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THERMOELECTRIC FLOW-TYPE HEAT TRANSFER INTENSIFIER

The design of a thermoelectric heat transfer intensifier is proposed in which a forced airflow in the respective gaps by means of fan assemblies is used to increase the coefficient of heat transfer between the thermoelement junctions and the media moving in transport zones. The model of the device based on the solution of heat balance equations for media flows in transport zones, thermopile surfaces, the gaps between transport zones and thermopile surfaces for direct flow conditions is considered. Theoretical studies of the heat transfer intensifier according to the developed model have been carried out.

Key words: thermoelectric heat transfer intensifier, thermopile, temperature, model, moving medium, coefficient of heat exchange.

Introduction

At present, the task of studying special technical means for ensuring intensive heat transfer from sources with high thermal loads to heat receivers is becoming topical in order to equalize the temperature levels of the objects. These issues are especially relevant for the utilization of heat generated during the performance of certain technological processes at the production site, removal of heat from the cooling fluids of fuel rods of nuclear reactors, and so on. [1].

One of the promising directions in the development of systems of this type is the use of thermoelectric energy converters that provide the construction of economical, small-sized heat exchangers with wide functionality to maintain a given thermal mode. Thus, in this area we can single out the papers [2 – 4], where the possibilities of using thermoelectric energy converters for intensifying heat exchange between the flows of two liquid or gaseous media. However, despite the availability of theoretical and experimental studies in this field, the question of increasing the intensity of heat exchange between media, optimization of energy and mass-dimensional parameters of devices is still of current interest.

The purpose of the work is theoretical study of a thermoelectric heat transfer intensifier wherein due to the use of a forced air flow along thermoelement junctions a higher coefficient of heat exchange is ensured between the latter and the media moving in transport zones the temperature of which is to be changed.

Design of a thermoelectric heat transfer intensifier

The design of a device for heat transfer intensification between the flows of two media has been developed. Its schematic structure is shown in Fig. 1, and appearance – in Fig. 2. The device consists of a thermopile 1 composed of identical in size and physical properties thermoelements, powered from electric energy source (not shown in fig.), both surfaces of which are at some distance from walls 2 of transport zones 3 with media 4 moving therein. At the beginning and end of transport zones 3 in the direction perpendicular to motion of media 4 mounted are fan assemblies 5, powered from the same source of electric energy as thermopile 1. Fan assemblies 5 serve to purge the air in the gap between walls 2 of transport zones 3 and the surfaces of thermopile 1, one fan unit working for injection of air flow, and the other – for its exhaust. Thermopile 1, transport zones 3 and fan assemblies 5 form a rigid mechanical construction by means of fixing accessories 6.

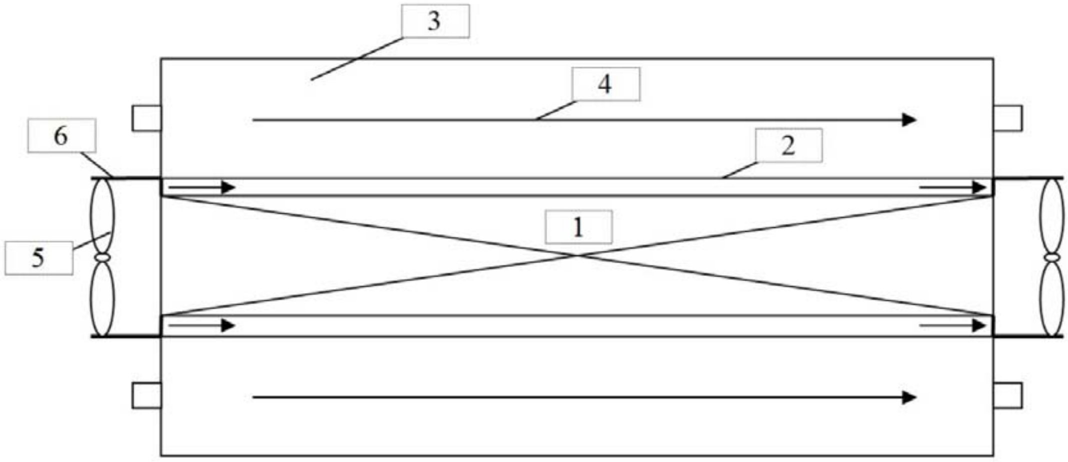

Fig. 1. Schematic structure of thermoelectric heat transfer intensifier

Fig. 2. Appearance of thermoelectric heat transfer intensifier

The thermoelectric heat transfer intensifier functions as follows. On passing through thermopile 1 of direct electric current from the source of energy, on some thermoelement junctions the Peltier heat will be absorbed, and on the other – released. If the cold thermoelement junctions are close to wall 2 of transport zone 3 with the hot moving medium 4, and the hot junctions of thermoelements – to the wall of transport zone with the cold moving medium, due to the available temperature difference there will be intensification of thermal energy exchange between the two medium flows. In so doing, purging of air in the gaps between walls 2 of transport zones 3 and the surfaces of thermopile 1 and fan assemblies 5 will allow increasing the coefficient of heat transfer between them due to ensuring the mode of forced convection whereby the value of given coefficient is higher than in the case of conductive mechanism of heat exchange.

Model of thermoelectric heat transfer intensifier

For the considered construction a mathematical model was developed describing electro- and thermophysical processes occurring in the device. The model is based on heat balance equations for medium flows in transport zones, thermopile surfaces, the gaps between transport zones and thermopile surfaces [5]. Condition of a direct flow is considered.

Heat balance equations in the gaps between the walls of transport zones and thermopile junctions for the above schematic are given by:

$$W'\frac{dT_1}{dx} = \alpha' L(T_{1TEM} - T_1') \tag{1}$$

$$W'\frac{dT_2}{dx} = \alpha' L(T_{2TEM} - T_2') \tag{2}$$

where $T_{1TEM,2TEM}$ are temperatures of the cold and hot thermopile junctions, respectively, $T'_{1,2}$ are the temperatures of air flow in the gaps, W′ is total heat capacity of air medium flowing along thermopile junctions (in the gaps) per unit time (equal to mass flow rate multiplied by medium specific heat), L is the length of transport zones, α' is coefficient of heat exchange between thermopile junctions and air medium in the gap.

Thermal balance equations for medium flows in transport zones are found from the relationships:

$$W_1\frac{dT_1}{dx} = \alpha_1 L(T_1' - T_1) \tag{3}$$

$$W_2\frac{dT_2}{dx} = \alpha_2 L(T_2' - T_2) \tag{4}$$

where $T_{1,2}$ are temperatures of cooled and heated media, W_1 is total heat capacity of the medium flowing along the cold junctions of thermopile per unit time, W_2 is total heat capacity of the medium flowing along the hot junctions of thermopile per unit time, α' is coefficient of heat exchange between the cooled air medium in the gap and cooled medium in transport zone, α' is coefficient of heat exchange between the heated air medium in the gap and the heated medium in transport zone.

Heat balance equations on thermopile junctions on the side of thermoelements are given by:

$$\alpha'(T_1' - T_{1TEM}) = \bar{e}\mathrm{j}T_{1TEM} - \frac{1}{2}\mathrm{j}^2\rho d - \frac{\lambda}{d}(T_{2TEM} - T_{1TEM}), \tag{5}$$

$$\alpha'(T_{2TEM} - T_2') = \bar{e}\mathrm{j}T_{2TEM} + \frac{1}{2}\mathrm{j}^2\rho d - \frac{\lambda}{d}(T_{2TEM} - T_{1TEM}), \tag{6}$$

where $\bar{e}$ is the Seebeck coefficient of thermoelements, j is electric current density, ρ is electric resistivity of thermoelement legs, λ is thermal conductivity of thermoelement legs, is the height of thermoelement legs.

The system of equations (1) – (6) was solved by numerical method of finite elements. The results of calculations are represented in Fig.3. As a medium, water was used. The characteristics of thermoelements were as follows: $\lambda = 1.5$ W/(m·K), $\rho = 10{,}65 \cdot 10^{-6}$ Ω·m, $\bar{e} = 0{,}2 \cdot 10^{-3}$ V/K, $d = 0.003$ m. Coefficients of heat exchange: $\alpha_1 = \alpha_2 = 100$ W/(m²·K), the values of $W' = 90$ W/K, $W_1 = W_2 = 120$ W/K.

Dependences of the temperature of the media at the outlet of the heat transfer intensifier on the value of coefficient of heat transfer between thermopile junctions and the air medium in the gap at a fixed value of the thermopile supply current equal to 5 A are shown in Fig.3.

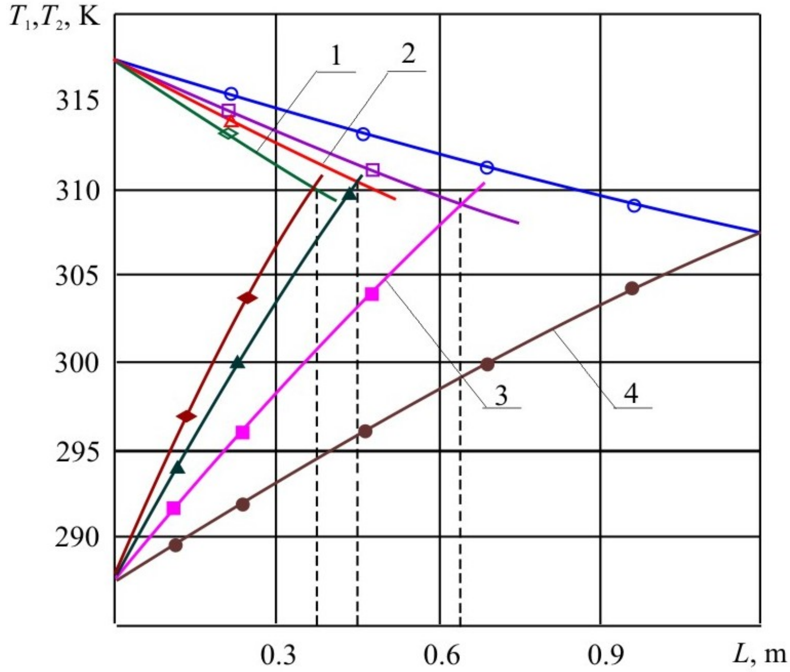

Fig. 3. Change in medium temperatures at the outlet of heat transfer intensifier versus the length at different values of α′ (1 – α′ = 90; 2 – α′ =80; 3 – α′ = 70; 4 – α′ = 60 W/(m²·K)

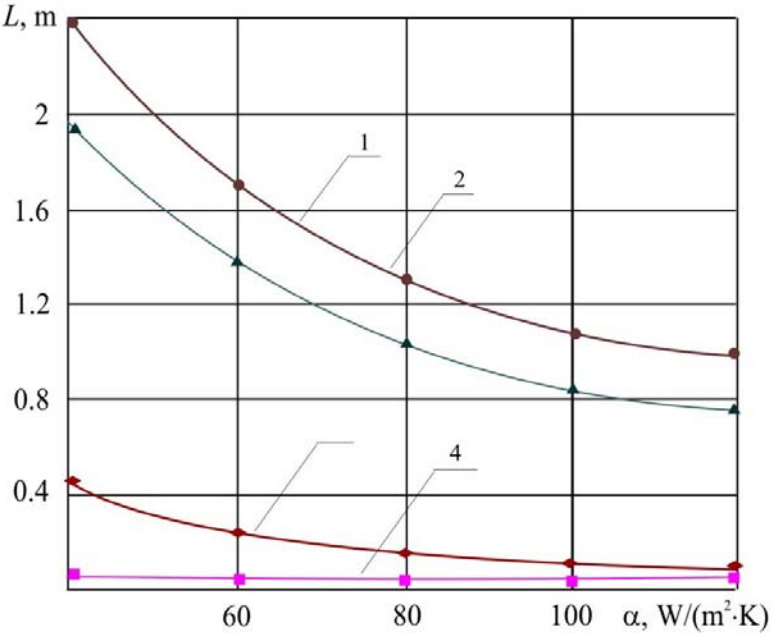

Fig. 4. Limiting lengths of thermopile in the intensification mode versus filling ratio at different values of temperature difference at the inlet to heat transfer intensifier (1 – ΔT = 40; 2 – ΔT = 30; 3 – ΔT = 10; 4 – ΔT = 5 K; I = 5A

According to the data obtained, the increase in the value of α' allows reducing (increasing) their temperature at the outlet of heat exchange unit for its equal length. Thus, a change in α' by 10 W/(m^2·K) changes the temperature of cooled medium on the average by 2 K, and heated – by 3 K.

Fig.4 represents the plots of change in the limiting lengths of thermopile depending on the value of α', i.e. for those lengths whereby the temperatures of liquids at the outlet of heat transfer intensifier are equal to each other. As follows from the presented data, the greater the difference in the temperatures of the coolant at the inlet to the device, the greater the length of the thermopile needed to maintain the intensification mode. The plots are monotonously decreasing depending on the coefficient of heat exchange between the thermopile junctions and the air medium in the gap. The greater the difference in temperatures at the inlet, the more drastically decrease the functions $L = L(\alpha')$ at constant supply current I = 5A.

Conclusions

1. Construction of a thermoelectric heat transfer intensifier is proposed wherein to increase the coefficient of heat exchange between thermoelement junctions and the media moving in transport zones use is made of a forced air flow in the corresponding gaps through use of fan assemblies.
2. The model of a thermoelectric heat transfer intensifier is developed which is based on solving heat balance equations for medium flows in transport zones, thermopile surfaces, the gaps between transport zones and thermopile surfaces for direct flow conditions.
3. It was established that increasing the value of coefficient of heat exchange between thermopile junctions and air medium in the gap makes it possible to reduce (raise) their temperature at the outlet of heat exchange unit with its equal length. In this case, a change in α' by 10 W/(m^2·K) on the average changes the temperature of cooled medium by 2 K, and heated – by 3 K4. It is established that increase in the difference in temperatures of media at the inlet contributes to a more drastic decay of the functions of dependence of limiting lengths of thermopile on the coefficient of heat exchange between thermopile junctions and air medium in the gap with constant supply current.

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