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Evaluation of Thermoelectric Generatos Application Efficiency in the Natural Gas Regasificators

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Abstract: The below study contains evaluation of the available cold energy during LNG gasification as well as possible application of thermoelectric generators for its utilization. Calculation of thermoelectric modules parameters is made for cryogenic temperatures conditions within LNG regasification packages.

Key words: Thermoelectric electric generator, alternative energy sources, utilization of cold energy, calculation, liquefied natural gas, gasification

INTRODUCTION

It is proposed to use Liquefied Natural Gas (LNG) in different systems of aerospace engineering. At present it is applied in different purpose generating unitsas well as in transport and gas supply of settlements and separate enterprises. At one of the steps of its application gasification is performed transformation from the liquid state into the gaseous one via environmental heat supply. At the same time, it is recognized that the use of environmental heat is not an energy consuming process. However, it is worth considering that for LNG liquefaction some substantial energy was spent earlier (about 1 kW h^{-1} of power per 1 kg of LNG which at the given gasification method is just discharged into environment. Thus, LNG (as any other cryo-product) contains the energy potential which could be used while it's returning into the initial gaseous state and hence, the LNG re-gasification process itself has a considerable potential for energy supply.

One of the methods of this potential use is application of thermoelectric generators for power production due to the difference of temperatures between LNG and environment.

This study gives evaluation of the available LNG cold energy with application of thermoelectric generators.

OPERATION OF THERMOELECTRIC GENERATORS (TEG) UNDER CRYOGENIC TEMPERATURE CONDITIONS

The most important characteristics of TEGs are power transfer coefficient (coefficient of efficiency) and power output:

$$\eta = \frac{T_h - T_c}{T_h} \times \frac{1}{1 + \frac{1}{m} + \frac{1}{Z \times T_h} \times \frac{(m+1)^2}{m} - \frac{1}{2} \times \frac{T_h - T_c}{T_h} \times \frac{1}{m}} \tag{1}$$

$$P = I \times U = \frac{a^2 \times (T_h - T_c)^2}{R} \times \frac{m}{(m+1)^2} \tag{2}$$

Where:

T_h = Temperature at the hot side of the module
T_c = Temperature at the cold side of the module
m = Ratio of load resistance to generator internal resistance
$Z = a^2\sigma/\lambda$ = Thermoelectric value of merit (Q-factor) of the module's material (Okhotin *et al*., 1971)
α = Seebeck coefficient
λ = Thermal conductivity of the material
σ = Electro-conductivity of the material
I, U = The module force and voltage accordingly

As a rule, parameter value of semi-conducting materials and the module is listed at various temperatures, the module sides differential temperatures and load resistance (Fig. 1-3). In spite of the fact that hitherto thermoelectric generators have been used only for heat utilization from "hot" sources and material characteristics were thoroughly studied at the temperatures of 300 K and higher, property research of thermoelectric semi-conducting materials in the context of cryogenic temperatures starts to be carried out (Sun *et al*., 2005; Kutasov, 2000; Chung *et al*., 2000).

Studies (Kutasov, 2000; Chung *et al*., 2000) list thermoelectric characteristics of Bi-Sb, $CsBi_4$ Te_6, $Bi_{2-x}Sb_x$ Te_3 (0.2<x<0.4) type semi-conducting materials. Parameter values such as Q-factor and Seebeck EMF of the above

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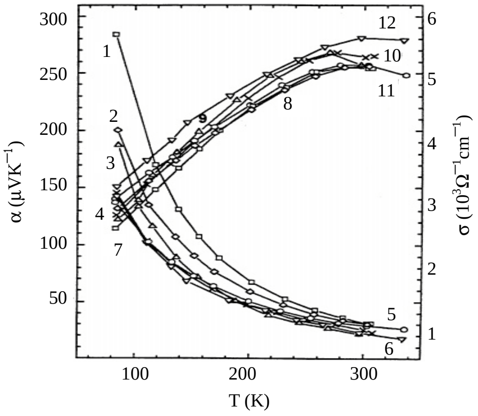

Fig. 1: Temperature dependence of electric conductivity σ (1-6) and Seebeck coefficient (7-12) in solid solutions Bi2-xSbxTe3 (1-5, 7-11) and Bi2Te3-ySey (6,12) (Kutasov, 2000)

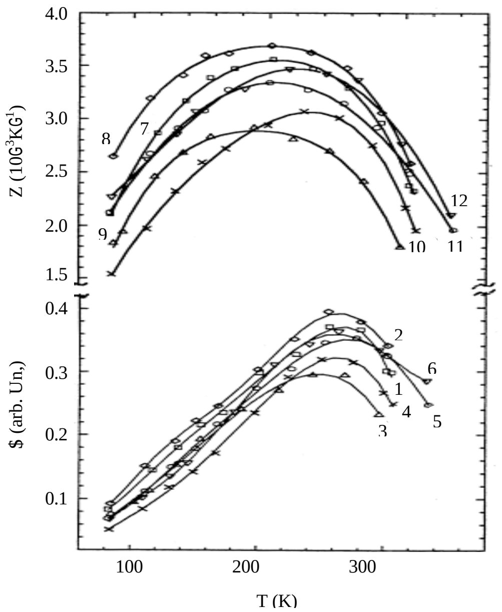

Fig. 2: Temperature dependence of the Q-factor Z (7-12) and β~ZT parameter (1-6) in solid solutions Bi2-xSbxTe3 (1-5, 7-11) and Bi2Te3-ySey (6,12) (Kutasov, 2000)

materials turned out to be approximately the same for the modules, meant for the temperature higher than the environmental one.

Evaluation of the available cold energy: In order to evaluate the cold energy, let's consider LNG gasification process with the following parameters:

$$P = 5\text{ bar};\ G = 1000\text{ kg h}^{-1} = 0.278\text{ kg sec}^{-1};$$
$$T_1 = 110\text{ K};\ T_2 = 135\text{ K};\ T_3 = 258\text{ K}$$

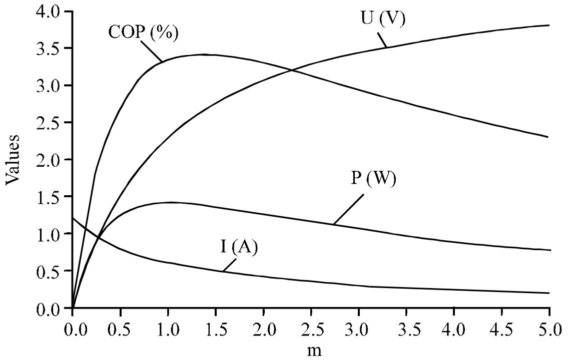

Fig. 3: Dependence of current strength I, voltage U, power P and coefficient of perfomance of the thermoelectric module with regard to the relation of load resistance to the internal one (Shostakovskii, 2010)

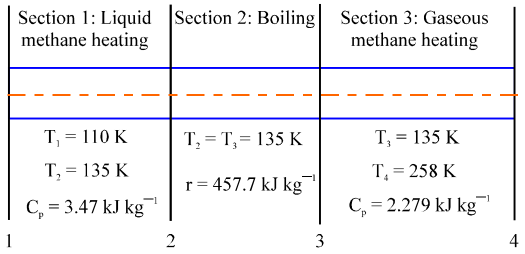

Fig. 4: Gasification scheme

Where:

P = Pressure of liquefied and gaseous methane (stays permanent at the whole section of gasification)
G = Methane mass flow rate
T_1-T_3 = Methane temperatures at Sections 1, 2 and 3 accordingly (Fig. 4)

The scheme most commonly used at production plants was chosen for calculations: Liquefied methane is supplied under the pressure of P = 5 bar from the tank with the temperature of $T_1 = 110$ K. At the first section of Fig. 4 it is isobarically heated to the boiling temperature of $T_2 = 135$K at the pressure of 5 bar. At Section 2 gasification (boiling) of liquid methane takes place at the fixed temperature and pressure. After all methane has been transformed into a gaseous phase, its isobaric heating is started up to $T_3 = 258$ K which is determined by the environment temperature (273 K) with regard to under-recuperation of 15°C (Zagorulchenko and Zhuravlev, 1969).

Methane heat capacity at each section was assumed to be constant and calculated per the average temperature of the section (Fig. 5 and 6).

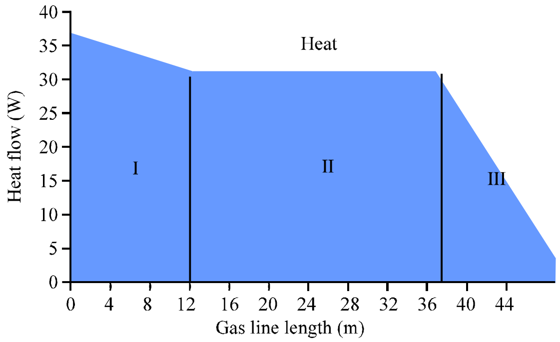

Fig. 5: Specific heat flow gasification section

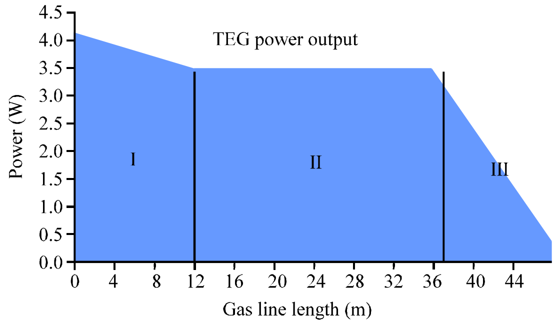

Fig. 6: Thermoelectric generators power output

SECTION 1: LIQUID METHANE HEATING

Heat capacity is:

$$C_p = 3.47 \frac{\text{kJ}}{\text{kg} \times \text{K}}$$

So, the thermal mass per second, required for heating of 1 kg of liquefied methane up to the boiling temperature will be equal to:

$$q_1 = C_p\,(T_2\text{-}T_3) = 3.47\ (135\text{-}110) = 86.750\ \text{kJ kg}^{-1}$$

Net heat per second for the whole volume of methane is:

$$Q_1 = G \times q_1 = 0.278 \times 86.750 = 24.117\ \text{kW}$$

SECTION 2: BOILING

Methane evaporation heat at the pressure of 0.05 MPa equals to $r = 457.7$ kJ kg^{-1}, then the net heat per second, required for the whole volume evaporation will be:

$$Q_2 = G \times r = 0.278 \times 457.7 = 127.241\ \text{kW}$$

SECTION 3: GASEOUSMETHANEHEATING

Heat capacity is:

$$C_p = 2.279 \frac{\text{kJ}}{\text{kg} \times \text{K}}$$

Then the net heat per second, required for the heating of 1 kg of the evaporated gaseous methane to the temperature of 258 K will be:

$$q_3 = C_p\,(T_3\text{-}T_2) = 2.279 \times (258\text{-}135) = 280.317\ \text{kJ kg}^{-1}$$

Net heat per second for the total methane volume:

$$Q_3 = G \times q_3 = 0.278 \times 280.317 = 77.928\ \text{kW}$$

Supplied heat cumulative value per three sections for 1 kg of methane:

$$q = q_1 + q_2 + q_3 = 86.750 + 457.7 + 280.317 = 824.767\ \text{kJ kg}^{-1}$$

The heat rate at the TEG cold ends for consumption of 1,000 kg h^{-1} of LNG will make:

$$Q_{\text{cold}} = Q_1 + Q_2 + Q_3 = 24.117 + 127.241 + 77.928 = 229.286\ \text{kW}$$

The TEG power output is equal to the difference of the heat rates of the TEG's cold and hot sides:

$$N = Q_{\text{hot}} \text{-} Q_{\text{cold}}$$

On the other hand, the power output, produced by the generator will be equal to the supplied heat at the hot end with regard to energy conversion coefficient:

$$N = Q_{\text{hot}} \times \eta$$

Then the heat rate at hot ends is:

$$Q_h = \frac{Q_{\text{cold}}}{1-\eta}$$

And the TEG power output is:

$$N = \frac{Q_{\text{cold}} \times \eta}{1-\eta}$$

Study gives the analysis of thermoelectric materials operation in the sphere of cryogenic temperatures

(Sun *et al*., 2005). The coefficient of conversion of the heat energy into the electric one is evaluated for the temperatures of both cold and hot sides and amounts to 130 and 290 K accordingly.

Then the available TEG power outputfor consumption of 1000 kg h^{-1} of LNG will be:

$$N = \frac{229.286 \times 0.096}{1 - 0.096} \cong 24.3\text{kW}$$

Specific power output per 1 kg will make:

$$N = G \times N = 0.278 \times 24.3 = 6.7554 \text{ kJ kg}^{-1}$$

It is possible to consider that the design power output of one thermoelectric module with the square of 60×60 mm is within the limits of 10-15 W, then about 1.800 modules will be required for 24.3 kW. Application of such a number of modules is quite complicated in terms of their location, commutation and response to the heating rate of the evaporator. Thermoelectric modules can be installed on the longitudinal finning of the gasifier piping or on the finning platform.

The cost of such a TEG package as of 2012 prices (the cost of one 60×60 mm module with the capacity of 13 W is 800 RUR.) may amount to 1.440 million RUR which at the cost of electric energy of 3.5 RUR per 1 kW h^{-1}, makes a direct payback period of 4-5 years.

Taking into account that 85% of the TEG capacity is being produced at Sections I and II (Fig. 5 and 6), there is a possible option to install modules only at these sections because more number of modules was required at Section III due to the less temperature drop for heat takeoff. A generator, installed only at Sections I and II will require about 1.300 modules. Herewith, the useful power output, produced by thermoelectric generators will amount to about 20.7 kW. It will lead to the simplification of assembly and reduction of the payback period up to 3-4 years.

CONCLUSION

Thus, the carried out preliminary research demonstrated the prospect of using of thermoelectric generators for cold energy utilization in LNG; operated regasificators.

REFERENCES

Chung, D.Y., T. Hogan, P. Brazis, M. Rocci-Lane and C. Kannewurf *et al*., 2000. $CsBi_4Te_6$: A high-performance thermoelectric material for low-temperature applications. Science, 287: 1024-1027.

Kutasov, V.A., 2000. High-performance thermoelectric materials for temperatures lower than 200K. Semicond. Phys. Tech., 34: 389-393.

Okhotin, A.S., A.A. Yefremov, V.S. Okhotin and A.S. Pushkarskii, 1971. [Thermoelectric Generators]. Atomizdat Publ., Moscow, Russia, Pages: 288, (In Russian).

Shostakovskii, P., 2010. [Thermoelectric sources of the alternative power supply]. Components Technol., 12: 131-138, (In Russian).

Sun, W., P. Hu, Z. Chen and L. Jia, 2005. Performance of cryogenic thermoelectric generators in LNG cold energy utilization. Energy Convers. Manage., 46: 789-796.

Zagorulchenko, V.A. and M. Zhuravlev, 1969. Thermophysical properties of gaseous and liquid methane. Publishing House of Board of Standards, Measures and Gages Under the Council of Ministers of the Union of Soviet Socialist Republics (USSR), Moscow, Russia, pp: 1-230.