

Impact of imperfect sealing on the flow measurement of natural gas by orifice plates

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Abstract: Orifice plate metering systems are largely used in Brazil for fiscal, allocation and custody transfer measurements of natural gas^[1]. The great advantage of this measurement technology is that the orifice plate does not need a flow calibration in a calibration laboratory since its discharge coefficient can be derived from empirical equations given in widely accepted standards of the natural gas industry as ISO 5167^[2] and API-MPMS/Chapter 14.3^[3], provided that the laws of dimensional and dynamics similarity are met by the measurement system in particular.

In addition to a careful check of the dimensional, form and surface quality requirements of the primary element, it is necessary to perform a calibration of the pressure and temperature sensors and transmitters, complemented by a correct configuration of the flow computer. Moreover, it is extremely important to carry out a proper installation of the orifice plate into the orifice plate holder to ensure the metrological reliability of the measurement system.

This paper shows an example of the consequences of an improper installation of an orifice plate in the orifice plate holder, which resulted in differences of 12.5 % on the measurement results.

Keywords: flow measurement, orifice plate, natural gas, metrological reliability.

1. INTRODUCTION

An orifice plate is a device used for measuring the volumetric flow rate of a fluid. Its operation is based on the same principle as a Venturi nozzle, namely Bernoulli's principle which states that there is a relationship between the pressure of the fluid flowing and its velocity.

The Bernoulli principle or Bernoulli's law is a statement of the relationship between flow speed and pressure in a fluid system. In essence, when the speed of horizontal flow through a fluid increases, the pressure decreases. A common example used to explain the Bernoulli effect is the flow of a fluid through a pipe. If the fluid is moving uniformly through the pipe, then the only forces acting on the fluid are its own weight and the pressure of the fluid itself. Now, if the pipe narrows, the fluid must speed up, because the same amount of fluid is traveling through a smaller space. However, if the fluid is moving uniformly, and the weight

has not changed, then the only way in which the fluid will move faster is if the pressure behind the fluid is greater than the pressure in front. Thus, the pressure must decrease as the speed increases. Figure 1 shows in a simplified way the Bernoulli's principle between two cross sections of a fluid flow in a pipe.

Energy per unit volume before = Energy per unit volume after

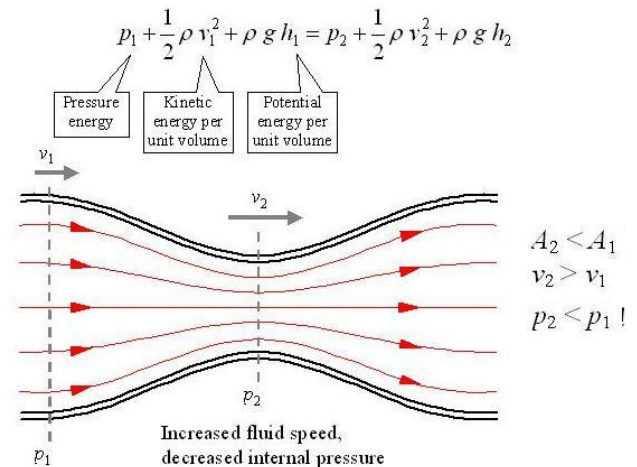


Fig. 1. Bernoulli's principle

An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, with the hole in the middle, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called *vena contracta* point (see Figure 2).

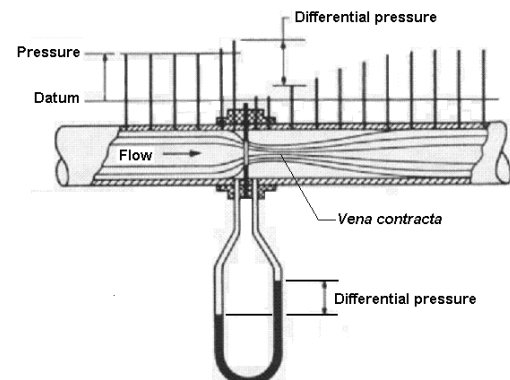


Fig. 2. Orifice plate measuring principle

As it does so, the velocity and the pressure changes. Beyond the *vena contracta*, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the normal pipe section and at the *vena contracta*, the volumetric and mass flow rates can be obtained from Bernoulli's equation. ISO 5167 standard establishes the following equation for mass flow, q_m , calculation:

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1} \quad (1)$$

where:

- C : discharge coefficient of the orifice plate
- β : diameters ratio ($\beta = d/D$)
- d : diameter of the orifice
- D : internal diameter of the pipe
- ε : expansion coefficient
- Δp : differential pressure
- ρ : density of the fluid

Similarly, the value of volume flow rate, q_v , is calculated from:

$$q_v = \frac{q_m}{\rho} \quad (2)$$

Typically, a natural gas measurement system based on orifice plate consists of three main parts, often referred to as primary, secondary and tertiary elements.

The primary element of the metering system is responsible for conditioning the flow properly and for generating a differential pressure signal proportional to the flow rate based on the laws of dimensional and dynamic similarities. In addition to the orifice plate itself, the primary element includes the orifice holder and the upstream and downstream straight pipe runs, the pressure taps, the thermowell and the flow conditioner or flow rectifier, if used. The secondary elements are the temperature and pressure sensors and transmitters, and the gas chromatograph, when used.

Finally, the tertiary element is composed of the electronic volume converter or the flow computer, responsible for processing the signals and calculating the flow measured over a period of time in a given volume referred to base conditions of pressure and temperature, for instance 101,325 kPa and 20 °C, respectively.

Figure 3 shows the main components of a flow measurement system based on an orifice plate.

Considering that in some applications the orifice plate needs to be replaced frequently, it is desirable that the orifice plate be installed in a dual chamber orifice assembly that allows the change of the plate without the need to interrupt the flow in the gas line.

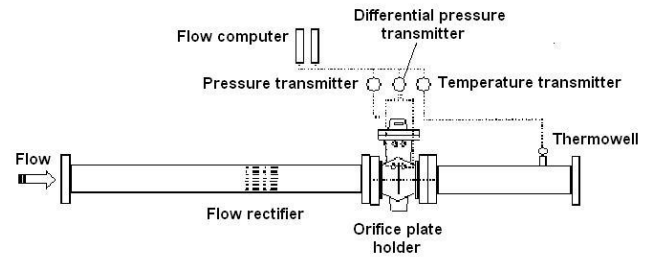


Fig. 3. Main components of an orifice plate metering system

The dual chamber orifice assembly, as shown in Figure 4, is suitably designed for on-line retraction and inspection of orifice plates in process full flow and pressure conditions.

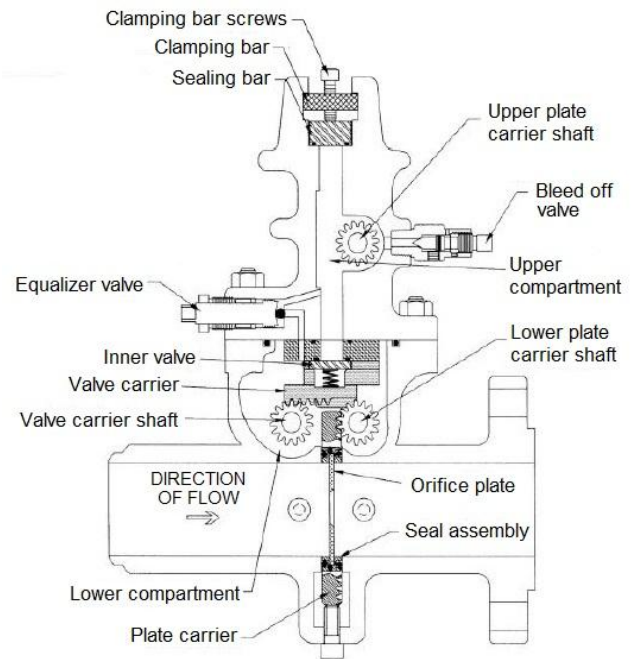


Fig. 4. Dual chamber orifice assembly

The orifice plate is kept inside the orifice plate carrier with a special seal ring, divided into two parts and joined by means of staples as shown in Figure 5.



Fig. 5. Teflon seals used to install an orifice plate

The orifice plate carrier is then moved in and out of the holder by means of the lower and upper plate carrier shafts.

2. THE CASE STUDY

The metering system analysed in this paper consists on a natural gas supply to an industrial plant. The measurement of this gas is performed by three parallel measurement systems similar to the sketch shown in Figure 3, each of which was designed with the same nominal pipe diameter of 8 inches and with the same nominal maximum flow capacity of 73,000 m³/h.

Each one of the primary elements of the measuring systems had been previously inspected individually and all were considered able to meet the dimensional, shape and surface quality requirements established in the ISO 5167:2003 standard.

The maintenance plan of this plant determines a routine calibration of the temperature, pressure and differential pressure sensors and transmitters at a rate of three times a year, while the dimensional, shape and surface quality inspection of the orifice plate is held two times a year and the straight pipe runs inspection occurs once a year.

The three measuring systems operated in parallel and in similar normal conditions. The measured flow rate in each of the systems was approximately 48 000 m³/h. The problem reported by the operator was that one of the measurement systems started to indicate a natural gas flow rate of approximately 42 000 m³/h, significantly below the indication of the other two measurement systems.

Table 1 below presents gas flow rates and the percentage difference between the indicated flow rate and the normal operating flow rate.

Table 1. Percentage difference between the flow rates

Indicated flow rate [m ³ /h]	Operating flow rate [m ³ /h]	Difference
42 000	48 000	- 12,5%

As was reported by the maintenance personnel, this flow reduction indication by the flow computer started to occur after a shutdown for maintenance of the industrial plant. During this shutdown, the gas measurement system was submitted to a metrological inspection when the dimensional, shape and surface quality parameters of the pipe runs and the orifice plates were verified. Additionally, the calibrations of the temperature, pressure and differential pressure sensors and transmitters were performed in the same period, besides the checking of the flow computers configuration.

3. METHOD

The person in charge for the operation and instrumentation of the measurement systems applied a request to IPT to carry out a verification of the calibration conditions of the temperature, pressure and differential pressure sensors and transmitters of the measurement systems with an indication that the flow was below the

normal operating conditions. If necessary, the instruments should be adjusted to obtain better results.

Considering that difference in measurements was considerably high, the following methodology was established for the identification of this divergence:

1. Checking of the parameters in the flow computer in order to verify if any changes occurred after the metrological intervention performed during shutdown. The verification was carried out by checking the parameters set in the flow computer, such as the internal diameters of the pipe and the orifice plate, the isentropic coefficient and viscosity of the gas, the reference pressure and temperature, the results of the last gas chromatography and the type of calculation of the compressibility factor. In addition, the flow calculation algorithm was verified by comparing the results indicated by the flow computer with those obtained by using standard software developed by IPT, based on ISO 5167:2003^[2] and AGA Report No. 8^[3].
2. Checking on gas leakage in connections of the tubing, in valves and manifolds and verification of the insertion depth of the temperature sensor in the gas flow.
3. Carry out a new calibration of the temperature, pressure and differential pressure sensors and transmitters to verify possible deviations above the control limits for the application.
4. Withdrawal of the orifice plate from orifice plate holder to check its physical conditions. Verification of the correct installation of the orifice plate and its sealing ring.

4. RESULTS

In a first step, the parameters related to the flow calculation were checked in the flow computer configuration. Evidences showed that the values of the internal diameter of the pipe and of the orifice plate, the isentropic coefficient and viscosity, the temperature and reference pressure had not been changed from the metrological intervention performed during the shutdown of the plant.

The results of the gas chromatography, obtained by a in line chromatography and sent to the flow computer, showed only a small variation, as can be observed in the molar fraction of methane as shown in Table 2 below, before and after the metrological intervention.

Table 2. Molar fraction of methane indicated in the flow computer

Molar fraction of methane (before)	Molar fraction of methane (after)
96,23 %	97,05 %

The flow computer was programmed to calculate the compressibility factor using the detailed method described

in the AGA Report No. 8 [4]. The variation of the molar fraction of methane caused no significant impact on the calculation of the gas flow rate that could justify the difference in the gas flow measurements.

The flow calculation algorithm was tested and the results indicated by the flow computer were compared with those given by the IPT standard calculation program. The results indicated that the values calculated by the flow computer were in close agreement with those calculated by the IPT program. Table 3 shows the values of the flow rates indicated by the flow computer and by the IPT program for different values of differential pressure, pressure and temperature within the range of operating conditions of the metering system.

Table 3. Sample values of gas flow rates for comparison

Operating conditions	Indicated flow rate [m ³ /h]	IPT calculated flow rate [m ³ /h]	Difference
$\Delta p = 25$ kPa Pressure = 3 000 kPa Temperature = 30 °C	39 546	39 545	0,003 %
$\Delta p = 35$ kPa Pressure = 3 500 kPa Temperature = 30 °C	50 718	50 716	0,003 %
$\Delta p = 50$ kPa Pressure = 4 000 kPa Temperature = 30 °C	65 017	65 014	0,004 %

After checking the flow computer, the calibrations of the temperature, pressure and differential pressure sensors and transmitters of the measurement system were carried out. Nevertheless, a leak test on pressure tubing was performed prior to the calibration of the sensors and transmitters. No leaks in pressure tubing or fittings were noted.

In the calibration of the Pt 100 Ω temperature sensor, inspection of the sensor probe showed that its insertion in the gas flow was identical to that found during the inspection performed during shutdown and it was within proper limits.

The results of the calibration of the temperature, pressure and differential pressure sensors and transmitters were within the tolerances allowed for the type of application. Table 4 presents the expanded uncertainties of the calibration results, at a 95 % confidence level, obtained during the shutdown and afterward. These uncertainties take into account the climatic conditions during the activities.

Table 4. Expanded uncertainties (U) of the calibration results

Parameter and calibrated range	$U_{95\%}$ (during shutdown)	$U_{95\%}$ (after shutdown)
Differential pressure 0 kPa to 62,2 kPa	0,12 kPa	0,02 kPa
Pressure 100,8 kPa to 5516 kPa	4,17 kPa	3,25 kPa
Temperature 0 °C to 100 °C	0,22 °C	0,19 °C

It was observed that the calibrations of these sensors/transmitters did not justify the difference in the flow rate measurements.

The last step of the inspection program was to remove the orifice plate from the orifice plate holder for inspection of its installation and physical conditions.

When the orifice plate was removed from the orifice plate holder, it was possible to see that it was not reversed and that the upstream face was in the right direction. However, it was observed that the Teflon sealing ring presented a small fracture in its downstream side, as shown in Figure 6. Possibly, this fracture of the sealing ring was caused by an unsuccessful operation to install the orifice plate in orifice assembly.

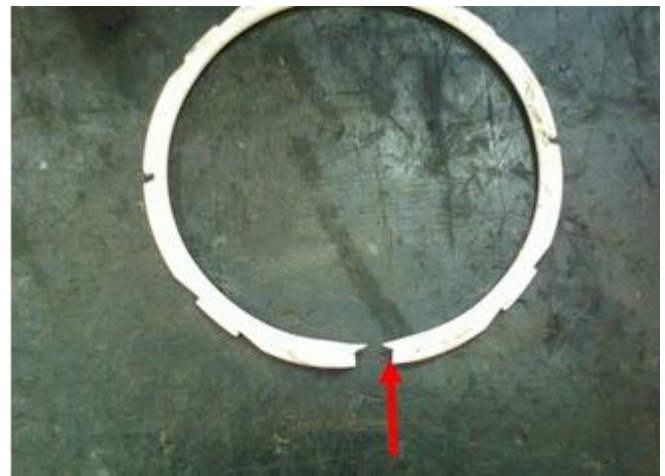


Fig. 6. Teflon sealing ring with a small fracture

Figure 7 shows the orifice plate with the sealing ring installed. It is possible to observe that the fracture in the sealing ring allowed the natural gas to flow through it, increasing the flowing area and reducing the differential pressure indication. Consequently, the indicated flow rate was lower than the effective gas flowing through the meter run.

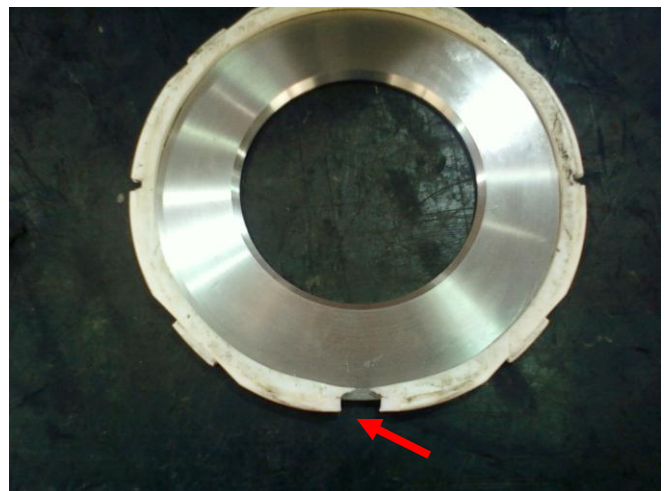


Fig. 7. Orifice plate installed in the damaged sealing ring

5. CONCLUSION

From the point of view of process control, flow measurement of fluids is one of the most important variables for the operation of an industrial plant. The flow measurement is essential in all phases of the manipulation of fluids, including production, processing, and distribution of inputs, products and utilities. It is associated with the mass balances in industrial processes and from the point of view, is directly linked to the activities of buying and selling of products.

Accurate measurement of the flow of a fluid requires a set of engineering activities that starts with the full understanding of the process being measured and involves the correct selection of the measuring instrument, its calibration, installation, configuration, operation and correct interpretation of the results obtained.

In a measuring station or an industrial plant, the flow meter is the element that quantifies the transfer rate of a fluid and thus guarantees the quality of a product, the safety of a process or accurately determines the volume of products traded between the parties involved. Nevertheless, we evidence in industrial plants often inappropriate use of meters to the proposed application, operated in an inappropriate condition or installed incorrectly, causing measurement errors that directly affect the production processes, product quality and, consequently, the financial results of the companies.

The paper showed that an innocent and simple faulty sealing ring was the main cause of the under measurement of a natural gas metering system, because the opening allowed the passage of gas through it, reducing the differential pressure and, consequently, reducing the flow rate indication by the flow computer.

Whenever differences in flow rate measurements are detected, it is necessary to analyse and evaluate all aspects that can affect the measurement, not only the calibration of the pressure and temperature sensors and transmitters.

REFERENCES

- [1] *Regulamento Técnico de Medição de Petróleo e Gás Natural* aprovado pela Portaria Conjunta ANP/INMETRO N° 1, de 19 de Junho de 2000.
- [2] ISO 5167 *Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full – Part 2: Orifice plate*, First edition, 2003.
- [3] API-MPMS / Chapter 14.3 Part 1, concentric, square-edged orifice meters (AGA Report #3); Part 2 Specification and installation requirements and Part 3 Natural gas applications.
- [4] AGA Report N° 8 *Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases*, Edition 1994, Revised 1999.