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METHODOLOGY FOR CAPACITY CALCULATION APPLIED TO THE BRAZILIAN NATURAL GAS PIPELINE NETWORK

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Abstract

The Brazilian law number 11909 from 2009, commonly known as “Gas Law”, improved the regulatory rules related to free access to the infrastructure of natural gas transportation and imbued the National Oil & Gas Agency (ANP - Agência Nacional de Petróleo, Gás Natural e Biocombustíveis) the attribution to set standards and criteria to determine the capacity of transport gas pipelines. Despite the legal framework establishing several definitions for transport, booked, available and idle capacity, no technical procedures to calculate those capacities were defined. International experience shows that several different methodologies were used accordingly with the specifics characteristics of legislation and gas pipeline infrastructure on each country.

In the Brazilian case, the legislator concerns in establishing the several definitions of capacity were focused on optimizing the transport infrastructure and promoting free access to it. This access must occur by a transport service contract, using firstly the available capacity (firm and extraordinary transport service contract) until it is fully used. In this way, a correlation can be identified between optimized technical values, linked to the gas flow on the pipelines, and commercial values, defined by contracts. With this focus, there is no meaning on declaring a single and static capacity for a pipeline as a whole and, in fact, the important values are the capacities for every delivery point were the gas would effectively be available for booking.

With this in mind, ANP developed a two-year project in partnership with PUC-Rio/SIMDUT that raised the main characteristics of all the transport gas pipelines, defined the minimum requirement for a thermal hydraulic flow simulator, standardized the capacity reports for the transport companies, created and documented models for all national gas pipeline to use thermal hydraulic flow simulation and defined the methodology to calculate capacity. This methodology follows a step-by-step system where initially the maximum transport capacity is calculated for each delivery point, without violating any technical or contractual condition of the pipeline network. To insure operational flexibility, the methodology subtracts from this calculated number the value related to an Operational Margin, specific to each pipeline or network. The resulting capacity is the commercial capacity. The available capacity is the difference between commercial capacity and booked capacity for each delivery point. Using mutually excluding available capacities as access criteria assures the methodology consistency. This must be applied to all delivery points and is linked to the physical and contractual configuration of the pipeline or network. Any modification implies recalculating the capacities and publishing the new values.

The methodology was applied to the national gas network, using historical delivery values, and the results were registered in standardized tables, validating the feasibility of the project. Complementary projects will be developed to incorporate each transport company definition of operational margin and to prepare the future transport contracts be in accordance with the methodology.

1. Introduction

The Brazilian Gas Law established several concepts for capacity that must be published by the transport companies:

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- Booked Transport Capacity: Daily volume of natural gas that the transport company must deliver for the carrier, accordingly with the contract established between them;
- Transport Capacity: Maximum daily volume that the transport company can deliver in a given gas pipeline;
- Available Capacity: Part of the transport capacity that hasn't been subject to a contract on a firm basis; and
- Idle Capacity: Part of the booked capacity that temporarily isn't being used;

To assure free access to the pipeline for any interested third party , the law defines the access in three forms: Firm, using the available capacity; Interruptible, using the idle capacity; and extraordinary, using the available capacity. This access must first be given to all available capacity to be contracted. Afterwards, the idle capacity can be commercialized. With the access format defined, the next logical step is to determine the value of each type of capacity. In this item, the Gas Law doesn't establish any standard technical procedure to define the capacity. Consequently, the gas transport companies divulge their capacity values using their own methodology and criteria.

Considering the legal capacity definitions and the attribution to promote access the capacity of gas transport pipeline, ANP developed a two year project with SIMDUT to define a single methodology to calculate capacity that could be applied to all Brazilian natural gas pipelines. An initial research about existent work was made in the national bibliography. Gama (2001) discusses the parameters that influence the maximum transport capacity of a natural gas pipeline. All discussions are based on a simple pipeline, but the definition of booked capacity and how the natural gas can be distributed to the city-gates isn't approached. Silva & Santos (2009) did an extensive bibliographic research on the subject on the international definitions and applications on capacity so as to draw a parallel with the national system. It highlights the importance of capacity definition and its role in the transparency and subsequent third party access to natural gas transport infrastructure. This work also stresses the importance of thermohydraulic simulation reports and the need for standards.

Additional research showed that, internationally, the GTE – Gas Transmission Europe, a subdivision of the GIE – Gas Infrastructure Europe, published in 2003 a report were it proposes a methodology to calculate the available capacity. In the report, the available capacity depends on the calculation of the technical capacity, which in turn depends on the technical characteristics of the system and the hypotheses used during the creation of the scenario for supply and demand of natural gas, but again the examples used are for fairly simple pipelines. The European Parliament published in 2009 a regulation (EC) No 715/2009 (www.eur-lex.europa.eu) that deals with the s to access the natural gas transport network, were it presents several capacity definitions similar to the ones on Brazil's Gas Law and, on the consolidated review of 2015, determines that "transmission system operators shall publish a detailed and comprehensive description of the methodology and process, including information on the parameters employed and the key assumptions, used to calculate the technical capacity".

Following this resolution, in Hungary, the operator FGSZ Natural Gas Transmission Private Company Limited by Shares (www.fgsz.hu) presents a methodology to calculate the available capacity for both the supplies and deliveries of the transport network, where the firm available capacity is obtained using the difference between the possible largest hydraulically transportable quantity and the allocated capacity by the system's user on a daily basis. Despite mentioning that the allocated capacities for internal distribution and storage by the operators must be considered, no details are given about the calculation methodology. The same line of thought is used by the Belgium Regulator. The CREG (Commission for Electricity and Gas Regulation, www.creg.binfo/pdf/Etudes/F1035ENG.pdf) and Pinon & Cuijplers (2006) present a methodology for capacity calculation to best suit the needs of the users and increase network efficiency. Initially the concept of useful capacity is introduced, which is the same as total theoretical capacity (or technical capacity) minus the capacity reserved by the operator to insure the integrity of the system and operational requirements.

The Portuguese Regulator, ERSE - *Entidade Reguladora dos Serviços Energéticos*, published (ERSE 2008) a methodology to determine the capacity of its natural gas transport network. Using this methodology, the available capacity for commercial purposes on the relevant places on the network is obtained using a computer simulation model of the network, where the boundary conditions are configured by the consumption profile of the city-gates expected for several time periods and the maximum possible value at the supplies, limited by technical configuration of these places.

In Spain, the standards for managing the natural gas system (*Boletim Oficial del Estado*, n. 115, 2005) use several definitions for capacity. The ministry for Industry, Tourism and Commerce (*Ministerio de Industria, Turismo y Comercio*, 2007) establishes that the capacity calculation of natural gas transport system is accomplished by combining the capacity of the elements that compose it, the maximum production of regasification plants, the maximum flow of gas pipelines and compressing stations, the maximum injection from underground storage and maximum flow from regulation and measurement stations. Initially the maximum capacity must be calculated taking the system to its limits or, in other words, until a restriction on the network is reached. With this value as a limit, in order to determine the viability of a new connection (supply or delivery) the behavior of the network will be analyzed from the base scenario and the capacity will be recalculated accordingly to increasing flow scenarios until a new limit is reached. Observing the procedures, it isn't clearly shown how to saturate the network to its limits.

In other European countries, like Germany (Bundesnetzagentur, 2009), United Kingdom, where one of the transport companies, National Grid Gas, publishes a document on their website (National Grid, 2009) and Norway, where the operator is GASSCO AS there are works done about methodology to calculate capacity.

In the Indian market, there is a concern by the legislator to establish concepts of capacity similarly to Brazil. The Petroleum & Natural Gas Regulatory Board issued a note in 2010 to provide access to the available capacity on a nondiscriminatory basis and to determine the transport rate. In the methodology, the gas pipeline must reach a steady state based on the contractual conditions (flow, pressure, temperature) of the supplies and deliveries. The pressure must be maximized accordingly with the MAOP or the maximum available pressure at the compressing stations and the pressure at the city-gates must be calculated considering the maximum contractual flow. After finishing the steady state, and assuming the supply doesn't have a flow limit, the scenario must run until any customer connected to the network reaches the minimum pressure at a city-gate or the maximum power available at a compressing stations is reached. The value found for capacity in this final scenario will be the maximum capacity for the network or pipeline.

In Argentina, Alvarez et al (2009) postulate that a gas pipeline project capacity is based on hypothesis made before construction and that real capacity represents the pipeline performance obtained after the beginning of the commercial operation. This reference says that any definition of capacity is a photography, a picture of the network at a point in time. It's notable that capacity is directly linked to contracts on a firm basis, contracts which must have set conditions to operate, such as flow and pressure limits. Alvarez et al also point out that this number only has value if accompanied by a report detailing the methodology and hypotheses used to calculate it. In relation to new demands (with or without adding new supplies or city-gates) a new calculation must be made to check the technical feasibility of the demand, without compromising previous contracts. An example is presented, where initially a steady state based on the existing demands for the city-gates and the maximum supply pressure is calculated. Then a hypothetical new demand profile is analyzed, and it is checked if the new profile can coexist with the old ones. In this specific case, the city-gates have a very variable daily demand schedule and the study will analyze if the transient regime can support the new demand.

With this international bibliography as support, ANP and SIMDUT developed a methodology for capacity calculation for Brazilian gas pipelines, considering the law's definition of capacity and the technical viability of its application. The goal of this paper is to present this methodology.

2. Methodology

2.1. Concept

The main concern of Brazilian legislators in establishing capacity definition is to optimize the use of transport infrastructure and to promote free access to it, using contracts of transport service, first using all of its available capacity (firm and extraordinary). Ergo, a relation between optimized technical values, linked with gas flow in the pipelines, and commercial values, defined by contractual conditions, can be made.

Unlike most European countries, all Brazilian gas pipeline network is used to transport gas consumed internally, without having any gas passing through the country for the purpose of export. In practical terms, for the Brazilian situation, the offer of transport service for hiring only makes sense when there is a specific destination in mind to where this capacity will be available. Considering that an amount of gas will only be available at a city-gate (PTE, acronym in Portuguese), the gas must come from one or more supplies (PTR, acronym in Portuguese), the capacity must be defined e declared not by pipeline, but by each city-gate where it will be delivered.

It's important to notice that a city-gate can be served by more than a single supply in the same pipeline or network. All supplies have project limitations for pressure and flow. To optimize access to the infrastructure, it's considered that the interest for the available capacity will come from new carriers, which will use different equipment than the ones dedicated for the established carriers. Considering this, the premise used is that the supplies only have pressure limitation when calculating capacity.

When discussing the evolution of the gas pipeline network over time, the methodology is based on a picture of the physical and contractual configuration of the network existing at the moment of the calculation. In the case of a new entry proposal to the network considering new supplies or city-gates, or if the capacity needed is higher than the one offered in the moment, a new study must occur considering the changes needed for the new situation. This should be made by the transporter after a third party makes a request.

At last, the concept of capacity calculation developed can be applied in a single pipeline, a section of it, or a network of pipelines. To simplify the calculation, whenever possible the network should be divided in smaller parts. This segmentation should be made following the logic of the results obtained using the whole network.

2.2. Computer Simulation Model

The use of computer simulation to study gas pipelines is used to project new pipelines or old ones, capacity study, future flow prediction, day to day operation, among others. The software to this purpose uses the conservation equations of mass, momentum and energy trough approximations and simplifications, such as single dimensional flow and Newtonian fluids. To build the models the physical characteristics of the pipelines must be reproduced. Parameters such as diameter, roughness, elevation profile, among others must be provided, as well as gas compositions. The operational variables, such as maximum operating pressure and equipment procedures must also be considered. Some concepts of operation and contractual obligations must be defined, since they can also serve as boundary conditions for the equipment.

2.3. Booked Transport Capacity

The firm transport contracts define a network operational condition that must be technically possible, to make sure they can be complied with. In this way, the characteristic of this condition is the starting point of the methodology. The booked transport capacity between a supply and a city-gate must be calculated accordingly with the following items:

a. At the supplies used in the analysis, the pressure condition must be limited to the Maximum Allowable Operation Pressure (MAOP) of the studied section of the pipeline.
b. In the case of branches that supply city-gates and have pressure control stations (ERP), the control pressure at the station must be the same as the MAOP of the branch.
c. The city-gates (PTE) analyzed must be set to the maximum flow on their contract, as long as it's smaller than city-gate maximum flow defined in its project.
d. The compressing stations must have their pressure sets defined in order to minimize power consumption while insuring the needed flow. The outlet pressure is limited by the pipeline's MAOP. The suction pressure and power limits must be observed.
e. The thermal hydraulic calculation simulated must identify the resulting pressure at the city-gates. These values cannot be inferior to the contracts minimum pressure. The resulting flow at each city-gate will be the booked transport capacity for each city-gate. The pressure variation along the pipelines and the value at the interest points (city-gates, connecting points, compressing stations, among others) represent the operational condition of the pipeline or network. It's important to notice that since the calculation is based on the physical condition of the pipeline or network, any changes must generate a new calculation.

2.4. Transport Capacity

The transport capacity for a city-gate in a pipeline or network must be calculated using the following steps:

a. The model must initially be configured according to the model used on item 2.3, Booked Transport Capacity.
b. The compressing stations must be configured to maximized flow on the city-gate studied, respecting the system limitations.
c. Using the model developed, the city-gate's flow must be maximized above its contract obligations until some limit in the system is reached, either technical or contractual (besides the city-gate being studied).
d. The resulting flow will be the Transport Capacity for that specific city-gate. It's important to notice that this capacity is based on the specific condition of the studied system. Any physical or contractual change must generate a new calculation.

Ergo, the transport capacity must be considered the maximum flow transported to a city-gate without considering factors such as operational flexibility and reliability, when using this methodology. When considering this factors, the transport capacity can decrease.

2.5. Available Capacity and Commercial Capacity

The available capacity, based on the Gas Law, is the difference between the transport capacity (using the procedure on item 2.4) and the booked capacity (using the procedure on item 2.3). However, the available capacity will be defined not for a pipeline, but for each city-gate. If the capacity calculated is offered, it could impair de system's operation, since it maximizes pressure limits, leaving no room for safety during normal operation conditions.

To avoid this situation, the concept of operational margin was introduced, to accommodate commercial and operational fluctuations. This margin is composed by the carriers demand for supply variations (imbalance) and by the operator demand, that requires some flexibility to accommodate changes in the operational configuration and system reliability. This margin does not include fails in the transport service, usually defined in the transport service contract. This concept also applies to pipelines interconnection points.

As a result, the concept of Commercial Capacity is defined by the difference between the Transport Capacity and the Operational Margin. If only part of the Commercial Capacity is booked, the rest will be the Available Capacity. A representation of this concept can be seen on Table 1.

Table 1 – Capacity for a City-gate and interconnections points

Transport Capacity		
Operational Margin	Commercial Capacity	
	Booked Capacity	Available Capacity

The existing contracts present variations for the contracted values on a firm basis, due to seasonal variations, so the available capacity will also have to reflect this variation and, as a consequence, different values of available capacity can exist for the same city-gate.

The fuel gas needed to operate the equipments (compressing stations, heaters, coolers, among others) and the lost and unaccounted for (LUAF) gas, as long as represented on the simulation model, are already considered in the capacity calculation accordingly to the methodology. It's not possible to define the parcel of fuel gas needed to comply with each city-gate's demand, being impossible do define a relation with the city-gate's transport capacity. However, it is possible to quantify the increment in fuel gas, named Additional Fuel Gas, needed between the base case (booked capacity) and the full use of the available capacity of a city-gate.

2.6. Idle Capacity

The Idle Capacity, also mentioned on the Gas Law, is the part of the Booked Capacity that isn't being used. The value can be calculated using past programmed schedule and the real delivery observed at each city-gate. However, to offer this capacity, one must be able to predict when it will occur in the future so that the Idle Capacity can be divulged and offered with sufficient time to be contracted.

Initially, an estimate of the Idle Capacity can be based on the monthly schedule. Afterwards, the carriers must request a forecast of the daily gas consumption to be received on the supplies and the specific delivery at the city-gates during the period. This request must be consolidated by the transporter, who will generate a transport schedule for the period. When calculating the difference between the booked capacity values and the schedule values, the resulting value will be the idle capacity for the period for each city-gate or supply. This process can be repeated based on the daily schedule for each city-gate, having a greater certainty since it will predict the next day. The monthly values present a more uncertain prediction, but are easier to contract and offer. Since this is an interruptible service, it's implicit that the Idle Capacity could not be fully available in case the firm based request has priority over it. It is necessary to establish criteria to define when the Idle Capacity should be offered, as well as how it should be offer and booked.

It's important to remember that, in the same way as the Available Capacity, the Idle Capacity will be defined using the methodology defined here, so it will be divulged by city-gate, and not by gas pipeline.

3. Applying the Methodology

3.1. Case 1

To exemplify the use of the methodology, a situation on a fictional pipeline is presented where there are booked capacity values at the city-gates and there is a demand to increase the booked capacity for two city-gates. To simplify the problem, the operational margin won't be considered on this example. The network configuration is presented on Figure 1. Table 2 shows the fictitious contracted flow values for the city-gates, as well as its technical and contractual limits. The MAOP for the pipeline is 100 kgf/cm²g. The pipe diameter is 12 inch. The total length is 210 km.

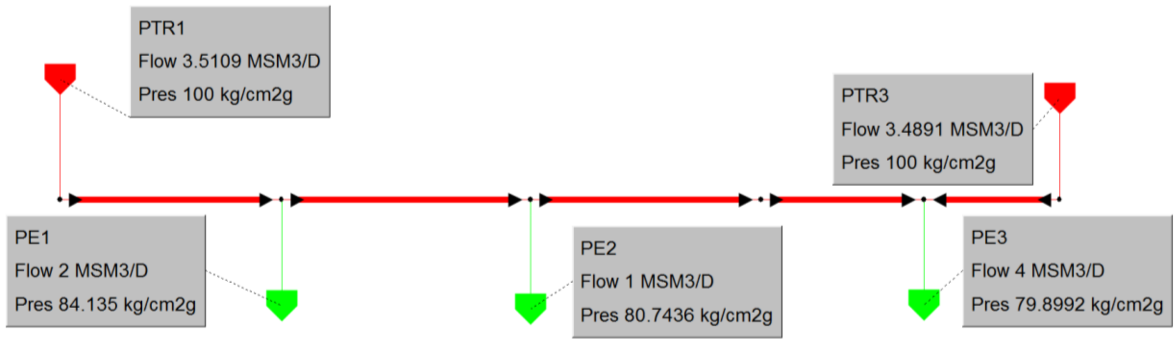

Figure 1: Network Configuration

Table 2: City-Gates Data

City-Gate (PTE)	Location (Km)	Minimum Pressure (kgf/cm²g)	Maximum Project Flow ($10^6 m^3/d$)	Booked Flow Capacity ($10^6 m^3/d$)
PE1	40	35	6.0	2.0
PE2	80	35	6.0	1.0
PE3	160	35	8.0	4.0

To calculate the capacities according to the methodology proposed, the following steps must be taken:

Step 1 – Adjust the supplies to their maximum pressure;
Step 2 – Adjust the contractual flows at the city-gates and run the simulation in this condition;
Step 3 – Raise the flow on PE1 until it reaches either the technical flow limit at the city-gate or a contractual limit on the system. The result is shown on Figure 2.

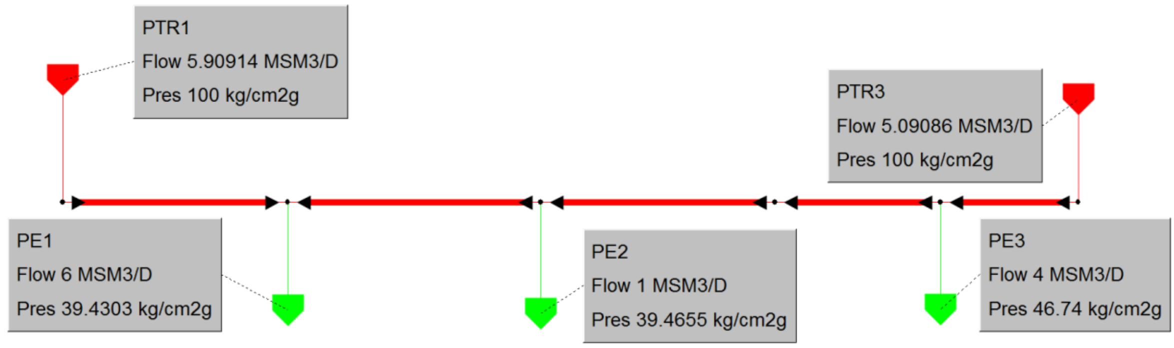

Figure 2: Transport Capacity results for PE1

- Step 4 – Raise the pressure on PE2 until it reaches either the technical flow limit at the city-gate or a contractual limit of the system. The result is shown on Figure 3.

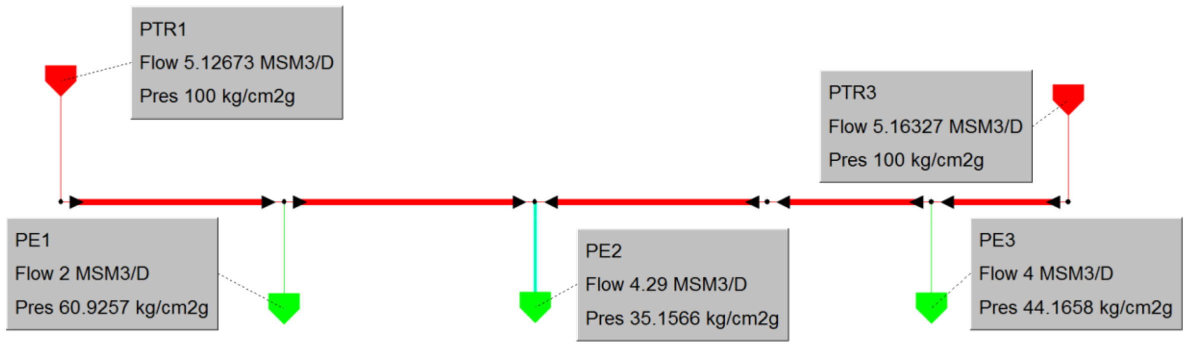

Figure 3: Transport Capacity results for PE2

- Step 5 – Raise the flow on PE3 until it reaches either the technical flow limit at the city-gate or a contractual limit of the system. The result is shown on Figure 4.

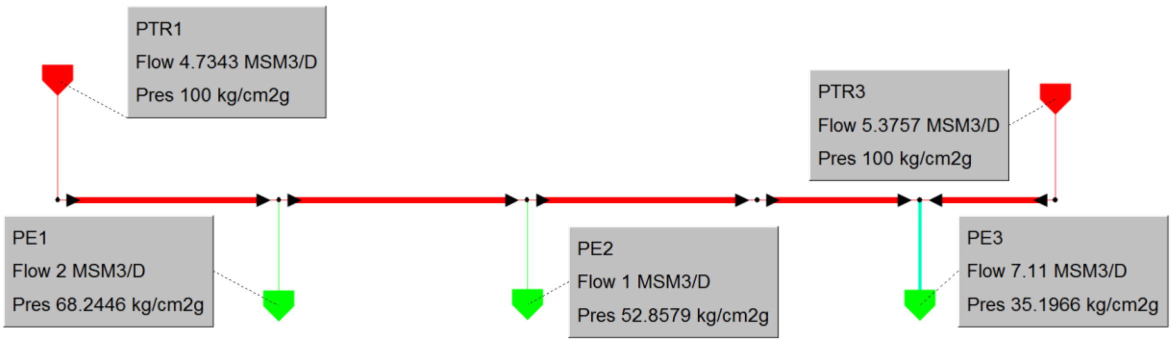

Figure 4: Transport Capacity results for PE3

- Step 6 – Build a table (Table 3) with all the capacity results for all the city-gates on the system.

Table 3: City-Gates Capacities

City-Gate	**Minimum Pressure (kgf/cm²)**	**Technical Flow Limitation (10^6m³/d)**	**Booked Capacity (10^6m³/d)**	**Transport Capacity (10^6m³/d)***	**Available Capacity (10^6m³/d)****
PE1	35	6.0	2.0	6.00	4.00
PE2	35	6.0	1.0	4.29	3.29
PE3	35	8.0	4.0	7.11	3.11

* The flow increase is obtained from both supplies PTR1 and PTR3.
** Values aren't cumulative. They are mutually exclusive.

3.2. Case 2

Table 3 shows that there is Available capacity in all the city-gates for an individual contract. In the case of an increase in consumption for more than one city-gate, it's necessary to run a specific simulation for that case. For instance, if the request for added flow contemplates an increase of 3.5 10^6m³/d in PE1 and 2.3 10^6m³/d in PE2. As can be seen on Figure 5, this increase is possible without hitting any of the technical and contractual limits of the system.

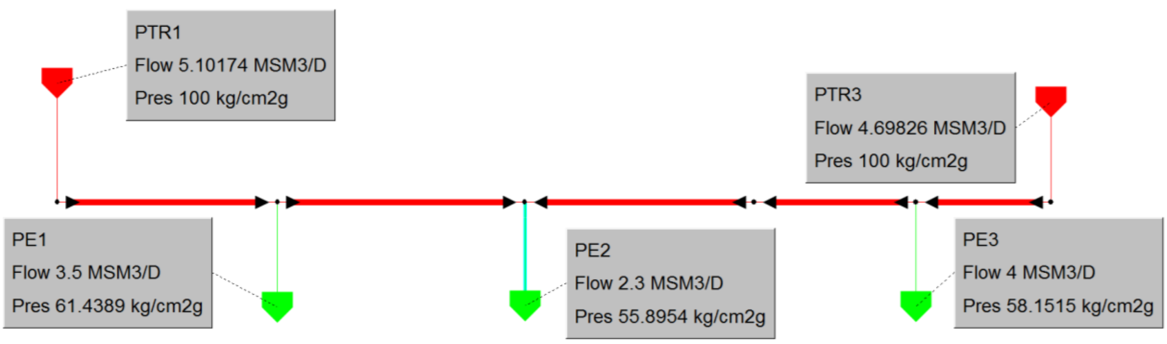

Figure 5: Flow Increase in PE1 and PE2.

After the increase in consumption at the city-gates, it's necessary to redo the capacity table considering the new values. Redoing the procedure will result in Table 4.

Table 4: City-Gates Capacities

City-Gate	Minimum Pressure (kgf/cm²)	Technical Flow Limitation ($10^6 m^3/d$)	Booked Capacity ($10^6 m^3/d$)	Transport Capacity ($10^6 m^3/d$)*	Available Capacity ($10^6 m^3/d$)**
PE1	35	6.0	3.5	4.76	1.26
PE2	35	6.0	2.3	3.28	0.98
PE3	35	8.0	4.0	5.19	1.19

* The flow increase is obtain from both supply PTR1 and PTR3.
** Values aren't cumulative. They are mutually exclusive.

3.3. Case 3

Using the same system as Case 1, where a network shown on Figure 1 has its capacity as shown on Table 2, is requested to have an increase in demand of two city-gates simultaneously, 4.0 $10^6 m^3/d$ on PE1 and 3.0 $10^6 m^3/d$ on PE2. Individually, it is possible to meet this demand. However, as seen on Case 2, when studying multiple increases, it's necessary to run the simulation for this particular situation. In this case, it's not possible to provide the new demand, since the system reaches a limit first (minimum pressure on PE2), as show on Figure 6.

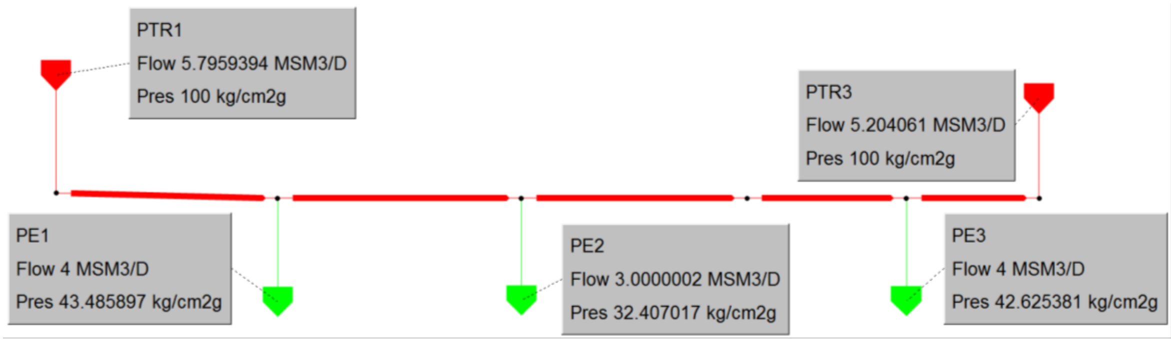

Figure 6: Simulation results for Case 3

Since the methodology shows that it's not possible to increase the flow for the demanded values in this system, a set of rules to prioritize the demands should be carried out.

4. Conclusion

This article presents a study on transport capacity for gas pipelines as used around the world and the methodology proposed for the Brazilian market, accordingly to Brazilian Gas Law. While there are similarities with other markets around the world, the focus of Brazilian Gas Law is on gas pipeline transport capacity, making it difficult to apply other methodologies directly. However, since the objective of pipeline transport it to supply the city-gates, this methodology changes the focus from pipeline capacity to apply the capacity definition for the city-gates and interconnection points themselves.

Nowadays, some of natural gas transport contracts in Brazil don't define transport capacity that will be delivered in each city-gate. It is relevant to highlight that the sum of all the flow limits for each city-gate on this contracts doesn't match the pipeline transport capacity. Using the proposed methodology, it's necessary to know each city-gates contractual flow to calculate the capacity.

The application of this methodology relies heavily on computer simulation model for a gas pipeline or network of gas pipelines. The current legislation already demands that the transport companies divulge their capacities trough hydraulic simulation reports, but usually those reports are poor on details of model construction data and boundary conditions, making it difficult to verify the results.

The relevance of Operational Margin was presented to accommodate the daily operational fluctuations of a gas pipeline. It's necessary to study all the elements that can affect the pipeline operation so that it can be incorporated to the Commercial Capacity. The transport companies must present their calculation methodologies for the Operational Margin, since they are the ones with the best knowledge of their systems and its peculiarities. The regulation agency (ANP) must then evaluate this methodology. , Once its applicability has been confirmed, the calculation methodology for the Operational Margin should be declared alongside the capacity reports.

Capacity calculations depend heavily on the quality of the information used to assemble the simulation models, as well as the boundary conditions used. With that in mind, ANP divulged in February 2016 a study where it used statistic methods to evaluate the values for Booked Capacity on the Brazilian Network. The study shows a flow historic for each city-gate, using observed consumption data divulged by the transport companies, and from that evaluates the best way to define the booked capacity.

A continuous work to keep the simulation model updated will be needed as well, since every change in the networks, such as a new city-gate entry, increase in the capacity of a supply point, a new compressing station, among others, will change the previous calculated capacity values.

In order to provide more transparency, the project documentation was made available for consultation on the ANP internet page (http://www.anp.gov.br/wwwanp/movimentacao-estocagem-e-comercializacao-de-gas-natural/transporte-de-gas-natural/consultorias-contratadas).

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