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NATURAL GAS SYSTEM - FLOW MEASURING AND VOLUMETRIC BALANCE

Homero Fenner Filho

PETROBRAS, Salvador, Bahia, Brasil

ABSTRACT: This paper presents a computational system developed for the gas measuring management and for the accounting balance closure of an entire gas network. The system calculates for each measuring point an uncertainty and a quality value, based on the gas features, the equipment and the variables involved in the flow rate calculation. A mathematical programming model closes the balance, minimizing the weighed sum of the network adjustments of the flow rates.

KEYWORDS: FLOMEKO 2000, Paper, Natural Gas, Uncertainty

1. INTRODUCTION

Petrobrás owns several systems of natural gas, composed by production areas, compression stations, pipelines, units of processing and distribution stations of this important fluid, distributed geographically in the Brazilian territory, and not yet interlinked in its totality.

As a gas system grows, its operative complexity increases, and the need of information for its management also increases, demanding better acting of the information systems.

The gas flows measuring in different points of the system assumes a fundamental paper in the obtaining of the necessary information to its accompaniment and control, and each measuring point presents different characteristics of equipment, facilities and type of gas flow.

Petrobrás has as work methodology the closing of gas balance every day. Most of measuring points are with orifice plate and electronic register of flow, but in many areas there are still circular letters, whose flow calculation is made manually, through planimeters. Automation projects with change of circular letters for electronic computers are in process; even so it will demand some time until its installation. However, even with the modernization of the measuring system and data acquisition, it won't get to eliminate the problems of measuring mistakes and consolidation of the balances totally.

2. THE PROBLEM

The closing of a daily balance in a gas system presents several difficulties. Mistakes happen in the measuring points that present different reliability degrees, being necessary to promote fittings in the read values. These fittings are sometimes made through subjective approaches, when they say respect to a same operational area, because the own operators making the balance, and this can generate mistakes of difficult detection. When there is difference of values among areas, the balance is consolidated starting from a negotiation among the responsible people for the task, prevailing a lot of times the value of the most important area, or a convenient value to the parts.

Mistakes, disseminated by all the areas, and without scientific treatment, cause problems of information and accompaniment of the gas volumes, because normally only the adjusted flow values are reported on information system, getting lost the historical of the mistakes.

The fact of if they don't register the fittings it causes difficulties in the maintenance programs of the instruments, because it is not had approaches for optimization, being adopted only periodic plans for each meter, or eventual maintenances due to some problem.

Bad historical of gas production causes problems in the accompaniment of gas reservoirs, harming the planning of its future levels of production and committing the calculation of the need of investments in each producing area.

3. THE IDEA

The elaboration of a system computational for management of the mistakes and closing of the balance appeared there are some years, inside of the operational areas. Specialists of gas and mathematics conceived the system, and it should assist to the following requirements:

· Analyzes each measuring point, attributing it an uncertainty and a quality value, with base in the characteristics of the meter, of the measuring pipeline section, and of the gas that is being measured;

· Close the balance contemplating the whole net of gas, eliminating the negotiation need among areas,

· Considers in the closing of the balance the characteristics physics of the processes of the gas, such as compression capacities, transport and production, promoting an analysis integrated between measuring and processes,

· Alter the values measured with base in the uncertainty and in the value of quality of the measuring points, eliminating the manual fittings,

· Close the balance in any situation, same having lack of some information, or when some meters are out of operation,

· Promote the control and recovery of the information through database,

· Alert for the meters with maintenance need, optimizing the use of the resources involved in this activity.

4. ERRORS AND UNCERTAINTY

Due to the physical nature of the measures, it is impossible to accomplish a measuring without mistake. The measuring is characterized better when an estimate of the value of the mistake accompanies the measured value of the physical greatness. This estimate can be presented like a range, in which the true value has high probability of being found. This range is denominated of *uncertainty*. The *confidence level* associated to the uncertainty is the value of the probability that the interval contains the true value. Its value is generally 95%. The difference among measured and true value is impossible of being determined, but the uncertainty can be dear.

The system considers the Norms ISO-5167[1], ISO-5168[2] e ANSI/API-2530 (AGA-3)[3],that are about the measurement of gas flow-rate in circular section, by means of pressure differential devices in primary element, in particular for orifice plate.

Many factors associated to the installation of a meter influence the general mistake of the measuring: representation of the reality by means of the flow equation, uncertainty on the physical properties of the fluid, imprecision of the measures of important installation parameters, secondary and primary elements, the effects of the temperature and others.

5. CALCULATION OF THE UNCERTAINTY

Based in the differential pressure generated by the restriction of the orifice plate imposed to the flow, the volumetric flow can be represented by

$$q = f\,(C, E, Y, d, D, h, \rho)$$

Where: q = volumetric flow [m^3/s]

C = discharge coefficient

E = velocity of approach factor

Y = expansion factor

d = diameter of the orifice plate [m]

D = internal diameter of pipeline [m]

h = differential pressure [Pa]

ρ = Density or specific mass [kg/m^3]

In the practice, these variables can be considered independent, to supply a simplified uncertainty calculation, that is obtained by the method of the empirical discharge coefficient for flange-tapped orifice meter.

The basic equation of volumetric flow is given for [4]:

$$q = C \cdot E \cdot Y \cdot (\pi / 4) \cdot d^2 \cdot (2h/\rho)^{0,5} \qquad (1)$$

where: $E = (1 - \beta^4)^{-0,5}$

$\beta = d / D$ Beta = reason of diameters (hole / tube)

If the fluid is incompressible, Y = 1, in the equation 1.

In the case of mass flow, have $q_m = \rho \cdot q$ [kg/s]

The uncertainty associated to the measuring is obtained with the quadratic sum of the relative partial uncertainties of the variables involved directly in flow calculation, and it could be expressed by [2]:

$$e_q = \partial q / q = (\Sigma S_i^2 \cdot e_i^2)^{0,5} \qquad (2)$$

where: S_i = sensitivity coefficients (S_C, S_E, S_Y, S_d, S_D, S_h, S_ρ)

ei = partial uncertainties (e_C, e_E, e_Y, e_d, e_D, e_h, e_ρ)

The sensitivity coefficients indicate the relative influence of each partial uncertainty in the calculation of the global uncertainty.

The partial uncertainties can be systematic or aleatory, in function of the processes used in the determination of each one of the variables.

The sensitivity coefficients are obtained of the expression [2]:

$$S_i = \partial R / \partial X_i \qquad (3)$$

where: $R = f(X_1, X_2, X_3, ..., X_k)$

When there is a well-known mathematical relationship among the result (R) and the secondary variables (X_1, X_2, ..., X_k), the sensitivity coefficient (S_i) of the secondary variable (Xi) can be obtained by partial derivation.

The sensitivity coefficient can be represented by:

$$S_i^* = S_i \cdot (X_i / R) \qquad (4)$$

In this case, S_i^* it is the percentual variation in R generated by a variation of 1% in X_i. This is the form to be used when the uncertainties are expressed as percentages of the associated variables.

Thus, the sensitivity coefficients will be obtained starting from the partial derivation of the eq. (1) in relation to the variables directly involved in the flow calculation. This procedure will determine the influence in q of the small variations that could occur in the variables.

In the measuring process for orifice plate, the main uncertainties are:

· Discharge coefficient (eC):

It is function of the number of Reynolds and of Beta. A simplified way to calculate this uncertainty is to use the maximum values presented by the Norm, as below:

β	$E_C = \partial C/C$
$\beta \leq 0,6$	0,6%
$\beta > 0,6$	β%

· Expansion factor (eY):

The expansion factor is calculated by an empiric equation, being used the upstream factor (Y1) or the downstream factor (Y2) of the primary element:

$$Y_1 = 1 - (0,41 + 0,35\ \beta^4)\ .\ x_1 / k \qquad (5)$$

where: x1 = h / P1 = acoustic reason

h = differential pressure

k = cp / cv = isentropic exponent

P1 = absolute static pressure at the upstream pressure tap

For the static pressure at the downstream pressure tap, is used $x_1 = h / (P_2 + h)$.

When the values of b, h, P, and k are known, the uncertainty of the value of Y can be calculated, being used the table:

β	$E_Y = \partial Y / Y$
$\beta \leq 0,75$	$4h / P_1$ %
$\beta > 0,75$	$8h / P_1$ %

· Differential pressure (e_h)

It is associated to the specifications of the register equipment, which can be a transmitter or a diaphragm meter. The manufacturer must provide the performance specifications for the differential pressure device. If the information aren't available, the value of 0,5% can be assumed to the ended of scale for circular letters, and 0,25% for computers. The uncertainty increases as the registration decreases in the scale of the letter, being given for:

$$e_h = URV.hmax / h \qquad (6)$$

where: URV = ended scale error (%)

hmax = maximum value of differential pressure of the equipment

h = registered medium value of differential pressure

The sensitivity coefficient for this uncertainty is 0,5. For other measure processes, type turbine, vortex, and coriolis, are just considered the uncertainty of equipment.

· Aleatory uncertainties of the fluid (e_a)

The variations of the physic characteristics of the fluid affect in an aleatory way the flow measuring. Aleatory mistakes resultants of numerous small influences that affect the results of the measuring system also happen (temperature, pressure and relative density), same when the fluid maintains its constant characteristics. Values for these uncertainties, given by AGA-8 [5] they are:

Variable	S	e_a (%)
Relative density	0,5	0,6
Pressure	0,5	0,5
Temperature	0,5	0,5 or from equipment
Z factor	0,5	0,1

Besides these, for each measure point are informed the normal values of temperature variation and density of the fluid. If this variation increases, the associated uncertainty increases too. It was established a calculation procedure for equipments without instantaneous data acquisition, based on the medium value and in the width of the ranges.

· Pulsation

The pulsation or turbulence in the fluid, due to alternative compressors or of another disturbance sources, causes problems in the measuring, because the basic principle of the measuring presupposes steady state flow. The pulsation index is the reason of the difference between the maximum and the minimum flow, with relationship to the medium. Keyser [4] established an empiric equation, in 1981, for the maximum mistake:

$$B(\%) = 20 \;.\; \exp\left[-\left(2{,}7 - 7{,}2 \;.\; I_p\right)^2\right] \qquad (7)$$

$$I_p = (q_{max} - q_{min}) / (2 \;.\; q_{med}) \qquad (8)$$

· Liquid presence

In the flows of gas with liquid presence, to avoid that it causes liquid passage for the orifice plate, the plate should be holed in the inferior part. This small hole has its diameter defined in function of the hole of the plate and of the diameter of the tube [4], and it requires a correction factor. An additional uncertainty will be established, starting from the correction factor, given for:

$$e_F\,(\%) = 100 \;.\; (d_{small\ hole} / d_{orif\ plate})^2 \;.\; (1 - \beta^4)^{0,5} \quad (9)$$

The liquid presence and the existence of the small hole usually cause a smaller indication in the meter, in relation to the real flow. In the cases in that the small hole doesn't exist, a larger value of e_F is used.

· Meter tube, plate and taps specifications

Relative aspects are considered to the tube, plate, pressure taps, existence of flow retificador and distances of the point to the upstream and downstream accidents. A partial uncertainty is defined for each detail of the plate: orifice diameter (with 6 measures), edge, flatness, thickness, and bevel angle. The diameter of the hole to be considered is the average of the six measures that have to be done, and the uncertainty is calculated starting from the quadratic sum of the differences between each reading and the medium diameter. The specifications of the Norms [2,3] indicate a tolerance of 0,05% for the diameter and a partial uncertainty of 0,07% maximum.

In relation to the diameter of the tube, measures of the internal diameter should be accomplished, 4 measures in each section, to each 45 degrees, and the sections are:

- In the plan of taking upstream pressure;

- In the plan to 0,5 D to amount of the pressure taking;

- In a plan any among the two previous plans.

The medium diameter will be the arithmetic average of the 12 made measures, and the measures must be among 0,997 and 1,003 of this medium diameter, that means a tolerance of 0,3% [3]. The uncertainty is also calculated starting from the quadratic sum of the differences among each reading and the medium diameter, and its maximum value by Norm is 0,4%. When there is not any specific control of the internal diameter, and common tubes are used like measuring tubes, the tolerances increase for 1%, and the uncertainty increases even for values superiors at 1%.

The system owns approaches of increase the uncertainties for each item out of the Norms.

The distances and the type of accidents from all measuring point are reported to the system. The Norms [1,3] define the needs of minimum length for each space, and its rules are also placed in the system, so it has condition of making analysis and diagnosis on the points, identifying problems in the attendance to the rules, as well as to recommend diameters of correct holes to be installed. In case some length doesn't agree, additional partial uncertainties are generated, increasing the value of the total uncertainty.

6. VALUE OF QUALITY

For a measuring point, the quality value defines your relative reliability inside gas network, serving as compare parameter among its several measuring points. To determinate the quality value, relationship between the purpose of the measure, the total uncertainty and the historical of flow adjustment are used.

About the purpose of the measure, the points are classified in:

· Gas sale;

· Supply other units of Petrobrás,

· Transfer among areas;

· Internal measures in an area.

For each category a value of importance is attributed, used to compose the calculation of the quality value. The category of meters for sale of gas presents the largest value of importance.

With relationship to the total uncertainty, that is variable for each point in function of the measure, an inverse relationship was established, that provides to the system a larger possibility to adjust the measure flows in the meters that present larger uncertainty.

In relation to the historical of flow adjustment, an accumulation technique is used [6], for verification the change of tendency of the mistakes. Having tendency variation, it happens a reduction in the value of quality of the point.

7. MATHEMATICAL MODEL

The Linear Programming consists of an optimization of a mathematical model where all the relationships among the variables are represented by linear equations [7,8]. Petrobrás uses specific software for that problem type [9,10].

The difference between the measured value and the consolidated value, resultant of the closing of the balance, is called *deviation*. They were defined 3 deviation types in a measuring point:

· Deviation 1: natural deviation of the point. It can assume, as maximum value, the value of the total uncertainty, when this goes smaller or equal at 2%, that is a reasonable considered value for the measuring process. In the cases in that the uncertainty is larger than 2%, the deviation 1 is limited at 2%,

· Deviation 2: it can assume, as maximum value, the value of the uncertainty of the point, when this goes larger than 2%. Here they cause the normal fittings of the system, for occasion of the closing of the balance,

· Deviation 3: it doesn't have limit. It happens when it is necessary an adjustment greater then the uncertainty of the point, for occasion of abnormal mistakes.

The restrictions of the model also take into account the characteristics physics of the processes through where it passes the gas moved in the network. This has for objective to accomplish a simultaneous evaluation between measuring and processes, identifying common problems. In the case of not getting a viable solution inside of the patterns of the processes, a solution is generated with process deviation, giving indications for correction of the problem and submits the model again.

The main restrictions of the model, that look for to represent the reality of the processes in gas network [11,12], are:

· Nodal gas balance;

· Deviations in relation to the read values;

· Production of non-associated gas, compared to the capacity of the wells;

· Production relationship between oil and gas in the areas;

· Relationship between gas lift and oil production,

· Mass of gas inside pipelines;

· Estimate of gas condensation in pipelines and coolers;

· Flow through compressors in function of its hours of operation,

· Consumptions of gas in the network;

· Operation of the units of processing;

Whole the variables of the model are continuous, what allows to obtain a solution in a quite reduced time. The software uses the method *simplex* [10].

The objective function consists of minimizing the sum of all the deviations of the meters, pondered by its respective quality value, and to avoid any process deviation. The deviations of the type 1 allow to the model the choice of any adjustment in its strip; in the deviations of the type 2, they happen the quality values calculated with base in the importance of the point, in the total uncertainty and in the historical of the fittings; and in the deviations type 3, they are placed factors that only allow its use for occasion of abnormal mistakes.

8.SYSTEM OPERATION

The use of the system follows the following sequence:

· Getting data with application of own questionnaire for the measuring points, and of the elements of the network;

· Assembly of the tables of the model and tests of adherence and acceptance;

· Adaptation of the collection module and modernization of the daily data,

Once implanted, the daily sequence of operation of the system is:

· Feeding of the daily data read in the meters, manually or from automation systems, besides other necessary data to the system (pressures of the pipelines, hours of operation of the compressors...),

· Calculation of the daily uncertainty of each measuring and its quality value;

· Submission of the mathematical model, for closing of the balance;

· Analysis of the solution to verify there was not problems, what points need data correction, or made a new submission of the model.

9. CONCLUSIONS

The system assists to the proposed objectives, and it provides a standardized method of closing of the balances, with management of the gas measuring in an integrated way, without problems of negotiations among areas.

The historical of the measuring mistakes, accompanied by the accumulation technique, allows several advantages.

The mathematical model presented very good results, assisting to the proposed objectives, also presenting an excellent time of execution. The system is being implanted in the state of Bahia.

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11. AUTHOR:

Homero Fenner Filho

PETROBRAS E&P-BA/GEPRO/GEPLAP

Av. Antônio Carlos Magalhães, 1113 Sala 502

CEP 41856-900 Salvador, Bahia, Brasil

Tel 0-xx-713504254 Fax 0-xx-713504388

email homero@ep-ba.petrobras.com.br