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THERMOELECTRIC AIR CONDITIONERS FOR TANKS

The paper presents the results of studies on the possibility of using thermoelectric air conditioners to provide conditions for the tank crew, which is an important prerequisite for their combat missions. Bibl. 21, Fig. 1.
Key words: thermoelectric air conditioner, tanks, efficiency.

Introduction

General characterization of the problem. In modern armoured vehicles, in particular tanks of the leading countries of the world, air conditioning is actively used to ensure the working conditions of the crew. Particularly relevant is the use of such air conditioners at elevated ambient temperatures. The analysis of the literature shows that the presence of people under elevated ambient temperatures for a long time significantly reduces the efficiency of their work and, with a significant rise in temperature, there is even a risk of loss of consciousness. This jeopardizes the ability to perform combat missions. On the other hand, with a sharp decrease in air temperature inside the tank, there is a risk of acute respiratory diseases, which also reduces the efficiency of the tank crew [1].

The literature mentions the possibility of air conditioning in vehicles, in particular armoured vehicles, by various methods [2 – 8]. Particular attention is paid to the use of compression air conditioners. This is due to their relatively high efficiency. However, they also have a number of disadvantages, in particular, the presence of environmentally hazardous refrigerants, low reliability, sensitivity to mechanical overloads and spatial orientation, which significantly reduces the attractiveness of using such air conditioners. This situation is especially relevant when using these air conditioners in military equipment, due to the presence of increased requirements for its reliability. These disadvantages are eliminated by using thermoelectric conditioners [8, 19, 20].

The analysis of the literature shows that thermoelectric air conditioners are most widely used in the Russian Federation. All serial models of Russian tanks (including export models), starting with the T-90M "Proryv-3" (in service since 2018), are equipped with thermoelectric air conditioners manufactured by JSC Scientific and Production Corporation "Uralvagonzavod" named after F.E. Dzerzhinsky "(Russian Federation) [9, 10]. In addition, CJSC "Konditsioner" (Russian Federation) carries out mass production of thermoelectric conditioners for T-14 Armata tanks [11].

Active studies of thermoelectric air conditioning of tanks under high temperature conditions are underway in India [12, 13]. The thermoelectric air conditioner was integrated into Arjun's main Indian battle tank (in service since 2006) and successfully demonstrated at the Avad Main Research Laboratory (CVRDE), India and at the Mahajan Field Range in Rajasthan (Indo-Pakistan border) in June 2005 [13].

The development of thermoelectric air conditioners for military equipment (including tanks) is also underway in leading countries around the world, including companies like EIC Solutions Inc. (USA) [14], TECA Corporation (USA) [15], Marlow Industries, Inc. (USA) [16], Global Thermoelectric, Inc. (Canada) [17].

The above models of air conditioners have a number of drawbacks, in particular, a rather low coefficient of performance, which worsens their competitive capabilities in comparison with compression refrigerators.

The purpose of this work is to investigate the possibility of using thermoelectric air conditioners to provide conditions for the tank crew, which is an important prerequisite for their combat missions.

Physical model

Physical model of a thermoelectric air conditioner for tanks is presented in Fig.1.

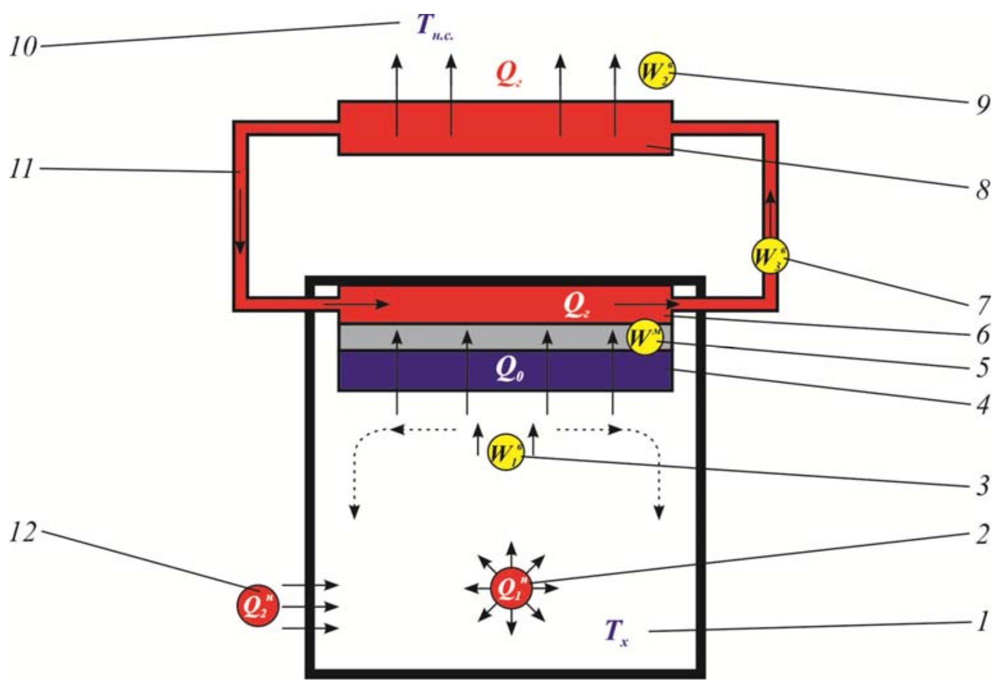

Fig. 1 Physical model of a thermoelectric air conditioner for tanks:
1 – cooled volume, 2 –release of heat Q_1 inside the cooled volume,
3 – air fan that consumes electric power W_1, 4 – cold air heat exchanger of the internal unit of thermoelectric air conditioner, 5 –thermoelectric energy converter that consumes electric power W,
6 – hot liquid heat exchanger of the internal unit of thermoelectric air conditioner,
7 – liquid pump that consumes electric power W_3, 8 – liquid-air heat exchanger of the external unit of thermoelectric air conditioner, 9 – air fan that consumes electric power W_2,
10 – environment, 11 – liquid heat carrier, 12 – heat inleak Q_2 through insulation.

It consists of two parts - an internal unit inside the tank which provides heat removal from the cooled volume 1, and an external unit which is located on the outer surface of the tank and serves to dissipate the heat flow into the environment 10. The internal unit of the air conditioner consists of a system for transferring heat flow from the cooled volume 1 to thermoelectric modules 5, which contains an air fan 3 and an air heat exchanger 4, and a system for removing heat flow from thermoelectric modules by a liquid heat exchanger 6 using a liquid pump 7. As a liquid heat carrier 11, a liquid with a low congelation point - antifreeze was used. The external unit of the air conditioner contains an air-liquid heat exchanger 8 with an air fan 9, which ensures the dissipation of the heat flux from the air conditioner into the environment. It should be noted that the source of heat inleak inside the cooled volume 1 is internal heat sources 2 (heat inleak from crew members and equipment working inside the cooled volume) and flows from the environment through the insulation of the tank 12, depending on the quality of thermal insulation and the temperature difference between the internal volume and the environment.

It should be noted that, according to sanitary requirements [1], the temperature difference between the ambient air and the volume of air cooled by an air conditioner should not exceed 15 K. However, depending on the value of the ambient air temperature, this difference is different [1]. These requirements were also used in the calculations.

Mathematical and computer description of the model

To describe heat and electricity flows, we use the laws of conservation of energy

$$div\vec{E} = 0 \tag{1}$$

and electric charge

$$div\vec{j} = 0, \tag{2}$$

where

$$\vec{E} = \vec{q} + U\vec{j}, \tag{3}$$

$$\vec{q} = \kappa\nabla T + \alpha T\vec{j}, \tag{4}$$

$$\vec{j} = -\sigma\nabla U - \sigma\alpha\nabla T. \tag{5}$$

Here, $\vec{E}$ is energy flux density, $\vec{q}$ is thermal flux density, $\vec{j}$ is electric current density, U is electric potential, T is temperature, α, σ, κ are the Seebeck coefficient, electric conductivity and thermal conductivity.

With regard to (3) – (5), one can obtain

$$\vec{E} = -(\kappa + \alpha^2\sigma T + \alpha U\sigma)\nabla T - (\alpha\sigma T + U\sigma)\nabla U. \tag{6}$$

Then the laws of conservation (1), (2) will acquire the form:

$$-\nabla\left[(\kappa + \alpha^2\sigma T + \alpha U\sigma)\nabla T\right] - \nabla\left[(\alpha\sigma T + U\sigma)\nabla U\right] = 0, \tag{7}$$

$$-\nabla(\sigma\alpha\nabla T) - \nabla(\sigma\nabla U) = 0. \tag{8}$$

These nonlinear differential equations of second order in partial derivatives (7) and (8) determine the distribution of temperature *T* and potential *U* in thermoelements.

An equation describing the process of heat transport in the walls of heat exchangers in the steady-state case is written as follows:

$$\nabla(-k_1 \cdot \nabla T_1) = Q_1. \tag{9}$$

where k_1 is thermal conductivity of heat exchanger walls, ∇T_1 is temperature gradient, Q_1 is heat flux.

The processes of heat-and-mass transfer of heat carriers in heat exchanger channels in the steady-state case are described by equations [18]

$$-\Delta p - f_D \frac{\rho}{2d_h} v|\vec{v}| + \vec{F} = 0, \tag{10}$$

$$\nabla(A\rho\vec{v}) = 0, \tag{11}$$

$$\rho \mathrm{AC_p} \vec{v} \cdot \nabla T_2 = \nabla \cdot Ak_2 \nabla T_2 + f_D \frac{\rho A}{d_h} |\vec{v}|^3 + Q_2 + Q_{wall}, \tag{12}$$

where p is pressure, ρ is heat carrier density, A is cross-section of the tube, $\vec{F}$ is the sum of all forces, C_p is heat carrier heat capacity, T_2 is temperature, $\vec{v}$ is velocity vector, k_2 is heat carrier thermal conductivity, f_D is the Darcy coefficient, $d = \frac{4A}{Z}$ is effective diameter, Z is perimeter of tube wall, Q_2 is heat which is released due to viscous friction [W/m] (per unit length of heat exchanger), Q_{wall} is heat flux coming from the heat carrier to the tube walls [W/m]

$$Q_{wall} = h \cdot Z \cdot (T_1 - T_2), \tag{13}$$

where h is heat exchange coefficient which is found from equatio

$$h = \frac{Nu \cdot k_2}{d}. \tag{14}$$

The Nusselt number is found with the use of the Gnielinski equation ($3000 < Re < 6 \cdot 10^6$, $0.5 < Pr < 2000$)

$$Nu = \frac{\left(\frac{f_d}{8}\right)(Re - 1000) Pr}{1 + 12.7\left(\frac{f_d}{8}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)}, \tag{15}$$

where $Pr = \frac{C_p \mu}{k_2}$ is the Prandtl number, μ is dynamic viscosity, $Re = \frac{\rho v d}{\mu}$ is the Reynolds number.

The Darcy coefficient f_D is found with the use of the Churchill equation for the entire spectrum of the Reynolds number and all the values of e/d (e is roughness of wall surface)

$$f_D = 8\left[\frac{8}{Re}^{12} + (A+B)^{-1.5}\right]^{1/12}, \tag{16}$$

where $A = \left[-2.457 \cdot \ln\left(\left(\frac{7}{Re}\right)^{0.9} + 0.27(e/d)\right)\right]^{16}$, $B = \left(\frac{37530}{Re}\right)^{16}$.

Solving Eqs. (7) – (12), we obtain the distributions of temperatures, electric potential (for thermoelements), velocities and pressure (for heat carrier).

The above differential equations with the respective boundary conditions were solved using Comsol Multiphysics package of applied programs.

Design results

An analysis of existing types of tank air conditioners [2-7] shows that the amount of heat flow to be discharged from the internal volume of the tank into the environment is 3 kW. At the same time, the highest regulated ambient temperatures can reach 500C. As noted earlier, according to sanitary requirements [1], the temperature difference between the ambient air and the volume of air cooled by an air conditioner should not exceed 10-15 K, depending on the ambient temperature.

In accordance with the specified requirements and the proposed physical model of the thermoelectric air conditioner, the energy characteristics of the air conditioner were calculated taking into account the energy consumption for ensuring heat transfer conditions.

Thus, to provide the required cooling capacity 3 kW at ambient temperatures up to 50 C and a temperature difference of~ 15 K, a power output of 2.5 kW is required, which corresponds to the energy efficiency value of $\varepsilon \approx 1.2$.

Comparison of the design results with the parameters of known thermoelectric air conditioners for tanks [2 – 7] shows their advantages in energy efficiency by 20-40%, which opens up good prospects for their practical use.

It should be noted that the requirements to be able to operate at elevated ambient temperatures are easily realized with the use of thermoelectric air conditioners (as opposed to using compression coolers), since with a rise in ambient temperature while maintaining the temperature difference, the efficiency of thermoelectric conditioners even grows [20].

In addition, an important advantage of thermoelectric air conditioners is the possibility of using them in heating mode, with their energy efficiency even increasing [21].

Conclusions

1. Physical, mathematical and computer models of thermoelectric air conditioner for tanks have been developed.
2. Design of thermoelectric air conditioner for tanks was performed with regard to requirements for their operation. Thus, to assure the required cooling capacity 3 kW at ambient temperature up to 50 C and temperature difference ~ 15 K, the required electric power is 2.5 kW, which corresponds to energy efficiency $\varepsilon \approx 1.2$.
3. Comparison of the design results with the parameters of known thermoelectric air conditioners for tanks shows their energy efficiency advantages by 20-40%, which opens up good prospects for their practical use.
4. It is determined that the energy efficiency of thermoelectric air conditioners is higher under the conditions of elevated ambient temperatures and when used in heating mode.

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ПРО ТЕРМОЕЛЕКТРИЧНІ КОНДИЦІОНЕРИ ДЛЯ ТАНКІВ

У роботі наводяться результати досліджень можливостей використання термоелектричних кондиціонерів для забезпечення умов перебування екіпажу танку, що є важливою передумовою виконання ними бойових завдань. Бібл. 21, рис. 1.
Ключові слова: термоелектричний кондиціонер, танки, ефективність.

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О ТЕРМОЭЛЕКТРИЧЕСКИХ КОНДИЦИОНЕРАХ ДЛЯ ТАНКОВ

В работе приводятся результаты исследования возможностей применения термоэлектрических кондиционеров для обеспечения надлежащих условий пребывания экипажа танка, что является важной предпосылкой выполнения им боевых задач. Библ. 21, рис. 1.
Ключевые слова: термоэлектрический кондиционер, танки, эффективность.

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