Investigation of heat transfer enhancement and thermal resistance of weakly inclined thermostabilizer

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Abstract. The paper presents results of the investigation of the thermal resistance in soil thermal stabilizers in the permafrost region. The schemes of the composite and single thermostabilizers, the dependences of the evaporator temperature of the heat stabilizer are presented. The thermal resistance is presented depending on the refrigerating capacity for Freon R22 and water.

1. Introduction
In Russia 60% of the territory is the permafrost area (Siberia, Far East). The development of these territories is difficult because of the severe climate and a number of features. One of these features is the behaviour of the soil at different time of the year due to temperature fluctuations. As a result, the soil becomes swollen, swells, and the foundations of buildings and structures, roads, oil and gas pipelines are destroyed.

For thermo-stabilization of the soil, its artificial freezing is used at the base of engineering structures. To do this heat stabilizers are used.

Thermostabilizer is a closed vapor-liquid thermosyphon. When supplying heat from the source to the evaporation zone, the heat carrier evaporates and vapor moves along the heat-insulated transport zone to the condensation zone, where it transfers the heat of the phase transition to the cooling medium. Condensate under the action of gravity moves to the evaporation zone, closing the process of heat transfer.

The use of a heat stabilizer to freeze soil at the base of extended objects is not effective, and sometimes it is impossible because of the short range of the device. Also, for installations with increased heat generation (oil pipelines, oil storages, gas pipelines, heating mains), the heat stabilizer cannot provide a high level of cooling capacity. The thermal stabilizer is used for temperature stabilization of soils at the base of extended objects. For the convenience of transportation, the thermostabilizer is made integral, and cooling of the condensation zone occurs year-round with the aid of a refrigeration compressor unit.

Tests show that on weakly inclined areas the area of the wetted surface decreases, and the cooling capacity of the weakly inclined heat stabilizer becomes lower than that of a vertical thermosyphon. Thermal resistance in vapor-liquid thermosyphon was investigated in [1]. In the experimental setup, which is a closed vertical vapor-liquid thermosyphon, a colloidal solution of water with nanoparticles...
of copper oxide with a size of 30 nm was used. The study showed that using a nanofluid, the thermal resistance is 30 to 90% lower than with water, and the range of performance has also been extended. In work [4] innovative designs of slope inclined thermal stabilizers of a ground were investigated. It was found that the use of vaporizer tubes of vapor-liquid heat stabilizers with a capillary-porous coating made it possible to obtain in the first approximation an efficiency coefficient $K = 3,4$. This means that the internal thermal resistance of the system with the evaporator from pipes with a capillary-porous coating is 3.4 times less than that of pipes with a smooth surface. Accordingly, with the same temperature difference on the condenser and the evaporator, we can transfer 3 times more thermal energy than when using the old design. The term of the thermal stabilizer will also last in the cold period of time, which will increase the volume of the ice massif.

Thus, the available studies show that the efficiency of the thermal stabilizer can be increased by intensifying the heat exchange in it. However, the existing data are extremely limited. In the present work, a study was made of the wall temperature distribution of the weakly inclined heat stabilizer model [5] on the sections of the evaporator with different surface structure and thermal resistance of the models of heat stabilizers. The coating of nanoparticles can be an effective approach of enhancement for boiling and evaporation process [6-7].

2. Method of research.

According to the research method, a coating of nanoparticles is applied in the evaporator zone of the heat stabilizer, which causes the liquid level to move on the inner surface and increase the area of the wetted perimeter. In Fig. 1 shows the positions of the liquid level on the inner surface of a uncoated pipe and with a coating of nanoparticles. The coordinate of the inflection point is related to the level of liquid in the pipe.

![Figure 1. Fluid level in a tube coated with nanoparticles (b). and without coating (a).](image)

In this paper, models are investigated: single and composite weakly inclined heat stabilizers. The working environment is Freon R22. Experiments are carried out with the onset of a steady-state heat exchange regime. As preliminary experiments showed, the model of the weakly inclined thermostabilizer stabilized within 30 minutes. After the steady-state regime was established with the help of a thermal imager, the thermograms of the 4 sections of the evaporator of the slightly-inclined single model with different structures were measured: uncoated, coated with nanoparticles (Al2O3, SiO2, particle diameter 100 nm), wire (diameter 0.5 mm, wire material: steel 40), with a coating consisting of nanoparticles and wire. The nanoparticle coating was applied using the technology [9]. The thermograms were used to find the temperature distributions in different parts of the evaporator. It is assumed that the position of the liquid level can be approximately determined from the inflection point on the temperature distribution of the evaporator wall. With the help of a thermal imager thermograms of the evaporator and condenser of the model of a composite weakly inclined heat stabilizer were removed and its thermal resistance was defined.
3. Experimental installation

In Fig. 2 is a model of a weakly inclined single heat stabilizer and sections of an evaporator with different structures: nanoparticle and wire coating, nanoparticle coating without wire, uncoated, with wire. The total length of the evaporator is 2 m, the length of each section of the evaporator with a different structure is 0.5 m. A certain structure was formed on each section of the evaporator and then the resulting parts were welded together. The thermal stabilizer model consists of an evaporator, a condenser, a refrigerating unit with a power of 800 W, operating on a freon R413a. The evaporator and condenser are made of a pipe with a diameter of 30 mm, a wall thickness of 2 mm, a stainless steel material. To reduce the thermal resistance, the thermal paste KPT-8 (thermal conductivity 0.65 - 1 W / m * K) is used in the areas of contact between the condenser and the cooling unit, as well as the heat flow and condenser sensors. The slope angle of the model of a weakly inclined heat stabilizer can vary from 0 to 15 degrees. The working fluid of heat stabilizer is Freon R22.

![Model of a weakly inclined heat stabilizer](image)

Fig.2. Model of a weakly inclined heat stabilizer: 1 - heat stabilizer, 2 - heat flow sensors, 3 - superheater, 4 - compressor, 5 - pressure switches, 6 - condenser, 7 - shut-off valve, 8 - throttling device.

Figure 3 shows a model of a composite weakly inclined heat stabilizer. Its parameters are similar to the parameters of a single weakly inclined heat stabilizer model.
Fig. 3. Model of a composite weakly inclined heat stabilizer.

When starting the refrigeration unit in the contact zone of the condenser of the weakly inclined thermostabilizer and the evaporator of the refrigerating circuit, the temperature is lowered. Freon R22 in the condenser of the heat stabilizer begins to condense, then flows into the evaporator where evaporation and heat removal from the ambient air occurs. Freon from the evaporator, due to the density difference, rises to the condenser and the process repeats. As a result, the model of a weakly inclined heat stabilizer transfers heat from the ambient air to the refrigeration unit.

The temperature of the evaporator wall of the single and slightly inclined thermostabilizer model was measured with a thermal imager. The thermal imager was tested at the stand for calibration of heat flow sensors. During calibration, the temperature of the cold and hot sides of the heat flow sensors was measured by thermocouples and a thermal imager. The surface of the thermal stabilizer model and the working surface of the heat flow sensors are covered with black paint. The emissivity of the colored surface is 0.95. In experiments, the density of the heat flux extracted from the weakly inclined heat stabilizer model was determined. Local heat flow sensors (length - 40 mm, width - 40 mm, height - 15 mm, surface area of 600 mm²) are used to determine the conditions of thermal loading. The scheme of the sensors is shown in Fig. 5 (a). The sensor consists of two aluminum square plates with dimensions: length - 40 mm, height 10 mm, separated by a square plate of stainless steel: length 40 mm, thickness 1.5 mm. On the top surface, a groove is milled for attaching with interference a connecting device that provides thermal contact between the sensor and the evaporator of the refrigeration circuit. The contacting surfaces are treated with KPT-8 thermal paste (coefficient of thermal conductivity from 0.65 to 1 W/ m ° K), the investigated surfaces are covered with a layer of black paint with a blackness ε = 0.95. The sensor is fixed on the condenser of the weakly inclined thermostabilizer model and the evaporator of the refrigerating unit by means of a clamp.

The calibration of each heat flow sensor is carried out on a special stand. At the stand, the sensor was heated by an electric heater and cooled by water circulating along the contour. When calibrating, the equalization of heat input and output was achieved. The result of calibration is the dependence of the amount of heat transmitted through the sensor on the temperature difference between its hot and cold side [10].

4. Results of the study
Below are the changes in the wall temperature of the heat stabilizer model in time, the wall temperature distribution of the weakly inclined heat stabilizer model in the nanoparticulate and wire coating section, the 5 degree gradient angle, the up to 200W cooling capacity, the wall temperature distribution along the length of the weakly inclined heat stabilizer model. The data were obtained
under the following conditions: coolant R22 coolant, tilt angle 1-15 deg, cooling capacity 200 W, for different surface structure of the evaporator model of a weakly inclined heat stabilizer.

In Fig. 4 shows the changes in the mean temperature along the length of the evaporator of the model of the composite weakly inclined heat stabilizer versus time. Stabilization of the temperature regime occurs in 30 minutes after the beginning of the experiment. The change in the wall temperature of the evaporator of the single weakly inclined heat stabilizer model is given in [10].

Fig.4. Temperature difference between the evaporator and the condenser of the composite weakly inclined heat stabilizer

The cooling capacity is determined with the help of heat flux sensors: on the model of a composite heat stabilizer there are 9 of them, on a single 10. They are described in [1]. As a result, the thermal resistance is determined as follows:

\[ R = \frac{\Delta T}{q} \]  

Where \( \Delta T \) is the temperature difference between the evaporator and the condenser of the model of the composite weakly inclined heat stabilizer, \( q \) is the thermal flux of the heat stabilizer.

In Fig. 5 presents the results of an investigation of the thermal resistance of a composite weakly inclined heat stabilizer at different angles of inclination. The cooling capacity in all cases varies from 85-80 watts. The data obtained with a thermal imager at different times and thermocouples are presented. The time intervals of the measurements are as follows: 10/16/2015, 10/12/2016, 11/17/2016.
Three distributions of the wall temperature were constructed for each section of the evaporator: at its beginning, middle and end, then the coordinate of the inflection point was located.

In Fig. 6 (a) shows the changes in coordinates of the points of inflection along the length of the evaporator for the model of the thermal stabilizer located at different angles: 1, 15 degrees, cooling capacity 200 W. The minimum were found on the distributions obtained: on the evaporator section of the uncoated model for all angles of inclination.
The following structures of the evaporator of the model of a weakly inclined single thermal stabilizer are presented: a combined coating of nanoparticles and wire, a coating of nanoparticles, a coating of wire, uncoated. The thermal resistance of the thermal stabilizer model decreases with an increase in the cooling capacity. The lowest value of the thermal resistance was obtained for the model of a single weakly inclined heat stabilizer coated with nanoparticles and wire in the evaporation zone. Thus, the obtained data show that the coordinate of the inflection point moves along the perimeter of the evaporator section of the thermal stabilizer model with increasing characteristic size of the surface structure.

5. References
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