Yu.M. Lobunets

Yu.M. Lobunets

Institute of Thermoelectricity, 1, Nauky Str.,
Chernivtsi, 58029, Ukraine

THE APPLICATION POTENTIAL OF THERMOELECTRICITY IN POWER ENGINEERING

The possibilities of using thermoelectric generators for conversion of transit heat flows in the industrial and power equipment are considered. The efficiency of such a scheme is shown to be 100%. The application potential of such TEG is outlined.

Key words: thermoelectric generator, low-grade heat source.

Introduction

The use of energy of low-grade heat sources is one of the central problems in the development of modern power engineering. Thermal waste from industrial enterprises, as well as natural heat accumulators (atmospheric air, water), are regarded as a significant additional source of energy that allows conserving conventional kinds of fuel whose resources are limited. Thermoelectric energy conversion is considered among possible technologies that allow using low-grade heat sources. It is noteworthy that thermoelectric method of energy conversion has peculiarities which allow raising the question of energy efficiency increase in basically different manner as compared to conventional technologies. I mean the possibilities of TEG application for conversion of transit heat flows into electric energy. The term “transit heat flow” in our case is related to flows in heat-exchange devices available in the majority of industrial and energy technologies. Our construction of heat-exchange type TEG put forward in [1] makes it possible to use a thermoelectric converter as a component of heat-exchange equipment without violating the basic functions of the latter. Part of the heat flowing in the heat exchanger is converted into electric energy. With regard to the fact that only this part of heat is eliminated from the main technological process, and the remaining heat finds useful application, as intended, it can be considered that the efficiency of thermal into electric energy conversion for such a scheme is 100%.

This paper deals with examples of possible use of such schemes, gives an estimate of technical and economic restrictions and application potential of heat-exchange type TEG.

Construction of heat-exchange type TEG

The scheme of the above TEG is similar to that of a plate-type heat exchanger where heat carrier flows exchanging heat are separated by metal plates with channels for passage of liquid formed between them by means of special spacers. The necessary number of plates forms a compact package that assures given power of heat exchanger (Fig.1). In the case of a TEG the function of plates is performed by thermopiles consisting of thermoelectric modules. Thus, a TEG can serve as a heat exchanger where part of heat flow passing between heat carriers is converted into electric energy.

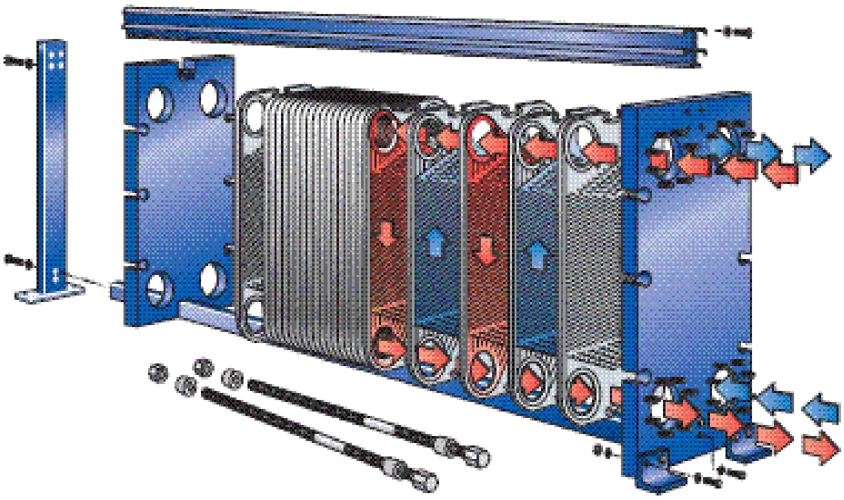


Fig.1. Plate-type heat exchanger [2].

Certainly, additional thermal resistance in the form of thermoelements deteriorates heat exchange characteristics of the device as a result of which its necessary size is increased. However, the device acquires new properties whose advantages can compensate the losses. To reveal the conditions whereby the scheme being analyzed allows achieving efficient solutions, it is necessary to consider technical and economic performance of TEG both from the standpoint of electric energy generator and from the standpoint of heat exchange equipment.

Comparison of characteristics of heat exchanger and its equivalent TEG

By comparison, let us take the simplest and common example, namely water heating in hot water supply system. Standard heat exchanger of AquaFlow heat supply station manufactured by Alfa Laval has the following characteristics [2]:

Table 1

Characteristics of the heat supply station

Thermal power, kW	Hot water flow rate, kg/s	Cold water flow rate, kg/s	Hot water temperature, input/output, °C	Cold water temperature, input/output, °C	Surface area, m^2	Heat-transfer coefficient, W/m^2K
1200	5.5	6.5	110/57	10/55	2.1	5376

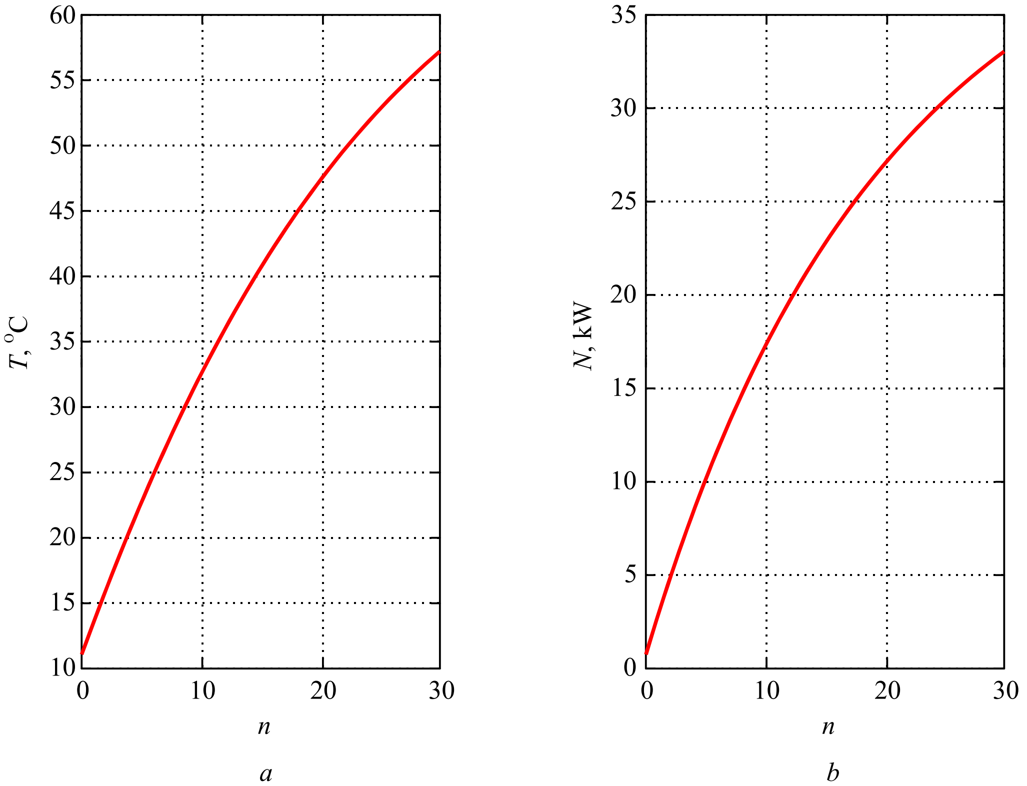
The main function of this apparatus is to heat water from 10°C to 55°C in the amount of 23.4 m^3 per hour. For this purpose, about 1200 kW-hour of thermal energy is spent for transit through heat exchanger plates from heating to cooling water. Characteristics of heat-exchange type TEG performing this function will be calculated by a procedure set forth in [3], taking as the input parameters the data listed in Table 1, as well as the following properties of thermoelectric modules:

- thermoelectric figure of merit of thermoelement material - 0.0029 K^{-1};
- thermoelement height - 0.05 cm;
- thermopile size – 50x100 cm;
- the height of channels between thermopiles – 0.5 cm.

The number of thermopiles in TEG will be selected keeping in mind the necessity of heating given water volume from 10°C to 55°C, noting that generator-heat exchanger channels are connected in series. The results of calculations are presented in Fig. 2 from which it is evident that in the case under study heat carrier reaches given temperature with the use of 30 thermopiles. TEG power in this case is equal to 33 kW, that is, about 2.75% of heat flow is converted into electric energy.

Characteristics of TEG according to Table 1 are given in Table 2.

As it follows from comparison of the data in Table 1 and Table 2, due to essential reduction of heat exchange coefficient, the heat exchange surface in TEG has increased approximately 7 fold. However, in reality such a TEG will have the approximate dimensions 50x100x35 cm, which is little different from the dimensions of the substituted heat exchanger. The main point which determines the advisability of using such a TEG is the cost of electric energy produced by it. A preliminary idea of the economic expediency of this scheme can be obtained from the estimation of the unit cost of installed TEG power as compared to other sources of electric energy. As the basis for comparison we will take the data given in [4], Fig.3.



a *b*

Fig. 2. Dependences of cold water temperature T (a) and TEG power N (b) on the number of thermopiles in TEG, n.

Table 2

Characteristics of TEG

Electric power of TEG, kW	Hot water flow rate, kg/sec	Cold water flow rate, kg/sec	Hot water temperature, input/output, °C	Cold water temperature, input/output, °C	Surface area, m^2	Heat transfer coefficient, $W/m^2\,°C$
33	5.5	6.5	110/64	10/57	15	979

To estimate the cost of TEG, let us consider the cost of its components and the approximate cost of works. Despite the uncertainty of such estimation, it can give certain idea on the order of cost of installed TEG power in kW. Thus, the basic components of TEG are:

Table 3

Basic components of TEG

Name	Cost	Quantity in TEG	Amount
Thermoelectric material	300 $US/kg	50 kg	15000 $US
Ceramic heat spreaders	0.03 $US/cm^2	30 m^2	9000 $US
Connecting plates (copper)	12 $US/kg	120 kg	1440 $US
Metal plates (titanium)	50 $US/kg	27 kg	1350 $US
Heat exchanger spacers	5 $US/pcs	32 pcs	160 $US
			27 450 $US

The cost of TEG assembling works can be appraised at approximately the same sum which totals 1700 $US/kW. This figure correlates well with the data for the basic sources of electric energy given in Fig. 4. Even if in reality it will double (which is possible, though the above estimate is rather exaggerated), nevertheless all capital outlays in TEG are well within the range of prices for the existing sources of electric energy (it should be also noted that there is a considerable reserve of increasing the economic efficiency of TEG due to optimization of its regimes and parameters).

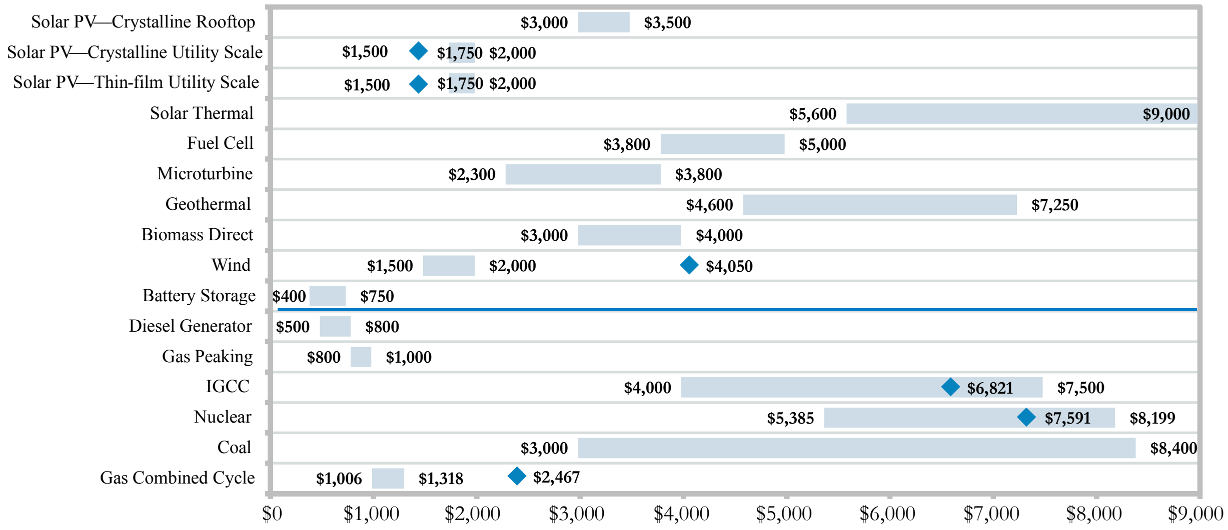


Fig. 3. Capital outlays on the unit of installed power $US/kW [4].

As regards the forecast cost of electric energy, the scheme of TEG in question offers the undeniable advantages due to high efficiency of thermal energy use. It can be estimated as not exceeding the cost of electric energy of the most efficient conventional sources using similar fuel (in this case gas), such as combined-cycle electric generating plants. According to [4], the range of electric energy cost for such sources is 0.052...0.096 $US/kW-hour.

Certainly, the application potential of TEG in power engineering goes beyond the example discussed. There are many opportunities of their use in various technological processes. One of the most large-scale can be the use of heat-exchange type TEG in the technological cycle of thermal power plants. For instance, in low-pressure water heaters [5] assuring water heating in steam-power cycle from 35°C to 150 °C. An introduction of such TEG can assure additional generation of 3...5% of electric energy, that is, the efficiency of electric power station will increase almost by 10%. Such prospects look fantastic, but there are all technical and economic prerequisites for that.

Conclusions

The analysis performed above offers exciting possibilities of heat-exchange type TEG application for using transit heat flows in industry and power engineering. Development of this line primarily requires creation of TEG equipment unified with standard heat exchangers which will make possible a widespread introduction of this technology.

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