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Increasing the Energy Efficiency of the Power Supply System on Liquefied Natural Gas through the Use of a Combined Cycle Gas Turbine Plant

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Abstract. The use of LNG for the production of additional energy is topical today. Very often LNG is used for gasification of settlements and industrial enterprises. LNG makes it possible to gasify objects remote from main pipelines for long distances by creating an LNG reserve directly from the consumer, avoiding the construction of expensive piping systems. However, in this case, there are large losses of cryoproduct and its low-potential heat. In this article, we propose a technical solution for compensating for the loss of cryoproducts during storage using an installation consisting of two circuits, one of which is a loss compensation loop and the other is a circuit for generating additional energy. The conducted researches showed that the use of this system allowed to return the previously used for liquefying electric power in the amount of 24%.

1 Introduction

At present, natural gas is becoming one of the most important sources of energy, as its reserves are huge, and it is environmentally friendly fuel in comparison with petroleum products. Natural gas in a compact for transportation and storage form can be contained in compressed (gaseous) and liquefied states. The most relevant at the moment is the use of liquefied natural gas (LNG) as an energy carrier for the same purposes as conventional natural gas, since this allows to reduce the mass-dimensional characteristics of tanks for storage and transportation [1].

In a liquefied state, natural gas at a pressure of 1 atmosphere is 640 times denser than under normal conditions, which significantly reduces the volume and weight of cylinders for storage and transportation, and also makes it technically possible for the accumulation, storage and delivery of large gas masses to the consumers at the required time [2]. For example, only in a liquefied state, methane makes it economically feasible to solve the problem of delivery to remote areas.

LNG enables gasification of facilities remote from long-distance pipelines over long distances by creating an LNG reserve directly from the consumer, avoiding the construction of costly pipeline systems [3].

Typically, gasification of LNG is mainly due to the heat of the environment. It is considered that the use of heat from the environment is not an energy-consuming process. However, it is worth mentioning that for the liquefaction of LNG, considerable energy was previously expended (about 1

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kWh of electricity per 1 kg of LNG), which for just this gasification experiment is simply reset to three times. Thus, liquefied natural gas (like any other cryoproduct) contains an energy potential that could be used to return it to its original gaseous state, and therefore the very process of LNG reagation has a significant potential for energy saving [4].

This energy is called cold energy and now there are a lot of science work in field of its using.

2 Application of LNG for gasification of settlements, industrial enterprises and production of additional electric energy

In case of need for gasification of remote settlements, industrial enterprises and autogas filling stations, supply of which is impossible through gas pipelines, the only way is to deliver natural gas in a liquefied state with its subsequent transfer due to evaporation into the gaseous state [5].

When supplying LNG to the gas distribution point and then through the local highways networks to residential houses, industrial enterprises and for refueling vehicles at the gas station, a regasification process in the evaporator is usually carried out, usually atmospheric type (Figure 1). This process is usually due to the supply of heat to the environment. However, with the regasification process, it is possible to return some of the energy expended for the liquefaction of natural gas.

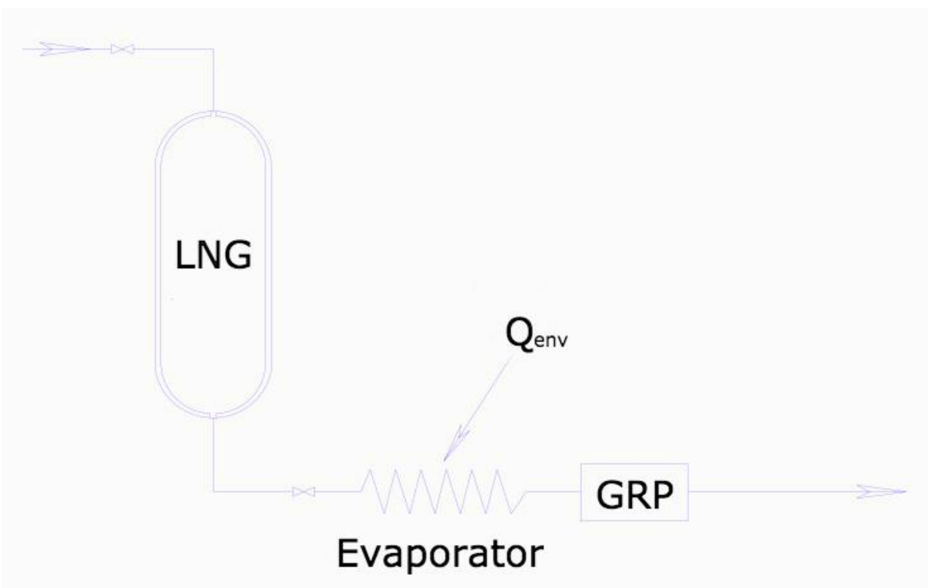
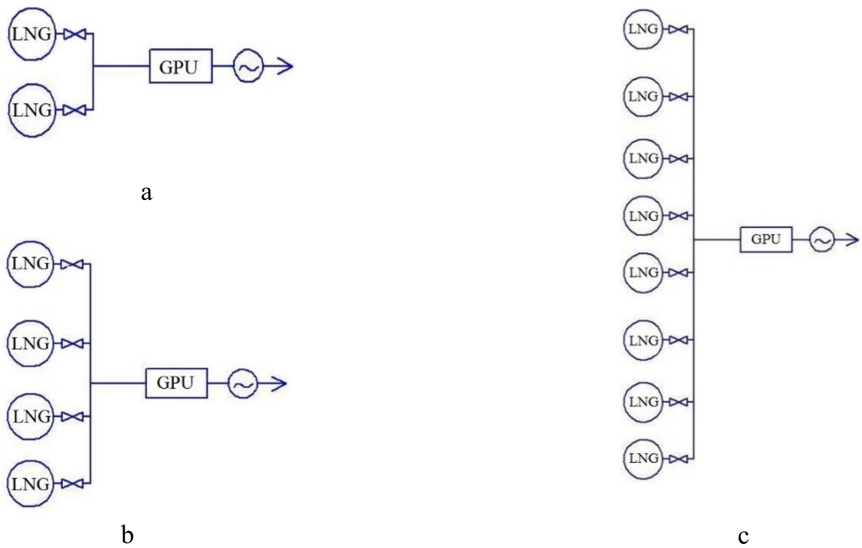


Figure 1. Diagram of the plant for regasification of LNG.

Based on the fuel consumption of the heat power plant and the combined-cycle plant G = 0.06 kg/s, it is necessary to have an LNG stock of 163 135.2 kg, taking into account the losses of the cryoproduct for evaporation. In Figure 2 (a, b, c) three different options for organizing an LNG storage facility are presented. The first combination consists of 2 tanks with a capacity of 496 m^3 (248 m^3 volume of one tank), the second one consists of 4 tanks with the capacity of 448 m^3 (112 m^3 volume of one tank), the third one - from 8 tanks with the capacity of 396 m^3 (49.50 m^3 volume of one tank). The organization and selection of more profitable LNG storage options is based on the calculation of the required fuel stock for the plant operation, the climatic conditions for the least evaporation losses during the idle time of the cylinders.

The number of tanks of certain volumes was selected on the basis of the mass of fuel required to operate the system for 32 days, which is 163 135.2 kg or 400.76 m^3 in the liquefied state (scheme b).



a - with two tanks, b - with four tanks, c - with eight tanks.
Figure 2 – Variant of organization of the LNG storage facility.

In scheme b (Table 1), each tank is designed for 8 days of continuous operation. While the first tank is used, the second tank is idle for 8 days, the third – for 16 days, and the fourth – for 24 days. Based on daily losses of selected reservoirs, the value of losses for the entire operation time of the plant is determined. Similarly, the waiting time for the remaining LNG storage options, which is presented in Table 2, has been calculated.

Table 1. Tank activation.

	Waiting time (inactivity), day								Total time
Number of tanks	1	2	3	4	5	6	7	8	
Scheme a	0	16	-	-	-	-	-	-	16
Scheme b	0	8	16	24	-	-	-	-	48
Scheme c	0	4	8	12	16	20	24	28	112

During operation, tanks are used alternately. Losses in the used tank are not taken into account, while in the remaining tanks losses occur while they are in the standby mode. The calculation of loss values is performed depending on the selected storage scheme and the characteristics of the tanks involved (Table 2).

Table 2. Losses of LNG for all time in all tanks in the schemes of organization of the storage park a, b, c.

The scheme	a	b	c
Number of tanks	2	4	8
V, m^3	248	112	49,50
M, kg	84 240	42 212	21 060
% per day	0,09	0,12	0,12
Losses in mass in one tank per day, kg	75,816	50,65	25,272
Losses for all time in all tanks, kg	1213,06	2431,2	2830,46

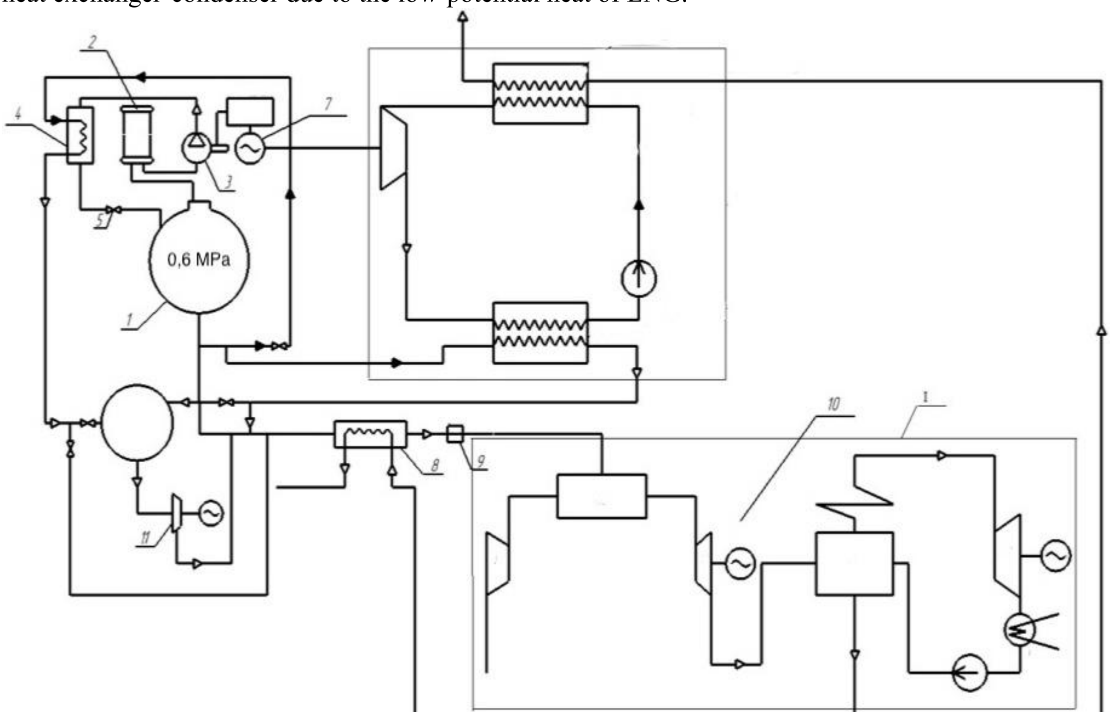
To compensate for the loss of the cryoproduct and its low-potential heat, a low-temperature power plant based on the steam-powered cycle was calculated.

Thus, to provide consumers with electric and heat energy, a combined-cycle plant (CCGT) with a capacity of 1 MW with a circuit for generating additional energy on the basis of a heat power plant was designed as an energy installation.

In this paper, we propose a technical solution for reducing the loss of cryoproducts during storage by using a plant consisting of two circuits, one of which is a loss compensation loop and the other is a contour for generating additional energy. The circuit for generating additional energy can be based on a steam power plant (Figure 3).

The principle of operation of the loss compensation circuit during evaporation is as follows. Liquefied natural gas is charged into the tank with a capacity in accordance with the selected scheme of the LNG storage facility (Table 2) at a temperature of 138 K and a pressure of 0.6 Mpa. The evaporated natural gas flows through the drain valve to the receiver. Accumulated losses per day are compressed by a centrifugal compressor up to 1 Mpa. The operating time of the compressor is 20 minutes. The drive of a centrifugal compressor is an electric motor powered by a thermoacoustic engine, a steam power plant and a Stirling engine, depending on the chosen scheme. After the compressor, the heated gas is cooled by liquid methane in the heat exchanger-evaporator and then throttled to 0.65 Mpa. Liquefied gas returns to the tank.

The contour of generating additional energy in the energy system is supposed to use a thermal power plant as the main power converter. The heat in the plant is supplied from the exhaust gases of the hcp in the heat exchanger-evaporator, and the condensation of the working fluid takes place in the heat exchanger-condenser due to the low-potential heat of LNG.



1 – tank with liquefied natural gas (LNG); 2 – gas receiver; 3 – the compressor; 4 – heat exchanger-evaporator; 5 – throttle valve; 6 – steam power plant; 7 – electric generator; 8 – heat exchanger-utilizer; 9 – reducer; 10 – Combined-cycle plant (CCGT); 11 – expansion turbine.

Figure 3. Schematic diagram of the installation based on the thermal power plant and CCGT unit.

3 Calculation of the heat-power and combined-cycle plant

It is the main circuit for the production of electrical energy and has the designation I (Figure 3).

The calculation of the cycle of a gas turbine unit (GTU) is made by characteristic points and is presented in Table 3. The GTU cycle is presented (Figure 4). Calculation of the cycle of a combined-cycle turbine by characteristic points is presenter in Table 4.

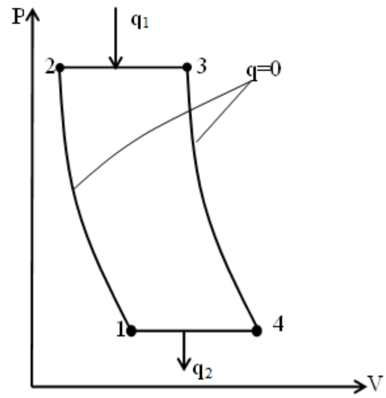


Figure 4. Gas turbine system cycle.

Table 3. Calculation of cycle GTU by characteristic points.

Initial data:	Results of calculation:
P_1 = 0,1 MPa	P_2 = 1,57 MPa
T_1 =288 K	P_3 = 1,57 MPa
T_3 = 1500 K	P_4 = 0,1 v
T_4= 683 K	T_2 = 547 K
Estimated capacity GTU was W_{GTU}=*897,1 kW*	

Table 4. Calculation of the cycle of a combined-cycle turbine by characteristic points.

Thermodynamic parameters	1	2	3	4	5	6
t, K	683	373	373	390	468	468
P, bar	14	1,0	1,0	2,1	14	14
I, kJ/kg	3278	2678	434,5	530	NA	2797
V , m^3/kg	0,222	1,685	NA	NA	NA	0,141
s, kJ/kg*K	7336	7378	1362	1442	2345	6451
The calculated power W_{ST}=111,2 kW.						

$$W_{STU(1)} = W_{GTU} + W_{ST} = 1008,3 \text{ kW}. \quad (1)$$

Similarly to the steam turbine unit, the turbine of the additional electric energy installed in the power generation circuit, which has the designation II, in which different working bodies, ethane or ethylene (and) were used, was calculated from characteristic points.

Turbine power of the circuit for generating additional electric energy:

- on ethane 51,4 kW;
- on ethylene 41,1 kW.

As calculations have shown, the greatest amount of additional electric energy can be obtained by using ethane as a working fluid.

The total capacity of the entire system will be 813.8 MWh for the entire period of the system operation.

4 Conclusion

Based on the conditions of the task, it is necessary to use 163135.2 kg of LNG for 32 days (768 hours), it is also necessary to note that 1 kilowatt-hour is needed to liquefy 1 kilogram of natural gas, accordingly, 163 135, 2 kWh of electrical energy, which is included in its cost. The calculated system, namely the circuits for generating additional electrical energy and compensating for losses will make it possible to obtain 51.4 kW or 39,475.2 kWh of electrical energy during the entire operation of the system.

Thus, the calculations show that the use of this system will allow to return the previously used energy for the liquefaction of 24%, thereby compensating for the partial costs of the fuel purchased.

References

1. Burtsev, S.A., Karpenko, A.P., Leontiev, A.I. A method for distributed production of liquefied natural gas at gas-distribution stations. (2016) High Temperature, 54 (4), pp. 573-576.
2. A.M. Arkharov, I.D. Kunis. *Cryogenic refueling systems of launch rocket and space complexes*, publishing house MSTU. NE Bauman, 2006.
3. G. Zhang, W. Xu, Y. Yang, D. Zhang, Energy Procedia, *Utilization of LNG cryogenic energy in a proposed method for inlet air cooling to improve the performance of a combined cycle*, **Volume 61**, p. 899-903, (2014).
4. Y. Xiong, P. Luo, B. Hua, Energy Procedia, *A novel CO2-capturing natural gas combined cycle with LNG cold energy utilization*.**Volume 61**, pages 899-903, (2014).
5. E.V. Blagin, A.I. Dovgyallo, S.O. Nekrasova, D.V. Sarmin, D.A. Uglanov, Applied Thermal Engineering *Estimation of the energy efficiency of cryogenic filled tank using in different system and devices*. 2016. **Volume 101**, 25 May 2016, Pages 537-544