

STATE-OF-THE-ART OF THE FLOW MEASUREMENT OF HYDROCARBON GASES IN CUBA.

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Abstract: This paper¹ intends to give a general overview concerning the state-of-the-art of the gas flow measurement in the Cuban petroleum industry.

Keywords: gas flow measurement, standards, uncertainty, Cuba Petróleo.

1 INTRODUCTION

In the last ten years hydrocarbons production, and specifically hydrocarbon gases production has grown considerably in Cuba. This fact has compelled the petroleum industry authorities in Cuba to develop a nation-wide strategy in flow and volume measurements in order to satisfy the new reality that this industry faces. The present paper aims to give a wide vision of the volumetric gas flow measurement in the Cuban petroleum industry, according to the new challenges it faces.

2 GAS PRODUCTION

The total volume of natural gas produced in Cuba is associated gas. Two main composition categories are found in Cuban reservoirs: Varadero and Jaruco. The main difference between the gas produced in those two fields is their sulphur concentration. These two reservoirs produce around 97% of the total national natural gas production, that surpassed a volume of 467 MM Nm³ last year [1].

In Varadero fields, wells grouped in clusters, send gas and crude production to nine collecting points, where gas primary treatment is made. The main objectives of the flow measurements made here are to monitor the wells global production and to fix and control gas/oil ratio for proper extraction regime of reservoir.

Differential pressure flow measurement rigs are used at this level, for both measuring flows from the wells and outputs from the collecting points. A typical set of measurement in this case consists in a flange tap concentric sharp edge orifice plate as primary element, and pressure, temperature and differential pressure transmitters, mostly in a 4-20 mA current loop.

Two fundamental drawbacks were found when using this flow measurement technique:

- Wide and variable ranges of flow rate *versus* low rangeability of these meters.
- Pulsating behaviour of flow rate.

A fact well known in flow measurement is the small turndown ratio of the orifice type flow sensors *vs.* their reliable and low-cost performance.

Flow measurements of the gas sent to the collecting points are implemented through orifice plates installed in parallel lines with different diameters. Covering the full range of expected flow, these sets of meters are fed by a common head, with only one meter is working at a time. Switching to each of the 2, 4 or 6" diameter measurement sets is made according to the flow value in each moment.

Trends to a pulsating behaviour were encountered when flow rate values were observed in some measurement points. Monitoring tasks of the fluctuating flow rate values in several measurement points were made, intending to determine the ratio between the amplitude of flow rate fluctuation and the time-mean flow rate.

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Table. 1. Data of 16 hours flow measurement in *CPV1, Varadero*.

Time	Mean flow rate (acfm) based on 16 readings per hour	q'_{rms}/q_{med}
4:00	353.4875	0.02187088
5:00	373.7375	0.05002048
6:00	370.2534	0.04929015
7:00	409.1255	0.05001266
8:00	399.9375	0.05001049
9:00	482.1875	0.05002238
10:00	461.3125	0.04970461
11:00	567.9887	0.05003021
12:00	589.8778	0.04569112
13:00	621.9892	0.04789563
14:00	630.7556	0.04913445
15:00	628.9796	0.04739871
16:00	567.9889	0.04021010
17:00	467.9878	0.04663341
18:00	431.2556	0.03619452
19:00	401.4545	0.04100583

Table. 2. Data of 16 hours flow measurement in *CPV4, Varadero*.

Time	Mean flow rate (acfm) based on 16 readings per hour	q'_{rms}/q_{med}
4:00	399.1125	0.06444114
5:00	400.2375	0.06479280
6:00	370.2534	0.08173230
7:00	423.8000	0.07244045
8:00	427.8625	0.07573174
9:00	401.2375	0.07668397
10:00	411.7375	0.07022933
11:00	400.8625	0.07858021
12:00	422.9250	0.07454368
13:00	417.9875	0.08126251
14:00	427.4250	0.08216600
15:00	473.2375	0.06586495
16:00	430.8000	0.07047855
17:00	406.3625	0.07364957
18:00	384.4875	0.06812652
19:00	351.3625	0.06311419

According to *ISO TR 3313* [2], the recommended criterion for U'_{rms}/U_{med} , where $U=q/A$ is the mean axial velocity of the flow in a circular duct and A represents the internal sectional area of the duct, is:

$$U'_{rms}/U_{med} \leq 0.05 \quad (1)$$

or equivalently: $q'_{rms}/q_{med} \leq 0.05 \quad (2)$

where q'_{rms} is the *root mean square* of the fluctuating part of flow rate q and q_{med} the time-mean value of q . Its instantaneous value is given by $q=q'+q_{med}$. The same meaning of the suffixes are valid for U .

These values allow to know whether or not the pulsating behaviour of the flow should be taken into account for uncertainty calculations. That is, values of (1) or (2) lower or equal than 0.05, mean that pulsating flow behaviour do not affect flow uncertainties calculation according to *ISO 5167* for differential pressure devices. Otherwise this value should be reduced, if possible, to the values stated above.

Different degrees of pulsating behaviour were found when data from field were analysed. Data available from meters installed in two measurement points, CPV1 and CPV4 are shown in Tables 1 and 2, as an example. Figures shown in the second column correspond to the mean flow rate of 16 readings, taken in one hour which yielded the q'_{rms}/q_{med} values, in the third column. This set of readings was repeated each hour during 16 hour a day. For CPV1 it was observed that values of q'_{rms}/q_{med} were lower than 0.05. Thus, this existing fluctuating behaviour was not great enough to be considered as a new error element.

On the contrary, in CPV4 (Table 2), it did not occur. A revision of the whole installation revealed the causes of this pulsating behaviour. Malfunctioning of input regulating valves was not isolating the measurement instruments from pressure changes in the feeding line. Aspects like increasing of the storing vessels capacities existing in this installation and re-adjustments made into the input pressure regulators allowed to decrease q'_{rms}/q_{med} to proper values.

Gas from these collecting points is delivered to a second level of processing, where it will be pumped to industrial customers, including power generation plants, natural gas liquefying plants, and finally, transmission pipelines toward processing plants for residential gas distribution network. All these transportation processes imply in flow measurement under *Custody Transfer* conditions.

3 CUSTODY TRANSFER MEASUREMENT

Petroleum industry conditions existing in Cuba until the end of the 80s permitted that non-standard procedures were used in oil and gas transactions. Gas production was limited to light hydrocarbons (naphtha) cracking plants in charge of domestic gas production. The incipient volume of natural gas associated to the extracted crude was mostly flared. This situation was changed at the very beginning of the next decade trying to follow international practice.

The three classical options in custody transfer flow metering, i. e., Positive Displacement (PD), Turbine and Differential Pressure (DP) flow meters had also been the main choices for custody transfer measurement stations in Cuba. In some areas these measurement techniques, for instance Diaphragm PD meters, have not faced significant threats by the newest technologies in flow measurement. Somehow, other PD applications, as well as Turbine and DP are suffering a gradual merging with other technologies in gas measurement, such as Ultrasonic Flow Meters (UFM) and Coriolis Mass Flowmeters (CMF). In Cuban Petroleum Industry no custody transfer application has been installed with this new technologies mainly because of the absence of national normative documents dealing with these meters. That is why a description of gas custody transfer covers just these three classical methods.

Following an old worldwide trend, Diaphragm Positive Displacement meters have been the natural solution for gas consumption metering on residential distribution networks in Cuba. More than one hundred thousand [3] of these meters, types G4 to G6, have been installed in the last years in Havana, trying to satisfy the increasing demand of this kind of service.

Regarding this, calibration facilities for periodical checking have also been acquired and installed in order to maintain the uncertainty values stated in the clients-supplier contracts. In this case, similar meters considered as standard are going to be used, through a comparison method of calibration. Realistic and accepted error values for these applications are $\pm 3\%$. Standard flowmeter calibration is performed by the manufacturer every 3 years, according to a contract. These values could only be properly reached, when some changes were made in the residential gas distribution network. These changes were mainly intended to pressure stabilisation in a tree-topology of this network.

Since the mid of 90s, the high repeatability, turndown ratio and accuracy of turbine meters have been checked in custody transfer LPG flow measurement, as part of an automated system for reception and storing of imported LPG. The cleanness and low viscosity of this fluid make it suitable for turbine meter application. Four and six inches measurement rigs are installed, consisting in double pick-up turbine

meters, straightener devices, and temperature and pressure sensors for volume corrections according to API standards. As one of the important elements of the turbine meter, bearing selection has been made considering the non-lubricating characteristic of the fluid. In this case, ball bearings with non-metallic (*Teflon*) retainers have been used with considerable success, enlarging the service life span of the meter.

Turbine flowmeters have found other applications in some custody transfer installations for natural gas. Measurement rigs in up to 6 inches have been installed in places such as the outlet of gas compression stations in transmission pipelines. But in this area, differential pressure devices keep leading the choices.

More than 95% of natural gas production custody transfer-related measurement in Cuba, considering all reservoirs, is implemented with orifice plate flowmeters [4]. The installations, made according to ISO 5167, allow uncertainty calculations made through a dimensional approach. Interchangeable plates measurement devices have been successfully used as a solution in measurement points where range of flow rate exceeds the typical turndown ratio of the meter. A brief review considering two sources of non-systematic errors that appeared in this kind of measurement is presented below.

Transactions of gas in custody transfer contracts are made in standard units. Flow rate and volume units are referred to base condition and it is also considered a super-compressibility factor, as a ratio of the gas base condition compressibility factor and fluid-flow condition compressibility factor. In this particular, one of the facts affecting uncertainty in natural gas flow measurement systems is the non-steady composition characteristic of crude-oil associated gas. On-line monitoring of the gas, through chromatographic analyses is one of the solutions that is being implemented in the most critical measurement points. This is an expensive solution and it is not able to be done in all measurement stations. Another cheaper solution could be a real off-line quantification of this composition changes and the estimation of its influence in the overall flow measurement uncertainty, in order to reflect this result in the system overall uncertainty.

On the other hand, a second fact detected as a particular affecting element in the performance of differential pressure flowmeters has been the fluid bi-phase behaviour, produced by the gas condensation through the pipelines where measurements are performed. This condensation depends on the gas (wet gas) composition, pressure and temperature throughout the pipeline. According to the quantity of liquid laying in the bottom of the pipeline, changes in the geometrical relation of the pipeline can occur, also affecting the β ratio of the orifice plate flowmeter, introducing an uncertainty increment. This effect was particularly influent in some clients measurement stations, which are located downstream the regulating stations of a long distance transmission pipeline. Curiously it did not happen to other clients in the same section of the network. Some studies were conducted and finally changes in the temperature-pressure operating profile were encountered, as result of an actual gas flow rate much higher than the one originally designed for this pipeline section. This flow increase was due to a crescent gas consumption. The installation of gas-liquid separators downstream these regulators was the immediate solution for this problem, but a more patient work to modify this pressure-temperature profile must be done, considering the upcoming enhancements in this distribution network.

4 METROLOGICAL SUPPORT

A complete metrological chain for flow, as an independent physical magnitude, still is a future goal in Cuba. This includes flow measurement for both gas and liquid. Nowadays there are not installations that could be considered as primary laboratories, not only because of the equipment, type of standard or range of work, but also due to the absence of a coherent policy that would establish methods and procedures to be used everywhere for calibration processes.

Measurement itself has been implemented according to international standards as ISO, AGA and API, fundamentally following their suggestions and recommendations in custody transfer operations. Although, regular updating in some of these important standards could result in a quite difficult task. Because of that and because of the own inertia of the whole system these standards implementation has been slower than it should be.

In this regard, an important aspect was the implementation of the ISO 5167, as a procedure to be employed for sizing, installation and usage of the orifice plate meter in different applications as previously mentioned. Before this implementation was made, in 1996, several standards from different countries and ages were used simultaneously, with a practical result of considerable contradictions,

due to the unmatched measured values between gas clients and suppliers and even between equipment manufacturer and the final user in the industry. This standard implementation in every level where differential pressure measurements were being applied, changed readings of flow rate values that in many cases were over or underestimated, yielded reliable error values and brought a useful tool for calibration and uncertainty calculations through the dimensional analyses.

To calibrate turbine meters there is a field flow range limited facility, equipped with two 4 inches turbine meters, acquired especially for this purpose. Periodical calibration, each 3 years, is guaranteed by the supplier. A master meter is placed in series with the meter under test, allowing 50 diameters upstream and 25 downstream for flow conditioning. Reading of pressure and temperature is also made during the calibration process. Using natural gas as a fluid for calibration, means to be as close as possible to the real operating conditions. This process can be oriented for determination of the K -factor of the meter under test, counting directly the quantity of pulses emitted by its rotor, or just comparing the indications of both flow rate and/or volumetric values for the two meters, the master and the tested one. The low amount of turbine meters in service for gas flow metering or any other sharing its working range demotivates investments in this particular field. But, on the other hand, elements that reinforce the harmonic integration of this kind of station as part of a unique system for the whole country should also be considered.

A similar scenery is shared by the PD Diaphragm meters. As was stated before, calibration procedures are implemented by the comparison of the readings of both meters, the master and the tested one. The difference here is that the quantity of this type of meter in service, allows improvements in equipment and infrastructure.

Terms used to express experiments results have also been changing from the familiar concepts of accuracy and precision to overall uncertainty, reproducibility, and so on. This is not such a simple change of terms. Calculation methods like ISO 5168 and more recently ISO *Guide for Expression Uncertainty in Measurement* have been useful tools to enhance the results of the experiments that had been made, expressing beyond the overall uncertainty, some of its individual components as repeatability or reproducibility when is required by the user.

In terms of the traceability pyramid, gas flow measurement in Cuba has settled some important elements in its very bottom. But there still is an absence of the subsequent elements that will allow this system to be considered as a coherent metrological structure, matching other physical magnitudes that already have it.

5 CONCLUSIONS

Gas flow measurement in Cuban petroleum industry is an open and continuously renewed system. The introduction of new measurement technologies must be guaranteed by its extended usage in this industry and technical procedures for its proper installation and application. Gradual merging with this new technologies is not the only important aim, but the work must also be focused on both directions, the development and reinforcement of a real metrological structure on its every stages, and, at the same time, the implementation of technologies that offers significant economical, technical and ecological benefits to the country.

6 REFERENCES

- [1] Cuba Petróleo; *Balance anual 1998*. Ministério de la Industria Básica, L Habana, 1998,
- [2] ISO TR 3313 *Measurement of pulsating flow in a pipe by means of orifice plates, nozzles or Venturi tubes.*, Genève, 1992
- [3] Cuba Petróleo, *Plan de gasificación de Ciudad de La Habana*. Ministério de la Industria Básica, La Habana, 1998
- [4] Cuba Petróleo; *Política de Automatización Comunicaiones y Computación*. Ministério de la Industria Básica. La Habana, 1997.

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