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Challenges of the upcoming German gas market conversion: contribution of LNG use for the low calorific gas network's safe and sustainable operation

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1. INTRODUCTION

The gas supply situation in Germany is determined mostly by domestic gas production as well as by imports from abroad. The main gas import countries are as follows: Russia, Norway and the Netherlands. Compared to the natural gases imported from Russia and Norway the natural gases produced in Germany and imported from the Netherlands are low calorific (L-gas). Together they cover about one third of the German natural gas consumption per annum which is a remarkable amount for the national economy.

Nevertheless it is to be expected that Groningen gas fields, the main German gas import source from the Netherlands, will cease production and thus the export to Germany within the next few years. This is predicted to decline in the second half of 2020 until it is completely shut down probably by 2030 [1]. The natural gas fields in Germany are being depleted as well, so one cannot rely on the long term production of the own natural gas.

The described challenge for the future of German gas supply allows taking into account two possible approaches which might guarantee a further sustainable and secure operation of gas networks and utilization units. These are a classic gas market conversion and a conversion of the natural gas itself.

The first one is the gas market conversion which means an elevation of actual amounts of the high calorific gas (H-gas) imports from Russia and Norway via pipelines and providing them into the L-gas networks. At the same time nozzles of the gas utilization units must be replaced and the pipelines are to be upgraded in order to allow the transport of H-gas towards the gas networks to be converted. The gas nozzles replacement is necessary to match the specified range of the Wobbe number of H-gas. This method requires high investment costs for the technical conversion. Alone the adjusting of household gas appliances to be affected, which count about 5 million units, requires up to one billion euros. In addition nozzles replacement by for industrial gas combustion units and the gas network upgrade result in costs that are being estimated by the German gas transmission network operators.

The second approach to be taken into account is the conversion of the natural gas itself due to the ballasting of the H-gas by injection of air or pure nitrogen into the natural gas stream and thereby lowering its Wobbe number to the L-gas' requirements. By the use of the imported natural gas via existing pipelines this method requires fewer costs for the upgrade adaption of the gas network and the utilization units. However, the build of air separation and injection units might raise the total costs.

In order to evolve the diversification of the gas supply chain the second approach might include an involvement of non-pipeline gas import. This can be achieved by means of liquefied natural gas (LNG). LNG transport to Germany might allow a participation of a considerably bigger number of gas market players than by the gas import via pipelines. Thus the energy supply diversification is enforced and energy prices become more flexible and market oriented.

Furthermore the evolving use of LNG for network-connected natural gas supply will give a boost to the inner non-network LNG market, thus to the development of a national small scale LNG infrastructure.

There are different ways to integrate LNG into the German gas networks. The existing pipeline connection between Germany and the Netherlands allows the use of the LNG landing terminal's capacities in Rotterdam (the Netherlands) for the benefit of the German L-gas networks [2]. However LNG must be transported in the gaseous form (further referred to as NG). Another attractive prospect for the LNG import into Germany will open up after the startup of the LNG landing terminal in Poland which remains under construction until the end of 2014 [3]. Germany's own LNG terminal projects must be taken into account as well. However there is no current discussion about planning of such a terminal on the German cost line.

2. TECHNICAL REQUIREMENTS FOR THE SUBSTITUTION OF L-GAS BY NG

To estimate the prospects of the future use of LNG some aspects must be considered. The main question to be answered is: what technical criteria are to be met to allow the substitution of L-Gas by NG and thus the use of LNG for network-connected utilization?

Generally there are some parameters to be matched. Depending on many factors (natural gas source, network configuration etc.) there are diverse parameters to be matched: Wobbe number, gross calorific value (further referred to as GCV), maximum contents of oxygen, propane and butane, relative density and methane number. According to the DIN 51624:2008 "Automotive fuels – Compressed natural gas – requirements and test methods", the contents of propane and butane as well as methane number are to be matched in case of the use of LNG as an automotive fuel [4]. Making LNG comply with this set of gas quality requirements can cause some effort. Let us have a closer look at this.

The main requirement to the quality of the NG which is to be injected into the gas networks, concerns the principle of the gas interchangeability, as defined by the Code of Practice G 260:2013 "Gas composition" by the *German Technical and Scientific Association for Gas and Water* (further referred to as DVGW).

To ensure the possibility to use more than one gas source in order to encourage the gas sources' diversification and to establish the gas supply reliability the Wobbe number has to be matched[1]. The range of the Wobbe number is shown in Figure 1 with the nominal value 44.6 MJ/m^3 for L-gases and 54.0 MJ/m^3 for H-gases[2] [5].

Bearing in mind the necessity to solve the upcoming gas import bottleneck, let us explore if LNG in the form of NG is suitable as a substitute for natural gases imported from the Netherlands or

[1] here and further in the text is meant its upper value W_s
[2] the reference temperatures being 25 °C and 0 °C for energetic and volumetric quantities respectively

produced in Germany. These are L-gases, which means the mentioned gas amounts have to be substituted by NG with Wobbe numbers in the range of 39.6 to 46.8 MJ/m^3 (Fig. 1).

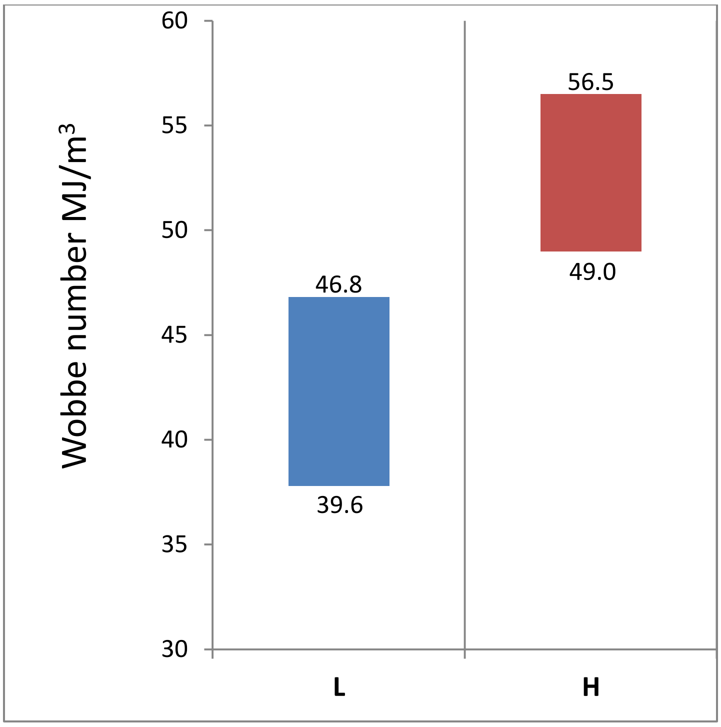

Figure 1 – Wobbe number range defined by DVGW Code of Practice G 260:2013. Reference temperatures 25 °C / 0 °C [5].

Origin	Nitrogen [mol%]	Methane [mol%]	Ethane [mol%]	Propane [mol%]	Butane and higher hy-drocarbons [mol%]
Algeria / Arzew	0.71	88.92	8.41	1.59	0.37
Nigeria	0.03	91.70	5.52	2.17	0.58
Norway	0.46	92.03	5.75	1.31	0.45
Qatar	0.27	90.90	6.43	1.66	0.74
Trinidad and Tobago	0.01	96.78	2.78	0.37	0.06

Table 1 – The average compositions of LNG (chosen as being representative among compositions reported by the different receiving terminals; calculated at -160 °C) [7].

Let us have a look at the current and upcoming LNG delivery situation in both the Polish and Dutch terminals. The main sources of LNG import are: Trinidad and Tobago, Nigeria, Algeria and Norway for the terminal in Rotterdam and Qatar for Poland [3, 6]. The average composition of the LNG according to the source is shown in Table 1.

Origin	**GCV [MJ/m³]**	**Wobbe number [MJ/m³]**	**Methane number**
LNGs			
Algeria / Arzew	43.38	55.00	75
Nigeria	43.32	55.39	75
Norway	42.58	54.68	78
Qatar	43.34	55.18	75
Trinidad and Tobago	40.94	53.99	89
Natural gases			
Russian H-gas	40.3	53.1	90
Norway H-gas	41.9	52.9	79
Netherland L-gas	36.8	46.0	88
German L-gas	35.4	44.7	97

Table 2 – GCV, Wobbe number and methane number of gas being delivered or to be delivered to the LNG terminals in Rotterdam and Swinoujscie and of natural gas being used in Germany. Reference temperatures are 25 °C / 0 °C [7, 8, 9].

Based on the chemical composition of the LNGs one can calculate the gas quality parameters of NG such as Wobbe number, GCV and methane number, whose values are presented in Table 2. There are also Wobbe number, GCV and methane number shown in Table 2. These are defined in the DVGW Code of Practice G 260:2013 for the natural gases being used in Germany for the public gas supply.

As it can be seen in Tables 2 and in Figure 1 the Wobbe numbers of NGs delivered or to be delivered to the terminals in the Netherlands and Poland do not match the required range set out in the DVGW G 260:2013 for L-gas, which means that these NGs cannot be used for substitution of L-gases in the gas networks without any treatment.

In addition to the Wobbe number the GCV has to be matched. The latter will be required in cases of necessity to allow the injection of NG into the gas networks for the purpose of its use as a part of gas mixture with L-gas flow. This option remains topical in the next 15 years till the L-gas supply shuts down completely. The mentioned necessity of the GCV matching can be explained by the overview over the Germany's gas billing system that is based on energy consumption while consumed volume flows are not taken into account. This is why gas distribution system operators are obliged to avoid deviations of GCV in their networks of more than ±2 % over the billing cycle [10]. The common way to achieve this is gas ballasting. An alternative for this can be the tracking of GCV at the points of NG admixture in the gas networks or entry/exit points, which mark borders between transportation and distribution networks.

A simple calculation allows an estimation of the effort to ballast NG with other gases (in our case air and pure nitrogen) in order to meet the GCV requirements (s. Fig. 2). This calculation has proved possible to ballast most of the NGs till the matching of GCV required. The exceptions are described below.

The blue bars in Figure 2 represent a share of NG in each case; the orange ones stand for the share of nitrogen required (pure or as a part of air used for ballasting). In case of NG ballasting by air the oxygen share in the gas mixture is presented in drops. All the calculated gas compositions also meet the criteria for the Wobbe number. This means, the injection of NG from Algeria, Nigeria, Norway and Qatar into German public gas networks can be technically guaranteed by their ballasting with air.

It has to be mentioned, that the German gas distribution and transportation networks allow oxygen content in the natural gases under 3 mol% (approx. 3.03 vol%) and 0.001 mol% respectively. Thus the injection of NG in all the German gas transportation networks requires the NS ballasting with pure nitrogen without any remarkable traces of oxygen. On the contrary the German gas distribution networks allow the admixture of oxygen in gas flow and so in NG. Figure 2 shows the required shares of nitrogen and permitted shares of oxygen in the ballasted NGs. The total share of the admixed air is the sum of the nitrogen and oxygen shares. With respect to gas transportation networks this sum shows the share of the pure nitrogen admixed.

The calculation shows that NG from almost all sources allows its ballasting with air. The exception is NGs to be distributed in the German L-gas networks. NG from all above mentioned sources has to be ballasted with pure nitrogen, otherwise the air ballasted NGs will content more than 3 mol% oxygen (range from 3.5 to 4.3 mol%). The determined values are marked with red boxes (s. Fig. 2).

In the case of injection of NG from Trinidad and Tobago into a gas network transporting or distributing Norwegian natural gas, the NG has to be treated by ballasting with propane instead of nitrogen or air. This can be explained by its significantly lower GCV than Norwegian pipeline gas one's. The amount of propane that has to be injected to the Trinidad and Tobago NG equals 0.1 vol% (about 0.38 vol% incl. the propane contained in the origin LNG). Nevertheless this value is within the permitted limit of 6 mol% defined by DIN "Automotive fuels...". An alternative use of the untreated NG from Trinidad and Tobago could be its injection into gas networks without admixing to the Norwegian natural gas.

The Wobbe number of all the NG mentioned above complies with the requirements for H-gas quality.

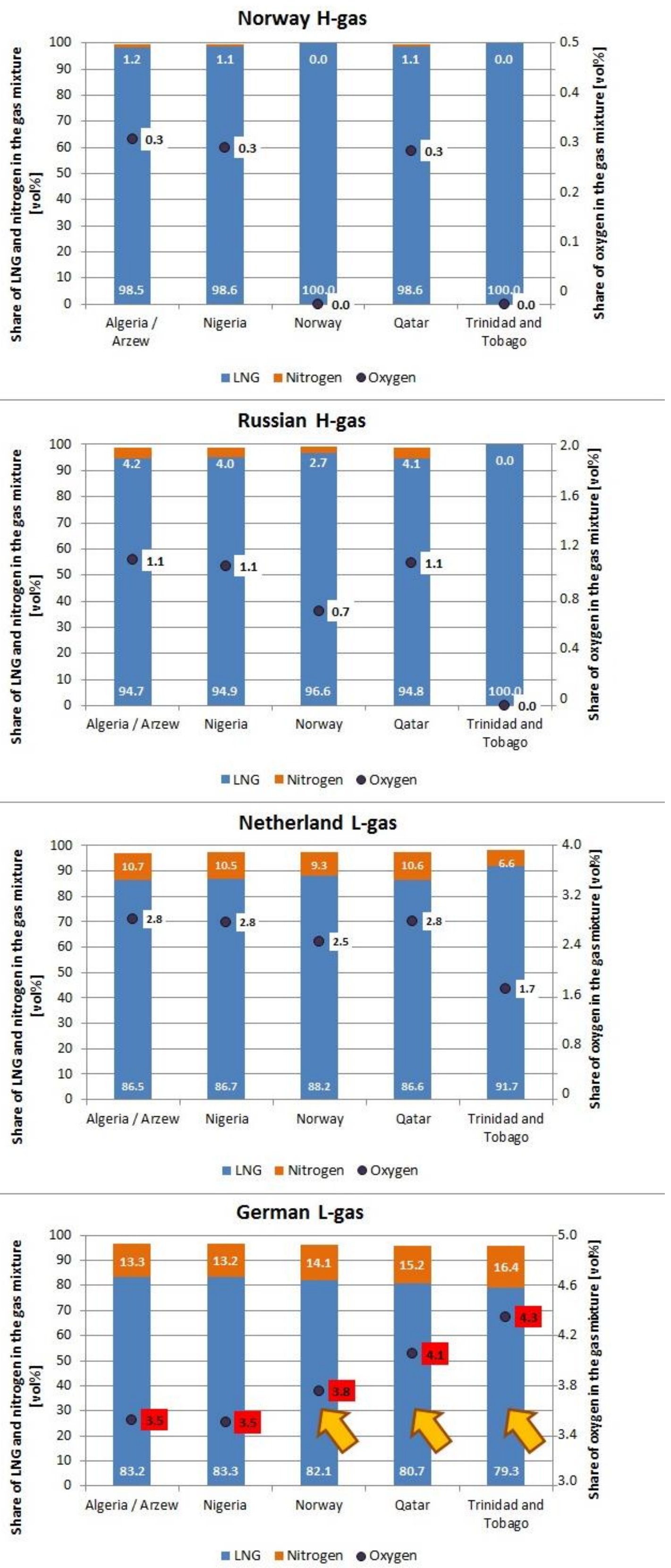

Figure 2 – Ballasting of NG to meet the GCV and Wobbe number requirements. Reference temperatures 25 °C / 0 °C [5, 7, 8].

According to the current DIN standard for the calculation of the compression factor of gases, the maximum permitted value for nitrogen equals 50 mol% [11] that is much less than the calculated values in each of the gas mixtures (s. Fig. 2). This means the use of NGs ballasted for industrial and domestic appliances is not endangered. But DIN “Automotive fuels...” says, the sum of the shares of nitrogen and carbon dioxide has to be less than 15 mol%, which means there are some restrictions of use NG as an automotive fuel [4]. NG from Qatar, Trinidad and Tobago ballasted with 15.2 and 16.4 mol% nitrogen respectively till the matching of the German L-gas quality cannot be used as an automotive fuel. Furthermore, a methane content of at least 80 mol% is mandatory [4]. Table 3 shows, that not each NG of the determined above ballasted does comply with the mentioned requirement. These are presented in red and italic. This means these ballasted NGs have to be excluded from automotive usage.

Natural gas quality	Origin of NG	Methane content [mol%]
Russian H-gas	Algeria / Arzew	84.2
	Nigeria	87.0
	Norway	88.9
	Qatar	86.2
	Trinidad and Tobago	96.8
Norway H-gas	Algeria / Arzew	87.6
	Nigeria	90.4
	Norway	92.0
	Qatar	89.6
	Trinidad and Tobago	96.4
German L-gas	Algeria / Arzew	***74.0***
	Nigeria	***76.4***
	Norway	***75.6***
	Qatar	***73.4***
	Trinidad and Tobago	***76.7***
Netherland L-gas	Algeria / Arzew	***76.9***
	Nigeria	***79.5***
	Norway	81.2
	Qatar	***78.7***
	Trinidad and Tobago	88.7

Table 3 – Methane content of NGs ballasted till the matching of qualities of natural gas transported and distributed in networks.

Let us have a look at the calculation of NGs from Qatar, Norway, Trinidad and Tobago that will be ballasted till the matching of qualities of German L-gas (s. Fig. 2, marked with yellow arrows). We find that matching the “±2 %-requirement” is impossible for this scenario. The gap between Wobbe number’s nominal value of these NGs and natural gas is too wide, so even after ballasting with air or nitrogen the Wobbe number of the resulting gas mixtures remains beyond the permitted limit for L-gas. This does not allow the injection of these NGs into the networks transporting or distributing German L-gas. So the further calculations for these three NGs are done to match the L-gas Wobbe number's range.

Furthermore all the technical requirements for substitution of H-gases by NGs from the above mentioned sources or admixing of them to H-gas flows are fully guaranteed. This can explained through the gas composition of LNG, which resembles the one's of H-gases.

The calculation also shows that all the determined gas mixtures (s. Fig. 2) feature the relative density range 0.59 to 0.69 which matches the requirements set in the DVGW Code of Practice "Gas composition" at 0.55 to 0.75 [5].

As has been mentioned before one of the important parameters of NG is the methane number. Due to gas engines' fuel requirements every fuel gas for automotive usage has to have a methane number over 70 in order to protect internal combustion engines from knocking [4]. Table 2 shows the calculated values of the methane number for some NGs. All of the determined values are within the limits of 75 to 89. The calculation also shows also that the gas mixtures from Figure 2 comply with the requirements to the methane number value.

3. CONCLUSIONS AND OUTLOOK

Against the backdrop of the latest efforts in the development of the European LNG distribution network, containing many projects especially in transportation sector as well as construction of new landing terminals, LNG distribution system in Germany remains under-developed. The use of LNG as a solution for the upcoming L-gas supply bottleneck as well as for diversification of L- and H-gas sources might give an impulse to the establishment of the German LNG market as well as non-network infrastructure as a positive side effect.

The technical requirements for the ballasting of the LNGs from the Algeria / Arzew, Nigeria, Norway, Qatar, Trinidad and Tobago for the benefit of the German gas consumers can be matched. The financial efforts of the LNG conversion itself have to be estimated and compared with those of the gas market conversion ones.

However the ballasting of gaseous LNGs with pure nitrogen instead of air is required in some cases, e. g. for the injection of NG into the natural gas flow. Therefore the implementation of appropriate technical measures is important. Relatively simple air admixing appliances that have been used for decades for ballasting of bio gases must be replaced with air separation units. The latter can raise the costs for the handling of the upcoming gas supply bottleneck.

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