COLD ACCUMULATOR WITH PHASE TRANSFORMATION

The purpose of this project is to develop and substantiate the parameters of new structures of seasonal batteries with phase transformation of the storage material, which allow to get rid of deformations and destruction of the contacting elements of the battery structure when the aggregate state changes. The design of a seasonal battery with a phase transformation of the storage material is based on a shell that allows to compensate for the expansion of the material when the aggregate state changes. Determination of the dependence of the energy parameters on the geometric parameters and thermophysical parameters of the constituent elements of the seasonal battery with phase transformation, which allow the battery capacity and power at different stages of discharge and charge. The study of the processes of phase transitions made it possible to establish the characteristic stages of battery charge and discharge: heating the material to the phase transformation temperature; heat transfer for phase transformation 0°C; heating the material after the phase transformation; cooling the material to the phase transformation temperature; heat removal for phase transformation 0°C (in some cases hypothermia up to 3-4°C is possible); cooling of the material after the phase transformation. The largest battery power values occur at the stage of cooling the material to the phase transformation temperature and heating the material after the phase transformation (25.62 kW). The lowest power of the battery (13.56 kW) is observed when the material is heated to the phase transformation temperature and the material cools down after the phase transformation, which is explained by the low heat exchange of the accumulating substance in the solid state. Based on the conducted research, recommendations have been established,

***Keywords**: battery, phase transition, crystallization, shell, cooling circuit*

Introduction

The global practice of using energy resources is focused on increasing the use of non-traditional energy sources and the development of energy-saving technologies. Rational use of energy resources is possible due to an active policy of energy conservation and the creation of efficient systems and energy equipment. In view of the increased requirements for the indoor microclimate, the energy consumption of heating and air conditioning systems has increased significantly, which is why there is a need to use environmentally friendly and energy-saving technologies. The main global trend in the creation of heating and air conditioning systems is the use of heat pumps that pump energy from the external environment and vice versa, often losing it. A sufficiently high effect of heating and air conditioning systems, which is explained by the preservation of heat, is achieved when creating heat accumulators, in particular underground. It should be noted that part of the energy in the case of geoaccumulators is dispersed into the mountain massif, which significantly reduces energy efficiency indicators. An alternative to this technology is the accumulation of cold in building air conditioning systems using a renewable seasonal cold accumulator with phase transformation, which is one of the ways to reduce energy consumption and an economically beneficial engineering solution.

The peculiarity of the solution proposed by the authors of the article is the double use of thermal energy accumulated in the battery with a phase transition for heating and air conditioning systems, depending on the need, which is caused by seasonal changes in ambient temperatures.

Review of sources

A number of works are devoted to the process of heat supply based on seasonal underground accumulators, offering a number of solutions for the use of near-surface capacitive heat accumulators [6-8]. In most cases, it is suggested to use water, paraffin, fatty acids and Glauber's salt as the accumulative material. Glauber's salt is the leader in the heat capacity of the phase transition. The main disadvantage of salt hydrates is their incongruent melting. Usually, during melting, a saturated liquid phase and a solid in the form of a lower hydrate of the same salt are formed, which is precipitated at the same time. In addition, melts of salt hydrates are characterized by supercooling, followed by explosive crystallization[9]. Also, one of the important properties of salts is high chemical activity, which significantly accelerates the process of corrosion of system elements.

Paraffin and fatty acids have a lower phase transition energy and low thermal conductivity, which significantly reduces the specific power indicators of the battery under conditions of the same area of heat exchangers. Also, a common disadvantage of paraffins, fatty acids and Glauber's salt is their high cost, compared to the cost of water.

The general problem of using materials with a phase transition is a change in the aggregate state, which firstly reduces or stops the processes of mass and heat transfer, and secondly, changes the specific density in the solid state. Thus, water increases its volume by 9-10%, which upon contact leads to equivalent deformations and destruction of the contacting elements of the design of the batteries, the radiator, and the case walls.

Considering the above, the main reason for the low use of seasonal accumulators with phase transformation is the lack of a design that could compensate for the change in the volume of the accumulative material when the aggregate state changes.

The purpose and tasks of the research

The purpose of this project is to develop and substantiate the parameters of new structures of seasonal batteries with phase transformation of the storage material, which allow to get rid of deformations and destruction of the contacting elements of the battery structure when the aggregate state changes.

To achieve the set goal, the following tasks were solved in the work:

- Development of a new design of a seasonal battery with a phase transformation of the storage material, which allows to get rid of deformations and destruction of the contacting elements of the battery design when the aggregate state changes;
- Establishing the dependence of energy parameters on geometric parameters and thermophysical parameters of the constituent elements of a seasonal battery with phase transformation;
- Establish recommendations regarding the prospects for the development and optimization of the design of seasonal accumulators with phase transformation of the accumulator material.

Material and research results

The main parameter that allows you to determine the main energy processes from the geometric parameters and thermophysical parameters of the constituent elements of the seasonal battery with phase transformation is the battery capacity. The process of charging and discharging a battery with a phase transition depends on the direction and stage of the phase transition. The name of the charge and discharge processes of the cold battery is the same as the name of the heat battery.

To solve the problem of creating a new design of a seasonal cold accumulator, a capsule design is proposed (Fig. 1). The accumulator consists of a tank 1 filled with antifreeze 2 based on ethylene glycol and propylene glycol with the possibility of changing the level. The supply and removal of heat from the heating and air conditioning system will take place through circuit 3. The water in the rubber capsule 4 is used as the accumulating liquid. To stabilize the position, the capsule is connected to the bottom of the tank with a rod 5. The tank has a thermal insulation layer over the entire area. 7.

The process of discharging the cold accumulator is accompanied by the supply of heat through circuit 3 with heating of antifreeze 2 and capsule 4 with ice. The process of heating the capsule takes place in several stages (Fig. 2, a):

- heating the material to the phase transformation temperature;
- heat transfer for phase transformation 0°C;
- heating of the material after the phase transformation.

The second stage, characterized by the process of changing the aggregate state, passes gradually from the bottom to the top, dividing the capsule conditionally into parts made of ice, in the upper part, and water in a liquid state in the lower part. In this way, heat exchange processes at height H capsules pass at different speeds due to different coefficients of heat transfer from liquid and ice to the surface of the capsule.

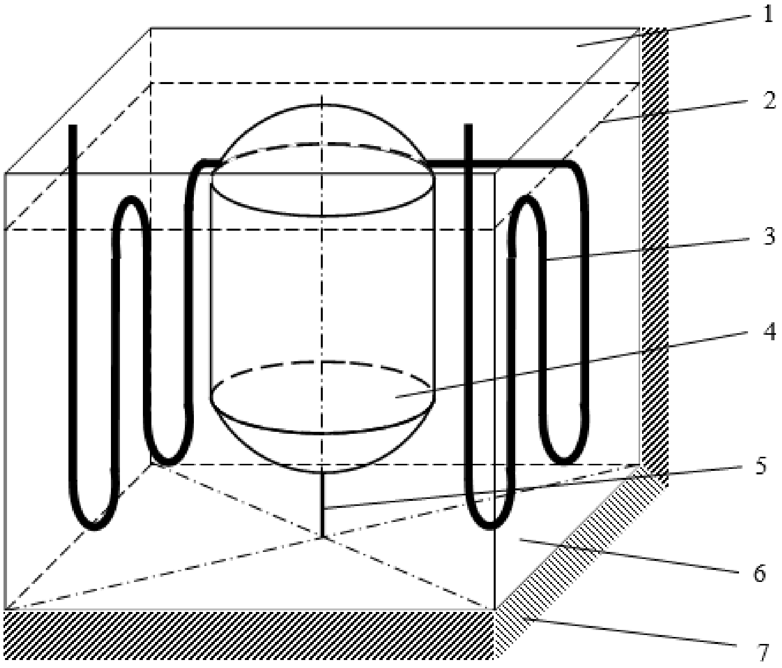
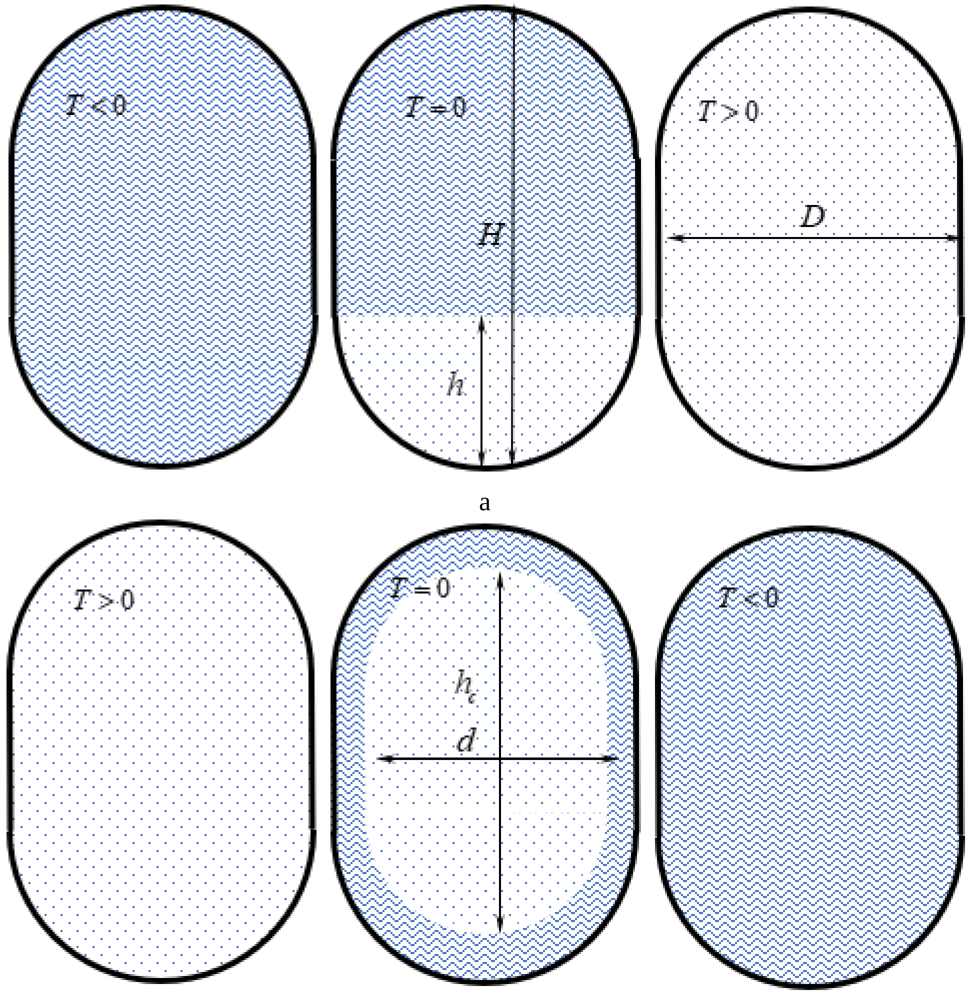


Fig.1 Construction of a seasonal cold accumulator

The process of charging the cold accumulator is accompanied, on the contrary, by the removal of heat through circuit 3 with cooling of antifreeze 2 and capsule 4 with water. The capsule cooling process takes place in several stages (Fig. 2, b):

- cooling the material to the phase transformation temperature;
- heat removal for phase transformation 0°C (in some cases hypothermia up to 3-4°C is possible;
- cooling of the material after the phase transformation.

Both for the case of discharge and for the case of charge, the cooling processes take place at different speeds in the volume of the capsule. Crystallization occurs simultaneously along the entire periphery, gradually forming a layer in height $\Delta = \left(D-d\right)/2$ dividing the capsule into parts of ice, which forms a capsule with water in diameter d and height h_c.



a

b

Fig. 2 Scheme of changing the aggregate state of the material of the cold accumulator:
a - battery discharge; b - battery charge

To determine the power, we will accept a number of simplifications of the calculation model. Consider the capsule as a cylinder in which the temperature of the accumulating substance is equalized by volume. This assumption can be made under the condition of low speed of heating and cooling processes. We will also make a similar assumption regarding the temperature of the antifreeze surrounding the capsule. The mass of the capsule shell, which is planned to be made of polymer, which allows the expansion of water during crystallization, is several orders of magnitude smaller than the mass of the accumulating substance, which allows its influence to be neglected.

Battery capacity according to the assumptions made:

$$Q_c = Q_l + Q_s + Q_f = m\left(c_l\left(T_1^c - T_0\right) + c_s + c_f\left(T_0 - T_2^c\right)\right), \quad (1)$$

Where Q_l - heating-cooling heat in the liquid state;

Q_s - heat of heating-cooling of the phase transition;

Q_f - heat of heating-cooling in the solid state.

m - the mass of the accumulating substance;

c_l c_f - heat capacity of water in liquid and solid state;

c_s - heat capacity of the phase transition;

T_1^c and T_2^c - minimum and maximum temperature of the accumulating substance;

T_0 - crystallization temperature.

Yes for the battery with the geometric parameters of the capsule $D = 4м; H = 4м$ the amount of energy that can be used to compensate loads is $4,63 \cdot 10^{10}$ $Дж = 1.11 \cdot 10^{10}$ $кал$

Let's determine the capacity of the battery at different stages of discharge and charge. The power of radiation or energy absorption is directly proportional to the total heat transfer coefficient of the antifreeze-sheath-accumulating substance system K, the surface area of the shell S and the temperature difference between the antifreeze and the accumulating substance ΔT :

$$N_c = KS\Delta T \ . \tag{2}$$

The power of the cold battery discharge process at different stages:

- heating the material to the phase transformation temperature:

$$N_c = K_{11} S \Delta T_1 ; \tag{3}$$

- heat transfer for the 0°C phase transformation:

$$N_c = ((D(H-h) + \frac{D^2}{4})K_{11} + (Dh + \frac{D^2}{4})K_{12})\pi\Delta T_2 ; \tag{4}$$

- heating the material after the phase transformation:

$$N_c = K_{12} S \Delta T_1 . \tag{5}$$

where K_{11} - in the solid state of the accumulative substance;

K_{12} - heat transfer coefficient of the system in the liquid state of the accumulating substance.

The process of charging the cold battery at different stages:

- cooling the material to the phase transformation temperature:

$$N_c = K_{12} S \Delta T_1 ; \tag{6}$$

- heat transfer for the 0°C phase transformation:

$$N_c = K_{13} S \Delta T_1 ; \tag{7}$$

- material cooling after phase transformation:

$$N_c = K_{11} S \Delta T_1 . \tag{8}$$

where K_{13} - heat transfer coefficient of the system during the partial transition of the accumulating substance from liquid to solid state.

A feature of the stage of the transition of the accumulative substance from a liquid to a solid state is the formation of a layer of ice on the surface of the shell in the middle of the capsule, which will significantly affect the heat transfer process.

The total heat transfer coefficient of the system for the liquid state of the system components (antifreeze, storage medium) [11]:

$$K_{12} = \frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2} \qquad (9)$$

where and are coefficients of convective heat exchange between the accumulative substance and the shell wall and the shell wall and antifreeze (400 and 300);$\alpha_1 \alpha_2 \frac{\text{Вт}}{\text{м}^2\,{}^0\text{C}}$

λ – thermal conductivity of the rubber shell is 0.414 W/(m·0C);

δ– thickness of the shell wall (0.01-0.02m).

Converting equation (9), the total heat transfer coefficient of the system is 18-32.$\frac{\text{Вт}}{\text{м}^2\,{}^0\text{C}}$

The total heat transfer coefficient of the system for the case of the solid state of the storage medium:

$$K_{11} = \frac{D/2}{\lambda_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2} \qquad (10)$$

where λ_i - thermal conductivity coefficient of the accumulative substance in the solid state.

Converting equation (10) the total heat transfer coefficient of the system 2 .$\frac{\text{Вт}}{\text{м}^2\,{}^0\text{C}}$

The total heat transfer coefficient of the system for the case of phase transition of the storage medium:

$$K_{13} = \frac{(D-d)/2}{\lambda_i} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}\,. \qquad (11)$$

At this stage of the battery charge, the heat transfer coefficient can vary in a wide range from 2 to 32.$\frac{\text{Вт}}{\text{м}^2\,{}^0\text{C}}$

To visualize the potential difference realized by the proposed design of the battery, we will construct diagrams of power values with certain geometric parameters (Fig. 3).

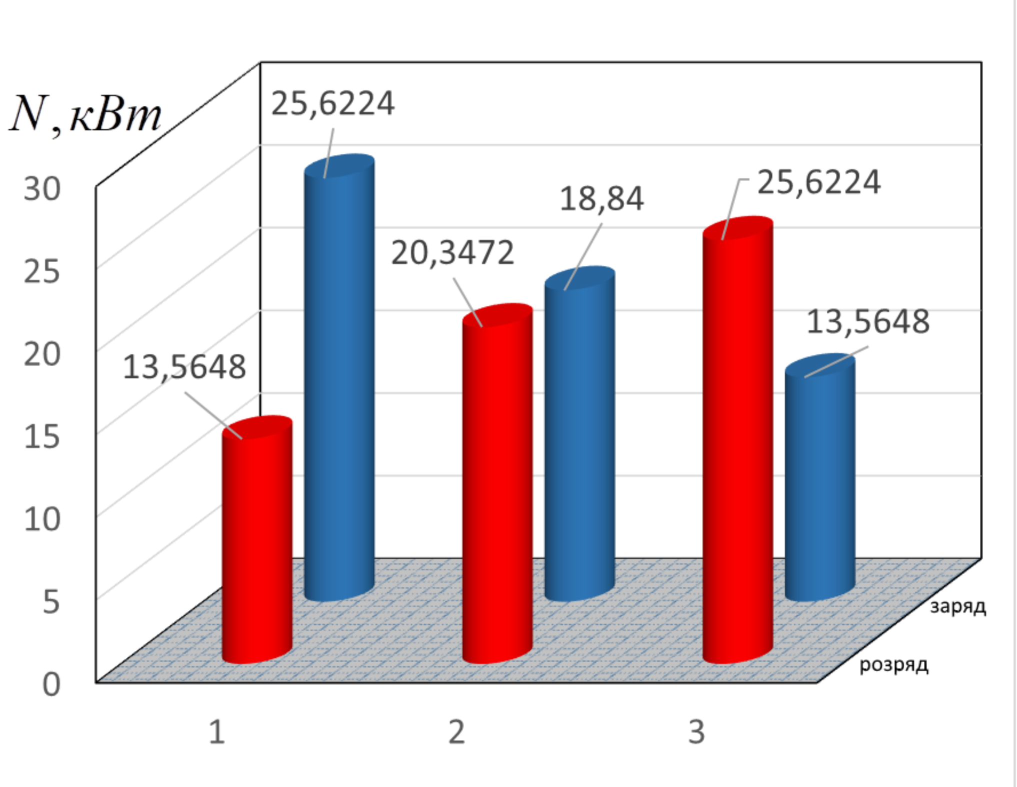


Fig. 3 Diagrams of the power values of the cold battery ($D = 4м; H = 4м$)

The analysis of the obtained values indicates that the largest battery power values occur at the stage of cooling the material to the phase transformation temperature and heating the material after the phase transformation (25.62 kW). The lowest power of the battery (13.56 kW) is observed when the material is heated to the phase transformation temperature and the material cools down after the phase transformation, which is explained by the low heat exchange of the accumulating substance in the solid state. Measures to increase the capacity of the battery can be the use of covers with a developed contact area due to corrugation of the surface or changing the shape, for example, toroidal shape.