ABSTRACT

The Mexican Energy Regulatory Commission, Comisión Reguladora de Energía (CRE), has recently approved the use of new short-term service agreements. The need for the agreements within the national gas pipeline system (SNG) was triggered by the development of pipeline infrastructure and is described in the national infrastructure plan developed by the Energy Ministry, Secretaría de Energía (SENER). The Mexican National Center for Natural Gas Control, CENAGAS, required a mechanism to include the new agreements in pipeline simulations. This paper explains the pipeline simulation techniques being implemented to model the new agreements.

The steady-state and transient simulation offers justification for the construction of new facilities; and establishes the operating requirements of new interconnections and the installation or reconfiguration of compressor stations. The paper also discusses how CENAGAS incorporates the pipeline simulation techniques for short-term service agreements into the existing capacity determination processes. The paper also verifies the parameters and assumptions that CENAGAS has determined are important for pipeline simulation of the new short-term service agreements.

INTRODUCTION

The Mexican energy industry has been in a process of significant reform since a constitutional amendment took effect in December 2013. The monopoly that Pemex once had is being broken up and divested. CENAGAS, a relatively new organization, has been brought in to manage, administer and oversee the operations, transportation and storage of natural gas within Mexican borders. CENAGAS also has responsibility of overseeing the bidding process through which private enterprise can invest in the energy sector.

The period 2010-2017 recorded an average annual decrease in production of 4.7%. In 2017, the national production of natural gas was 4.2 BFCD (Billion Cubic Feet Per Day). The south-east of the country contributed 70% of the national production, and from 2016 began to register production by the new oil operators, registering 20 and 35 MMCFD (Million Cubic Feet Per Day) for 2016 and 2017, respectively.

Natural gas production in Mexico is declining (33% in the period 2010-2017), and the import of natural gas has steadily increased, reaching 4.0 BCDF in 2017. Overall imports have tripled in the period 2010-2017, with a significant import growth of approximately 72% between 2014 and 2017. The outlook for Mexico is that demand will grow to approximately 9.7 BCDF by 2032 as shown in Figure 2.
Figure 1 shows the forecasted trend corresponding to the national supply of natural gas, combined imports and production. Imports transported by pipeline could reach 4 BCFD by 2032. Additional LNG has not been considered in the current plan. To cope with the growth in demand several different projects have been proposed. New compression stations and reconfiguration of existing compression stations or rehabilitation of existing infrastructure that will allow Mexico to have the pipeline capacity to comply with the customer requirements.

The transport, storage and distribution of natural gas in Mexico, has several stages. Produced or imported dry gas is transported from its point of origin to the points of consumption, which are sited in several ways. Large users or large interconnections will have direct offtakes. Distribution systems are interconnected in urban areas, or in industrial parks that will typically have a pressure step. The point of origin and responsibilities can be:

1. Gas Processing Centers (CPG); all are operated by PEMEX and are interconnected with the Integrated National Natural Gas Transport and Storage System (SISTRANGAS).
2. Interconnections with pipelines that come directly from the gas fields (National).
3. Interconnections at the border with pipelines abroad (USA), called “inpatient” ducts (Importations).
4. LNG regasification Plants (Importations).

In Mexico, the provinces with potential of natural gas reserves are shown in Figure 3. Based on the distribution of the original 3P (“Proven” reserves plus “Probable”, plus ”Possible” reserves) volume, the total national volume of natural gas is 258 BCF.

The liberalization of the market and the supply-demand dynamic have determined the speed at which Mexico is developing its pipeline infrastructure. Pipelines interconnecting Mexico with the US are allowing consumers to meet their demand needs by piping lower cost imports from the North American production. Mexico is currently importing almost 50% of its total natural gas consumption. Last year, the US exported a total of 4.2 BCFD to Mexico.

New projects set to be completed within the next few years will be responsible for this continued growth. As US-Mexico export capacity continues to grow, new challenges will emerge. Likewise, the construction of new inter-regional pipelines, and the expansion of existing facilities, are bringing benefits to regional markets where supply constraints are known, such as the expansion in the peninsula region.

This work highlights the steady-state and transient strategies which have been designed to establish the new pipeline infrastructure (new compression stations and reconfiguration of existing compression stations), the results and conclusions of the simulations were used by CENAGAS to guarantee the transport capacity required to meet the demand for natural gas in the coming years.

**Natural Gas Infrastructure.**

One of the Energy Reform advances during 2015 was the transfer of the assets of the National Gas Pipeline Systems (SNG) and Naco-Hermosillo from Pemex to CENAGAS. This meant PEMEX transferred to CENAGAS nearly nine thousand kilometers of pipelines, with a capacity of more than 5 BCFD of natural gas, the initial infrastructure that CENAGAS received is shown in Figure 4.

Among the natural gas transport systems in Mexico, the most important is SISTRANGAS. It is a set of interconnected and integrated systems., made up of:

- National gas Pipeline System (SNG).
  - Owned by the National Center for the Control of Natural gases (CENAGAS), which serves as the central system;
- Six Private peripheral systems.
  - Managed by CENAGAS and can be seen in Figure 5.

In addition to the integrated systems, SISTRANGAS operate other private, non-integrated gas pipelines for tariff purposes, which complement the natural gas pipeline transport network in the country, currently around 14,400 km and expected to reach 19,000 km, including those projects that are in development.

According to SENER, in the period 2012 to 2018, 3392 km have been added to the pipeline network of Mexico, and it is estimated that 8552 km more will be added at the end of the 2019. This is because of completion of delayed and planned projects that are fundamental to the development of the natural gas market in the country.

CENAGAS, as a “watchdog” of SISTRANGAS, ensures efficient and equitable competitive market conditions, conveys and stores the largest amount of natural gas in the country, and fosters third-parties. Thereby, CENAGAS, as a Natural-Gas transportation permit holder (Transporter), oversees managing the operation and maintenance of the infrastructure transferred from PEMEX.

**Scope**

With the assets transfer from PEMEX, the Transport and Storage Unit (UTA) of CENAGAS is now responsible for the operation and maintenance of the National Pipeline System (SNG). This system has 8611 kilometers of pipelines and a capacity of more than 5 BCFD of natural gas. See Figure 6.
The expansion of natural gas infrastructure has been a result of growing U.S. natural gas imports, and a current decline in Mexico’s energy production coupled with growing natural gas demand and domestic pipeline network expansion. This growth is largely being driven by the power sectors. As a result, CENAGAS has laid out recommendations to increase domestic pipeline interconnections, to further distribute natural gas throughout the country, and to meet the requirements of user supply and demand. See Figure 7.

**PIPELINE SIMULATION DEVELOPMENT**

The planned expansion of the Gas Pipeline Network (2015 – 2030), requires extensive simulation of the network. CENAGAS-UTA, developed a pipeline simulation system with the purpose of verifying the growth of supply and demand whilst avoiding the critical operating conditions due to insufficient capacity in the SNG. The configuration of the system adopted for the development and integration of the hydraulic models, considers all the main pipes of the SNG, from 4 "to 48" diameter, with a total length of 5348 miles (8610 kilometers) and includes the pipe elevation profile. This configuration is shown in the pipeline system schematic in Figure 8.

**Steady-State Analysis**

To determine the impact of growth on the network Steady-State analysis was used. Estimates of growth were gathered from the various natural gas outlook sources and year on year analysis performed.

The steady-state analysis provided a general overview of what facilities planning would be required over the 5-10 years; and it also provided a set of initial conditions from which to execute the transient analysis to allow us to study diurnal loads.

The steady-state scenarios considered the historical average of the supply and demand of each year from the period 2015-2018. Each year was regarded as a steady-state scenario, described in Table 2. These simulations established the base or initial scenario (current conditions) to configure the transient scenarios from 2019 to 2023.

The main pipeline system is over 30 years old and the physical configuration of the network is complex. The concepts of equivalent series and parallel systems were used to simplify the calculation of the operating conditions of the National Pipeline Gas (SNG) of CENAGAS, so it was necessary to evaluate through steady-state simulations the physical parameters such as roughness and the gas equation to determine whether the network may meet the predicted demands.

Using roughness values of 0.005 in (12.7 microns) and the natural gas friction factor equation Colebrook, the pipeline simulation system was tuned using real data obtained from the SCADA platform and the daily reports of the operating conditions, obtaining as pipeline efficiency on average of the 96%. With these parameters the base model was configured for all simulations of steady-state and transient analysis, to meet the predicted demands. See Table 1.

### Table 1. Typical pipe configuration for the network

**Supply and Demand assumption**

Based on the pipeline simulation system developed for the SNG and considering historical values (2015 to 2018) of the imports; the national production and demand of natural gas is shown in Figure 9. Simulations were carried out in steady-state to establish the maximum transport capacity of the SNG, the pipeline simulation system is thus a valuable tool to identify and evaluate capacity and flow requirements in pipelines.

The evaluated capacity and linepack are shown in Table 2.

### Table 2. Evaluated capacity and linepack for SNG

The current infrastructure of natural gas assets is shown in Figure 8 and considers the current imports. Simulations were executed in steady-state to establish the current transport capacity of the SNG, as seen in Table 3.

### Table 3. Current capacity and linepack for SNG

The analysis of the simulations in steady-state indicate that in
the period of 2016 to 2018 some electrical consumption had dropped and migrated to other pipelines, resulting in a decrease in the actual transported capacity of SNG. 4 compressor stations have stopped operating.

### Transient Analysis

The steady-state simulations were performed based on the estimated supply and demand for each year from 2019 to 2023. The results of each prospective scenario were programmed as follows: 2019-2020, 2020-2021, 2021-2022 and 2022-2023. The configuration of the time series in the pipeline simulation system is shown in Tables 4 and 5.

The integrated results of the transient flow simulations allowed to identify network constraints and how to reduce these restrictions, for example:

- Increasing installed compression power at one or more stations.
- Capacity bottlenecks existing pipelines or sections of the pipeline.
- A combination of both power and pipe capacity limitations.

The transient analysis established the critical times when planned project execution needs to take place to modify the infrastructure of the network. In this case study the goal was to predict when compressor stations need to be commissioned to meet demand.

Evaluation of the transients begins with a balanced base case (current values), given the assumptions presented in Fig 9. Considering capacity and linepack parameters indicated in Tables 3, 4 and 5, different transient flow simulations were completed to evaluate the short-term infrastructure requirements. Sensitivity to different factors was tested (e.g., capacity bottlenecks, incremental flow, pressure drop on specific segments, lack of compression at a certain date, etc.).

### Results

Based on the assumptions made in the analysis of steady-state and transient simulations, in the period 2019 to 2023 the gas demand in SNG increases by 11%, as per Figure 10, and the supply increases 10%, per Figure 11. According to the results of the simulations, the national pipeline system (SNG) will have to be reinforced with incremental compression, to handle a total flow of at least 6100 MMSCFD in 2026. Additional storage will be needed as line pack in the national pipeline system is being used in lieu. See Figure 12.

<table>
<thead>
<tr>
<th>Name</th>
<th>Current Values</th>
<th>2019-1s</th>
<th>2019-2s</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply_1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>239</td>
<td>334</td>
<td>334</td>
<td>334</td>
</tr>
<tr>
<td>Supply_2</td>
<td>0</td>
<td>0</td>
<td>84</td>
<td>84</td>
<td>230</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Supply_3</td>
<td>340</td>
<td>366</td>
<td>380</td>
<td>391</td>
<td>408</td>
<td>410</td>
<td>410</td>
</tr>
<tr>
<td>Supply_33</td>
<td>250</td>
<td>270</td>
<td>285</td>
<td>290</td>
<td>302</td>
<td>310</td>
<td>316</td>
</tr>
<tr>
<td>Supply_34</td>
<td>270</td>
<td>291</td>
<td>302</td>
<td>310</td>
<td>323</td>
<td>330</td>
<td>335</td>
</tr>
<tr>
<td>Supply_35</td>
<td>200</td>
<td>206</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Total</td>
<td>5080</td>
<td>5100</td>
<td>5156</td>
<td>5303</td>
<td>5528</td>
<td>5536</td>
<td>5611</td>
</tr>
</tbody>
</table>

Table 4: Trend of supplies for transient analysis

<table>
<thead>
<tr>
<th>Name</th>
<th>Current Values</th>
<th>2019-1s</th>
<th>2019-2s</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery_1</td>
<td>250</td>
<td>270</td>
<td>285</td>
<td>290</td>
<td>302</td>
<td>310</td>
<td>316</td>
</tr>
<tr>
<td>Delivery_2</td>
<td>270</td>
<td>291</td>
<td>302</td>
<td>310</td>
<td>323</td>
<td>330</td>
<td>335</td>
</tr>
<tr>
<td>Delivery_3</td>
<td>200</td>
<td>206</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Total</td>
<td>5080</td>
<td>5100</td>
<td>5156</td>
<td>5303</td>
<td>5528</td>
<td>5536</td>
<td>5611</td>
</tr>
</tbody>
</table>

Table 5: Trend of deliveries for transient analysis
CASE STUDY:

Reconfiguration of the Cempoala compressor station in Veracruz, Mexico

The CFE growth forecast indicates increased electricity demand in the Center and Southeast region of Mexico. Even considering the new interconnections to the Pipeline National System (SNG) to reinforce the supply balance in the southeastern, the Yucatan peninsula, suffers from recurring gas supply shortages. Imports from the United States do not reach the southeast pipelines, which are supplied mostly with associated gas from the oilfields from the southern coast (National Productions). These injections have been declining, and most of the gas injected into the region’s gas pipelines is shipped north to demand centers in central Mexico. The required demand cannot be provided, so it is necessary to reconfigure the Cempoala compressor station in Veracruz, Mexico to allow gas to move to the central and south zone. In the current infrastructure, the Cempoala compressor station is not operating and normal direction of flow on the SNG is from the south toward central and towards the southeast. See Figure 13.

Different transient flow simulations were performed to evaluate the short-term infrastructure requirements of the reconfiguration of the Cempoala compressor station to complete the required demand in the southeastern region.

In Figure 14, the capacity for Cempola compressor station is shown and indicates that in the period 2019-2023 start up with a capacity of 1100 MMCFD is required.

With transient simulations, the power requirements are 15000 hp. Once completed the reconfiguration would allow the 1400 MMCFD compressor station to move gas south through central Mexico and toward the southeast, in the reverse direction of the current flow on that section of the SNG.

The parameters obtained from the simulations for the design of the station of compression of Pátzcuaro are: capacity: 250 MMCFD and horse power: 6300 hp.

The parameters obtained from the simulations for the reconfiguration of the station of compression of Cempoala are for one step are: capacity: 1400 MMCFD and horse power: 18000 hp.

CONCLUSIONS

In conclusion, Figure 14 shows the different projects that are been planned based in the transient simulations. They include new compression and rehabilitation of existing compression.

- Pátzcuaro Compressor Station is being designed as a new station.
- Cempoala Compressor Station is an existing station being reconfigured. Construction is planned to start in 2018 and end in 2019.

REFERENCES

1. Natural Gas Outlook 2017 - 2031, SENER
2. Integrated National Natural Gas Transportation and Storage System.
4. Status of Gas Pipelines June 2018, SENER.
5. Reservas de Hidrocarburos en México. Conceptos fundamentales y análisis 2018. CNH

BENEFITS

In the period in the period of 2016-2017, the pipeline simulation system CENAGAS employed was developed to reinforce the main functions for natural gas provision and transportation in the most secure, efficient and reliable way possible. To date the UTA has developed and integrated different hydraulic models. These simulations were performed to evaluate the following short-term infrastructure requirements:

1. New compressor station in Pátzcuaro
2. Analysis of the demand in the Center region
3. Reconfiguration of the Cempoala compressor station to improve the capacity in the southeast region.

AUTHOR BIOGRAPHY

Cesar Naranjo has been involved in Pipeline Simulation for more than 25 years, working with the Mexican Institute of Petroleum (IMP), Petroleos Mexicanos (PEMEX) and National Center for Natural Gas Control (CENAGAS). He holds an undergraduate degree in Chemical Engineering from the National Autonomous University of Mexico (UNAM), has been a thesis advisor as "Software for the detection of leaks in liquid transport ducts through the transient flow model" and “Simulation of Hydraulic behavior of a distribution network of natural gas to transient flow ". His current role at CENAGAS is the simulation coordinator and applications of the SCADA of the pipeline transport systems of the (SNG) and the Naco-Hermosillo system (SNH).
Paul Dickerson has been involved in Pipeline Simulation for more than 20 years, working with LICenergy, Energy Solutions International and Emerson. He holds an undergraduate degree in Computer Systems Engineering from the University of Sunderland and Global MBA from Durham University. His current role at Emerson is the Technical and Engineering Product Manager for pipeline management solutions.
FIGURES

Figure 1 – Trend natural gas import and national production expected in the period 2015 to 2032

![Natural Gas Import and National Production (2015-2032)](image)

Figure 2 – Trend natural gas demand projections 2017 to 2032

![Natural Gas Demand (2015-2032)](image)
Figure 3 – Distribution of the original 3P volume of natural gas

<table>
<thead>
<tr>
<th>Province</th>
<th>Key</th>
<th>Reserves (MMMCFC)</th>
<th>Prospects (MMMCFC)</th>
<th>Total (MMMCFC)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1P</td>
<td>2P</td>
<td>3P</td>
<td>Conventional</td>
</tr>
<tr>
<td>Burgos</td>
<td>1</td>
<td>1.1</td>
<td>1.7</td>
<td>2.3</td>
<td>13.1</td>
</tr>
<tr>
<td>Sabinas, Burro - Picachos</td>
<td>2</td>
<td>0</td>
<td>0.1</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Golfo de México profundo</td>
<td>3</td>
<td>0.4</td>
<td>0.9</td>
<td>2</td>
<td>44.4</td>
</tr>
<tr>
<td>Tampico-Misantla</td>
<td>4</td>
<td>1.2</td>
<td>5.4</td>
<td>10.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Sureste*</td>
<td>5</td>
<td>6.7</td>
<td>10.2</td>
<td>13.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Veracruz</td>
<td>6</td>
<td>0.6</td>
<td>1.1</td>
<td>1.8</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>10</strong></td>
<td><strong>19.4</strong></td>
<td><strong>30.1</strong></td>
<td><strong>76.3</strong></td>
</tr>
</tbody>
</table>

* Including: Cinturón Plegado de Chiapas y Plataforma de Yucatán
In the transfer of assets CENAGAS receives, 11,347 km of transport Pipelines:
- 9,118 km Operated by PEMEX (SNG)
- 2,229 km Operated by third parties
Figure 5 – SISTRANGAS Pipeline System
Figure 6 – Current Infrastructure of Natural gas

CURRENT INFRASTRUCTURE OF NATURAL GAS

- Pipelines operated by CENAGAS
- Pipelines operated by private parties
- CENAGAS compression stations
- Private compression stations
Figure 7 – Expansion of the Gas Pipeline Network (2015-2030)
Figure 8 – National Pipeline System (SNG) Schematic

The hydraulic model has configured:
Supplies: 34
Deliveries: 100
Pipes: 698
Generators: 22
Block Valves: 813
Check Valves: 9
Regulators: 42
Figure 9 – National supply, Imports and Demand of the SNG

Figure 10 – Supply forecast transient analysis for the SNG
Figure 11 – Demand forecast transient analysis for the SNG

Figure 12 – Linepack trend transient analysis for the SNG
Figure 12 – Current infrastructure for Southeast Region
Useful Conversions:

54 kg/cm²/g = 783.2 psig; 66 kg/cm²/g = 957.2 psig

650 km = 403.9 miles
Figure 14 – Short-term infrastructure requirements were evaluated from transient analysis for the SNG