INTERCHANGEABILITY AND WOBBE INDEX USED AS QUALITY PARAMETER FOR LIQUEFIED NATURAL GAS

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1. Background

The natural gas (NG) is projected like one of the most important energy sources in the future, due to its reduced contaminant effect and relatively low cost compared with liquid combustibles, like fuel oil or gasoline. Currently, Liquefied Natural Gas (LNG) is a common way to commercialize NG around the World. The main advantage of liquefaction process is the reduction by about 600 times of the total volume required for NG storage and transportation.
Venezuela has big quantities of proven NG reserves (148 BCF). The country has to take profit of these reserves and monetize them in all possible ways [1]. Venezuela's geographic location gives open access to most important oil markets, such as: Europe and USA. Historically, has sold to those regions the main part of its oil production and, few quantities are exported to Central America and Caribbean countries. In addition, Argentina, Brazil and, Chile have become in potential oil gas consumers.
In order to verify the potential markets for the LNG that will be produced in Venezuela, it is important to analyze the influence of different gas compounds interchangeability on the final product; considering the specifications and gas compositions required by each country or region. A key interchangeability parameter is the Wobbe Index (WI). WI is used to compare the combustion energy output of different composition fuel gases in an appliance (fire, cooker, etc.), it changes with gas composition.
There are some options to control gas interchangeability. The conditioning of LNG could be done: 1) in the production source, 2) before the pipeline entrance and, 3) before reaching the final customer [2].

2. Aims

The main purpose of this study was analyzing the influence of different gas compounds interchangeability on the quality of LNG that will be produced in Venezuela, using the Wobbe Index as interchangeability parameter. The specific objectives of the present study were:
1) Study the WI ranges of different regions, especially the potential markets for Venezuelan LNG, such as: Spain, USA, and, South America.
2) Design a proposal to establish the possible WI values of LNG, that guarantee its quality, taking into account aspects like as: international prices, quality gas specifications, available and higher future demand markets. The proposal was supported by an economical and technical analysis.

3. Methods

It was collected data of potential markets for the Venezuelan LNG [3, 4, 5] and the current situation of different liquefaction and regasification plants around the world [4, 6]. It was analyzed compositional gas data from different wells and fields located in the Northeastern Coast of Venezuela, and from Venezuela's Delta Platform (see Table 1).
The gas fields considered in this study are briefly described below:
Dragón-Patao Fields: The Patao Field is located in the north-east of the Paria Peninsula and cover an area of 242 km2. The Dragón Field is the Eastern field of the Mariscal Sucre Project (MSP), and it is bounded on the East by Trinidad and Tobago [1] (see Figure 1).
Deltana Plataform: The Deltana Platform Project is situated in the Eastern Venezuela Basin; it is bounded on the Southeast by Trinidad and Tobago and to the Northeast by Delta Amacuro State. The total natural gas reserves in the area are estimated in 38 billion cubic feet (bpc). This Basin covers an underwater area of 48000 km^2 in the Atlantic Ocean, and it is the most promising offshore field in Venezuela. It began its exploration phase in early 2002 with an initial investment of 375 million dollars [8].
The Deltane Plataform is divided in five blocks (see Figure 2). The first one (64 km^2) is reserved to PDVSA, the National Oil and Gas Company. Chevron Texaco and Conoco Phillips have the concession on the 2nd and 3rd blocks (169 km^2 and 4031 km^2, respectively). Statoil has a license for block 4 (1433 km^2). The block 5 (3744 km^2) is under study. Chevron successfully completed its exploration campaign of block 2; after the perforation of three gas wells, the proved reserves were increased in 5,7 bpc, validating Chevron

commercial perspectives. The same company perforated the first well in the block 3 obtaining good results [8].

Table 1. Comparison of Wobbe Index from Venezuela's Northeastern and different Venezuelan LNG possible markets.

Location	Minimum Wobbe Index (BTU/scf)	Maximum Wobbe Index (BTU/scf)
United States	1060	1400
Brazil (North)	1086	1207
Brazil (Center and South)	1248	1435
Spain	1295	1551
Argentina	1270	1401
Delta Platform Initial Exploration Phase (DPIEP)	1196	
Dragón and Patao Fields (D&P)	1326	
Block 1 of Dorado 1X Well, Delta Platform (D1X)	1535	
Block 2 Lorán-Manatí Well, Delta Platform (L&M)	1370	
Average Gas Entrance LNG-CIGMA Plant (CIGMA)	1356	

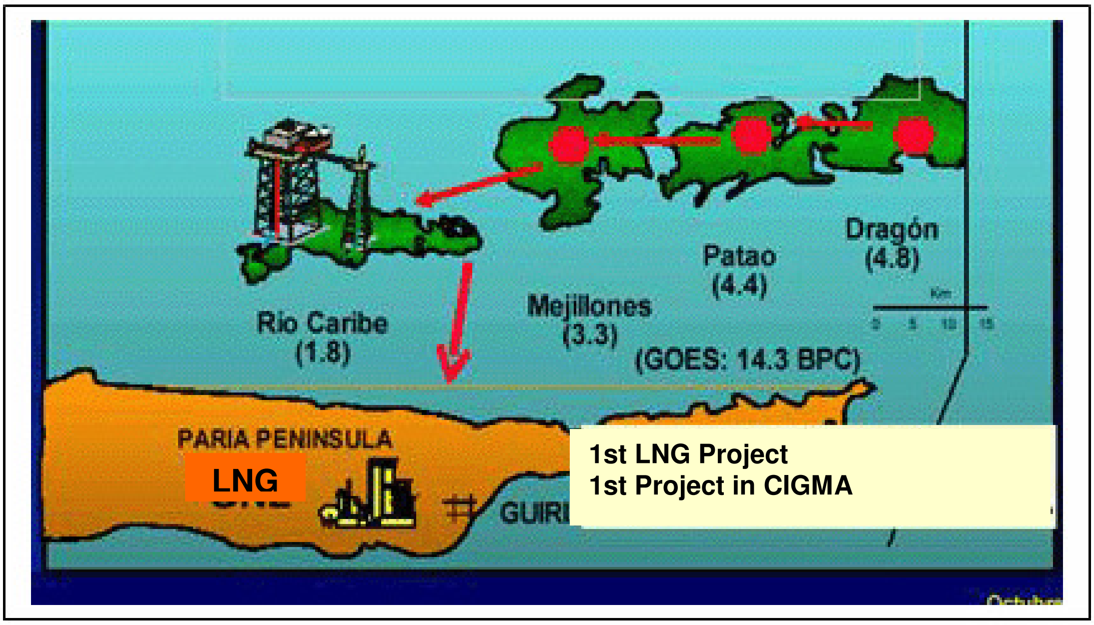

Figure 1. Location of Natural Gas Fields Mejillones, Patao, and Dragón [7]

Industrial Complex Gran Mariscal de Ayacucho (CIGMA): This Industrial Complex is planned as the new pole of development in Venezuela. It is situated in the Paria Peninsula, Northeast of Venezuela. It will cover 6300 hectares in solid ground and approximately 11000 hectares offshore. This important and significant complex will function as a gathering and conditioning center for the production of natural gas from the Northeastern region of the country (Deltane Plataform, North and Gulf of Paria). The complex envisages engineering works such as sea production platforms, which will be built in Venezuelan territory, a gas pipe that will transports gas 150 kilometers offshore and a liquid extraction plant, with a total investment of 4500 million Dollars [1].

Figure 3, shows the different allocations that will be included in the industrial areas of CIGMA: petrochemical and fertilizers plants, gas to liquid (GTL), and, of course, the LNG plants. The stages I and II implies the construction of LNG plants and their terminal boards, GTL plants, administrative offices, solid waste treatment and, service bays. The stage III includes the construction of fertilizers plant, oil and products storage. The stage IV corresponds to petrochemical plants.

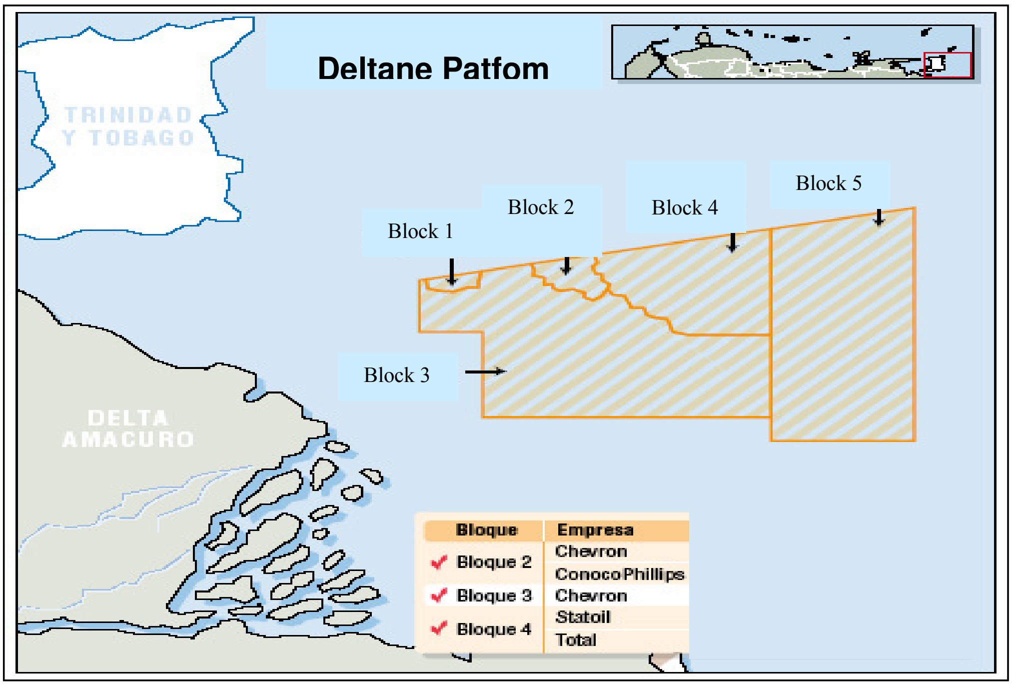

Figure 2. Location of different blocks on Venezuela Deltane Platform [8]

ETAPAS	PERÍODO	PARCELAS HABILITADAS	AREA NETA (Ha)	PARCELAS DE SERVICIO	CORREDORES DE SERVICIO (KM)
I - IV	2004 - 2035	22	3200	8	57

Figure 3. Stages of construction and division of different industrial areas in the CIGMA Project [9]

The countries selected as eventual customers for Venezuelan LNG were: United States, Brazil, Argentina and, Spain. The minimum and maximum Wobbe Index of those countries were graphed, and it was analyzed the trend of the values in order to determine an optimal WI that cover the largest quantity of available markets. In addition, in Table 1 it is indicated the values of WI used in the countries mentioned above, and the WI calculated based on gas compositions from different Venezuelan Northeastern wells or fields.
To determine the WI it was used the equation 1, where GHV means gross heating value measured in BTU/scf.

$$WI = \frac{GHV}{\sqrt{specific\ density}} \quad (1)$$

Figure 4 shows the curve of minimum and maximum WI for different countries or regions. It was selected 1340 BTU/scf as an optimal value for maximum WI. The Venezuelan LNG WI should be similar to this value.

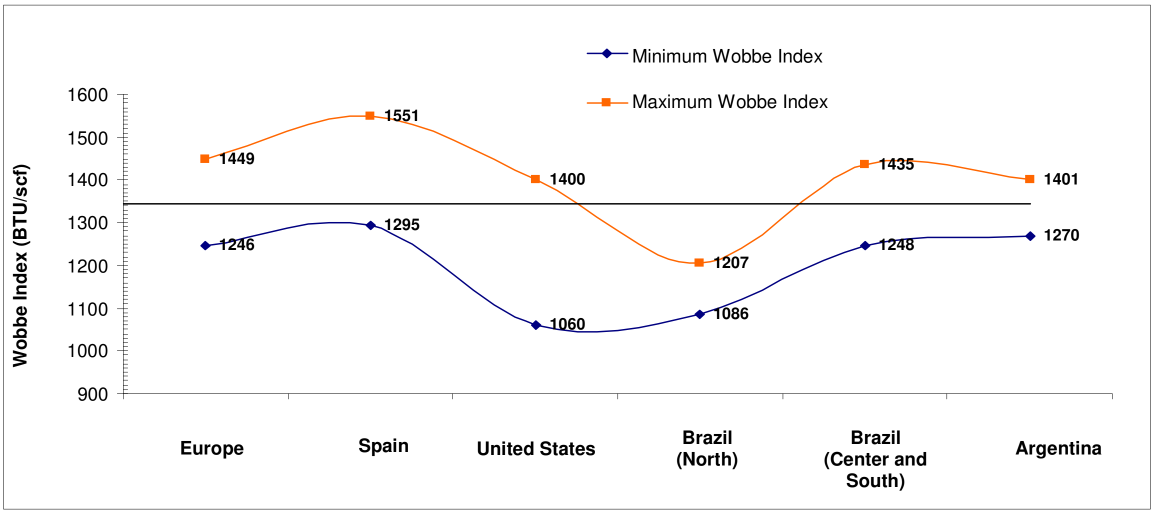

Figure 4. Minimum and maximum Wobbe Index ranges for different European and American countries

Figure 5 shows the composition análisis of the different gas samples considered in this study.

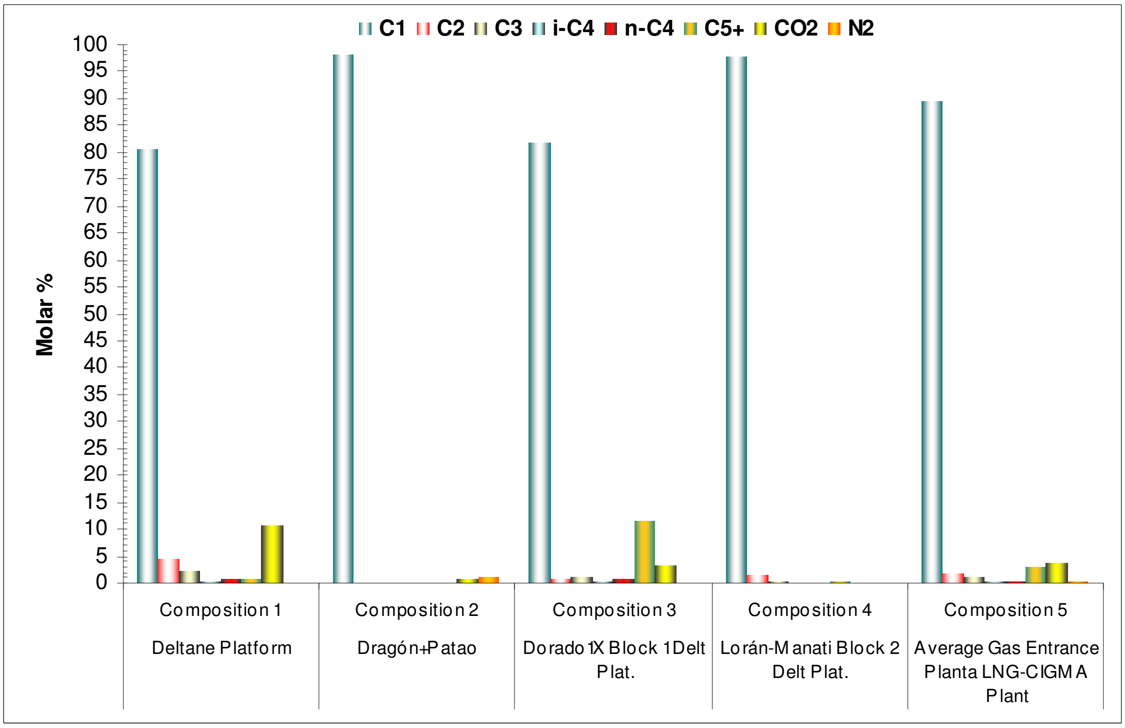

Figure 5. Initial compositional analysis for samples gas from Venezuela's Northeastern

It was presented a proposal to adjust the Venezuelan LNG WI, in order to approximate to the optimal determined value. This proposal was supported by an economic and technical analysis considering aspects such as: gas conditioning, natural gas liquids (NGL) extraction, barrels of NGL recovered per day and profit generated by them. The amount of natural gas obtained after the liquids extraction was also determined and its economical value ($/day).

4. Results

It was selected the gas conditioning in the production source as the economic option and, the NG liquids extraction as the technical option. The NGL extraction has more economical viability because the heavier fractions contained in NG could be commercialized in the local and international market. The ethane extracted fraction could be used in the Petrochemical Plant that will be installed in the Industrial Complex Gran Mariscal de Ayacucho.
The enrichment of natural gas using the removal or reduction of inert compounds could be developed in widespread NG treating facilities. The methods to remove these compounds depend on scale economy, feed gas concentration and the specifications of gas product. The processes most frequently used to remove CO_2 content are:

- Liquid absorption with amines.
- Solid bed Adsoption (molecular sieves).
- Membranes.

In most of the applications, liquid absorption is the preferred route, because of its availability in large scale plants and its selectivity in CO_2 removal.
The Nitrogen removal or reduction is less common, but it could be done simultaneously with the CO2 removal. There are several methods; however, the cryogenic extraction is the most used at commercial level. The available processes are:

- Cryogenic removal of N_2.
- Adsorption by pressure oscillations.
- Liquid absorption (Mehra Process).

One of the disadvantages of cryogenic process to extract the Nitrogen is it high cost. In addition, it is required the upstream CO_2 removal, accompanied with dehydration in order to prevent the freezing of some compounds into the cryogenic plant.
The extraction method proposed in this study is mechanical refrigeration, because its low cost and the heating value not affect the gas richness. The typical percentages recoveries obtained with this type of extraction are: propane 85%, butane 94% and, pentane plus (C_5^+) 98% [10].
Figure 6 presents a comparative trend between the different Wobbe Index before and after the extraction process.
The sample gas from Lorán-Manatí well, presented an initial and final WI of 1370 and 1345 BTU/scf, respectively. These WI values are close to the optimal proposed (1340 BTU/scf), in consequence, this gas would not require any additional operation of conditioning or treating.
The sample gas from fields Dragón and Patao (D&P) showed an initial composition of dry gas with low C_4-C_5 fractions and nothing of C_6^+. The initial WI was 1326 BTU/scf and after NG liquids separation it was reached a final value of 1309 BTU/scf. With the last WI value no further conditioning operations, such as CO_2 extraction, would be required to approximate to optimal WI value.
To enrich NG with low WI value (1196 BTU/scf), like the sample gas from DPIEP, there are some alternatives, and two of them are: inerts elimination, or liquefied petroleum gas (LPG) injection. The disadvantage of the last alternative is its associated high cost, and the difficulty of supply big quantities of LPG, required for increasing the WI value. In addition, the LPG injection could cause negative effects on the hydrocarbons dew point, promoting operational problems.
Sample gas from D1X well presented an initial WI value of 1535 BTU/scf caused by high heavy fractions content. After NG liquids extraction the WI decrease to 1262 BTU/scf, much below respect the optimal chosen value of 1340 BTU/scf. The average entrance gas to LNG-CIGMA plant, resulted from combination of different gas streams, and its CO_2 content is similar to the sample from D1X well (3.28 vs 3.65 molar %). The initial CIGMA WI was 1356 BTU/scf, and the final value was 1256 BTU/scf. To increase the final WI of the last sample, in order to achieve the optimal value, it would be necessary the CO_2 extraction and NG liquids separation.
Table 2 shows recoverable barrels (bbl) and dollars per day obtained after the NG liquids extraction. The calculations were based on Hub Mont Belvieu prices ($/Barrel) [11]. To obtain high profits by NGL sales (D1X, CIGMA and, DPIEP cases), the liquids extraction is a good alternative, but it implies a residual gas with low

Wobbe Index. In consequence, to commercialize this gas like LNG, it would be necessary the CO_2 and nitrogen extraction, hence, investment costs of conditioning and treating infrastructure increase.

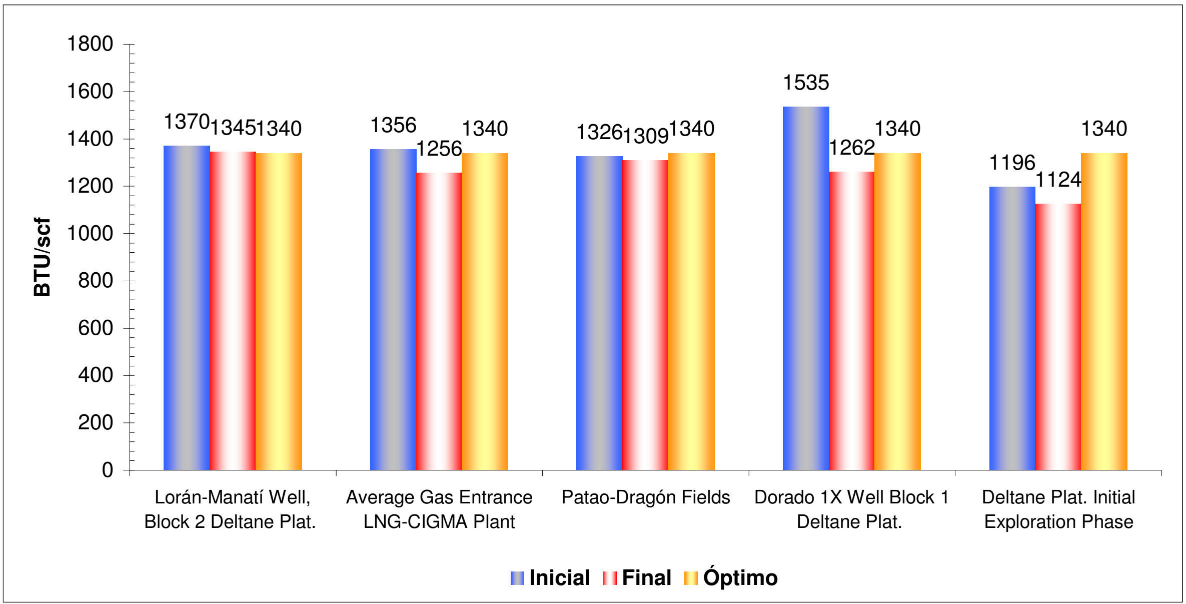

Figure 6. Wobbe Index tendencies for samples gas from Venezuela's Northeastern.

Table 2. Barrels/day and dollars/day obtained by NG liquids recovery.

Well or Field	C_3 Recovered		iC_4 Recovered		nC_4 Recovered		C_5^+ Recovered	
	bbl/ day	$/day	bbl/ day	$/ day	bbl/ day	$/ day	bbl/ day	$/ day
Delta Platform Initial Exploration Phase (DPIEP)	7666	1341550	2257	470584.5	2523	521315	5168	1348848
Dragón and Patao Fields (D&P)	481	84175	181	37783.5	87	17976.4	209	54549
Block 1 of Dorado 1X Well, Delta Platform (D1X)	3713	649775	1850	385725	3915	808937	66950	17473950
Block 2 Lorán-Manatí Well, Delta Platform (L&M)	1581	276675	451	94033.5	348	71905.5	1208	315288
Average Gas Entrance LNG-CIGMA Plant (CIGMA)	3360	588000	1185	247072.5	1718	354981.8	18384	4798224

5. Conclusions

- The interchangeability and Wobbe Index are key factors to assure the Venezuelan Natural Gas quality. This gas could be commercialized in the future in International Markets with high quality standards and high economic yield, such as: United States and Europe.
- The sample gas from Lorán-Manatí well presented a Wobbe index very similar to the optimal WI value determined in this study, 1340 BTU/scf. This gas would not require any additional process of conditioning or treating
- To enrich gas with low Wobbe index, (D1X well, Delta Platform Initial Exploration Phase and, Average Gas Entrance LNG-CIGMA Plant), it is recommended the inert gas elimination. The injection of LPG presents the disadvantage of high cost associated with the difficulty to supply the big quantities of LPG

required to increase the Wobbe Index. In addition, it could promote adverse effects on the hydrocarbons dew point creating operational problems.

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