Rio Pipeline 2015 Conference & Exposition September, 22-24

IBP1096_15

PIPELINE THERMO-HYDRAULIC SIMULATOR APPLIED TO DELIVERY POINTS' GAS QUALITY DETERMINATION PROCESS

Thomaz Sulocki de Carvalho[1], Philipe Barroso Krause [2], Tulio Campos Lourenço[3], Lucio Abdala de Santana Maia[4]

Abstract

Determining the gas quality of natural gas delivery points is not only compulsory for transmission pipeline companies, in order to comply with the national regulatory agency (ANP) ordinances, but also mandatory from the business perspective, for both the transmission fee and the commodity price depend on the energy delivered, in terms of Higher Heating Value (HHV). So, the energy or HHV is calculated through the analysis of the flowing gas by devices known chromatographs, for each delivery point or city-gate. However, since not every point has a field-installed gas chromatograph, the pipeline operator needs to link actually calculated HHVs to the city-gates that have no local analysis. These calculated HHVs are obtained from devices installed in other stations such as hubs or receipt, delivery and interconnection points. Taking into account all the regulatory, commercial and financial issues, and in order to perform these links precisely, TRANSPETRO has decided to use a pipeline thermo-hydraulic simulator. The technique consists of considering significant variables of the pipeline, namely the volume balance, receipt and intermediate pressure values and the pipeline inventory, to achieve the most accurate results on linking HHVs to delivery points. This methodology represents a noticeable improvement if compared to the previous one, which only considered the volume balance. In spite of that, there is still some room for improvement, since the current simulation considers a steady state, and it is known that the flow, pressure and inventory changes may influence the final result. Therefore, the future challenge is to evolve from steady state to transient state simulation, which must come along with an increased reliability of the field automation to succeed.

1. Introduction

Revenue for transmission is performed in energy (the base rate is R$/MMBTU), and not by volume (m³). For this, you need to associate each volume received or delivered in a custody transfer station to a property of the gas that allows the conversion into energy base. The property chosen was the Higher Heating Value (HHV), which unit is the kcal per m³. Thus, we obtain by multiplying the volume by the HHV, the amount of energy transmitted or delivered (kcal or MMBTU).

The HHV, defined as the sum of the energy released as heat and energy spent on vaporization of water that forms an oxidation reaction, is calculated using formulas described in international standards such as ISO-6976, or ASTM 3588 among others and use as a basis the gas chromatographic analysis. It then becomes extremely important to determine the chromatography or the HHV received or consumed in each custody transfer metering station.

However, we face a problem due to this need: not every delivery point (PTE) has a chromatograph (GC) locally installed to analyze the gas delivered, since it's an equipment with high acquisition costs and high maintenance. Yet, it's in accordance with the ANP Resolution 16/2008. This resolution establishes the specification of natural gas of national origin or imported to be sold throughout the country and mentions in Article 6 paragraph II, that the requirement for local analysis, which would require a dedicated chromatograph, is required only in custody transfer stations with capacity above 400 thousand cubic meters/day and subject to reversal flow.

Thus, on one hand we have to know and determine the chromatography and/or the HHV at each delivery point, but on the other hand, we do not have a chromatograph in each of them. And even in places where there is local

[1] Master, Mechanical Engineer – PETROBRAS TRANSPORTE S.A.
[2] Master, Mechanical Engineer – SIMDUT
[3] Electrical Engineer – PETROBRAS TRANSPORTE S.A.
[4] Chemical Engineer – PETROBRAS TRANSPORTE S.A.

chromatography, if it enters into failure, we must determine a chromatography at this point. The question is how to attend such demands?

Historically, the answers to those questions were based on a volumetric balance, done in an Excel spreadsheet. In the meantime, the requirements concerning reliability of results and reduction of uncertainty (not to mention, eventually, the Company's image) turned this methodology outdated to this new reality. The search for a new tool that could supply all new wishes converged for the use of a thermo-hydraulic simulator. This tool is able to consider a large number of variables inherent to the process of gas transmission.

This paper presents the use of this new tool, considered to be more precise and powerful, to determine gas quality of custody transfer delivery points.

2. Previous Concept to Determine Gas Quality in Delivery Points

For a better understanding of the determination of gas quality, we must first understand the process of insertion of chromatography into flow computers, referred as "writing" in this paper, installed on delivery points. There are basically two ways to write chromatographic analysis on a flow computer, which runs the volume calculations. The first writing is done locally, i.e. there is a chromatographic analysis available at the delivery point. The second is a remotely process, i.e. when chromatographic analysis is obtained from another source. The diagram in Figure 1 shows these two modes of writing. When there is a chromatograph at a PTE, the analysis results are sent to the programmable logic controller (PLC) station, which in turn distributes the information to the flow computer and SCADA (Supervisory Control and Data Acquisition). When there is no chromatograph on the site, it is necessary to determine a chromatograph of origin. After this choice, the information of the test results is sent to the PLC of the originating station, which passes it to the SCADA. The SCADA will share the information with the destination station PLC, which will write the composition in the flow computer.

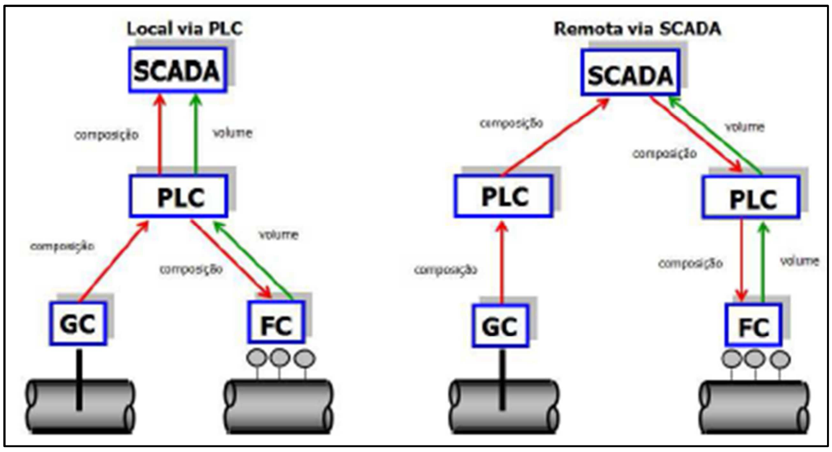

Figure 1 – Modes of writing chromatography on flow computers – on the left, one single station, with a Flow Computer and a Gas Chromatograph; on the right, two stations, one with the Flow Computer, and the other with the Gas Chromatograph.

Therefore, we realize the importance of correct choice of chromatography source. Usually, to set the chromatography to be written in flow computers in points without analysis, we define as the source analysis always the closest point, while observing the most representative gas stream. However, in this fact lies a deep concern. Since the definition of the composition to be written in points that do not have local online chromatograph necessarily involves the analysis of the gas stream, how to ensure that the composition analyzed by the nearest station is the most representative of the gas delivered in those points?

In general, we seek to determine what is pictured in Figure 2.

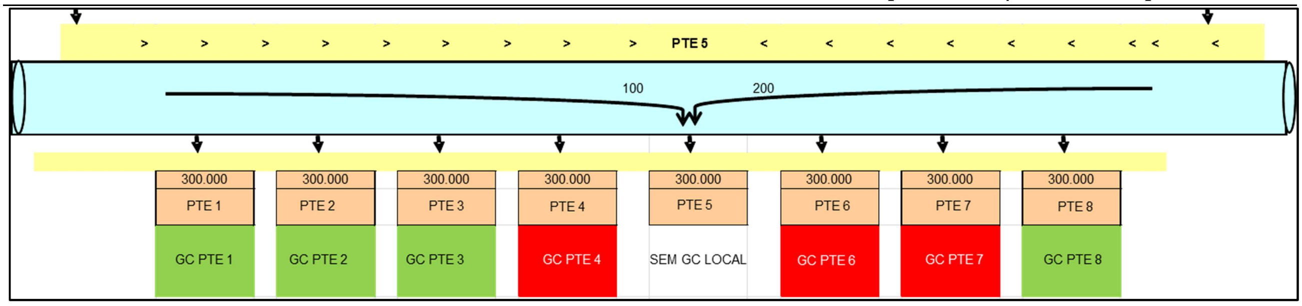

Figure 2 – Gas tracking concern

We want to know where the mixture is (in the above case the PTE 5). To do so, we manage the valid GCs on flow computer at a way such that in the example of Figure 2 we have:

- GC PTE 4, GC PTE 6 e GC PTE 7 with GCs on failure;
- GC PTE 8 must have it analysis written on flow computers of: PTE 8, PTE 7, PTE 6 e PTE 5 (the most representative stream);
- GC PTE 3 has its analysis written on flow computers of PTE 3 an PTE 4;
- GC PTE 2 writing on PTE 2 flow computer and GC PTE 1 writing on PTE 1 flow computer.

There are weak points in this method. By a volumetric balance, we may have different results according to the point or meter where we begin to "discount" the gas (what in the end results in the 100/200 mix proportion). TRANSPETRO's natural gas network has many sources, various interconnections and pipelines with different pressure class, setting the network mesh a unique feature and a different scenario every day. To illustrate the difficulty of this reality, we exemplify a study of case.

We start by the analysis of Figure 3, with the determination of gas quality in a gas pipeline with two reception points and several delivery points distributed along the pipeline. For the first case, we started the volumetric balance by the reception point (PTR) NORTE. Based on the volume of gas received at this point, we discount the gas delivered in each PTE and declared in "Consumo/Vazão" column, until the column value "Vazão Linha Tronco" is inferior to the value of "Consumo/Vazão". In Figure 3, this occurred in PTE 7: the flow at “Vazão Linha Tronco” of 336,048 m³ from the PTR NORTE was not enough to supply the station with consumption of 489,079 m³. So, it was necessary to use the gas stream from PTR SUL on the amount of 153,031 m³. The gas mixture was in the PTE 7 at the proportion of 68.71% for the stream PTR NORTE and 31.29% for the stream PTR SUL. In this case, if PTE 7 did not have a gas chromatograph, its gas quality should be determined by a GC with a similar stream, namely the NORTE stream (CORRENTE NORTE).

GASODUTO OU LOCAL	PTR / PTE	CONSUMO / VAZÃO (Mm^3/d)	CORRENTE	VAZÃO LINHA-TRONCO	% DA ORIGEM DO GÁS
GASODUTO	RECEBIMENTO DO PTR NORTE	2.700.000,00	CORRENTE NORTE	-	100,00%
	PTE 11	0,00		2.700.000,00	
	PTE 10	1.585.677,00		1.114.323,00	
	PTE 9	771.089,00		343.234,00	
	PTE 8	7.186,00		336.048,00	
	PTE 7	489.079,00	CORRENTE NORTE	336.048,00	68,71%
			CORRENTE SUL	153.031,00	31,29%
	PTE 6	56.171,00		652.269,00	
	PTE 5	0,00		708.440,00	
	PTE 4	11.628,00		708.440,00	
	PTE 3	74.339,00		720.068,00	
	PTE 2	97.773,00		794.407,00	
	PTE 1	1.122.606,00		892.180,00	
	RECEBIMENTO DO PTR SUL	2.014.786,00	CORRENTE SUL	2.014.786,00	100,00%

Figure 3 – Gas quality along pipeline (distribution starting by PTR NORTE)

The proposed exercise seeks to show the ambiguity of this methodology, and that's why we will do the opposite. Let's start discounting the gas at PTR SUL, as shown in Figure 4. The procedure adopted is the used previously: we discount the gas consumed in each PTE and declared the "Consumo/Vazão" column until the column value "Vazão Linha Tronco" is inferior to that one. In Figure 4 example, the mixture point is now PTE 9: the flow at “Vazão Linha Tronco” of 156,004 m³ from the PTR SUL was not enough to supply the station with consumption of 771,089 m³. So, it was necessary to use the gas stream from receipt the PTR NORTE on the amount of 615,085 m³. We prove so far that the results between these two examples are different, since this situation puts the mixture not in the

PTE 7, but in the PTE 9, at different proportions as well (79.77% for the stream PTR NORTE and 20.23% for the stream PTR SUL). The PTE 7 and PTE 8, which had previously a gas quality similar to PTR NORTE, have in this case a gas quality similar to PTR SUL stream. This fact implies differences in both calculation of volume and calculation of energy, given that different compositions provide distinct HHVs.

GASODUTO OU LOCAL	PTR / PTE	CONSUMO / VAZÃO (Mm^3/d)	CORRENTE	VAZÃO LINHA-TRONCO	% DA ORIGEM DO GÁS
GASODUTO	RECEBIMENTO DO PTR NORTE	2.700.000,00	CORRENTE NORTE	-	100,00%
	PTE 11	0,00		2.700.000,00	
	PTE 10	1.585.677,00		1.114.323,00	
	PTE 9	771.089,00	CORRENTE NORTE	615.085,00	79,77%
			CORRENTE SUL	156.004,00	20,23%
	PTE 8	7.186,00		156.004,00	
	PTE 7	489.079,00		163.190,00	
	PTE 6	56.171,00		652.269,00	
	PTE 5	0,00		708.440,00	
	PTE 4	11.628,00		708.440,00	
	PTE 3	74.339,00		720.068,00	
	PTE 2	97.773,00		794.407,00	
	PTE 1	1.122.606,00		892.180,00	
	RECEBIMENTO DO PTR SUL	2.014.786,00	CORRENTE SUL	2.014.786,00	100,00%

Figure 4 - Gas quality along pipeline (distribution starting by PTR SUL)

Given those weaknesses, a new solution was necessary in order to provide repeatable and reliable results. The major frailty of this simple volumetric balance is not considering the pressures on pipelines and inventory fluctuation, which provides multiple results to equal situations.

The use of a tool as a thermo-hydraulic simulator allows this improvement, since it is possible to enter and consider the pressures and inventory changes of the system, and also compensate imbalances; and that is why it is considered the most appropriate tool for the gas quality determination process.

3. New Solution to Determine Gas Quality in Delivery Points

3.1. Generalities of Thermo-Hydraulic Simulations

The problems involving fluid flow in pipelines usually require the calculation of flow, pressure loss, temperature or diameters. These problems use the principles of conservation of mass, momentum and energy, often applied to one-dimensional flows. Due to the complexity of the problem, their solutions, in general, are only obtained by means of computer programs specifically developed for this purpose. A Pipeline thermo-hydraulic simulation is a useful tool to support operation, design development and reliability analysis.

We found several tools on the market of this nature and it is up to the user to choose the one that suits best. The softwares chosen and used in TRANPETRO are the Pipeline Manager (PLM) and the Pipeline Studio (PLS). The first one is an online software, extremely important for the training and certification of operators who will supervise and carry out the transmission of gas. It also works as a predictive tool where you can simulate failure scenarios in a range of 8 hours ahead ("look ahead") to observe the system behavior. In turn, the PLS is a more appropriate software to support the operation through the programming of interventions such as pigs launch, stops and starts of compression stations and gas reception points as well as forecast future scenarios of short, medium and long term.

In order to complete the simulation model, the physical characteristics of the network, such as lengths, diameters, locations of supply and city-gates, compression stations and control equipment were collected. The maximum and minimum pressures were established based on performance standards of the Company. The simulation model was developed with the commercial software Pipeline Studio from Energy Solutions. The following general assumptions have been used to build the model:

a) Isothermal flow at 20ºC.

b) The friction coefficient was evaluated by Colebrook equation. The wall roughness and efficiency was adjusted for each pipeline according to the simulation team experience.

c) Equation of state: Sarem

d) Constant viscosity equal to 0.012999cP.

e) Simplified natural gas composition: 0.60 specific gravity, 0.00% of carbon dioxide. The HHV is different for each supply, so that the different compositions could be tracked along the pipeline.

f) The knot space used was approximately one tenth of the pipeline length.

The advantages of using thermo-hydraulic simulations are enormous when we want to estimate gas flow. We obtain more repeatable results and greater accuracy and reliability, taking into account that they were provided based on flow algorithms. We can, however, mention some disadvantages that can be a barrier to its use, and they include increased operational costs, since there is needed a trained and qualified workforce (most of the time, engineers) to simulate and mainly interpret the results, and also acquisition costs of the software.

3.2. Pipeline Thermo-Hydraulic Simulator applied to Delivery Points Gas Quality Determination Process

We emphasize at the outset that there is a great advantage in using a thermo-hydraulic simulator, due to the tools' sufficient capacity and robustness to provide reliable results for gas transmission. In a simulation for determining gas quality, the technological and the conceptual gain compared to the previous method, namely the volumetric balance, coincides directly with the premisses adopted for this study.

The basic premise is the simulation in steady state, based on the real received and delivered volumes of the previous day, acquired through SCADA system. In addition, it is considered as input data the average pressures of reception points and pressure control systems for gas pipelines, such as valves or compression stations operation. The changes in pipelines inventory are observed and interpreted in order to balance the reception points so to translate the real system behavior. Based on this, we can simulate a truer reality of past events and determine, with confidence and accuracy, all gas mixtures and where they occur. We then overcome one of the major problems faced on the volumetric balance, which was the ambiguity of results, and guarantee the closest solution to the real system behaviour with the highest level of confidence.

The natural gas transmission network of TRANSPETRO has several interconnected pipelines, except for the one located at the Northern region of the country. All these pipelines have interactions and, with some abstraction, we can say that a bolivian molecule of gas received from GASBOL in São Paulo, at the Southeast region of the Brazil, can be delivered in Ceará, at the Northeast region of the country. Due to this complexity, the question to be asked when we simulate the gas pipeline network is whether to use a single integrated network or a subdivision of the whole network into smaller systems in order to establish traceability of the gas quality determination process.

The use of an integrated network generates a high computational cost and convergence problems due to the large number of variables and restrictions. Alternatively, it was proved to be possible to work with results obtained from segregated (and previously validated) networks, based on models that had already been developed and were familiar to the execution team. The use of this alternative has brought questions about the ideal point to split the networks. It is important to look first for the flow direction. Supplies points are always a good spot. Nevertheless, if it is in the middle of a network, a mass balance has to be done in order to match the amount of flow in each direction. The best option has proved to be when the compression station is working, because the flow direction is known and it splits the network in two sub-networks: one at low pressure and other at high pressure.

The other question to be answered is: how many sub-networks could be created without causing loss of information. The complexity of the sub-networks and work effort to manually input the boundary conditions from one to other sub-network at the split point must be evaluated. The decision once again was based on the execution team experience. Due to the characteristics of the Brazilian colonization, the major cities and industrial districts are distributed along the coast. Besides, the main natural gas fields are offshore or near the coast. As consequence, the gas network has been developed as a line (mostly) along the coast. The constitution of the single-line transmission network in certain regions, in addition to the knowledge of the gas flow, allowed a division where the interconnections (usually the ends of the pipelines) do not require knowledge of the pressure value as an input, since the goal is to represent the flow held the previous day at that point. If there is any change of flow that alters the system behavior, the information of operational meters distributed along the pipeline are used, which allows the simulation executioner to adjust the simulation of that particular scenario to what has really happened on that day. As the division into subsystems does not degrade the information or the results, it was the solution adopted. This option proved to fasten convergence and make interpretation easier.

Finally, it is important to know that two specific TRANSPETRO pipeline systems do not need to be simulated to track gas quality: one, in the Northern region, called Urucu-Manaus pipeline, which has only one reception point, with no gas mixture along the pipeline, what naturally dismisses a simulation for gas quality determination purposes; and another in the Northeast region, in Bahia State, represented by the pipelines that interconnects multiple gas hub stations (Catu, Camaçari and São Francisco do Conde), with minimum inventory, no transient throughout the day and uni-directional flow.

3.3. Routine of Simulation and Results Application

The methodology to determine the gas quality is constantly being improved. By the time this paper is issued, it will have been a little over a year since its official implementation (May 1st of 2014). In the first few months, a lot of details that were not an issue in the day-to-day operation simulation (used for operation and supervision purposes, at the control room center) were discussed and changed in gas tracking simulation. Yet more: changes were made the other way round, as enhancements of the gas tracking simulation models were implemented on the operation models.

In the simulation routine, the first step is to acquire the volume data from all supply or reception points, delivery points and pressure transfer stations (stations that supply flow to lower pressure pipelines) and pressure data from key points in the network, such as the supply points, compressor stations and pressure transfer stations. It's important to guarantee that the volume and pressure data of borderline points (points at the division of the network, used in multiple models) are matched in all simulations.

The second step is to check if the diference between all the supplies and deliveries is similar to the difference in inventory that occurred within the day. Since TRANSPETRO checks the inventory, this allows to identify quickly if some of the data obtain directly from the SCADA is incompatible with the real operation. Another check is if the flow or pressure exceeds operational or usual limits in each point, which can pinpoint quickly a data error. After the check, the data is inputted in the model.

Since the simulation occurs in a steady state, it must have an equal input and output flow, a feature that does not normally occurs in real gas pipeline operation. The difference, however, can be easily observed on the pipelines inventory and applied to the supplies, in order to equalize inputs and outputs of the pipeline system. The original volumes entered for the delivery points remain unaltered. The decision of which supply to increase or to decrease depends on its distance to the pipelines that had significant inventory change. This adjustment is extremely important in some pipelines, specially the long distance ones, due to the multiple pressure drops and pressure values, caused either by its length or by compressor stations installed along the pipeline.

Once the simulation is concluded, the result is what can be observed in Figure 5. In this real example of a simulation result in Pipeline Studio (PLS), there can be seen two flow streams. The first one, shown in a blue colored line, represents the gas flowing from the left to the right, which is confirmed by the black arrows direction. The second one, shown in a yellow colored line, represents the gas flowing from the right to the left, also confirmed by the black arrows direction. The intersection between blue and yellow streams is the gas mixture point. In this case, this point is “UTE Termoaçu”, and it is painted in yellow because this gas stream (1,804 thousand cubic meters/day) is more representative than the blue stream (243 thousand cubic meters/day).

What the daily simulation result visually shows is that delivery points connected to the same stream color have the same (or very close) gas quality, meaning that if there is no local GC in an specific point, information of remote GC connected to that same stream color can be used, either to provide correction of gas composition on flow computers (chromatography writing), or to obtain the HHV and eventually the energy delivered.

In this specific example, the mixture point, “UTE Termoaçu”, has a local GC. So, the simulation result would only be useful if that GC failed for a moment or had to be maintained, for example. In these situations, it would be necessary to use the gas quality from the nearest GC point on the right, which is “UN-RNCE Guamaré”.

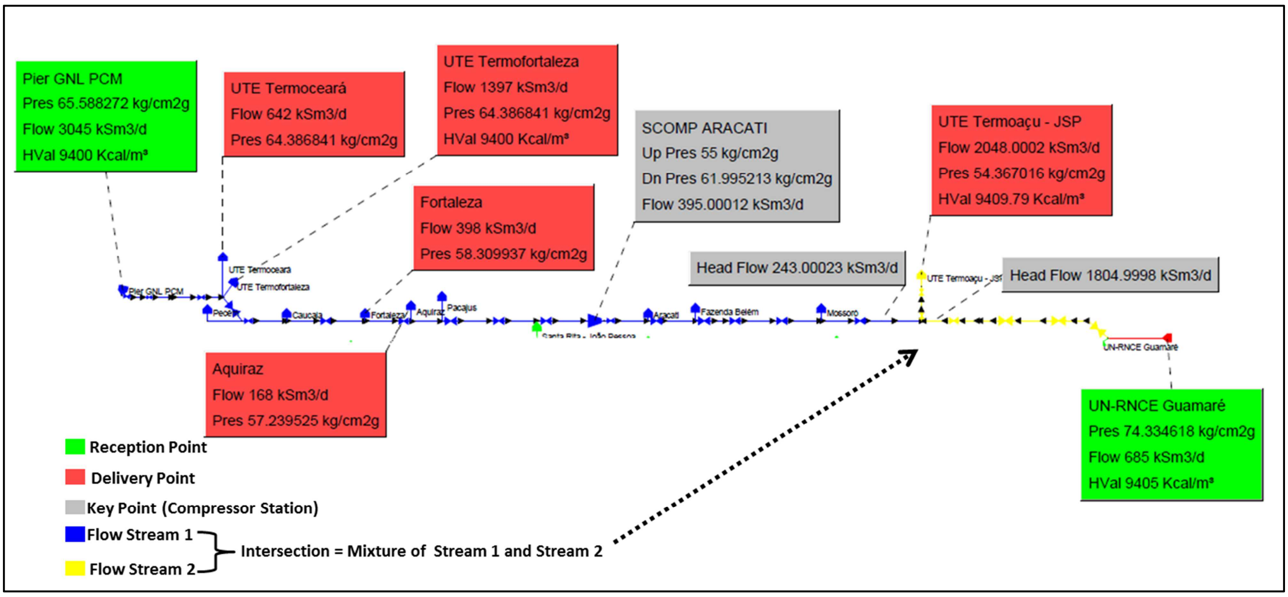

Figure 5 – Real Simulation Result in PLS

Based on the visual interpretation of the gas flow streams and mixture points, which stands on a robust simulation and eventual accurate results, TRANSPETRO’s engineers and technicians are able to properly operate associations among gas chromatographs and flow computers through SCADA system, and also operate the volume and energy validation software that both generates reports to the clients and sends information to the billing software of the company.

4. Future Improvements

Despite steady state simulation method has promoted significantly improvement the quality of the results for

GC associations and gas tracking over the volumetric balance method, there is still room for progress and enhancements. The use of a real time transient simulation of the network would provide even more precise results, for variations of flow and pressure would be considered, since the their values would be the instantaneous ones, not an average.

This issue becomes important especially on situations when large inventory changes (imbalances) on the pipeline, during a certain period, represent the source of gas for some deliveries points (the gas from a reception point does not reach the delivery one). Because the present methodology is in steady state mode, where the volume received equals volume delivered, these situations are not simulated, but inferred by correcting the imbalance on apposite reception points, as mentioned before.

So that the on-line simulator functions properly, it must be fine-tuned and have continuously connected to the SCADA data points, such as flow, pressure, gas composition and inventory, with uninterrupted communication. This condition is essential in order to insure that the model is replicating the real operation as close as possible.

Currently, TRANSPETRO's team is facing some issues at this matter, trying to establish reliable and continuous communication between SCADA and the on-line simulator, and then increase confidence to implement the upgrade from the steady-state mode to on-line mode.

The main difficulty is related to loss of signal for some instruments, mostly gas chromatograph data. For the simulation to determine the quality of gas being delivered in each delivery point, it must know the full spectrum of the gas being received into the supplies at all times. Whenever the simulator does not have the input of one or more components, it loses the convergence of the calculations. Besides the chromatograph data, the failure or bad data of other variables such as temperature, flow and pressure, can corrupt the simulation and even lead to simulation shut down or present erroneous results.

5. Conclusion

On TRANSPETRO's day-to-day operational routine, it is necessary to determine the gas composition of every delivery point, either to comply with ANP ordinances, to correct the compressibility of the volumes, or to define the HHV of the gas delivered, since gas transmission contract tariffs are based on energy (R$/MMBTU).

The initial methodology established for this routine, based on a volumetric balance performed in an Excel spreadsheet, indicated some weaknesses, such as lack of repeatability of the results. Therefore, TRANSPETRO's Operations Team decided to adopt a new methodology, stood on a robust Thermo-Hydraulic steady-state simulation software.

The use of Thermo-Hydraulic Simulations in the "gas composition versus delivery point" association, or "gas quality tracking" process, brought more accuracy, repeatability, traceability, and also readiness and comprehensibility of the gas directions, streams and mixture points of the pipeline network, mainly because of the visual friendly aspect of the result diagrams. This new process not only promoted significant improvement of the results, but also confidence and transparency of the whole gas measurement process, what eventually contributes to the company's image forward to the clients.

However, challenges will continue to be sought. The next step is to stabilize communication between the on-line simulation software (PLM) and SCADA. Once this link is reliable, the on-line simulation will be implemented, and the state-of-art for this process achieved.

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