Prospects for the use of electric heaters with self-installing thermal contact based on nano-modified materials for aerospace engineering

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Abstract. The article presents the study of heat generation in the heating element, revealed the working temperature and the nature of the distribution of the temperature field. A method of experimental research has been developed that allows one to determine the thermophysical parameters and the distribution of the temperature field on the surface of the materials under study. It is established that the phase transition temperature is shifted by 2 °C, and the measured thermal conductivity increased for modified heptadecane to a value of 0.3 W / m °C. It was revealed that the use of a material with a phase transition provides the effect of a self-adjusting thermal contact. Improvement of thermal contact occurs within 20 seconds due to a phase transition in nano-modified heptadecane with its volume increasing by 2%.

1. Introduction

The scientific and technological revolution of our time is associated with the emergence and development of nanotechnology, which are attributed to the core of a new, sixth technological order. The global market for nanotechnologies and nanomaterials is rapidly increasing, which is explained by the growing demand for them from all industries, primarily aerospace, automotive, electrical.

The role that Russia plays in the global nanotechnology market is not yet very significant. In particular, on such indicators as the number of patent applications in the direction of nanotechnology, filed in IP5 for 2010-2013, Russia lags behind, for example, 40 times from the USA, 30 times from Korea, and 12 times from China. In terms of the number of enterprises performing research and development in the field of nanotechnology for 2016, Russia also lags far behind the leading countries: the USA, Germany, France, in particular, 15 times, 12 times and 6 times, respectively. Solving the problems of nanotechnology development is associated with the development of innovative technologies in which new types of materials will be used. New materials developed in the framework of nanotechnology can play a special role in the aerospace sphere, which is connected with new developments of aviation technology in the Russian Federation. An important task for aviation is to increase the energy efficiency of aircraft heating systems and anti-icing agents in terms of weight reduction (by 30% compared with traditional electric heating means) and increasing power density (at least 50% compared with traditional electric heating means), as well as create a self-resetting thermal contact.
The large internal volume of the aircraft and the duration of flights in various types of weather conditions place special demands on the reliability of heating systems. Increasing energy efficiency can be achieved by combining several functions in one device at once - a heater and a heat accumulator. Conventional materials such an effect can not be achieved. At the same time, developments in the field of nano-modified heat accumulators are purely experimental in nature and are considered solely in terms of studying the physics of the influence of nanomaterials on the accumulation and distribution of heat in various types of materials. Various types of electric heaters also cannot be used as combinable devices for precise heating, since their control requires external control.

In an article [1], a composite based on high-density polyethylene with graphite nanofibres and carbon black is used to produce an electric heater. In [2], polypropylene with a hybrid filler, which consists of graphite oxide with multi-layered carbon nanotubes (binary filler) and multi-layered carbon nanotubes, is used as the basis of an electric heater. In [3], the authors investigated flexible heating elements based on silicone. The use of self-regulating heaters [1-4] is not effective for aircraft construction, since such heaters have a high specific mass with a low level of body emissions, which range from 10 to 120 W / m.

It is possible to increase the efficiency of electric heating systems for heating the cabin of the aircraft using heat-accumulating materials. Serially, this approach is not used, but there are materials developed that can accumulate thermal energy [4, 5]. Paraffins have acquired particular importance as heat-accumulating materials [6, 7]. For their nanomodification, carbon nanotubes are used [7]. However, the authors of [4-7] investigate specific temperature ranges of the phase transition of heat-accumulating materials that do not allow them to be involved in aircraft industry.

In this regard, issues should be considered with the possibility of developing electric heaters with a self-establishing thermal contact and the possibility of accumulating thermal energy.

Objective: to investigate and make recommendations on the use of electric heaters with self-heating thermal contact and the possibility of accumulation of thermal energy for use in the heating and air conditioning of aircraft.

In this regard, the tasks addressed by the article include: study of the thermophysical properties of nano-modified heat-accumulating materials; the study of heat generation in an electric heater with a material in which there is a phase transition effect; investigation the effect of self-thermal contact.

2. Methods and Materials

Heptadecane (Alfa Aesar, Karlsruhe, Germany) acts as heat-storage material. Its modification is Fluoroplastic F4 (NPP Plastopolymer, Russia) is used to obtain the electric heater. For modifying fluoroplastic F4, CNTs (manufactured by Nanotechcenter, Tambov, Russia) are used with a 30% bulk additive. For the supply of electrical voltage was used nickel foil thickness of 10 microns. Heptadecane (Alfa Aesar Karlsruhe, Germany) acts as a heat-accumulating material. Carbon nanotubes were used to modify heptadecane. Further, the material is made in the form of multilayer plates.

Method of nano-modification of heptadecane.

Heptadecane is poured at a temperature of 50 °C in a silicone container. After that, CNT are introduced by sieving, through metal sieves (mesh size 40 µm). The mixture is treated with ultrasound with a frequency of 22 kHz with stirring with a mechanical stirrer (50 rpm) and a constant temperature of 50 °C. After 20 minutes of mixing, 30% by weight of the fluoroplastic emulsion F4 is added to the mixture of heptadecane and CNT. The resulting suspension is applied on a flat glass coating. After that, the material is placed in a vacuum dryer for 3 hours. Hitachi H-800 in vacuum under 20 kV. Thermal insulation is based on microsphere-based thermal insulation (Izolat, Russia).

Figure 1 shows the structure of an electric heater with a heat storage layer and thermal insulation.
Figure 1. Layers of functional material
1 - heat-accumulating layer, 2 - self-regulating electric heater layer, 3 - thermal insulation layer.

The device shown in figure 2 is used to study the self-establishing thermal contact. The device includes two Peltier elements. Between which there is a heater equipped with a layer with nanomodified heptadecane. On one side, the Peltier has a 20 W axial fan, and on the other side, a passive aluminum radiator.

Figure 2. Device for the study of the self-aligning thermal contact.

For the study self-aligning heat contact on the bottom of the Peltier element is applied a voltage of 10 V, which leads to lowering the temperature to 10°C for 10 minutes. Next, turn on the heater (at a voltage of 200 V) and the upper Peltier element.

Measurement of the thermophysical parameters of the modified paraffin was made by TC-λ-400 device (the Thermal conductivity measurement, Kazakhstan). TC-s-400 device (the thermal conductivity measurement, Norway) was used for the heat capacity measurement at the monotone heating mode at an average rate of 0.1 °C/s under adiabatic conditions. The principle of measurement is based on the application of the method of monotonic heating of the sample in the adiabatic regime.

To study the temperature field on the surface of the heater the thermal imager Testo -875 was used.

3. Results and Discussion
Figure 3 shows the SEM image of CNTs that were used to modify heptadecane.

Figure 3. SEM image of CNTs
Figure 4 shows the temperature dependence of the heat capacity of heptadecane and modified heptadecane. The shift of the phase transition temperature occurs by 2 °C, with this measured thermal conductivity increased for modified heptadecane to a value of 0.3 W / m °C (for pure heptadecane 0.2 W / m °C). For the modified heptadecane, an improvement in its physico-mechanical characteristics is observed, which makes it possible to form from it films with a thickness of 2-3 mm.

At the same time, the materials obtained have a high heat capacity of the phase transition at the level of 5.5 kJ / kg °C. Phase transition is observed in the temperature range of 19-22 °C, which allows to accumulate heat generation from passengers who are in the cabin. This suggests the possibility of thermal control.

Figure 4. Temperature dependence of heptadecane with carbon nanotubes: 1 - heptadecane + fluoroplastic F4; 2 - heptadecane + fluoroplastic F4 with CNTs.

Figure 5 shows the thermogram of the electric heating layer with a supply voltage equal to 220 V.

Figure 5. Thermogram on the surface of the electric heater

Stabilization of heat occurs at a temperature of 56 °C, which ensures a comfortable temperature in the cabin and reduces the load to the onboard power supply system. Specific gravity the ratio of the mass to the power is set during production of the material. The resulting electric heater in the presence...
of the self-regulatory effect of the high value of the ratio of mass to power and can be located at the level of 300 W or 3 kW/sq. m.

Figure 6 presents a study of thermal contact between the heating surface of the heater and the heat exchanger.

![Figure 6. Distribution of the temperature field in the system the heater-heat exchanger.](image)

Figure 7 shows the temperature profile in the contact zone of the heater – heat exchanger 10 seconds after turning on the heater.

![Figure 7. Temperature profile in the contact zone of the heater – heat exchanger.](image)

Over 20 seconds, the process of phase transition in nanomodified heptadecane with a volume increase of 2%. This leads to the clamping of the heater with the heat exchange element. In this case, the change in the temperature profile has the form (figure 8).
Figure 8. Distribution of the temperature field in the heater-heat exchanger system.

Figure 9 shows the temperature profile in the contact zone of the heater - heat exchanger 20 seconds after the heater is turned on.

From comparison of figures 7 and 9, an improvement in the distribution of the heat flux into the cross section between the heater and the heat exchanger follows. This is a consequence of the phase transition in nanomodified heptadecane. The temperature rises and stabilizes, which ensures a stable heat flow. When an object is heated by electric heaters [1-3] as the temperature rises, it can cause a decrease in heat exchange contact.

4. Conclusion
Studies of heat generation in the heating element were carried out. The working temperature and the nature of the temperature field distribution were revealed. The temperature dependence of the heat capacity of nano-modified heptadecane with a fluoroplastic emulsion was studied. It is established that
the phase transition temperature is shifted by 2 °C, and the measured thermal conductivity increased for modified heptadecane to a value of 0.3 W/ m °C. It was revealed that the use of a material with a phase transition provides the effect of a self-adjusting thermal contact. Improvement of thermal contact occurs within 20 seconds due to a phase transition in nano-modified heptadecane with its volume increasing by 2%. This allows to improve heat transfer and efficiency of heaters, which are distributed over large areas. Studies have shown that the implementation of the module in which the combination of the heater, thermal accumulator and thermal insulation occurs improves the efficiency of the aircraft’s heating system and ensures a reduction in mass-dimensional parameters.

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