TECHNICAL PROCEDURES FOR USING SYNTHETIC NATURAL GAS AS AN ALTERNATIVE TO NATURAL GAS IN DIFFERENT SUPPLY CONDITIONS FOR INDUSTRIAL CUSTOMERS

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ABSTRACT

The Synthetic Natural Gas (SNG), as considered in this work, is a blend of Liquefied Petroleum Gas (LPG) and air used to replace Natural Gas (NG). This paper describes different strategies for using SNG as an effective substitute of NG in base-load, backup, and peak-shaving supply conditions to overcome NG supply interruptions from Local Distribution Companies (LDCs) for industrial consumers. The replacement of NG by SNG for industrial uses must deal with technical difficulties, which do not always allow both gases to be immediately exchangeable. The authors point out some of the difficulties involved in the process and propose ways to overcome them during a gas replacement process.

KEYWORDS

Synthetic Natural Gas; Liquefied Petroleum Gas; propane-air blend; gas replacement; gas exchangeability

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1. INTRODUCTION

The Synthetic Natural Gas (SNG), sometimes referred to as Substitute Natural Gas, can generally be described as a variety of manufactured gases from coal, oil derivate, or biomass. The Synthetic Natural Gas (SNG) considered in this paper is a blend of Liquefied Petroleum Gas (LPG) and air used to replace the Natural Gas (NG).

The replacement of NG by pure LPG certainly requires changes in most of the burners and flow trains since those two gases belong to different gas families. Therefore, the exchangeability between NG and LPG is not straightforward. For example, in a steel mill, there are hundreds of gas burners, which require great amounts of investment and are responsible for production losses during the conversion from NG to LPG and from LPG to NG at a later stage. Such situation causes undesirable business disruption, which makes the NG and LPG usually not exchangeable in practice. Nevertheless, the use of SNG seems to be a more suitable alternative for substituting NG for industrial customers. The blend of LPG with air at a specific ratio will dilute the pure LPG and allow the substitution of the NG in the existing burning systems.

SNG can then be adopted as an alternative to NG when industrial consumers have to deal with eventual disruptions in the supply of NG from LDCs. It can also be used when industrial customers have to provide an early gas supply, i.e., when businesses have to supply the gas even when the NG distribution grid is not yet available.

Using SNG is not the only alternative to substitute NG. Under special supply conditions, the NG delivered through pipelines by the LDCs can also be replaced by Liquefied Natural Gas (LNG) and/or by the Compressed Natural Gas (CNG) delivered by alternative logistic systems based on boats, barges, trains, or trucks. This paper will explore how the adoption of SNG might be a more flexible and cost-effective solution to overcome temporary shortages in NG supply, as described in an experience that took place in Brazil.

Supplying LNG or CNG is a complex task due to the large investment required in the process. Moreover, differently from the LPG, which can be kept liquefied indefinitely, under lower pressure, CNG requires costly transportation and

compressing efforts. The LNG needs to be kept under cryogenic temperatures to avoid the boil off, which limits its storage and transportation times.

As described in Section 2, the SNG is more suitable for operating in short periods of time in backup or peak-shaving supply conditions. Moreover, there are interesting cases justifying the adoption of SNG in base-load supply conditions. Yet, the replacement of NG by SNG for industrial users must deal with great technical difficulties considering that the perfect gas exchangeability is not a straightforward task.

Section 3 focuses on the most common method used to guarantee the exchangeability between two gases, which is based on the Wobbe Index. In industrial applications, this method used for NG and SNG can sometimes lead to problems such as incomplete combustion and flame instability. More adequate procedures, as explained in Section 4, were introduced in the Brazilian experience and led to convenient results. Eventually, changes in the combustion parameters are proposed taking into account how the gas-air ratio in the burner system is controlled.

2. TYPICAL SNG APPLICATIONS

Emulating NG with SNG is a conventional proposal, which can be used in base-load, backup, and peak-shaving systems as shown in Sections 2.1 to 2.3. The use of SNG is not a new idea; it started over 50 years ago (Ely Energy, 2004a). However, the advent of more sophisticated controlling systems based on the Programmed Logic Controllers (PLCs) provided a better gas quality as an outcome as well as more safety throughout the process. The applications of SNG can be summarized in three major strategies:

- (i) Overcoming the lack of NG in base-load supply for few years due to NG supply constrains;
- (ii) Backing up NG delivery interruptions drawn from accidents, interruptible contracts, or any sort of maintenance needed in the transportation or distribution systems;
- (iii) Dealing with NG supply restrictions in peak hours, due to upper limits in the contracted demand, or high pressure drops in old and under dimensioned gas pipelines (peak-shaving).

2.1 SNG for base-load

Base-load systems using the SNG are the best way to overcome base-load restrictions on NG supply, lasting over just a few years. The foremost alternatives are to feed the SNG into the NG grid and blend the two gases; or to dedicate a gas grid to operate exclusively with SNG. In either way, the internal gas pipelines, the control systems, and the burners will be ready to receive the NG whenever it becomes available.

A SNG base-load system can help to anticipate the gas supply for NG grids built in regions with no immediate access to the NG. Such solution was pursued in Uruguay, with a LDC called Conecta, which operated with SNG before the Country started importing NG from Argentina. Less frequently, the SNG base-load system is conceived to operate in longer terms serving consumers located where the NG grid is not expected to reach.

Another strategy was proposed in Brazil to reduce the overall NG supply risk from the LDCs. There, a few large industrial customers already connected to the NG grid, and holding a significant share of the total NG consumption, were chosen to be eventually converted to operate with the SNG. Such strategy sought to alleviate any long-term major supply restrictions for the rest of the NG grid.

2.2 SNG for backup

The need for energy backup is related directly to the risk of interruption in the existing main energy supply system. Concerning the use of NG, usually the main causes for supply interruptions are the unexpected accidents or the necessary stops for maintenance in transportation and distribution systems. In both cases, the pressure in the NG grid tends to fall. The amount of time over which the gas pressure will still allow the consumers to be supplied of the product depends upon several factors such as the grid volume, the initial pressure, and the gas demand downstream the interruption point.

When a NG supply break occurs close to the end of a single pipeline, the pressure can drop down in just few minutes in case of a high gas demand. Such perspective turns the provision of SNG backup systems almost mandatory in order to avoid business interruption and/or further losses for the customers.

Another reason to justify the existence of a SNG backup system is to allow an industrial consumer to improve its NG contracting strategy changing (totally or partially) from firm to interruptible contracts. Usually interruptible gas contracts lead to important fuel cost reductions, particularly under major gas price fluctuations. Still, the consumer will have to count upon the SNG to substitute the NG whenever the NG supply is interrupted by the LDCs.

In an emerging NG market, such as Brazil, the gas provision for the anchoring industrial customers is based on restricted supply alternatives, which increase the risk and the concerns related to NG supply interruption. Very expensive equipment such as high temperature furnaces in the glass works, steel mills, ceramic industries, or foundries cannot run out of gas without the risk of permanent damages. The installation of SNG backup systems proved to be a suitable solution.

2.3 SNG for peak-shaving

The use of SNG for peak shaving must be understood under two perspectives: the daily and the seasonal peak shaving. The first is required daily, over just few hours in weekdays, when the flow rate in the NG grid reaches its maximum value. The pressure drops at the end of the distribution system creating bottlenecks, which make it difficult to match the expected demand in the grid. The restrictions become more critical when the gas grid operates with old and/or underdimensioned pipelines, which reduce even more the capacity for the LDCs to supply the market.

The use of SNG peak-shaving stations at the end of the NG grid allows LDCs to aggregate new costumers into the gas grid with minor investment. Instead of investing heavily to expand and/or modernize the whole NG grid, which may not be possible or profitable, the SNG will help to cope with the punctual bottlenecks.

Similarly, SNG peak-shaving facilities might be suitable to balance the NG supply system and match the total gas demand in the high season. Usually the high season may take place during the winter in the cold countries and throughout the summer in the hot countries. The restrictions in the NG supply are registered over the entire peak

season and not only for few hours a day. The shorter is the average high season, the more competitive is the SNG for seasonal peak shaving, as compared to other solutions such as liquefied natural gas (LNG) or underground NG storage.

In a tropical and rainy country like Brazil, daily peaks are more common to happen than seasonal peaks. Yet, Brazilian winters can be dramatically dry, implying in less water availability to the national hydropower system. The electricity sector will, then, demand large amount of NG for power generation. Therefore, in Brazil, the high season in the NG market may occur in the beginning of the summer, at the end of the dry season. The NG-fired power stations will operate and reduce the NG availability for other users. The need for SNG will increase during the high season.

3. TECHNICAL ASPECTS OF THE GAS REPLACEMENT

Usually, it is not possible to exchange gases from different families without any change in the user's burning system. According to Reed, the most common method to evaluate the exchangeability of fuel gases must take the *Wobbe Index* into account (Reed, 1986).

3.1 Explaining the *Wobbe Index*

The *Wobbe Index* (also called *Wobbe Value* or *Wobbe Number*) is defined by Equation 1 (Williams & Lom, 1974):

$$W = HV / (SG)^{1/2} \quad (1)$$

Where:

W – *Wobbe Index*

HV – Calorific value (usually gross)

SG – Specific gravity

The unit of the *Wobbe Index* is the same unit of the calorific value (so it could be kJ/m³, kcal/m³ or BTU/ft³). Physically, the *Wobbe Index* represents a factor that is proportional to the flow of energy through an orifice submitted to a differential pressure.

In the case of a burner nozzle with a defined gas orifice submitted to a given differential pressure,

the pressure upstream is delivered by the burner flow train while, downstream the nozzle, the pressure of the combustion chamber is equal to the atmosphere. According to Equation 1, if only the calorific value of the gas increases, the heat flow will also increase as well as the burner power. On the other hand, if only the specific gravity of the gas increases, the heat flow will decrease, which means a lower burner power.

Admitting that both the heat demanded by the process and the volume of air or oxygen delivered to the combustion are not supposed to change, then, the replacement of two fuel gases must keep the same burner power. Therefore, according to Ely Energy (2004b), the *Wobbe Index* is one way to indicate the gas exchangeability. In other words, by comparing two fuel gases, both characteristics, i.e., the calorific value and the specific gravity will likely vary at the same time. Only gases with the same *Wobbe Index* as formulated above may provide the same burner power.

3.2 The *Wobbe Index* and the families of fuel gases

The International Gas Union (IGU), as registered by Pritchard et al. (1977), usually classifies the fuel gases in three "families" according to their respective *Wobbe Index*, at 15°C, and atmospheric pressure at sea level (101.3 kPa absolute):

(i) The 1st family is constituted by the coke-oven gas, the town gas or the manufactured gas (usually made from coal or naphtha), and the hydrocarbon-air mixtures, which have the *Wobbe Index* ranging from 17.8 to 35.8 GJ/m³ (Giga Joules/ m³);

(ii) The 2nd family is formed by the NG and the equivalent SNG, presenting the *Wobbe Index* within the range from 35.8 to 53.7 GJ/m³;

(iii) The 3rd family is composed by the LP Gases, i.e., the propane, butane and other blends, with the *Wobbe Index* ranging from 71.5 to 87.2 GJ/m³.

Theory usually points out that the *Wobbe Index* must be kept unchanged when two fuel gases are substituted without changing the heat input rate across the burner. Thus, the replacement of two fuel gases from the same family can be pursued without changing the main characteristics of the combustion (i.e., the burner power and the flame stability).

Table 1. The NG and the SNG's main characteristics.

CHARACTERISTICS	UNIT	NG	SNG
Gross caloric value	kJ/m ³	39,356	58,841
	kcal/m ³	9,400	14,000
Net caloric value	kJ/m ³	36,006	53,629
	kcal/m ³	8,600	12,809
Wobbe index (gross)	kJ/m ³	49,349	49,349
	kcal/m ³	11,787	11,787
Wobbe index (net)	kJ/m ³	45,149	45,149
	kcal/m ³	10,784	10,784
Specific gravity	None	0.636	1.411
Density	kg/m ³	0.763	1.696
Stoichiometric air	m ³ air / m ³ gas	10.3	13.9 (*)

Remarks: m³ at 20°C and 101.3 kPa abs.

(*) the air content in SNG was taken into account.

Accordingly, the most suitable alternative gas to replace the NG is indeed the SNG, keeping the same *Wobbe Index*. As stated by **Williams and Lom (1974)**, the replacement of the NG by the SNG is not supposed to cause any problem if their *Wobbe Indexes* do not differ in more than about 5%. To get such SNG with a *Wobbe Index* equivalent to the NG, the LPG-air ratio (in volume basis) must be 51.3% of LPG and 48.7% of air. Based on such LPG-air ratio, the NG and the SNG will present the main characteristics as shown in Table 1.

Some aspects can be highlighted from Table 1: (i) Comparing the heat values of both gases, 1 m³ of SNG is equivalent to 1.49 m³ of NG; (ii) The NG is lighter than air while the SNG is heavier than air; (iii) The stoichiometric combustion air to be delivered to the burning system is 13.9 m³/m³ of SNG (and considering the air content of 0.5 m³/m³ of SNG itself, the total stoichiometric combustion air equals to 14.4 m³/m³).

As stated by **Denny et al. (1962)**, such a SNG is not hazardous because the LPG-air ratio is still far from the LPG inflammability limits. The inflammability limits for commercial propane and butane, the main components of the LPG, vary within the range from 1.8% to 10% of LPG (in volume basis) in the gas-air mixture (**Jenkin, 1965**). Consequently, there is no risk to deliver the SNG from the blenders to the burners by pipelines.

Another important feature is that besides the specific gravity of the LPG (between 1.7 and 1.8)

and air (equal to 1.0) being so different, the SNG is considered as a homogeneous mixture, as stated by the Graham's Law – the law of gas diffusion (**Taylor, 1973**).

4. THE REPLACEMENT OF NG BY SNG IN PRACTICE

As discussed above, the theory states that the main property to be kept unchanged in order to guarantee an adequate replacement of NG by SNG is the *Wobbe Index*. Yet, this statement is only accurate when the gas flow across the burners is controlled by a pressure differential. Therefore, in the cases where the residential as well as the commercial gas consumption is dominant, focusing on the *Wobbe Index* method to guarantee the exchangeability between the NG and the SNG usually leads to a satisfactory solution; feeding the SNG into the NG grid and just blending the two gases will provide suitable answers for the customers.

However, in industrial burner systems, flow meters usually will control the gas-air ratio. In such a situation, holding the *Wobbe Index* unchanged may not guarantee the equal heat input rate across the burners. Therefore, the *Wobbe Index* method alone may not guarantee directly the perfect gas exchangeability. Performing additional changes in the combustion parameters as well as checking the

flame conditions are required to avoid important technical difficulties for the customers.

The following five conditions must be considered during a gas substitution in industrial users: (i) Both gases must provide equal heat input rates; (ii) The system as a whole, including the pipelines, valves, control equipment, burners, draft devices, and other equipment such as heat recovers, regenerators, and dust collectors, must be in grade to handle both fluids; (iii) The flame stability at the burners must be maintained; (iv) The heat transfer from the flame to the equipment must keep the same pattern; and (v) The flue gases inside the equipment must have the same function, so as to provide the same grade of oxidizing, neutral, or reducing atmosphere (Reed, 1986).

When a PLC controls the gas and air flow rates across the burner in order to set up the power and the flue gas characteristics of the combustion, the assumption of unchanged *Wobbe Index* is no longer enough to guarantee an adequate gas replacement. For example, one might suppose that a PLC sets up the maximum power of a burner at gas and air flow rates respectively equal to 100 m³ of NG/h and 1,080 m³ of air/h. By replacing NG by SNG without any additional change, the power would significantly increase becoming out of the maximum range established for the burner by the PLC. The flow rate of 100 m³ of SNG/h is equivalent to 149.5 m³ of NG/h, which is almost 50% higher. Burning such flow of SNG with the same air flow rate of 1,080 m³ of air/h would result in incomplete combustion. Therefore, although NG and SNG have the same *Wobbe Index*, they cannot be replaced straightforwardly. It is necessary to change the gas-air ratio in the PLC software as well.

Still, following the same example, the SNG flow rate equivalent to 100 m³ of NG/h would be 67.1 m³ of SNG/h (taking into account the net calorific value). As discussed above, the combustion gas-air ratios for the NG and the SNG are respectively 1:10.8 and 1:14.6, considering an excess of 5% in the combustion air. Therefore, the new flow rates to be set up by the PLC would be 67.1 m³ of SNG/h and 980 m³ of air/h.

In other words, the above gas replacement conditions (i) and (ii) can only be attained by producing a SNG based on a LPG-air ratio that guarantees a *Wobbe Index* equal to the NG, as well as by setting up new gas and air flow rates in the software of the PLC.

Similarly, the attainment of the other gas replacement conditions listed above, (iii) to (v), cannot be assured just by assuming the unchanged *Wobbe Index*. They must be followed and checked during the commissioning of each burner with the SNG.

The flame stability at the burners depends upon several factors such as flame velocity, flammability limits, temperature at the burner, power range, and gas-air ratio (in premix burners). Two phenomena that can occur are flame lift and flashback. Since both gases, the SNG and the NG, present the same characteristic of low flame velocity within the same power range, flame instability may occur mainly in the premix burners.

Particularly, the burners already presenting bad performance in terms of flame stability, when firing NG, will most likely show similar problems when burning SNG. The stability of the SNG flame must always be checked within the burner over the whole power and temperature range (from ambient to maximum temperature). If several burners fire in the same combustion chamber, flame stability conditions must be verified in all on/off combination of burners.

As far the pattern of heat transfer is concerned, the heat transfer from the flame to the equipment will slightly change during the gas replacement as the heat released from the SNG flame, which is somewhat a more radiant flame, differs from the heat obtained from the NG flame. Usually, such difference is small and, in most cases, the changes in heat released by convection are enough to compensate for the difference. The more the heat released by radiation is, the less the heat released by convection will be and vice versa). Yet, the influence of this parameter must be taken into account in terms of process productivity.

In terms of flue gases conformity within the equipment, the three "T" factors must be observed to maintain high quality combustion: time, turbulence, and temperature (Ministry of Power, 1958). As shown in the Table 1, the combustion air-gas ratio for NG and SNG are very different. Therefore, changing the turbulence condition between the gas and the air may have significant impacts in the combustion, since the SNG will leave the burner nozzle at lower velocities than the NG. As a result, the atmosphere inside the equipment due to the flue gases may experience oxidation or

reduction. Final adjustments are always necessary when using flue gas analyzers to check out oxygen and carbon monoxide contents, unburned fractions, and NO_x formation, and to set up proper new conditions for air combustion and turbulence.

5. FINAL DISCUSSION AND CONCLUSIONS

Since 1995, the use of NG has been increasing significantly in the Brazilian energy mix. The supply has been expanding and growing volumes of NG are being produced in offshore fields as well as being imported from Bolivia. The acceptance of the NG by the consumers has been expanding due to its large availability, which reduces the concerns regarding the security of supply. Major marketing efforts developed by the NG industry, including the LDCs, are building up a new “gas culture” in the country. Gradually, consumers are accepting the use of NG as an environmental friendly alternative to fossil fuels.

From 1995 to 2000, the Brazilian NG market expanded primarily based on industrial users. Yet, after a major electricity shortage in 2001, Brazil promoted an aggressive NG-fired power generation program, building up gas stations to supplement its dominant hydropower system. From 2002 to 2007, the share of gas-fired power plants in the total power capacity increased from 4% to 7%. The gas demand for power generation grew substantially faster than the demand for other uses (**Brazil's Energy and Mines Ministry, 2008**).

However, NG-fired power stations production fluctuates depending on the annual rains and the water availability in the hydropower system. As a consequence, the gas availability for other uses also swings from long moments of excess supply to short periods of scarcity. Moreover, the government imposes that power and residential sectors have priority in receiving NG in case of any temporary shortage. This contributes to the perception of risk of lack of continuity in attending the demand for gas by industrial users.

Such situation amalgamates industrial gas consumers as well as the entire gas industry to find alternative solutions for a more reliable gas supply. As a consequence, temporary solutions to cope with eventual NG shortages and/or interruptions have been addressed and carried out by some LDCs

and industrial consumers. Proposed strategies target low investments and small changes in consumers' burner systems to be easily reversible in the future. The use of SNG to replace NG has been suggested as the most suitable solution.

The replacement of NG by SNG through the use of adequate technical procedures was adopted in Brazil and proved to be a flexible solution to industrial applications overall. Reducing the number of industrial users to be converted to SNG was also considered to be the best strategy to avoid the technical difficulties.

So far, tests blending SNG with NG in the NG grid operated by the LDCs have not been carried out in Brazil yet. Applications have been restricted to SNG backup systems, which are installed primarily in industrial sites with high temperature processes such as glass works, steel mills, foundries, and ceramic industry. For those customers, the perception of NG supply insecurity was already high enough to justify the introduction of SNG. Running out of gas would represent expensive losses due to business interruption and equipment damage.

The practical experiences pursued in Brazil offer applicable concepts for many other countries, particularly in emerging gas markets dealing with similar risks of NG supply instabilities. This experience revealed the weaknesses of just taking the *Wobbe Index* method as a criterion to guarantee the exchangeability between NG and SNG. The adequate replacement of NG by SNG (and vice versa) depends upon the introduction of additional technical procedures, including changes in the combustion control systems.

This paper highlighted that a mere consideration of the *Wobbe Index* method to define the delivery conditions for the SNG represents an unsuitable practice when the burning systems are controlled by PLCs, as it happens in most industrial processes nowadays. Introducing changes in the PLC software allows reaching the proper burning system configuration according to the features of both NG and SNG. The proposed procedures handle with different combustion air-gas ratios. They also seek to follow up and preserve flame stability, heat transfer pattern and flue gases composition, which proved to be an essential condition to guarantee the suitable operation of any gas replacement.

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