Polish LNG terminal influence on natural gas quality available in the Polish gas transmission network

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Abstract. Technical start of LNG terminal in Swinoujscie, was a significant milestone in the history of Polish natural gas network development. Polish gas market is now open for suppliers from all over the world. Energy security has been significantly increased. LNG terminal availability may guarantee security of supply and also stabilize composition and other physicochemical NG parameters. The analysis of NG characteristic changes after the start of deliveries from LNG terminal is presented in this document. Concentration of methane, ethane, propane, nitrogen and parameters like gross calorific value and Wobbe index for 16 regularly distributed exit points were investigated. The chosen parameters and ingredients were matched with gas from vaporization process. 913 days before and 912 days after the terminal launch were chosen. Quality measurements of NG were made by Gas Transmission Operator GAZ-SYSTEM S.A. with chromatographs and published on their official website. Volumes of LNG vaporized during the tested time were consumed by increased demand of end users and developing underground gas storages. NG from terminal was not a substitute of fuel from other import directions. It has been proven that gas from LNG terminal could have direct and indirect influence for gas collected in exit points. Indirect influence appeared with increasing distance from Swinoujscie entry point. South-east parts of Poland were totally free of LNG regasification process influence. High purity and higher energy density of NG from vaporization process has positive influence for transmitted gas quality. Gas mixture from interconnection points, LNG terminal and domestic production meets the standards of NG quality. This mixture can be used by all end users without complaints.
1. Introduction

The history of the first Polish LNG terminal dates back to 2006 when the Polish government introduced a bill that started the project of building the LNG terminal in Swinoujscie [1]. It happened immediately after the first act of Ukrainian and Russian gas conflict in January 2006 [2]. First molecules from LNG vaporization process in the Polish LNG terminal were received ten years later, in January 2016. First deliveries were typical for technical start process with different vaporization efficiency and discontinuous work. Technical acceptance and commercial opening took place between April and July of 2016. Liquefied natural gas from Qatar, Norway and the United States of America had been delivered since [3]. Polskie LNG S.A., the subsidiary of Gaz-System S.A. is the owner and operator of LNG terminal in Swinoujscie.

Lack of uniform and standardized composition is characteristic for natural gas. It can be described as a mixture of combustible hydro-carbons, non-flammable ballast [4] and single water molecules. Wobbe index is one of the most important quality parameters characterising this fuel. It determines the interchangeability of gaseous fuels according to the French Delbourg method [5]. Wobbe index may vary from 12,500 [kWh/m³] to 15,806 [kWh/m³] in group E Polish gas transmission network [6]. Gross calorific value is also an important parameter especially for electric energy production from NG. The Sulphur content is vital from the environmental point of view. Sulphur compounds have a direct effect on the emission of hazardous substances into the atmosphere. The aforementioned physicochemical NG parameters and range of their variability are specified in the approved network codes. Minimum and maximum methane number, hydrocarbon concentration are not described in current Polish standards [7].

End users NG consumption level grows continuously in Poland [8]. Technical regasification capacity of the described LNG terminal makes natural gas from cryogenic ships an important alternative for NG imported fuel from the East. Russian gas with stable composition may be replaced by fuel from suppliers from all over the world. It raises questions about the LNG terminal operating range and potential impact on the quality and parameters of natural gas used by end users at exit points.

Scientists and industry are focused on the possibilities of alternative gaseous fuels use. The most promising fuels to use are hydrogen and biomethane. Blending of hydrogen with NG was tested and research shows that it is possible to prepare and model a blending process respecting imposed physicochemical parameters [9]. There are available studies discussing the issue of maximum hydrogen blend levels, what is significant because of fundamental differences from basic components of natural gas [10]. In terms of composition and parameters vaporized LNG is similar to gas transmitted in high methane pipelines and their blending was not an object of research until now. Impact of LNG for the gas quality on the end users in Polish transmission system was not analysed before.

2. Aim and scope of study

The aim of the study was to analyze the impact of LNG terminal in Swinoujscie on fuel quality in exit points of high pressure gas network pipelines and indicate changes of physicochemical parameters stability after the start of vaporization process. Next step was concerned about the range and impact of LNG terminal on transmission network, which belongs to operator Gaz-System S.A. In addition to fuel supplied in liquefied form, fuel supplied by the pipelines system from abroad was taken into account in this work.

3. Methods of research and analysis

Daily measurements of volumes and physicochemical parameters were obtained from Gaz-System S.A. measuring installations and chromatographs [11]. Measurements for 1815 consecutive days were selected to compare physicochemical parameters of gaseous fuel. 913 of them occurred before and 912 after the first dose of evaporated LNG was delivered to the system (period from July 2013 to June 2018).
From all measured parameters, content of methane [%], ethane [%], propane [%] and nitrogen [%]; upper Wobbe index [kWh/m³] and gross calorific value [kWh/m³] were selected as important for determining the origin of the fuel. Wobbe index is a ratio between gross (GCV) or net calorific value (NCV) and the square root of natural gas relative density [12]. The Wobbe index is calculated with the Equation 1. For upper Wobbe index calculations gross calorific value (GCV) is used.

\[ Wi = \frac{CV}{\sqrt{a}} \]  

Equation 1

From 934 physical exit points from the high pressure gas network, 16 were selected for research and analysis. Selected points and their localization on the grid is shown in Figure 1. Evenly spaced points on the gas pipeline network were selected for the tests, which was important to determine the range limits of the LNG regasification fuel availability.

The quantitative effects of evaporated LNG on the total volumes of gas delivered to the transmission system have been checked.

3.1. Direct influence of LNG terminal on gas quality in the system exit points.

GRG- Generalized Reduced Gradient method was used to clearly indicate the origin of the fuel (the point of delivery to the transmission pipelines). A simple program was prepared with the use of VBA and the SOLVER application. The program was prepared to solve a system of equations and indicate a measurement, where the physicochemical parameters of the received fuel in the tested exit point corresponded to the fuel supplied to the port in Swinoujscie. If fuel collected at the exit point had a similar composition to vaporized LNG, it was assumed that such a point can be described as a point with a direct LNG terminal influence.

| No Point ID | Localization       |
|-------------|--------------------|
| 1           | 760139 Goleniow     |
| 2           | 760142 Janczewo     |
| 3           | 760104 Oborniki     |
| 4           | 760025 Krzemieniewo |
| 5           | 760016 Kolo-Borki   |
| 6           | 650049 Wiczlino     |
| 7           | 540208 Plock        |
| 8           | 540168 Marki        |
| 9           | 588013 Kownaciska   |
| 10          | 430268 Pulawy       |
| 11          | 540057 Wolborz      |
| 12          | 302856 Lublinie     |
| 13          | 288001 Katy Wroclawskie |
| 14          | 302120 Zawilka      |
| 15          | 430206 Zawila       |
| 16          | 430005 Jaroslaw     |

Figure 1. Examined exit points.
3.2. *Indirect influence of LNG terminal on gas quality in the system exit points.*

For measurements that did not fulfil the conditions described in point 3.1, a statistical analysis was carried out. It was necessary to show changes in distribution of measurements recorded before the start of LNG vaporization and the currently available natural gas parameters.

4. Results and discussion

4.1. *Quantitative analysis of gas from LNG vaporization.*

Analysis of the amount of gas delivered to the transmission system shows systematic increase of the consumption possibilities of the Polish gas market. Presented trend is confirmed by published reports of the Ministry of Energy. The gas consumption level in Poland has raised from 15.9 bln m$^3$ [13] (~177 TWh) in 2013 to 17.9 bln m$^3$ (~199 TWh) in 2018 [14] according to available reports.

The capacity of underground gas storage facilities has increased significantly. It is worth noting that in 2013 working volume of all Polish high-methane gas storage facilities was around 1.8 bln m$^3$ (~20 240,25 GWh), in 2015 – few months before the technical start of LNG terminal in Swinoujscie – 2.5 bln m$^3$ (~28 041,60 GWh), to reach the level of 3.0 bln m$^3$ (~33 201,20 GWh) in 2018 [15].

In Figure 2 the changes of the gaseous fuels supply from historical directions and from LNG terminal are presented. It is easy to see that gas from LNG vaporization process is an additional volume of fuel. LNG deliveries did not have a significant impact on other supply directions for the tested time range until 2018. Deliveries through the connection point with Czechia are characterized by intensity of use during winter season.

![Figure 2. Physical flow of natural gas in entry points.](image-url)

4.2. *Direct influence of LNG terminal on gas quality in the system exit points.*

The study of the direct impact of natural gas from the LNG terminal on the physicochemical parameters of the received gas was the primary and main goal of this document. The comparison of LNG parameters supplied to the terminal and the NG parameters in all 16 points was conducted. Collected results, especially: content of methane and ethane [%], Wobbe index [kWh/m$^3$], as parameters identifying fuel origin are presented in this paper. 10 exit points out of chosen 16 for research were powered directly from terminal (1,2,3,4,5,6,7, 12,13,14). The nearest exit point and two
most distant exit points from entry point in Swinoujscie were selected for further presentation. Figures 3a, 3b and 3c show data for Goleniów (1). This point is geographically closest to Swinoujscie. This measuring point is located on a pipeline with high technical transmission ability. The curves for the Wobbe index and for the hydrocarbons content almost coincide with the fuel vaporized at the LNG terminal.

Figure 3a. CH₄ content in NG at Goleniów exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 3b. C₂H₆ content in NG at Goleniów exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 3c. Wobbe Index in NG at Goleniów exit point and in vaporized LNG at Terminal entry point in subsequent days.

For points located near the Silesian agglomeration like Lubliniec (12) and Zabkowice (14) similar analogies are to be found, but not as frequently. Both points are far removed from Swinoujscie and they are the last and furthest points with gas parameters corresponding to those of LNG fuel. Samples with highest matching of gas parameters were observed during the last phase of tested days, which has been presented in Figures 4a, 4b and 4c for Lubliniec point and 5a, 5b and 5c for the Zabkowice point. The lowest gas content from LNG vaporization in received gas mixture may be associated with the proximity of other fuel sources, including Ukraine, Germany and denitrification facilities. It could have been assumed that as the distance from the terminal increases, gas from LNG will be increasingly diluted by gas from other sources before the start of the study. It was confirmed by presented results.
Figure 4a. CH₄ content in NG at Lubliniec exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 4b. C₂H₆ content in NG at Lubliniec exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 4c. Wobbe Index in NG at Lubliniec exit point and in vaporized LNG at Terminal entry point in subsequent days.
Figure 5a. CH₄ content in NG at Zabkowice exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 5b. C₂H₆ content in NG at Zabkowice exit point and in vaporized LNG at Terminal entry point in subsequent days.

Figure 5c. Wobbe Index in NG at Zabkowice exit point and in vaporized LNG at Terminal entry point in subsequent days.

4.3. Indirect influence of LNG terminal on gas quality in the system exit points.

No direct relationship between vaporized LNG and natural gas from the 6 other exit points was found. Technical start of LNG terminal in Swinoujscie caused physicochemical parameters stabilization for 5 of them (8,9,10,11,15). These points were located in the central and south-eastern parts of Poland. The availability of high-methane natural gas from Belarus, Ukraine and the proximity of the connection with the Yamal gas pipeline [16] result in the fuel being a mixture of NG from those sources (in some cases the NG comes only from one of those directions). Transmission network operating mode for any given day could dictate the composition of available gas. This theory is confirmed by the measurements presented in Figures 6a and 6b for the Wolborz point (11) and in Figures 7a and 7b for the Kownaciska point (9).
The stabilization of physicochemical parameters for indicated exit points was a result of steady and continuous supplies from Belarus direction.

From all tested points on the gas transmission network map, only Jarosław (16) did not show any relation to the physicochemical parameters of the LNG. Long distance from Swinoujście, availability of Ukraine interconnector, domestic production, and Underground Gas Storages with high withdrawal capacities could be the reasons, that the Podkarpackie voivodship can still be considered as an area that is a source of fuel for the high pressure transmission system. This region is still free from the influence of LNG supplies and vaporization process.

4.4. Variability of physicochemical parameters for NG from LNG vaporization process.

Gross calorific value and composition boundary conditions tests are necessary to complete analysis of gas quality in LNG terminal entry point. Physicochemical parameters of the delivered LNG during the examined period and their comparison with the values specified in the Transmission Network Code are presented in Table 1. The study omits the analysis of parameters like winter and summer water dew point and dust particles with diameter exceeding 5µm, because they are particularly dependent on technical infrastructure and not the fuel composition itself.

In this respect, it is worth mentioning that Gas Transmission Operator can agree to deliver gas with lower gross calorific value than shown in Table 1. The lowest acceptable value for high-methane gas in Polish gas network is 9,444 [kWh/m³] [17].

On the basis of Table 1 it is possible to conclude that LNG as a fuel is characterized by high calorific value and is free of impurities such as sulphur and mercury.
Table 1. Requirements concerning the quality of transmitted natural gas [17].

| Specification                  | Unit             | System  | LNG min   | LNG max   |
|--------------------------------|------------------|---------|-----------|-----------|
| Min. gross calorific value     | kWh/m³           | 10,556  | 11,231    | 11,898    |
| Range of the Wobbe index       | kWh/m³           | 12,500 - 15,806 | 14,970    | 15,230    |
| Hydrogen sulphide              | mg/ m³           | ≤ 7.0   | 0         | 0.1       |
| Carbon dioxide                 | %                | ≤ 3.0   | 0         | 0.007     |
| Mercury vapours                | µg / m³          | ≤ 30.0  | 0         | 0         |
| Mercaptan sulphur              | mg/ m³           | ≤ 16.0  | 0         | 0         |
| Total sulphur                  | mg/ m³           | ≤ 40.0  | 0         | 0.1       |

5. Conclusions

Technical start of LNG terminal opened Polish gas market for suppliers from all over the world. LNG vaporization facility with cryogenic tanks, significantly increased Polish security of supply and energy security. From an economic point of view it should be considered clearly as a positive aspect of launching the LNG terminal. Delivered LNG did not replace any of the traditional imported fuel directions for tested date range. Gas from Swinoujscie was consumed by increasing end users and UGS demand and it was a supplement of historically consumed volumes.

High quality and purity of vaporized LNG can be used for blending process with gas from other sources with lower physicochemical parameters. Fuel in pipelines will meet the existing standards, after blending during gas transport. This is a vital information for the end users and TSO. If users receive a fuel that does not meet the minimum standards, they can suspend its receipt or receive a special discount [18]. It is really important on west parts of Poland, where high-methane natural gas from domestic production and from denitrification process include more nitrogen than on the east part of the country.

Presented analysis allows to determine the virtual boundaries of LNG terminal impact for Polish high pressure gas network. Studied range of collected data indicates that the Warsaw ring and the Silesian Agglomeration are the furthest points directly supplied by the vaporized LNG. It should be considered as positive impact because of mentioned blending process and higher security of supply. South - east parts of Poland were totally free of LNG regasification process influence. Territories between presented areas were characterised by higher stabilization of the physicochemical parameters of NG. It could be the result of the local use of fuel from nearest sources and entry points. End users, especially from chemical industry are receiving NG with more stable compositions than before technical start of LNG terminal.

It should be pointed out, that the designated boundaries of LNG terminal impact may move further east, especially in case of possible reductions of NG transit through the territory of Ukraine to Western Europe.
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