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PRODUCTION OF LIQUEFIED NATURAL GAS FROM NATURAL GAS

PROIZVODNJA TEČNOG PRIRODNOG GASA IZ PRIRODNOG GASA

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Ključne reči
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Abstract

Production of liquefied natural gas (LNG) from natural gas is justified in the case of transport by LNG mobile machines. LNG has a temperature of -164 °C and density of 460 kg/m^3. Density of gas at normal pressure is 0.75 kg/m^3, whereas LNG has a density over 640 times the density of natural gas. In other words, the equivalent of 1.5 litres LNG is 1 m^3 of natural gas. The transport of 1 tonne of LNG to the designated location is equivalent to 1400 m^3 of natural gas. A consumption of 6 million tonnes of LNG per year is equivalent to a 300 MW power plant energy production; or approximately 70000 m^3/h water consumption. The conversion of natural gas to a liquid state is carried out in several stages. First, all impurities are removed, primarily carbon dioxide, and sometimes minimal balances of sulphuric compounds. The gas is then gradually cooled until it reaches approximately -164 °C. Water is then removed that could otherwise turn into ice crystals and block installation components. The next step is the removal of most heavy hydrocarbons.

Izvod

Proizvodnja tečnog prirodnog gasa (TPG) iz prirodnog gasa je opravdana u slučajevima transporta TPG mobilnim mašinama. TPG ima temperaturu od -164 °C. Gustina TPG iznosi 460 kg/m^3. Gustina gasa pri normalnom pritisku je 0,75 kg/m^3, tj. TPG ima gustinu 640 puta veću od gustine prirodnog gasa. Drugim rečima ekvivalent od 1,5 litara TPG je 1 m^3 prirodnog gasa. Prilikom transporta TPG do mesta potrošnje, 1 t je ekvivalentna 1400 m^3 prirodnog gasa. Potrošnja 6 miliona tona TPG godišnje je ekvivalentna proizvodnji elektrane od 300 MW ili potrošnji vode od oko 70 000 m^3/h. Konverzija prirodnog gasa u tečnom stanju se obavlja u nekoliko faza. Prvo se uklanjaju sve nečistoće, sav ugljen-dioksid, a ponekad i minimalni sadržaji sumpornih jedinjenja. Gas se zatim postepeno hladi, obično dok se ne dostigne temperatura -164 °C. Zatim se odstranjuje voda, koja bi se inače pretvorila u kristale leda i blokirala instalaciju. Sledeći korak je uklanjanje većine teških ugljovodonika.

INTRODUCTION

The first pilot plant for natural gas liquefaction (LNG) is built in the United States in 1940, by Hope Natural Gas. Its successful work was the basis for the design of industrial installations to regulate peak consumption. Installation performance of 83.8 tonnes per day was put into operation in 1941 by the East Ohio Fuel in Cleveland.

The liquefaction plant working on providing substantive demand represents a major industrial complex, consisting not only of the preparation units and liquefaction of gas, but storage and cryogenic tanks, equipment for LNG tanker loading jetty and a number of subsidiary farms, designed to meet the enormous needs of the plant's electricity and water for cooling.

In this paper production of LNG is presented, with basic data needed for the structural integrity aspects. Main issues are with highly loaded pressure vessels, /1-5/.

NATURAL GAS LIQUEFACTION TECHNOLOGY

The process of liquefying natural gas can be divided into 4 stages: production, preparation and transportation of natural gas by pipeline to the plant for liquefaction; processing, liquefaction, storage and loading to specialized LNG tankers; marine transportation of LNG, usually over long distances, to the country of marketing; unloading of the LNG at the receiving terminal, regasification, storage and delivery to the final consumer through pipelines. These four stages are interrelated and form a chain from a gas well to the end consumer. Any weak link in the chain can jeopardize the entire LNG project, /6/.

At atmospheric pressure, the LNG is liquid. After that, the LNG is placed in specially isolated huge tanks of capacities from 60000 to 100000 m^3, and then is loaded into cryogenic tankers for transport.

Seven different natural gas-to-liquid technologies are used worldwide. To date, the clear leader in this field is the Air Products company. Their processes AP-SMR™, AP-C3MR™ and AP-X® make up 82% of the total market. The only competitor to these processes is the technology Optimized Cascade developed by ConocoPhillips. In turn, the above liquefaction technologies as a rule are used for the production of large volumes of LNG destined for export.

However, compact installation liquefaction has great potential, intended for internal use at industrial enterprises. This type of installation can be found in Norway, Finland, and Russia. In addition, local installation of LNG can be widely used in China, where the manufacture of vehicles running on LNG is actively developing today. Introduction of small installations might allow China to scale up the existing transport network of LNG vehicles.

APPLICATION OF CRYOGENIC GAS MACHINES (CGM) WORKING ON A STIRLING CYCLE

At the heart of Stirling Technologies is the idea of creating the liquefier with cryogenic gas machines (CGM) working on a Stirling cycle. The natural gas liquefaction process goes without prior compressing at atmospheric pressure. This allows the installation of NG liquefaction based on CGM Stirling compact and is simple to maintain.

An important feature is the possibility of liquefaction by Stirling MAG 100% low pressure inlet gas, unlike the traditional liquefier (butterfly-effect installations and vortex tubes), that require high pressure (not less than 4 MPa), and the availability of production pipelines to reset the unliquefied part (up to 97%) primary gas. CGM Stirling represent a successful combination in a single unit: the compressor, detander, and heat-exchange devices, while freezing the impurities of NG is handled by a special device. Freeze out impurities without additional costs for chemical cleaning NG result in a liquid product that corresponds to the requirements of TU 51-03-03-85 and GOST 27.577-87 on motor fuel, /7/.

The installation of over 1 t/h LNG is meant to be used as a traditional way of liquefying, widely known in cryogenics (such as CJSC 'Sigma-Gaz' JSC, 'Ural Transgaz', American company 'Kryopac', and others), and a new cycle of natural gas liquefaction based on combined internal and external cooling. Internal cooling is achieved by isobaric expansion of natural gas and its partial liquefaction, after which the unliquefied part, presented in the form of low-pressure vapour undergoes an external cooling condenser CGM Stirling performance.

Depending on the performance, the required individual complexes equipped with LNG are serially produced by the domestic industry with one and two cylinders CGM Stirling (ZIF1000, ZIF2002). Techno-economic calculation is made by specialists from the St. Petersburg Foundation for the support of the military-industrial complex when comparing different types of CGM, manufactured both in our country and abroad, as well as in terms of single and serial production of filling points from Stirling CGM (Table 1).

Solo fuelling points (Fig. 1, LLC 'EKOSOJUZ', St. Petersburg) are intended for the production of cheaper and cleaner alternative motor fuel, and may be located at:

- private households-cottages and villas (refills from 1 to 10 autos of the type ‘Volga’ per day);
- farms (for charging up to 5 motor tractor units);
- remote or separate public facilities with a small number of vehicles (customs offices, forest borders, and so on).

Table 1. Characteristics of foreign and Russian CGM Stirling.

Model CGM	Production (l/h)	Electric motor power (kW)	Machine weight (kg)	Company
PPG2500	700	120	5500	North American Philips
WKS	900	170	6000	Werkspor
Model D	1100	280	7000	North American Philips
SGL1	18	11	250	Stirling
Model A1	14	10	250	North American Philips
ZIF700	14	17	500	Plant Arsenal
CGM9000	120	110	1500	Geliimash

Figure 1. Small garage installation for vehicle gas fuel.

For farms and at other sites where there is no electricity, gas is provided by drive motor. The main sources of natural gas for individual items are production pipelines with pressure from 0.1 to 0.6 MPa. Garage LNG fuelling points should be established, taking into account the quantity and type of road transport in the fleet, /8/.

Installation of Gazotron-2 (LLC ‘EKOSOJUZ’, St. Petersburg) is used to source liquefaction of natural gas according to GOST 5542-87 and getting cheaper and cleaner fuel gas corresponding to TU51-03-03-85.

The main parameters and characteristics of the installation receiving liquefied natural gas (LNG):

- plant productivity (l/h), no less than 20 l/h;
- gas input pressure (MPa), not above 0.1 MPa;
- release installation mode (min), no more than 90 min;
- duration of uninterrupted work (h), not less than 8 h.

A distinctive feature of the installation is possible by refrigerant cycle cryogenic gas cars. The cryogenerator provides the temperature level at -196 °C and works on the reverse Stirling cycle (working fluid - helium). The gas liquefaction process is made by direct contact fluidization gas with cold surface heat exchanger shell wall. The low temperature required for the liquefaction of gases is produced in the upper cavity adjacent to the compressor heat exchanger liquefier, through periodic expansion of helium in this cavity, /9/.

The process of getting a cold environment is based on the principle of lowering the temperature preselected compressed and cooled in the refrigerator and regenerator of helium at its expansion. Through the repetitive cycle of compression and expansion of helium the temperature reaches 200 °C. The resulting cold fluid passes through the walls of the shell gas heat exchanger, which after condensation drains via liquefier.

Installations of receiving LNG can be connected to the urban gas distribution networks and can be widely applied in dense urban areas, localities, as well as in enterprises and in rural areas. Working pressure of inlet gas is 0.1 - 0.02 MPa. Its work is possible when connecting to a regular communal gas pipeline, i.e. from home gas range or from a boiler room in the cottage. For this purpose it is enough to have a separate room, such as a separate box, and kit garage cryogenic equipment, which includes a production block, operator, and storage unit, with filling devices.

PRODUCTION AND SHIPMENT OF LNG AT FREE-STANDING GAS FILLING STATION

The technology is intended for the organisation of production and shipment of liquefied natural gas at motor gas inflate compressor station (MGICS) with the aim of increasing the ratio of their loading and obtaining an additional product. The installation is based on the throttle branch high pressure cycle with a tentative cooling of natural gas using a freon refrigerating machine.

High-pressure gas from the compressor (K) freestanding gas filling station, forming a direct stream passes heat exchanger-recuperator (TOR1) and enters the freon evaporator heat exchanger-evaporator (TI). In the heat exchanger-evaporator the cooling gas has direct flow of high pressure by evaporation of liquid freon. Chiller (XM) provides liquid freon in the heat exchanger-evaporator and pumps the freon while the boiling vapours are generated.

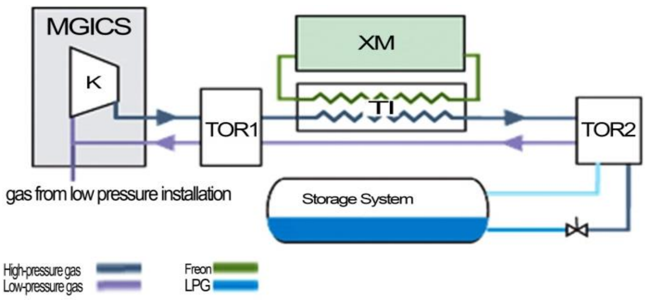

Figure 2. Installation scheme of obtaining LNG.

Passing through the heat exchanger-recuperator (TOR2), the high pressure gas continues to cool. After heat exchange in the exchanger-recuperator the choked gas is at high pressure with partial liquefaction. Vapour-liquid mixture enters the storage system where vapour-liquid mixture separation is formed. The liquefied natural gas remains in the storage system, and the cold gas low pressure storage system appears in heat recuperators (TOR2) and (TOR1). Leaving the heat exchanger-recuperator (TOR1), low pressure gas enters the compressor stations and is compressed to a high pressure.

Table 2. Technical data technology.

Productivity (kg/h)	1100
Performance MGICS (Nm^3/h)	3700
Power consumption (kW/kg of LNG)	0.8
The quality of products	TU 51-03-03-85
Mode of operation	continuous
Term of service	not less than 15 years

Installation of the new generation (ING), Table 3, is made at the Baltic shipyard in Saint Petersburg in 2002, installed on Urban junction station (UJS) in Vyborg (Lentransgaz 'LLC'). In accordance with the scheme of high-pressure gas from the input pipeline UJS, it passes through the heat regulating throttle valve in the liquefier-separator, where we have a partial gas liquefaction in the form of dispersed in-gas stream drops of LNG and their separation.

Table 3. LNG specifications.

ING specifications	
Working pressure (MPa)	3.0, … , 7.5
LNG pressure (MPa)	0.2, … , 1.6
Gas consumption (Nm3/h)	3000, … , 18000
Productivity (kg/h)	to 800
Weight (tonnes)	20
Mode of operation	Continuous

The finished product appears in the storage tank, and the unliquefied flow is directed to heat exchangers for cooling direct high pressure gas stream. An increase in the cooling capacity of the main throttle installation cycle is achieved through the introduction of an additional external cooling circuit direct flow based on Vortex tube divides /10, 11/. The presence of external cooling circuit, combined with the system of regulation of the quantity and quality of the finished product on the basis of two throttle regulating valves allows you to fine-tune the installation modes when you change the input and output parameters of the UJS. The fundamental technological installation is shown in Fig. 3.

So, according to preliminary estimates, the cost of one litre of LNG, resulting from a production in modular units of NG liquefaction based on Stirling technology does not exceed 0.06 USD, with a payback of garage items themselves, as based on CGM 2.5 years less than Stirling. It is possible to create several small natural gas liquefaction capacities from 1000 up to 20000 tonnes of LNG per year, which fully comply with the prospective needs of the region. Calculations show that the increase in the cost of LNG, relative to the cost of gas before UJS, does not exceed 14 USD/tonne of product.

Currently 11 countries are exporting LNG from 12 LNG complexes (Table 4). New projects are under construction in Australia, Russia, Norway and Egypt, together with the planned expansion of existing capacity by 2007 (Fig. 4) to increase the annual capacity of liquefied natural gas to approximately 200 million tonnes, which is about 10% of the global gas consumption. Qatar, Nigeria, Indonesia and Australia are considering not only the development of existing facilities, but also commissioning new capacities. Moreover, Iran, Yemen, Equatorial Guinea, Angola, Venezuela, Bolivia, and Peru, are considering exporting LNG as a way to monetize their gas resources.

Figure 3. Installation for receiving LNG.

Table 4. Operating LNG plants as of November 30, 2003.

Country/Plant	Quantity Mtons/year	The main consumer
Abu Dhabi/ Das Island	6.0	Tokyo Elec.
Algeria/ Arzew GL1Z	7.9	Gaz de France
Australia/ North West Shelf Project	7.5	Tokyo Elec., Chubu Elec., Kansai Elec.,Chugoku Elec.,Kyushu Elec., Tokyo Gas, Osaka Gas,Toho Gas
Brunei Syria / Lumut	7.2	Tokyo Elec., Tokyo Gas, Osaka Gas, Korea Gas
Indonesia/ Arun	12.8	Tokyo Elec., Tohoku Elec., Korea Gas
Malaysia/ Bintul	7.6	Tokyo Gas, Tokyo Elec., Other Jpn.Utilities, Korea Gas, Chinese Petroleum
Nigeria/ Nigeria LNG	8.7	Enagas, Enel, Botas, GdF, Transgas, Gas Natural
Oman / Oman LNG	3.3	Osaka Gas, Kogas, One-off sale in Europe and the United States
Qatar/ Qatargas	8	Chubu Elec.,7 Japanese utilities, One-off sale in Europe and USA
Trinidad/ Atlantic LNG	9.6	Tractebel, Gas Natural, BP, BG,Repsol, Gasd'Euskadi
United States/ Kenai	1.9	Tokyo Gas, Tokyo Elec.
TOTAL	131.7	

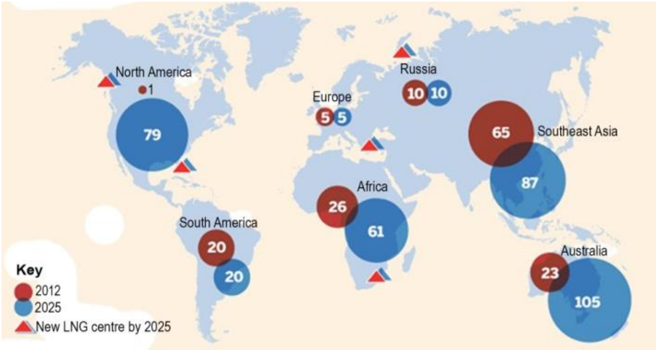

Figure 4. LNG capacity by region (million tonnes/year).

PROJECT 'VLADIVOSTOK-LNG'

The project assumes construction near Vladivostok (Primorsky Region) of the plant for LNG production with a capacity not less than 15 million tonnes of LNG in a year. First 5 million tonnes line in a year are planned to enter in 2018. Gas Sakhalin (Sakhalin-II and Sakhalin-3 projects), the Yakut, and Irkutsk centres of gas production will become the resource base for the plant, /12, 13/.

In South Korea, the Side Track for water floating LNG storage is developed for Lithuania. Floating LNG storage is based on the order of the company Hoegh LNG. The Lithuanian Government has already contracted on the lease. Storage capacity will reach 170000 m^3. The floating storage infrastructure to be created is a central part of an LNG terminal in Klaipeda, /14/.

Gas delivery to consumers in the form of LNG will add to the cost of extraction and pumping gas through the pipeline inlet nozzle overhead for liquefaction (from 50 to 100 USD per 1000 m^3) and transportation (30 to 150 USD per 1000 m^3, depending on distance). The cost of the regasification adds about 10 to 20 USD for 1000 m^3. For example, the United States purchased gas costs 4 USD for MBTE (140 USD for 1000 m^3), and the economically justified delivery in Asia is at a price no lower than 10 USD for MBTE (350 USD per 1000 m^3). A capital cost at 5 billion m^3/year of LNG project will be:

- liquefaction plant 1400-2000;
- LNG ships (amount of 130000 m^3) 200-250 (5 pieces);
- terminals and a regasification plant at 200-250.

A total of 2.6-3.5 million USD.

GAS PROCESSING CENTRIFUGAL INSTALLATION

The installation is intended for preparation of associated (petroleum) gas separation and feeding consumers: dry purified gas OST 51.04-93 and OST 51.40-93, broad fractions of light hydrocarbons (NGL), gas, gasoline, aviation fuel condensed (AFC) and stable condensate (LPG-propane-butane). The installation can also be used for the production of liquefied natural gas (LNG) anywhere, that allows you to apply it if it is not possible to supply gas to transit pipes as a result of accidents or unauthorized action transiters, as well as in places where gas pipelines are laying economically impractical or impossible.

The main advantages of this complex are its small size, energy independence, and lower cost. Production of this complex can be established at engineering plants and does not require the use of imported materials, /15, 16/.

The basis for obtaining the LNG lies in the centrifugal gas processing installation. Bulk natural gas under high pressure in the installation is thermal stratification. At the heart of the thermal stratification effect lies the pipe Market-rank's effect. This bundle is provided by centrifugal forces that make central layers of gas stretched and cooled adiabatically, and the peripheral segments of pipe walls are stifled adiabatically and heated. Flows of cooled and heated gas in the tube space-time are divided into the outlet and can be made to the following sequentially located tube (step) to increase temperature stratification.

Temperature difference in promotion of gas in one stage can reach up to 100 °C, and it means that already in the first stage when the gas freezing occurs at room temperature and the moisture is removed (at temperatures below 0 °C), i.e. it is drying. In the next phase at -78 °C the condensed carbon dioxide can also be removed. Thus, in the second and subsequent stages low-temperature fractions are removed. This process is called scavenging. The cleaning process can remove heavy high-temperature fractions of natural gas, each with a dew point.

This consistent cooling allows the removal of high-temperature fractions and liquefaction at -164 °C to get almost pure methane. Figure 5 presents the concept of cascade centrifugal units. The gas flow is made to spin in a separate centrifugal installation (tube) in a specially shaped nozzle, of an optimal design that is determined by the difference of pressures and thermal physical properties applied to the gas intake. Dimensions of the pipes depend on the performance. For example, for an annual filing of 40 million entry m^3 of gas, the pipe length is up to 2 m, and the diameter may be up to 300 mm. The appearance of CIP is presented in Figs. 6 and 7, as a mobile plant for receiving LNG of ‘Kryopac’ company, United States. Thus, existing technologies provide the production and transportation of LNG on an industrial scale.

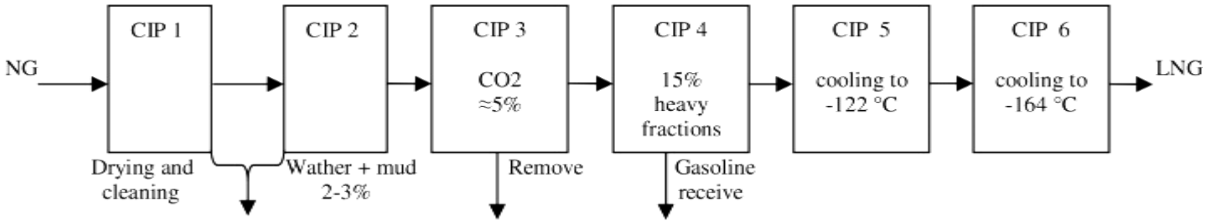

Figure 5. Concept of multi-stage processing of natural gas in centrifugal installations (CIP) for drying, cleaning, cooling, and liquefaction.

Figure 6. The appearance of CIP.

Figure 7. Mobile plant for receiving LNG gas processing, installation company Kryopac, United States.

CONCLUSION

If the distance of the user from the vendor is not more than 3000 km, delivery tankers are economically more efficient than transportation by pipeline. Investments are 10-40 % and the profitability index is 16.25 %. Automation and control system, as well as safety valves include all necessary locks and alarm systems for emergency settings and ensure safe and reliable operation without constant maintenance.

In particular, the first gas liquefaction plants in the 60-ies had a specific rate of capital intensity of 500 USD/t; plants built in the 70-ies and 80-ies 400 USD/t; and plants that started operation at the end of the 90-ies had 250 USD/t, and several recently introduced into operation enterprises 200 USD/t. So now, virtually every automobile company may set up a receiving point of the liquefied natural gas of capacity from 10 up to 150 kg/h, based on cryogenic gas machines.

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