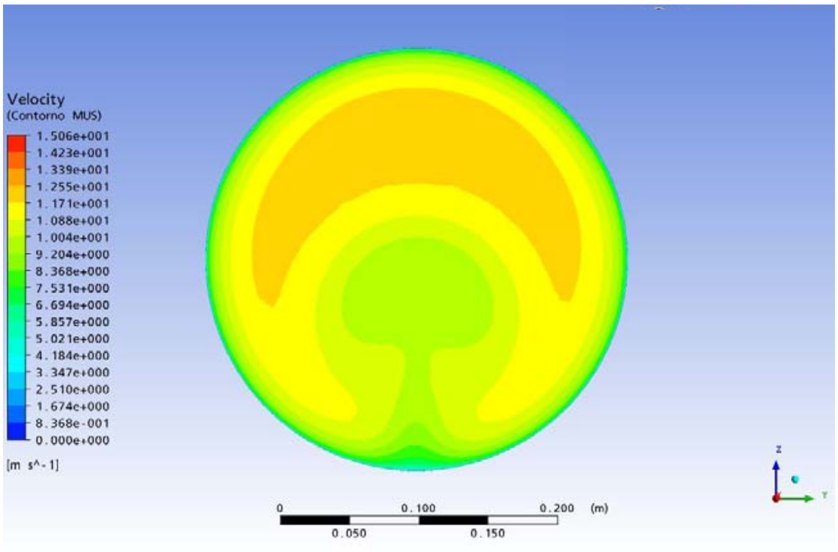
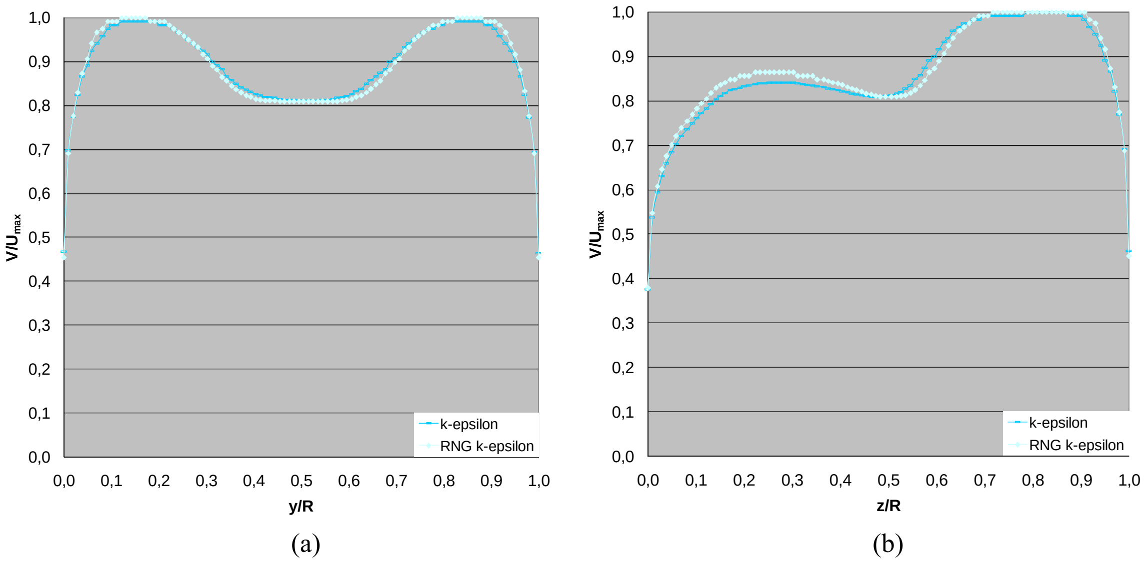


Figure 7. Velocity contour plot at metering plan cross section

The effects of different turbulence models on the velocity profiles behavior were verified, as well. As can be seen in Fig. 8, for two orthogonal planes, the results are not so discrepant at least for graphical comparison. In such simulations, mesh convergence was not tested, but it was used the same mesh parameters from run 4 at Tab. 2.

Such result does not agree with conclusions from Hilgenstock and Ernst (1996), since they observed significant discrepancies for the same turbulence models, but with distinct piping arrangement.

In that work it is explored the arrangement composed by upstream double bend out-of-plane, generating a flow distribution distinct of present simulation and differences between two simulations demonstrated to be more pronounced.



(a) (b)

Figure 8. Comparison of turbulence models: k-ε and RNG at measuring section: (a) y-plane, (b) z-plane

5. ACKNOWLEDGEMENTS

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