Investigation of the effect of nanoparticle coatings on the transport properties of a thermostabilizer evaporator

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Abstract. In the work, porous coatings of alumina nanoparticles are investigated. The coatings were formed by various methods. The dependence of the lift height of the nanofluid on its volume was established. The properties of the coating are compared with and without microtrenches.

Introduction
Permafrost regions occupy about half of the globe. Due to the melting of the ground, the construction of various structures becomes difficult and dangerous. When soil is deformed, the building collapses. The installation of thermal stabilizers in the soil under the object allows to solve this problem. An important task is to reduce the thermal resistance of such devices. The thermal resistance of the combined thermostabilizer depends on the characteristics of the joint, the surface structure of the evaporator, the material and the orientation of the pipes, coolant [1]. To improve the transport of liquid from the lower generatrix to the upper in a slightly inclined tube of the heat stabilizer evaporator, it is proposed to form a porous coating of nanoparticles on its surface. The deposition of nanoparticles on the surface of the evaporator of the heat stabilizer will lead to improved heat transfer and lower thermal resistance [2,3].

The formation of a microstructure with trenches improves the transport properties of the coating. In [4,5], it was proposed to form spiral trenches in a layer of nanoparticles by twisting and evaporating a solution of aluminum oxide nanoparticles in a mixture of water and isopropyl alcohol. It was found that the lift height of the fluid, the relief of which is formed in the form of spiral trenches, doubles compared to a uniform layer.

In [6], the effect of alumina nanoparticles on the thermal efficiency of a thermostabilizer was studied. It has been established that the addition of aluminum oxide and surfactant nanoparticles to water makes it possible to increase its thermal efficiency. When using water without additives, dry spots formed on the surface, which led to an increase in the thermal resistance of the thermal stabilizer; this effect did not occur when aluminum oxide nanoparticles were added.

In [7], the effect of alumina nanoparticles on the thermal resistance of a thermal stabilizer was studied. It has been established that the addition of aluminum oxide particles to the working fluid makes it possible to obtain a coating on the pipe walls, which leads to a decrease in the thermal resistance of the heat stabilizer.
The effect of nanoparticles on heat transfer and thermal resistance of a heat pipe evaporator was studied in [8]. It has been established that the deposition of nanoparticles on the surface of a copper evaporator allows one to increase the during evaporation up to two times and reduce the thermal resistance of the evaporation section.

Surface wetting was studied in [9]. The coating was created on an aluminum-magnesium alloy surface using a nanosecond pulsed laser. The experiments were carried out under conditions of supply and removal of fluid through an opening on the bottom side of the substrate. Before coating, the samples were polished with diamond paste and felt. Using an X-ray setup, a change in the surface of the test samples was detected due to an increase in oxygen concentration, which affected the contact angle. The surface retained hydrophilic properties for 120 days, but then the contact angle increased due to the manifestation of hydrophobic properties of the surface.

To modernize thermostabilizers, it is necessary to study methods for reducing their thermal resistance and methods for improving fluid transport.

**Obtaining aluminum oxide nanoparticles**

Alumina nanoparticles were obtained using the following technologies: thermal decomposition of aluminum sulfate at a temperature of 1200 °C, obtaining a sol in a colloidal liquid of aluminum sulfate and potassium hydroxide with gel conversion, thermal decomposition of aluminum sulfate at a temperature of 1200 °C on the surface of cellulose.

The sol-gel method is based on the creation of a dispersed mixture of aluminum hydroxide in an alkaline medium, followed by the transfer of the sol to the gel and its further heat treatment. Solutions of aluminum sulfate and potassium hydroxide were prepared. Aluminum hydroxide was obtained in the reaction vessel by the chemical reaction of aluminum sulfate and potassium hydroxide. Then, a nonionic surfactant (PEG) was added to the solution to stabilize and hold for two days. After exposure, the solution was filtered using a Class 4 Schott filter funnel. The resulting solution was dried at a temperature of 120 °C until the water was completely removed. At the last stage, the dry precipitate of aluminum hydroxide was subjected to thermal decomposition at 900 °C for 30 minutes. By this method, coarse particles of alumina were obtained (Fig. 1a).

The method of thermal decomposition of aluminum sulfate consists in calcining a dry powder of aluminum sulfate in a crucible at a temperature of 1200 °C. After calcination, the alumina powder was placed in a mortar and large decomposition products were ground for 5 minutes. The crushed structure of alumina obtained in this way is similar to a sponge, and the particles have sizes from 1 to 10 microns.

To reduce the size of the resulting particles, cellulose from 100% cotton was used [10]. A solution of aluminum sulfate was prepared at the rate of 50 g per 400 ml of distilled water. Cellulose was wetted in solution and placed on a baking sheet. Within an hour, cotton wool was dried at a temperature of 190 °C in an oven. After drying, hard bars were obtained with aluminum sulfate particles deposited on the fibers. The bar was placed in a crucible, where it was thermally decomposed at a temperature of 1200 °C. The structure of alumina obtained by this method is similar to many fine fibers, and the particles are smaller than 1 micron. The coating was formed on a rectangular metal substrate. To clean the substrate, it was treated with abrasive paper. To remove the abrasive residue, the surface was washed with a potassium hydroxide solution, then with distilled water to remove alkali residues. The porous coating was formed in several stages. First, a colloidal solution of nanoparticles in water with a concentration of 0.01 ± 0.005% was prepared. To equalize the particle size distribution, the solution was intensively mixed and homogenized by flowing through a needle under high pressure. After the solution was filtered using a Schott filter grade 5 funnel.

Upon receipt of the porous coating, a colloidal liquid was applied through a needle to a substrate, which was heated to a temperature of 200 °C. Upon boiling of the nanofluid on the surface of the substrate, the liquid phase evaporated, and the nanoparticles deposited on the plate to form a coating [11]. To strengthen the adhesion of nanoparticles to the surface, the plate was heated to a temperature close to the sintering temperature of the particles with the substrate.
Figure 1. Photos of a surface coated with alumina particles. a - particles obtained using the sol-gel method, b - particles obtained by thermal decomposition of aluminum sulfate, c - particles obtained by thermal decomposition of aluminum sulfate on cellulose.

As can be seen, during thermal decomposition of aluminum sulfate on the surface of cellulose, particles are obtained with a smaller size than during thermal decomposition without applying aluminum sulfate. When choosing the sol-gel method, the particles formed large spherical agglomerates.

Transport properties of a coating of alumina nanoparticles

In the experiments, the dependences of the lifting height of distilled water, isopropyl alcohol, a solution of ammonia, ethanol, and acetone on the volume of nanofluids deposited on a steel substrate were obtained at a temperature of 25 ℃ and a humidity of 61%. The substrate was rectangular in shape with a width of 1 cm and a length of 5 cm. Samples were mounted vertically and mounted on a magnetic plate, and liquid was supplied to the lower base of the metal plate using a thin needle, as shown in Figure 2. The height of the liquid was determined by video recording.

Figure 2. Diagram of a method for measuring the lifting height of a liquid. 1-substrate, 2-lift fluid, 3-needle, 4-ruler, 5-HD camera

It was found in experiments that with an increase in the amount of nanofluid on the substrate, the coating thickness and the height of the liquid rise. The maximum liquid lifting height is set for distilled water. It was found that with an increase in the amount of deposited nanofluid, the rise height of the nanofluid increases and reaches a constant value. Agglomerates of nanoparticles lead to the rise of liquid in the coating to a greater height. Therefore, it can be assumed that the deposition of nanoparticles with agglomerates on the surface of the evaporator of the heat stabilizer will lead to an improvement in the transport of the coolant and a decrease in its thermal resistance. The measurement results are presented in Figure 3.
Figure 3. The dependence of the lifting height of the liquid from its volume: 1-distilled water, 2-isopropanol, 3-ammonia, 4-ethanol, 5-acetone

The formation of microtrenches in a coating of alumina nanoparticles

To improve the transport properties of the coating, a structure was formed in the form of microtrenches, similarly to the method described in [4]. To form the coating, an A85 aluminum substrate was chosen.

The experiments were carried out at a temperature of 28 °C and a humidity of 72%. The aluminum surface was treated with abrasive paper with a grain size of 2500. Then the substrate was washed with a solution of potassium hydroxide to remove residual abrasive, and then with distilled water to remove alkali.

To form a coating with a microstructure, a solution of nanoparticles in distilled water with a concentration of 0.01% was prepared and mixed with isopropanol in a ratio of 1 to 99. A mixture of water-isopropanol-nanoparticles was obtained. The concentration of nanoparticles in solution was 0.0001 ± 0.005%. Before application, the solution was kept for an hour to precipitate large particles.

The nanofluid was deposited on an aluminum substrate. To accelerate the evaporation process, a blower was used with an air flow temperature of 510 °C and a flow rate of 700 l / m. A mixture of alcohol and nanoparticles was fed to the surface of aluminum through a burette. After the deposition process, a microstructure with trenches was formed on the surface of the substrate, as can be seen in Figure 4.
Comparison of transport properties of coatings

To study the effect of microtrenches on the transport properties of coatings, the heights of liquid rise on the surface with and without micro relief were measured. The dependences of the lifting height of distilled water and acetone were obtained for coating with and without microtrenches. The experiments were carried out at room temperature (using a mercury thermometer 28) and a humidity of 71%. Samples were installed similarly to the circuit in Fig. 2. The measurement results are shown in Figure 5.

It has been established that the formation of a coating with microtrenches makes it possible to increase the height of liquid rise by 5 mm. On a surface with such a coating, the liquid rises through the trenches to a great height.
Conclusion

1. The technologies for producing a coating of aluminum oxide nanoparticles with and without agglomerates by boiling a colloidal solution on a substrate are described.

2. Samples were obtained coated with aluminum oxide nanoparticles and the lifting height of various liquids was measured: water - 21 mm, isopropanol and ethanol - 7 mm, acetone - 8 mm, ammonia - 4 mm.

3. Nanoparticles form agglomerates with sizes from 1 to 5 microns. The height of the liquid rise in the case of a coating with microtrenches is 5 mm greater than for coating with agglomerates of nanoparticles.

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References

[1] Yu A Kuzma-Kichta, N S Ivanov, A V Lavrikov, Yu P Shtefanov, I F Prokopenko and P I Skvortsov 2019 Reduction thermal resistance methods in the thermal stabilizer Journal of Physics: Conference Series 1370 012051 doi:10.1088/1742-6596/1370/1/012051
[2] Dzyubenko B.V., Kuzma-Kichta Ya. A., Leontiev A.I., Fedik I.I., Kholpanov L.P. 2016 Intensification of Heat and Mass Transfer on Macro-, Micro-, and Nanoscales Begell House ISBN: 978-1-56700-284-3
[3] Kuzma-Kichta Yu. A., Shtefanov Yu.P., Prokopenko I.F., Zhukov V.M., Lavrikov A.V., Shustov M.V., Stenina N.A., Levashov Yu.A. 2017 Investigation of heat transfer enhancement and thermal resistance of weakly inclined thermostabilizer Journal of Physics: Conference Series. V.89
[4] Yu Kuzma-Kichta, A Lavrikov, A Ustinov Nanoparticle capillary layer for improving thermosyphon MicroMAST 2016: First International Conference on Multiscale Applications of Surface Tension
[5] Lavrikov A.V., Kuzma-Kichta Yu.A., Shtefanov Yu.P., Prokopenko I.F., Ivanov N.S., Stenina N.A. The formation of spiral trenches in a layer of nanoparticles on the surface of an evaporator of a heat stabilizer Heat and mass transfer and hydrodynamics in swirling flows: abstracts. 7th All-Russian Conference with International Participation, 2019. p. 126
[6] Karen Cacua, Robison Buitrago-Sierra Surfactant effect in the thermal performance of a two-phase thermosyphon using Al2O3 nanofluid Joint 19th IHPC and 13th IHPS, Pisa, Italy June 10-14 2018
[7] J Agnieszka Wlaźlak1 Bartosz Zajączkowski1 Michał Woluntarski Surfactant effect in the thermal performance of a two-phase thermosyphon using Al2O3 nanofluid Joint 19th IHPC and 13th IHPS, Pisa, Italy June 10-14 2018
[8] Rahmatollah Khodabandeh, Richard Furberg Heat transfer, flow regime and instability of a nano- and micro-porous structure evaporator in a two-phase thermosyphon loop International Journal of Thermal Sciences 49 (2010) page 1183-1192
[9] Kuznetsov G.V., Feoktistov D.V., Orlova E.G., Batishcheva K., Ilenok S.S. Unification of the textures formed on aluminum after laser treatment Appl. Surf. Sci. 2019. V. 469. P. 974–982
[10] Kuzma-Kichta Yu.A., Ivanov N.S., Lavrikov A.V., Kiselev D.S., Method for producing aluminum oxide nanoparticles. Patent No. RF 2665524
[11] Kuzma-Kichta, Yu.A., Lavrikov A.V., Parshin N.Ya., Turchin V.N., Ignatiev D.N., Shtefanov Yu.P., Method for the formation of nanorelief on heat-exchanging surfaces of products Patent of the Russian Federation No. 2433949