Technology of Low-Tonnage LNG Production Based on the Potential of Existing Gas Networks

D V Gilmutdinov¹, P E Mikriukov², A V Kolchin³

¹Master’s Student, Ufa State Petroleum Technological University, Transportation and Storage of Oil and Gas Department, 1 Kosmonavtov Street, Ufa, 450061, Russian Federation
²Master’s Student, Ufa State Petroleum Technological University, Transportation and Storage of Oil and Gas Department, 1 Kosmonavtov Street, Ufa, 450061, Russian Federation
³Senior Lecturer, Ufa State Petroleum Technological University, Transportation and Storage of Oil and Gas Department, 1 Kosmonavtov Street, Ufa, 450061, Russian Federation

E-mail: kolchin-alexander@mail.ru

Abstract. Numerous natural gas liquefaction technologies for the main gas pipeline are known, however, this process is little used for the potential use of electric energy and is poorly implemented at the GDS, where it is possible to carry out low-tonnage LNG production. The object of research is gas distribution station (GDS) "Novo-Alexandrovka" with a capacity of 45 m³/hour. In the course of the research work the technological scheme of liquefaction of natural gas was developed on the basis of the available parameters at the mentioned GDS. This topic is topical due to the annually growing demand for liquefied natural gas. Currently, the LNG market in Russia especially is not developed due to the lack of proper regulatory governability of use and production, lack of cryo-filling stations and a clear program of development of gas vehicles. It is proposed to introduce a liquefied natural gas unit with a main temperature reduction unit through adiabatic expansion in turboexpander. The paper discover construction decisions and analysis of the dependence of the liquefaction temperature of natural gas on the inlet pressure into the gas distribution network as well as The technical and economic characteristics of the implementation of the liquefaction unit at the “Novo-Alexandrovka”.

1. Introduction

Every year, natural gas strengthens its position in the global energy sector. The share of hydrocarbon gases in the global energy system reaches almost 48%.

The main way of gas delivery to the consumer is pipeline transportation, but for technical and economic reasons it is not always expedient. To supply natural gas to the consumer over long distances, technologies of gas conversion into a liquid state and pipeline-free transport in tankers, railway tanks and others are used. Moreover, PJSC Gazprom's strategic goal in the area of energy saving for the period from 2011 to 2020 is the efficient use of non-renewable energy resources through the introduction of an energy saving technology.
Numerous natural gas liquefaction technologies for the main gas pipeline are known, however, this process is little used for the potential use of electric energy and is poorly implemented at the GDS, where it is possible to carry out low-tonnage LNG production.

In LNG exporting and importing countries two terms are distinguished: 1) Liquefied Petroleum Gas (LPG) and 2) Liquefied Natural Gas (LNG). The first refers to C3 and C4 hydrocarbons, while the second refers to C1, C2 and C3 hydrocarbon mixtures derived from natural gas. The main advantage of liquefied gas in comparison with "dry" gas is its ability to transport it economically without pipelines over long, medium and short distances. In the LNG industry, it is used for heat treatment of metal and, if necessary, it can temporarily replace natural gas in technological processes. LNG motor fuel is also superior to gasoline. With the same LNG consumption rates with diesel fuel, the price of NGV fuel is 1.5 to 2 times lower.

2. Problem statement
This topic is topical due to the annually growing demand for liquefied natural gas. Currently, the LNG market in Russia is not developed due to the lack of proper regulatory governability of use and production, lack of cryo-filling stations and a clear program of development of gas vehicles, their conversion to liquefied natural gas. However, the policy of state regulation in the field of LNG use and production has changed. For 2020, it is planned to introduce dozens of normative and technical documentation in the field of liquefaction, in 2019 large-tonnage LNG production is not subject to mineral extraction tax, as well as the price for 1 m3 LNG is set cost-effective for production.

Thus, the small-scale production of liquefied natural gas (LNG) is an industry that has great potential. Additionally, it should be taken into account the government program for the gasification of rural settlements in the Russian Federation issued in 2001 and required an increase of the gasification level up to 85% from 68.6% in 2018. The growth of sparsely populated areas in relative distance from existing gas distribution or trunk networks assume that the issue of developing this alternative method of liquefaction of natural gas becomes an urgent matter.

3. Research technique
The object of research is gas distribution station (GDS) "Novo-Alexandrovka" with a capacity of 45 m3/hour. Composition of raw natural gas was assumed as a normal mixture of hydrocarbons and referred as commercial gas that faced requirements of STO Gasprom 089-2010 and shown in Figures 2-3.

The facility was simulated in static with a use of HYSYS software (version 8.4) on a base of a Peng Robinson property package. Analysis was based on the following premises:
1) heat loss to the surroundings and pressure loss in interconnecting pipelines is negligible;
2) raw natural gas is saturated with water vapor at given pressure and temperature;
3) liquid carryover to the gas lines from separators is negligible;
4) the value of log mean temperature difference between two gas streams is 10˚C and between gas and condensate streams is 15 °C;
5) there is no hydrate formation processes. In other case methanol consumption should be estimated.

To compensate the possible disagreement between parameters of the real facility and of the simulated one because of the separator performance water and hydrocarbon dew points for commercial gas were taken from 3 to 5 °C lower than standardized values.

The specification for commercial gas was determined in accordance with requirements (STO Gasprom 089, 2010) for frigid microclimatic region for the most severe operation condition which is winter.

In the course of the research work the technological scheme of liquefaction of natural gas was developed on the basis of the available parameters at the "Novo-Alexandrovka" GDS. The technological scheme is shown in Figure 1.
Figure 1. Liquefaction Technological Scheme.

The LNG production process is as follows. With GDS, gas under pressure is withdrawn to the hydrate formation prevention unit (depending on GDS it can be withdrawn after cyclone dust collectors, but to the reduction unit) and is delivered to the inlet of the LNG plant. Natural gas is dried up, after which the stream is divided into a liquefied and turboexpanding stream, which is liquefied and directed to the CO2 purification unit. The liquefied and turboexpander flow is then routed to a pre-exchanger, where the turboexpander and the liquefied flow reduce their temperature from the gas flow of the LNG tanks and turboexpander flow after the main heat exchanger. The turboexpander flow after the preheat exchanger enters the turboexpander, where the temperature drops due to the pressure drop (Joule-Thompson effect) and the turboexpander flow cools the liquefied stream after the main heat exchanger. A two-phase mixture of natural gas is then fed into a separator where the liquid phase is separated. The LNG from the separator is discharged into the cryogenic tanks of the storage unit. The steam phase is mixed with the turbo expander flow and is heated in heat exchangers and fed to the GDS outlet.

The main advantage of this technological scheme is the possibility of using potentially high pressure at the GDS without preliminary gas compression to create sufficient pressure difference for adiabatic expansion in the turboexpander. On this basis, an electric power generator can be installed on the same shaft as the turboexpander, which will provide autonomous power supply not only to the liquefaction unit, but also to the entire gas distribution station.

4. Analysis of gas distribution system with liquefaction process

Before liquefaction, natural gas must be dried and purified. As the process can be automated in absorption plants, the drying and purification processes have been simulated in these plants.

The main parameters of the absorption method of natural gas drying on diethylene glycol (DEG) and triethylene glycol (TEG) have been calculated. The economic efficiency of TEG application is proved. The ratio between the flow rate and the price of DEG and TEG solution is presented below:

\[ Q_{\text{DEG}} \cdot C_{\text{DEG}} = 17088,41 \cdot 70 = 1196188,7 \text{ RUB}; \]

\[ Q_{\text{TEG}} \cdot C_{\text{TEG}} = 1353,69 \cdot 130 = 175979,7 \text{ RUB}. \]

The absorption drying process was then simulated in the Aspen Hysys software. The simulated process, as well as the basic parameters of the cleaning units are shown in Figure 2.
For efficient drying of natural gas, the TEG concentration was 98%. The rest 2% is water.

After drying of natural gas, the gas is purified of carbon dioxide. Diethanolamine with a 35% concentration was simulated as an absorber in the plant. The simulated process in Aspen Hysys is shown in Figure 3.

After modeling the process of natural gas drying, it is necessary to simulate the technology of LNG production at the “Novo-Aleksandrovka” GDS. Selection of parameters (temperature, pressure) at the nodes was carried out based on the graph of gas entropy dependence on temperature. The graph is shown in Figure 4. The orange color on the graph shows the dependence of gas entropy on the temperature at atmospheric pressure, blue color shows the dependence of gas entropy on the temperature at the inlet pressure of natural gas at the GDS "Novo-Aleksandrovka" ("P" _"en" =4.7 MPa).
The process of liquefaction is as follows:
1) Cooling of the total amount of gas from ambient temperature \( T_{\text{v.c.}} = T_1 \), to the dew point;
2) Gas condensation in the range of variable temperatures \( T_r - T_k = T_2 - T_3 \);
3) Cooling of gas that does not condense from \( T_2 \) to \( T_3 \). But most often, partial gas condensation takes place at point \( 3' \);
4) Overcooling of liquid from boiling point temperature \( T_k = T_3 \) to supercooling temperature \( T_n = T_4 \).

After the temperature values at the liquefaction units have been obtained, the technological scheme of liquefaction has been designed, which is presented below after the process modeling in Figure 5.

In addition to the installation itself, the figure shows the flow rates and temperatures at the liquefaction units as well as the molar component composition of the gas before and after liquefaction.

The application of the turboexpander unit as a source of electrical energy is studied. The main parameters of the turboexpander, obtained in accordance with the methodology of calculation of R Gazprom 2-6.2-600-2011 "Application of turboexpander power plants and calculation of their main parameters", are presented in Table 1 and Figure 6.
Figure 6. Turboexpander unit.

Table 1. Main parameters of the turboexpander.

| Parameter, unit of change                      | Significance   |
|-----------------------------------------------|----------------|
| Compressibility factor                        | 0.8939         |
| Gas inlet enthalpy, kJ/kg                     | 1359.4         |
| Gas enthalpy at the outlet, kJ/kg             | 1315.2         |
| Electrical power of turboexpander, kW         | 842            |
| Annual number of hours in operation, h        | 7000           |

In addition to the use of a turboexpander in a plant to increase the pressure of the gas phase from cryogenic tanks, the main parameters of the ejector were calculated. The appearance of the ejector is shown in Figure 7. Table 2 presents the main parameters.

Figure 7. Ejector.
Table 2. Basic Ejector Parameters.

| Parameter, unit of change. | Significance |
|---------------------------|--------------|
| Ejection factor           | 2.41         |
| Gas velocity in the critical section of the ejector nozzle, m/s | 767.22 |
| The area of the critical section of the nozzle, mm² | 15.69 |
| Ejector nozzle radius, mm | 2.23         |
| The area of the ejected flow, mm² | 27.54 |
| Flow range of the ejected flow, mm | 2.96 |
| Mixing chamber radius, mm | 6.19         |
| Mixing chamber length, mm | 123.8        |

5. Conclusions
The following recommendations were drawn from the research work:

1) In a comparative analysis of the technologies of low-tonnage LNG production, it was determined that with the parameters at the inlet of the low pressure gas distribution network of 4.7 MPa and a potential increase in gas consumption up to 100,000 m³/3 It is advisable to use a liquefaction plant with a turboexpander and the possibility of using the potential for electricity generation. The amount of electricity produced varies from 600 to 850 kW∙h

2) It is proposed to introduce a liquefied natural gas unit with a main temperature reduction unit through adiabatic expansion in the turboexpander. Optimal input parameters of pressure and temperature are within the range of Pen = 4 - 4.7 MPa, Ten = minus 50 - minus 55 ° C. Optimal output parameters of pressure and temperature at the outlet are about Pex = 1 - 1.2 MPa, Tex = minus 100 - minus 110 ° C;

3) The dependence of the liquefaction temperature of natural gas on the inlet pressure into the gas distribution network is constructed and analyzed. It has been established that the liquefaction temperature of natural gas depends on entropy nonlinearly. From the received dependences it is possible to define what values of temperature and pressure at the inlet to the gas distribution station are necessary for maintenance of the necessary expense of the liquefied natural gas QLNG = 5693 m³/ч. The liquefaction coefficient of this unit was K_liq=13 %;

4) The technical and economic characteristics of the implementation of the liquefaction unit at the “Novo-Alexandrovka” State Distribution Station are determined and studied. Electricity savings from the introduction of the installation on the gas distribution station about 80-100 kW∙h. Payback period of the project is 3-6 years.

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