UDK [УДК] 662.994
DOI 10.17816/transsyst2018041043-057

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# APPLICATION OF THERMAL ACCUMULATOR WITH SOLID HEAT ACCUMULATING MATERIAL AS A METHOD OF COOLING OF LIFE SUPPORT AND FREIGHT PROTECTION SYSTEMS FOR VACUUM MAGNETIC LEVITATION TRANSPORT

**Aim:** The development of vacuum maglev transport implies solution of an important issue, namely, disposing thermal energy in an air free space. The application of the thermal accumulator (TA) with solid heat accumulating material (SHAM) or melting heat accumulating material (MHAM) as a cooling method for the life support and freight preservation systems (LSaFPS) of vacuum maglev transport is justified by impossibility of thermal energy to be transferred inside the vacuum tube by virtue of convection. Besides, when the accumulators are discharged at the destination points, the saved thermal energy may be used as an additional energy source, thus increasing energy efficiency of the transportation system as a whole.

**Methods:** In the work given, the authors have used the heat engineering calculation with the application of the similarity theory.

**Results:** Application of the life support and freight preservation systems (LSaFPS) of vacuum maglev transport will help in solving a problem of removal of excess of thermal energy in the conditions of lack of heat convection and also in increasing energy efficiency of the entire system.

***Keywords*****:** vacuum maglev transport, life support and freight preservation system (LSaFPS), solid or melting heat accumulating material, heat removal, disposal of thermal energy, energy efficiency.

This work was supported by the Russian Foundation for Basic Research (RFBR) within the framework of the scientific project of the office of the Russian Railways No. 17-20-04121.

Received: 29.01.2018. Accepted: 20.02.2018

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# ПРИМЕНЕНИЕ ТЕПЛОВОГО АККУМУЛЯТОРА С ТВЕРДЫМ ТЕПЛОАККУМУЛИРУЮЩИМ МАТЕРИАЛОМ КАК СПОСОБ ОХЛАЖДЕНИЯ ЧАСТИ СИСТЕМЫ ЖИЗНЕОБЕСПЕЧЕНИЯ И ГРУЗОСОХРАНЕНИЯ ВАКУУМНОГО МАГНИТОЛЕВИТАЦИОННОГО ТРАНСПОРТА

**Цель:** Развитие вакуумного магнитолевитационного транспорта подразумевает решение такого важного вопроса как утилизация тепловой энергии в пространстве с разреженной воздушной средой. Применение теплового аккумулятора с твердым теплоаккумулирующим материалом или плавящимся теплоаккумулирующим материалом как способа охлаждения части системы жизнеобеспечения и грузосохранения (СЖОиГС) вакуумного магнитолевитационного транспорта обусловлено невозможностью передачи тепловой энергии внутри вакуумного трубопровода путем конвекции. Кроме того, при разрядке аккумулятора на пункте прибытия накопленная тепловая энергия может быть полезно использована в качестве вторичного источника тепловой энергии, тем самым повышая энергетическую эффективность системы в целом.

**Методы:** В данной работе авторы используют методику теплотехнического расчета с применением теории подобия.

**Результаты:** Применение тепловых аккумуляторов в системах СЖОиГС вакуумного магнитолевитационного транспорта позволит решить задачу отвода избытков тепловой энергии в условиях отсутствия конвективного теплообмена, а также повысить энергетическую эффективность всей системы в целом.

***Ключевые слова***: вакуумный магнитолевитационный транспорт, система жизнеобеспечения и грузосохранения, твердый аккумулирующий материал, плавящийся теплоаккумулирующий материал, теплоотвод, утилизация тепловой энергии, энергетическая эффективность.

Received: 29.01.2018. Accepted: 20.02.2018 

## Introduction

Considering its peculiarities, the life support and freight preservation system of (LSaFPS), namely the ventilation and air conditioning systems of passenger transport units of vacuum maglev transport [1], is one of the most crucial elements which secure comfort and safety of passengers.

The air conditioning system of the transport unit, as well as the thermal balance calculation methodology, is given in detail in [2, 3].

Generally, the on-board air conditioning system in a hermetic vehicle at any atmospheric conditions and for all transportation modes, should maintain the set pressure, temperature, humidity, physical and chemical composition of the air, and the admissible level of noise [4, 5].

The inability to apply the ventilation and air conditioning systems, similar to those deployed on railway transport, is justified by inability to remove the excessive thermal energy outside [6]. In this case, it is relevant to consider autonomous systems for discharging and accumulating the thermal energy.

## Setting the tasks

As the main task, the development of methodology, which enables choosing both accumulating substance for removing the excessive thermal energy, and modes of work and processes of charging and discharging thermal accumulators of autonomous on-board LSaFPS [7, 8] in vacuum maglev transport, is considered.

Another task is the development of methodology of heat engineering calculation with the aim to determine air temperature drops, and air conditioning and ventilation monitoring panels, meeting technical requirements.

In order to carry out heat engineering checking calculation of the vehicle with pillowplate heat exchange, the following source data are required:

- cruise velocity $V$,
- vehicle interior volume $V_{vehicle}$,
- square of the surface under heating $S$,
- vehicle length $l_{vehicle}$,
- vehicle height $h_{vehicle}$,
- pillowplate height $h_{panel}$,
- pillowplate length $l_{panel}$,
- number of pillowplates $n_{panel}$,
- average air temperature in the vehicle $t_{vehicle}$,
- average temperature of internal walls of the vehicle $t_{walls}$,
- acceptable air temperature drops along the length and height of vehicle $\Delta t_{vehicle\ height}$ and $\Delta t_{vehicle\ length}$,
- acceptable temperature drops of internal wall surface $\Delta_{temp.\ internal}$ in its height,

Received: 29.01.2018. Accepted: 20.02.2018

- acceptable air speed in vehicle $v_{vehicle}$,
- number of passengers in vehicle,
- thermal, mass and mechanical properties of heat and sound insulation materials,
- alteration of pressure in the vehicle.

The calculation of the pillowplate heat exchange system for cruise velocity mode with possible lowest external air temperature is carried out by virtue of fixed-point iteration. The heat engineering and hydraulic calculation are made for one pillowplate, assuming that the heat exchange and resistance of all plates are equal. The major objective of the heat engineering calculation is to determine air and pillowplate temperature drops with all the above-mentioned technical requirements fulfilled. When calculating the system, operating in mixed mode, the following parameters are sequentially determined – mass airflow through one plate.

The calculation of pillowplate heat exchange system for stable velocity mode of the vehicle with standard parameters of external medium is made in the vacuum tube. The heat engineering and hydraulic calculation is done for one plate, assuming that the heat exchange and resistance of all plates are equal.

The simplified scheme of the interior of the vehicle with air conditioning flows is given in the fig. 1.

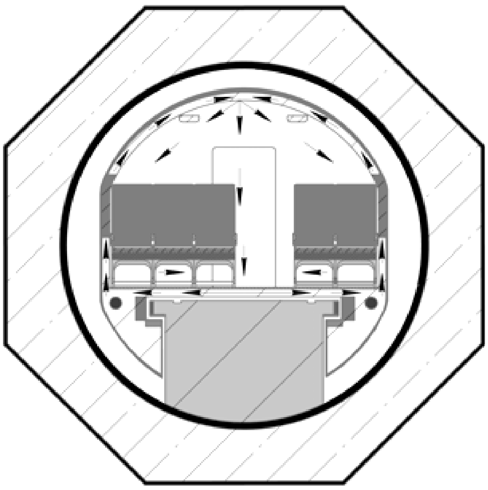

Fig. 1. The simplified scheme of the interior of the vehicle with air conditioning flows

## Assumptions

To assess the heat emission of the part of the LSaFPS the following source data are accepted:

$P_{vehicle}$, Pa – pressure of the interior of the vehicle;

$V_{vehicle}$, m$^3$ – interior volume of the vehicle;

$t_{air}$,°C – entering air temperature.

The mass airflow through one plate:

Received: 29.01.2018. Accepted: 20.02.2018 

$$G_n = \frac{G_{ch}}{nn},\ kg/h,$$

where $G_h$ – amount of air per one hour needed for one plate, determined by conditions of vehicle ventilation:

$$G_{ch} = n \cdot \rho \cdot Vvehicle.$$

The heat transfer coefficient from the plate wall to the air in the vehicle:

$$a(vehicle) = \frac{Nu_{vehicle} \cdot \lambda_{vehicle}}{h}.$$

Amount of heat, transferred from the plate to the interior of the vehicle:

$$Q_{plate1} = k_{plate1} \cdot F_{plate1} \cdot (t_{average\ of\ plate} - t_{vehicle}).$$

Average air velocity in the plate, m/s:

$$v_n = \frac{G_n}{F_n \cdot \rho_{\text{ср}} \cdot 3600}.$$

The Nusselt number [9]:

$$Nu_{plate} = 1{,}02 \cdot \mathrm{Re}^{0{,}38};\ Nu_{plate} = 1{,}128 \cdot \mathrm{Re}^{0{,}7}.$$

Heat balance in the vehicle:

$$Q_1 + Q_1' + Q_{illum} + Q_{plate1} + Q_{floor} + Q_{ceil} = G_h \cdot c_{average} \cdot \Delta t_{int},$$

where $\Delta t_{int}$ – alteration of the air temperature in the vehicle;

$Q_1$ – amount of heat, emitted by passengers;

$Q_1'$ – amount of heat from one plate;

$Q_{illum}$ – amount of heat from electric equipment (illumination, generators, accumulators);

$Q_{plate1}$ – amount of heat transferred from the plate to the interior of the vehicle;

$Q_{ceil}$ – amount of heat transferred through the ceiling and lateral walls of the vehicle;

$Q_{floor}$ – amount of heat transferred through the floor of the vehicle.

Received: 29.01.2018. Accepted: 20.02.2018

Due to the considered mode of transport having almost no convection, the heat transfer from the LSaFPS to the exterior medium is impossible. Consequently, it is relevant to consider thermal accumulators, installed inside the capsules, as the medium for discharging the excessive heat energy.

The general classification of the thermal accumulators [10] is shown in the fig. 2.

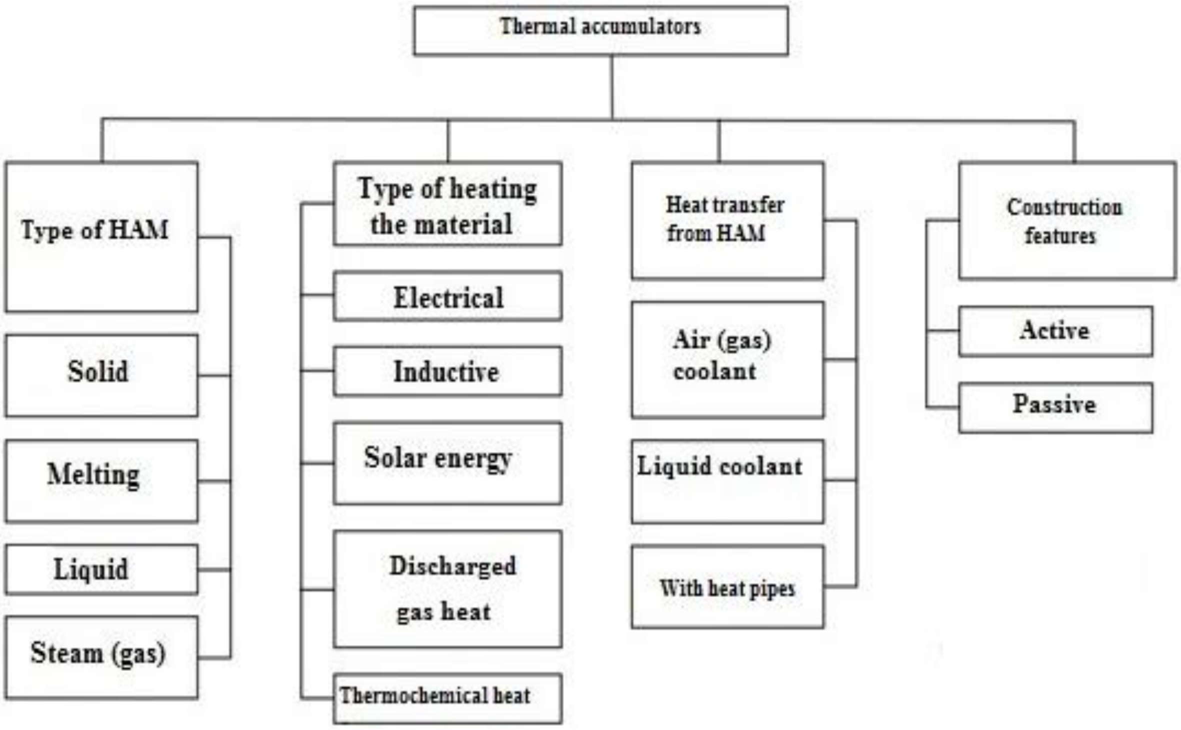


Fig. 2. The classification of the thermal accumulators

Regarding the mode of transport being considered, in order to simplify the structure, the solid body thermal accumulators or accumulation of the energy by means of phase transition heat will be suitable [11]. The application of liquid thermal accumulators leads to necessity in installing additional equipment, which ensures circulation of the coolant.

*The accumulation of heat by solid bodies by means of increasing their internal energy*. The accumulation medium in this case is a solid body, which is heated and cooled without phase transition. The thermal storage at the same time is defined by internal energy being a constituent of enthalpy.

*The accumulation based upon phase transition heat* means mainly the accumulation of melting heat, which usually runs with slight volume changes. Sometimes, the solid-liquid phase transition is combined with the solid-solid transition at the temperature which is slightly lower than the melting point. It is frequently suggested to additionally use heating energy (internal energy) of liquid and/or solid phase of the medium.

Received: 29.01.2018. Accepted: 20.02.2018

Regarding the vacuum maglev transport, it is relevant to consider thermal accumulators with solid heat accumulating material (SHAM) [12], which will simplify the structure and facilitate operation of the LSaFPS of the transport unit.

## Materials and Methodology

In this paper, the authors have used the heat engineering calculation method for the thermal accumulator with solid heat accumulating material (SHAM) [13, 14].

When calculating the heat balance, it is important to know the specific values of heat capacity, enthalpy (internal energy), and phase and chemical transformations [15].

The heat transfer by conduction is described by the Fourier's Law, according to which the amount of heat $dQ_\tau$ , running in a period of time $d\tau$ through the surface *dF*, normal to the direction of the transfer, equals:

$$dQ_\tau = -\lambda \frac{dt}{dl} dF d\tau,$$

where λ – heat transfer coefficient, W/(m·K);

$\frac{dt}{dl}$ – the thermal gradient, i. e. the alteration of the temperature per unit of length in the direction of heat transfer.

*Heat transfer by means of conduction through the wall.* The amount of the heat transferred through the flat wall per 1 hour may be defined by the heat equation as the amount of heat passing through a square of infinitely small thickness *dx* inside the wall:

$$\frac{dQ_\tau}{d\tau} = Q = -\lambda \frac{dt}{dx} F.$$

Integrating the alteration of temperature along the entire length of the wall, we obtain:

$$Q = \frac{\lambda}{\delta} F (t_{wall1} - t_{wall2}).$$

Received: 29.01.2018. Accepted: 20.02.2018

*The heat transfer by means of convection*. *The convective heat transfer* is the heat transfer by volumes of medium by means of their mutual motion in the direction of the heat transfer. The motion of heat from wall to wall is called the heat transfer. The amount of heat transferred is determined by the Newton law:

$$Q = \alpha F (t_1 - t_{wall}).$$

where α – heat transfer coefficient, W/(m2·K).

*The mean temperature difference.* In the overwhelming majority of cases, the temperatures of media in the process of heat transfer will change as a result of the running heat transfer and, consequently, the mean temperature will also change ($t_1$ – $t_2$) along the surface of the heat transfer. Therefore, the mean temperature difference along the length of the apparatus $\Delta t_{mean}$, however, since this change is not linear, the logarithmic temperature difference is calculated.

$$\Delta t_{mean} = \frac{(t_{1'} - t_{2'}) - (t_{1''} - t_{2''})}{\ln \dfrac{t_{1'} - t_{2'}}{t_{1''} - t_{2''}}} = \frac{\Delta t_{'} - \Delta t_{''}}{\ln \dfrac{\Delta t_{'}}{\Delta t_{''}}}.$$

In order to determine the amount of heat transferred by air to the heat accumulating material of the LSaFPS, it is first important to determine the mass of the heat accumulating material (HAM):

$$V_{\text{energy}} = V_{\text{total TESM}} - V_{\text{pipe}},\ \text{m}^3,$$

where $V_{\text{tot HAM}}$ – total volume of the thermal accumulator, $\text{m}^3$;

$V_{\text{pipe}}$ – volume of pipes of the coolant and heat receiver, $\text{m}^3$.

The mass of the HAM:

$$m = \rho_{\text{HAM}} \cdot V_{\text{HAM}},\ \text{kg},$$

where $\rho_{\text{HAM}}$ – density of the heat accumulating material.

Amount of heat transferred to the HAM:

$$Q = c \cdot m \cdot \Delta t,\ J.$$

To facilitate calculation of the thermal accumulator, let us conditionally divide the calculation by 2 parts – thermal accumulator charging and thermal accumulator discharging.

The determination of mass flow rate of the coolant in charging operation of the thermal accumulator.

Received: 29.01.2018. Accepted: 20.02.2018

The mass flow rate of the coolant on the basis of the heat balance equation:

$$Q = G_{air} \cdot \Delta i_{air}.$$

where $\Delta i_{air}$ – alteration of the enthalpy of the coolant (air), J/kg;
$G_{air}$ – mass flow rate of the coolant (air), kg/s;
$Q$ – amount of heat, transferred to the HAM, J:

$$\Delta i_{air} = C_{air}(t''_{air} - t'_{air}); \quad G_{air} = \frac{Q}{\Delta i_{air}}.$$

The determination of temperature conditions for operation of the thermal accumulator:

$$t_{average\ HAM} = \frac{(t''_{HAM} - t'_{HAM})}{2}; \quad t_{average\ air} = (t_{average\ HAM} - \Delta t_{average});$$

$$\Delta t_{average} = \frac{(t'_{air} - t''_{HAM}) - (t''_{air} - t'_{HAM})}{\mathrm{In}\dfrac{t'_{air} - t''_{\mathrm{HAM}}}{t''_{air} - t'_{\mathrm{HAM}}}}.$$

By means of the obtained values $t_{average\ HAM}$ and $t_{average}$ the required thermal and physical characteristics of the coolants are determined.

The value of the actual velocity of the coolant (air):

$$w_{gas} = G/F \cdot r,$$

where $G$ – volumetric flow rate (air), $m^3/s$;
$F$ – passage area of the pipe, $m^2$;
$r$ – internal radius of the pipe, m.

The Reynolds number:

$$Re = w_{flux} \cdot d \cdot \rho_{gas} / M_{gas},$$

where $\rho$ – density of the coolant (air), $kg/m^3$;
$w_{flux}$ – velocity of flux, m/s;
$d$ – characteristic length of the element of the gas flux, m;
$M$ – coefficient of viscosity of the coolant (air), kg/(m·s).

The value of the heat transfer coefficient is determined from the equation:

$$Nu = \alpha \cdot d / \lambda,$$

where $\alpha$ – heat transfer coefficient, $W/(m^2 \cdot {}^{o}C)$;
$d$ – characteristic length of the element of the flux, m;
$\lambda$ – heat conductivity of the medium, $W/(m \cdot {}^{o}C)$.

Received: 29.01.2018. Accepted: 20.02.2018

Considering the criterion equation (applicable to air and water):

$$Nu = 0{,}021 \cdot Re^{0{,}8} \cdot Pr^{0{,}43} \cdot \lambda_{gas},$$

we obtain

$$\alpha_{gas} = 0{,}021 \cdot \lambda_{gas} / d_{internal\ diameter} \cdot Re^{0{,}8} \cdot Pr^{0{,}43} \cdot \Psi_{gas},$$

where $\Psi = 1{,}05$ – coefficient taking into account the influence the temperature factor for the air under cooling.

The determination of mass flow of the coolant during charging operation of the accumulator is carried out similarly.

The heat transfer coefficient is determined by the formula:

$$K = 1 / (d_{average} \cdot (1/a_{gas} \cdot d_{internal} + 1/2 \cdot \lambda \cdot ln \cdot d_{external}/d_{internal} + \\ + 1/a \cdot d_{ext}) + R_{poll}),$$

where $d_{ext}$ – external diameter of the pipe;

$d_{int}$ – internal diameter of the pipe;

$R_{poll}$ – thermal resistivity to pollution of the pipe.

When calculating K, it is important to observe the following rules:

if $\alpha_{gas} > \alpha_{air}$ then $d_{average} = d_{ext}$;

if $\alpha_{gas} = \alpha_{air}$ then $d_{average} = (d_{int} + d_{ext}) / 2$;

if $\alpha_{gas} < \alpha_{air}$ then $d_{average} = d_{int}$.

With small thickness ratio of the wall of the pipe $d_{external} / d_{internal} < 1{,}5$ one could use the following relation:

$$K = 1/(1/a_{gas} + \delta_{wall} / \lambda_{wall} + 1/a + R_{poll}).$$

Determination of the duration of full charging:

$$d = E_{accum} / N_{discharging},$$

where $E_{accum}$ – accumulator capacity, kWh;

$N_{discharging}$ – capacity of discharging, kWh.

## Results

Regarding the vacuum maglev transport it is relevant to consider the thermal accumulators with SHAM, which will simplify construction and facilitate operation of the LSaFPS of the transport unit.

The fig. 3 shows the enlarged scheme of the operation process of thermal energy accumulator, which not only enables removing heat emissions inside the transport unit, but also utilising this thermal energy.

The fig. 4 shows the scheme of the option № 2 of beneficial use of the thermal energy emitted during discharge of the thermal accumulator. The option

Received: 29.01.2018. Accepted: 20.02.2018 

which predisposes removing thermal energy (Option № 1), differs from the proposed one in including tank cooler in the contour of "cold water".

One of the ways to solve the issue of heat removal in the vacuum tube and prevention of thermal deformations of its structure may become application of melting heat accumulating materials (MHAM), placed in the shell of the vacuum tube. This option may be used as an alternative to heat insulating materials.

## Discussion of the Results

The issues considered in this paper, as well as the methods proposed, enable full solving the set tasks. The application of the thermal accumulators as units of autonomous ventilation and air conditioning systems enables not only increase of the level of passengers' comfort, but also a significant reduction of power consumption of these systems. Besides, the issue of environmental safety of this kind of equipment is settled, since they do not use CFCs, required for conventional air conditioning systems.

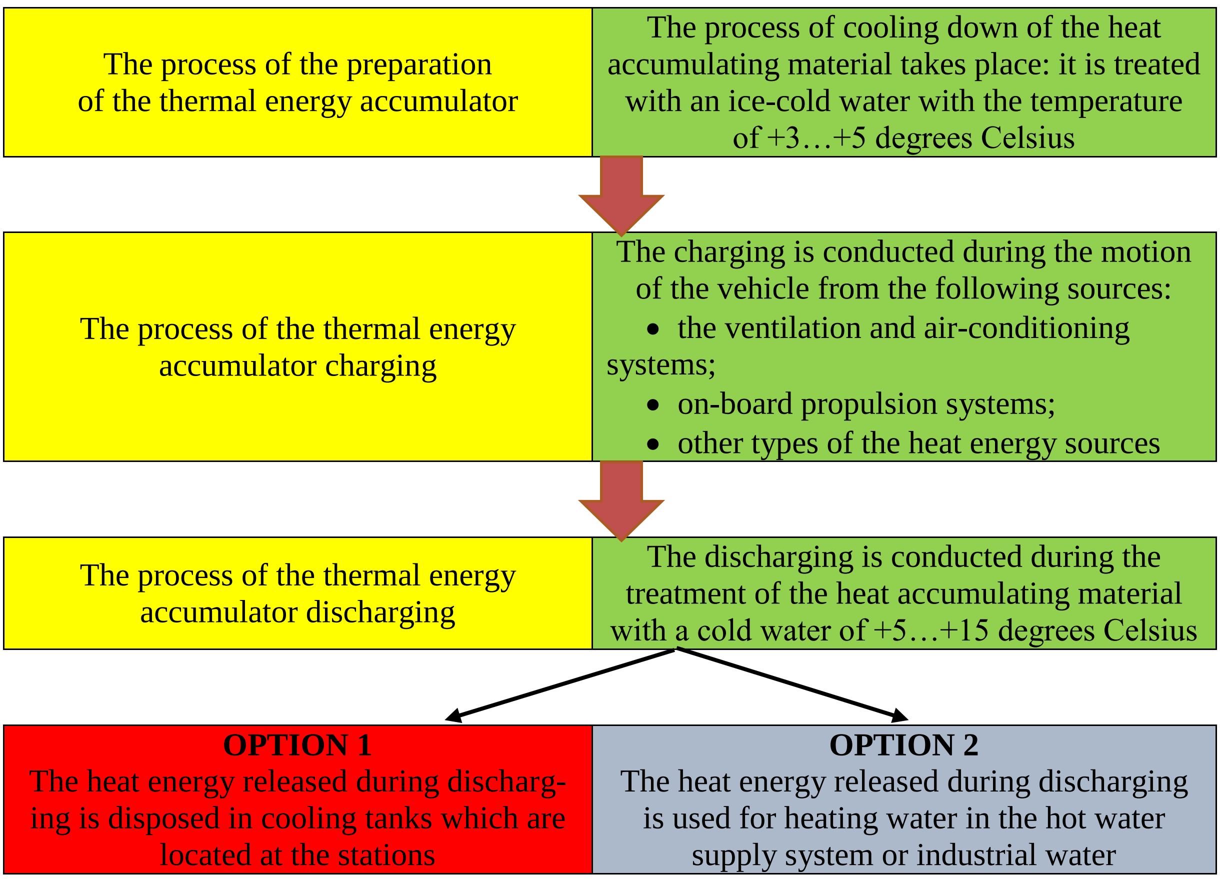


Fig. 3. The enlarged scheme of the operation process of thermal energy accumulator

Received: 29.01.2018. Accepted: 20.02.2018

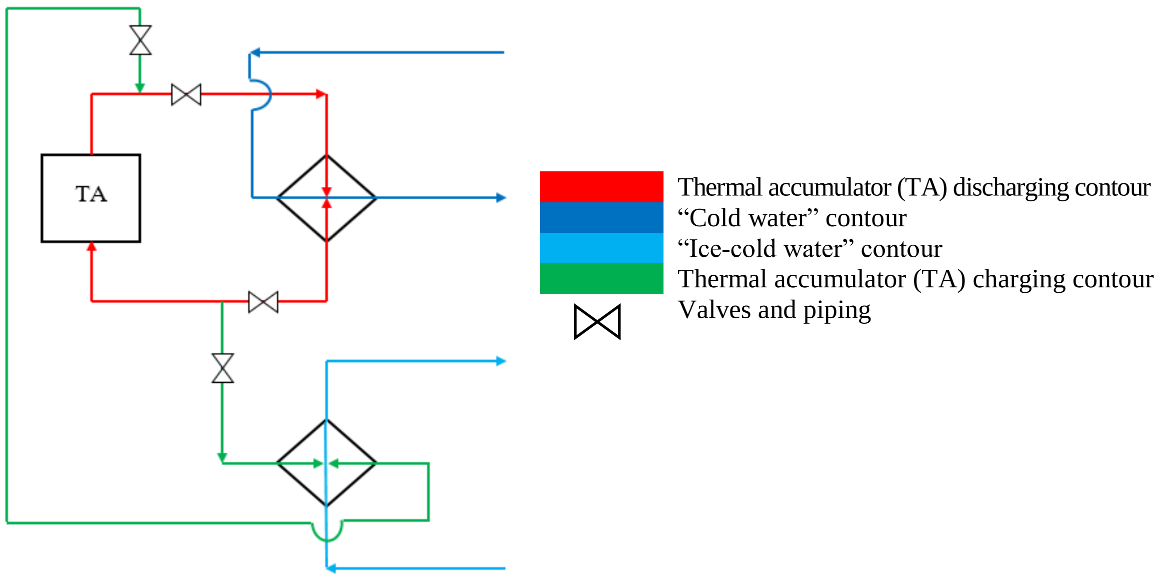


Fig. 4. Principle scheme of beneficial use of the thermal energy emitted during discharge of the thermal accumulator

## Conclusion

The proposed system enables proper ensuring the required parameters of microclimate in the passenger or freight transport unit. The paper suggests the method which enables precise choosing both the material of the thermal accumulator and modes of its performance, depending on the operation conditions of the vacuum maglev transport units.

The proposed system has a number of significant advantages, namely:

- the cooling system does not require extra power consumption;
- the problem of heat removal in rarefied air medium;
- the joint application of this system with the stationary charging systems for thermal accumulators will enable increase of energy efficiency of the entire transport systems.

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Received: 29.01.2018. Accepted: 20.02.2018

**To cite this article:**

Krasnov AS, Zimenkova TS, Kaznacheev SA, Aksenov NA. Application of Thermal Accumulator with Solid Heat Accumulating Material as a Method of Cooling of Life Support and Freight Protection Systems for Vacuum Magnetic Levitation Transport. *Transportation Systems and Technology*. 2018;4(1):43-57. DOI: 10.17816/transsyst2018041043-057.

**Цитировать:**

Краснов А.С., Зименкова Т.С., Казначеев С.А., Аксенов Н.А. Применение теплового аккумулятора с твердым теплоаккумулирующим материалом как способ охлаждения части системы жизнеобеспечения и грузосохранения вакуумного магнитолевитационного транспорта // Транспортные системы и технологии. – 2018. – Т. 4, № 1. – С. 43-57. DOI: 10.17816/transsyst2018041043-057.

Received: 29.01.2018. Accepted: 20.02.2018