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Study of thermal effect based on liquid crystal nanoparticles

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ABSTRACT

Introduction. Currently, the development of composite systems doped with nanoparticles and based on liquid crystal (LC) media is being actively pursued. The latter, having unique properties, can be used to improve various LC devices. For this purpose, it is very important to investigate the mechanism of change in the properties of liquid crystal systems from the size and concentration of nanoparticles. Recently, a sufficient number of methods have been applied to measure the flow of liquid or gas based on different physical principles. Information about the average mass flow rate of a liquid or gas can be obtained by a measurement method based on steady-state heat injection into the flow. The average flow velocity can be measured by electromagnetic and ultrasonic sensors, while the average volume flow rate can be measured by hydrodynamic (aerodynamic) as well as mechanical turbine methods. In heat transfer and mass transfer, convective motion in a fluid medium plays an important role in the vast majority of natural phenomena and technological processes. Many processes of convective mass transfer and heat transfer in chemical, petrochemical, construction, nuclear and other industries are carried out in heat pipes. Up to the present time the question about efficiency of heat pipes application with bodies from composite materials also remains open. In the presented work the following objectives were set: to assemble an experimental setup to study the thermal effect (flow), to conduct studies of temperature change on the surface of the conductor of the compound based on nanoparticles of liquid crystals and viscosity of liquid crystals from the concentration of nanoparticles. **Methods and Materials.** In this experimental work, a heat flux acts in the region of the outer boundary of the conductor. Note that the redistribution of the thermal field is influenced by such processes as heat conduction and heat transfer. To observe the thermal effect, compounds based on liquid crystal nanoparticles were used. Nanostructured liquid crystal systems have a unique property as fluidity inherent in ordinary liquids. For opaque conductor walls, a method for determining the direction of heat flow is proposed. Earlier experimental studies have shown that temperature measurement is possible only by pyrometric method. Therefore, the redistribution of temperature change on the conductor flow surface was recorded using an optical pyrometer that perceives thermal (infrared) radiation. In this work, a compound based on liquid crystal nanoparticles, namely with the addition of cholesteryloleate, was used as a base. **Results and discussion.** In the course of the study, temperature dependences in the heat flow zone of the conductor in the absence and in the presence of liquid motion were experimentally obtained. Dependences of temperature change on the surface of the conductor with compounds based on nanoparticles of liquid crystals have been measured. Inhomogeneous redistribution of the thermal field is shown. The results of the study of the dependence of the viscosity of nematic liquid crystals on the concentration of nanoparticles are presented. **Conclusion.** The above data show that the thermal effect on the surface is not uniformly distributed. For visualization of the thermal effect, compounds based on nanoparticles of liquid crystals turned out to be more effective. A technique has been developed to determine the direction and calculate mathematically the magnitude of the liquid heat flux in the opaque conductor flow. It should be noted that the viscosity of liquid crystals changes when nanoparticles are coupled.

KEYWORDS: viscosity, fluid motion, liquid crystals, concentration, nanostructured systems, nanoparticles, conductor, temperature, temperature inhomogeneity, thermal effect.

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INTRODUCTION

Nanostructured and highly dispersed systems and have chemical, electrical, magnetic, mechanical, optical and other properties. The formation of nanostructured systems can lead to changes in physical properties, namely: change the strength, yield strength, heat capacity, temperature, magnetic transitions, etc. Therefore, having unique properties, can widely attract the attention of specialists in physics, chemistry, materials science, biology [1–3].

It is now known that the flow of liquids and gases through water, oil and gas pipes is encountered in many different areas of industry. The physical and chemical laws of flow of liquids and gases play an important role in the separation process.

In opaque conductors, the task of determining the direction, measuring the magnitude of the fluid flow and the flow rate of the fluid volume in the conductors arises. There are several ways to determine the thermal effect and temperature [4–8]. In this work, the thermal effect was measured by pyrometric method.

Consider two bodies, bring them into contact and heat them.

We know that the temperature will change in time. The contact of the bodies leads to an increase in the motion of the smallest particles, and accordingly there will be an exchange of energy between the smallest particles. The exchange of energy transferred between tiny particles from a hotter body to a colder one is called heat effect (flux). Thus, heat spreads from a point of higher temperature to a point of lower temperature in all directions. For the thermal effect to occur in different surfaces of space, it is enough to create different temperatures in these surfaces with the presence of a temperature difference [9–13].

Heat pipes are the most important elements of thermal power plants, which are self-contained, hermetically sealed, two-phase heat transfer devices. Let us enumerate their advantages: simplicity of construction; ability to withstand large heat flows at insignificant temperature differences; small mass; heat pipe can operate in a wide temperature range; in addition, the thermal conductive properties of heat pipes are higher than those of the most thermally conductive metals [14–19].

The principle of operation of heat pipes is that heat transfer occurs due to the fact that the liquid is vaporized in the hot section of the pipe, then condensed in the cold section. The liquid returns to the evaporator due to capillary forces [18–23].

The difficult problems encountered in creating heat pipes are material compatibility.

Research and repair of pipelines using composite materials proves to be highly effective [24–28].

METHODS AND MATERIALS

In all bodies, heat transfer depends on temperature redistribution. For the appearance of heat redistribution, a temperature difference is necessary.

To study the heat effect, an experimental setup is assembled which consists of a thermostat, a heater and a thermocouple. Water in the thermostat at constant temperature is passed through the conductor. A plate heater is used to heat an area of the outer surface of the conductor flow. The temperature in the heated area is determined by a thermocouple whose readings are displayed on multimeters [29–31].

In the experiment, a heat flux acts in the conductor area. Note that the redistribution of the thermal field is influenced by such processes as heat conduction and heat transfer. In heat conduction, heat transfer occurs at the molecular level between different parts of bodies. In Brownian motion of molecules, atoms or nanoparticles colliding with each other, energy transfer takes place between molecules, atoms or nanoparticles respectively. When a current flows through a conductor, power is released, while the current density also increases and all this leads to an increase in heat generation and temperature.

To utilize the redistribution of heat in conductors in calculations, we propose an expression of Fourier's law:

$$q = -\beta T,$$

where β – is the heat conduction coefficient; T – temperature.

As a result of non-uniform heating of the conductor, heat flows are observed. Redistribution of the temperature field is a rather difficult task. Earlier experimental studies have shown that temperature measurement is possible only by the pyrometric method. According to the pyrometric method, the sample under study should be covered with a thin layer of material.

To observe the thermal effect, compounds based on liquid crystal nanoparticles were used. Liquid crystals have a unique property such as fluidity, which is inherent in ordinary liquids.

Based on the electronic spectra, the sizes of liquid crystal nanoparticles were calculated to range from 1.7 nm to 4 nm. The compounds themselves are presented in Table 1.

Table 1 shows that cholesteryloleate was used to obtain liquid crystal compounds in all ratios, to the base of which various acids were added in different quantitative ratios. In this work, the liquid crystal nanoparticle based compound numbered I was used.

The following scheme was used to obtain the experimental compounds. At the beginning, all compounds in the ratios presented in Table 1 were placed in a glass

Table 1
Name of mixture components

Mixtures	Liquid crystal compounds	Quantitative ratios of compounds
I	Cholesteryloleate and hexyloxybenzoic acid	6:2
II	Cholesteryloleate and nonyloxybenzoic acid	3:1
III	Cholesteryloleate and butyloxybenzoic acid	5:2

vessel. In the first case, the particles were stirred with a special glass stick, and the compounds were brought to a homogeneous mass. The second case allowed to obtain a homogeneous distribution of nanoparticles. In the third case, the prepared compounds were heated to the temperature until complete melting.

RESULTS AND DISCUSSION

The obtained compounds were deposited as a thin film on the surface of the conductor (approximately 10 μm). Further on the surface of the conductor, heat dissipation was carried out with the formation of multiple colors. Measurements were carried out using an optical pyrometer, with the heating region taken as the origin of the report.

At the place where heating is carried out, heat absorption occurs. At the same time, the heat field rushes away evenly and gradually. Recall that the distribution of heat is affected by thermal conductivity and heat transfer.

We measured the dependences of temperature change on the surface of the conductor with compounds based on liquid crystal nanoparticles. As a result of the experiment we obtained three dependences of temperature change on the surface of the conductor in the heating zone and in the cooling zone.

Fig. 1 shows the graph of temperature change dependence in the conductor heat effect zone in the absence of liquid motion.

Fig. 2 shows the graph of dependence of temperature redistribution in the conductor heat effect zone when there is fluid motion.

The graphs presented in Figs. 1 and 2 have nonlinear dependences, and all curves have a well-defined maximum, which shifts in the heat effect zone in the presence of fluid motion [32, 33].

From Fig. 3 we can see that at the place where the cooling of the conductor flow is carried out, the graph of the temperature redistribution dependence has asymmetric changes.

Thus, from the conducted experimental studies we obtained the presence of the thermal effect of the liquid [34]. As a result, we note that in the presence of fluid motion and in the absence of fluid motion there is a non-uniform distribution of the temperature field.

The velocity of liquid motion was calculated by the following formula:

$$v = Q/S, \quad (1)$$

where Q – fluid volume flow rate, m^3/s; S – conductor cross-sectional area, m^2.

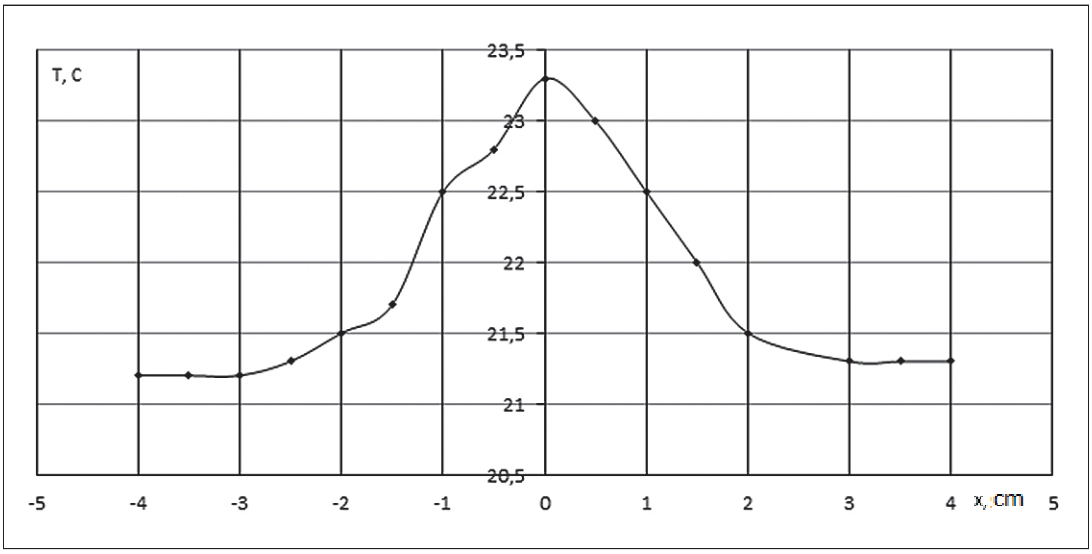

Fig. 1. **Graph of dependence of temperature change in the conductor heat effect zone in the absence of fluid motion**

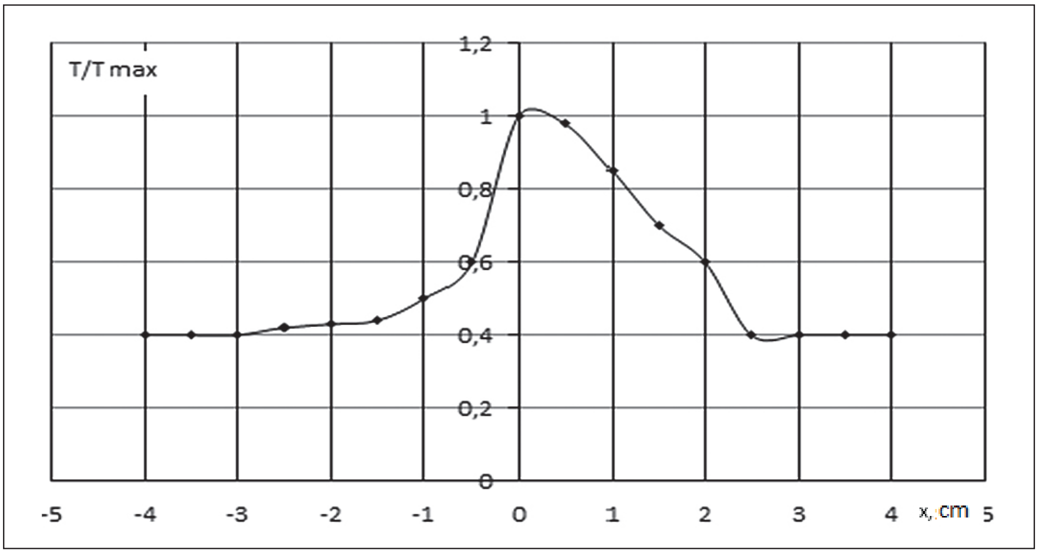

Fig. 2. **Graph of temperature change dependence in the conductor heat flow zone in the presence of fluid motion**

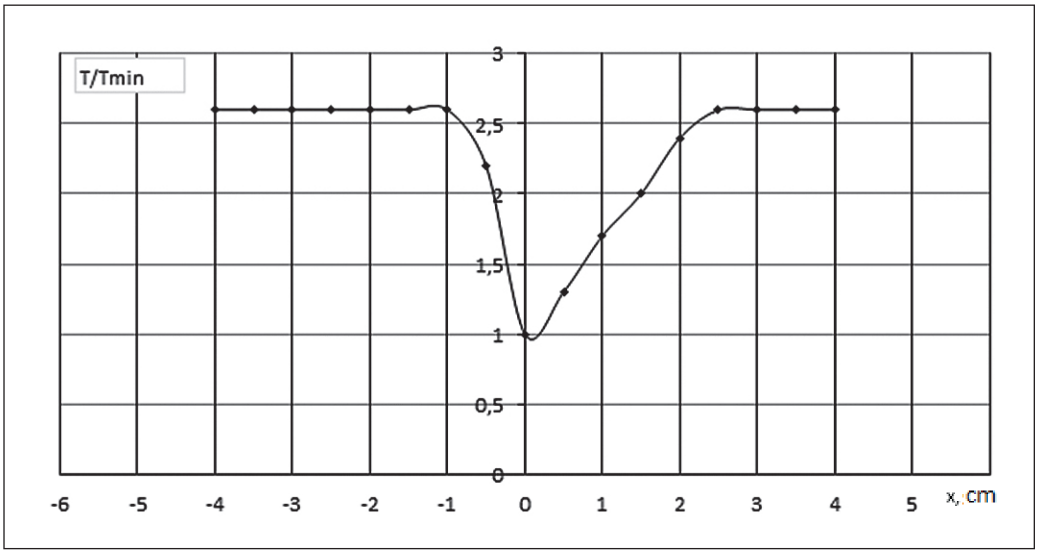

Fig. 3. **Graph of dependence of conductor temperature change in the cooling zone**

The heat flux flow rate was calculated by the formula:

$$Q = V/t, \qquad (2)$$

где V – liquid volume, m^3; t – time, s.

To observe the direction of thermal effect, we mathematically calculated the values of liquid velocity υ and liquid volume flow rate Q using the above formulas [35]. The obtained values are presented in the following Table 2.

Using Table 2, we constructed spectra (Fig. 4) of temperature redistribution on the surface of the conductor for different velocities of fluid motion. The first spectrum corresponds to the velocity υ_1 = 0.0995 m/s, the second spectrum corresponds to the velocity υ_2 = 0.0331 m/s and the third spectrum υ_3=1.660 m/s.

Table 2
Characteristics of fluid velocity and fluid volume flow rate

Velocity of the fluid, υ, m/s	Fluid volume flow rate, $Q \cdot 10^{-5}$, m^2/s
0.0995	1.66
0.0331	5.00
1.6600	0.83

From Fig. 4, we can see that with increasing values of fluid velocities the spectra of temperature redistribution and thermal effect narrows.

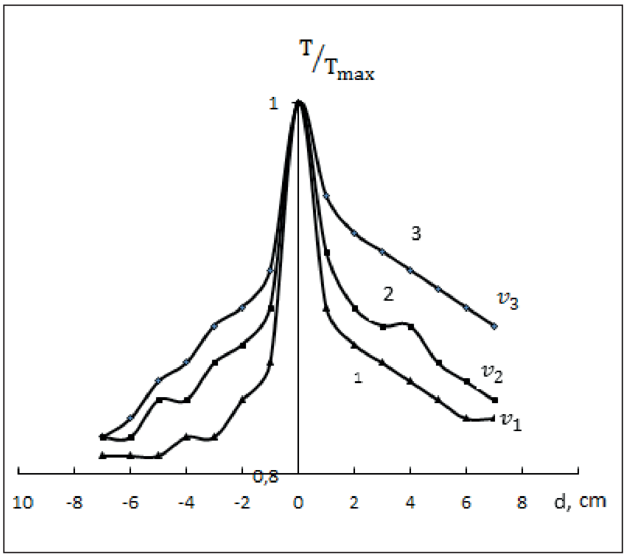

Fig. 4. **Temperature redistribution spectra on the conductor surface for different fluid velocities**

The following graph shows the dependence of the heater power on the conductor surface on the liquid flow velocity (Fig. 5).

As can be seen from Fig. 5, to maintain a constant temperature with increasing velocity, it is necessary to increase the heater power. Up to a velocity of 0.155 m/s, a linear dependence is observed, with further increase in the values of flow velocity, the graph becomes more gentle. Probably, at this point the mode of liquid movement changes.

Analyzing the obtained dependencies, we can mathematically calculate the value of the liquid flow [36].

Consider a liquid with temperature T, which moves in a conductor with transverse surface S. The temperature change of the liquid along the conductor is equal to:

$$dT = (t,x) = \frac{\partial T}{\partial t}dt + \frac{\partial T}{\partial x}dx\,,$$

$$\frac{dT}{dx} = \frac{\partial T}{\partial t} + \frac{\partial T}{\partial x}\frac{dx}{dt}.$$

Since $dx/dt = v$, then $dT/dt = (\partial T/\partial t + \partial T/\partial x)v$.

where $\partial T/\partial t$ – is the particle derivative of temperature by temptation; $(\partial T/\partial x)v$ – is the convective term characterizing convective heat exchangers.

If the temperature remains constant in time $\partial T/\partial t = 0$, then we obtain the expression:

$$\frac{\partial T}{\partial x} = \frac{1}{v}\cdot\frac{dT}{dt}. \tag{3}$$

According to equation (3), the more the fluid is in motion (increasing velocity), the less heat exchange with the external environment occurs, as shown in Fig. 5. The dependence of the heater power for maintaining a constant temperature on the surface of the flow conduit on the fluid flow velocity is characterized at first by a very rapid increase in power, and then has a linear evolution (decreasing power). This is probably due to the fact that the more the fluid is in motion, the more heat is exchanged by convection.

When heat transfer occurs, multiple colors appear on the surface of the conductor.

Fig. 6 shows the image when there is no fluid movement on the conductor.

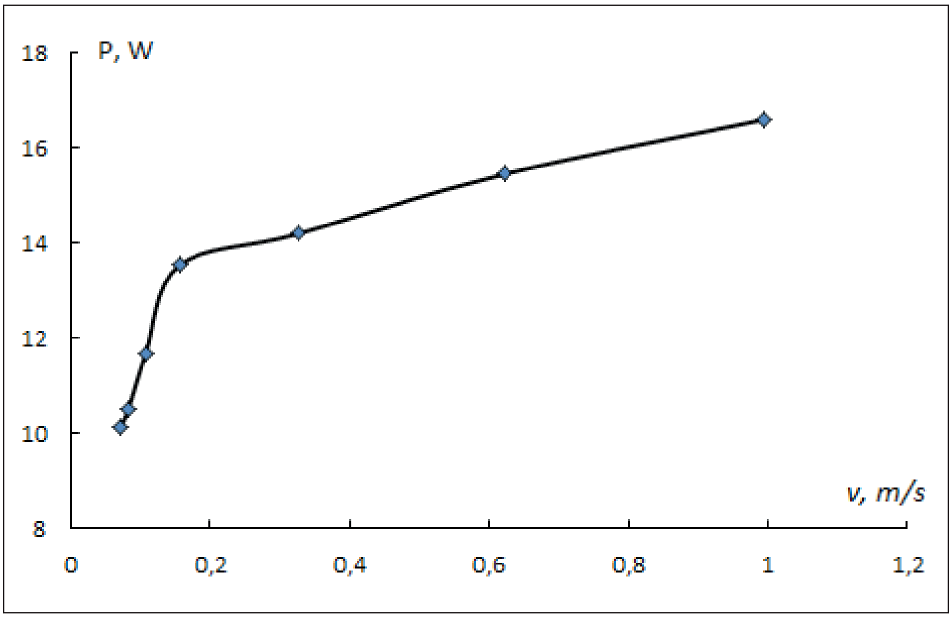

Fig 5. **Graph of dependence of the heater power on the conductor surface on the fluid flow velocity**

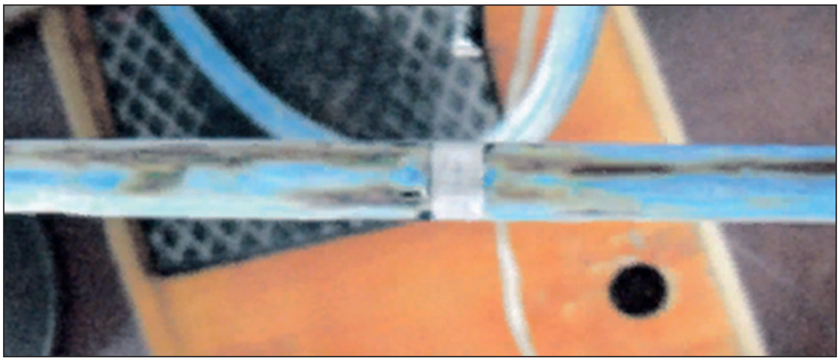

Fig. 6. **Image of heat flow in the absence of heating and fluid motion**

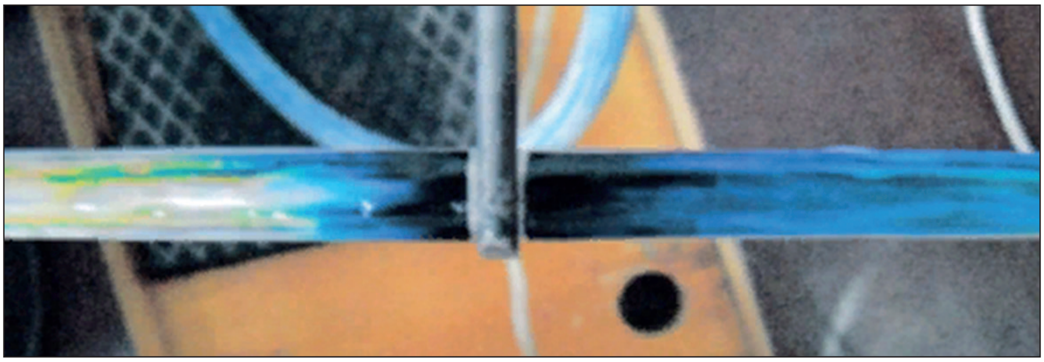

Fig. 7. **Image of heat flow in the presence of fluid motion**

If there is fluid movement in the conductor, heat flow occurs and the image changes (Fig. 7).

From Fig. 7, it can be seen that white color fits the cold zone and blue color fits the warm conductor zone.

Further additionally, the effects of viscosity of liquid crystals from the concentration of nanoparticles are considered in this work. For this purpose, nematic liquid crystals with addition of nanoparticles (*Ta–Si*) with different concentrations have been considered in the study. Here is the structural formula of nematic liquid crystal 4-nitrobenzylidene-4'-heptoxyaniline: $C_7H_{15}–O–C_6H_4–N = CH–C_6H_4–NO_2$.

The concentration of nanoparticles was varied from 0.25% to 3%. Using a laser analyzer, the sizes of *Ta–Si* nanoparticles were determined. The average diameter of *Ta–Si* nanoparticles was found to be about 8 nm. Table 3 shows the results of measurements of viscosity of nematic liquid crystals from the concentration of *Ta–Si* nanoparticles.

It can be seen from Table 3 above that the viscosity of liquid crystals increases with increasing concentration of *Ta–Si* nanoparticles.

Table 3

Results of nematic liquid crystal viscosity measurements on the concentration of *Ta–Si* nanoparticles

Nanoparticle concentration *Ta–Si*, %	Viscosity, *η, mPa·s*
Liquid crystal	
0.25	315.1
0.50	354.7
1.00	374.6
2.00	385.2
3.00	433.4

The above data show that the thermal effect on the surface is not uniformly distributed. Note that the induced local temperature change on the surface of the conductor shows the asymmetry of the temperature field. This further proves the existence of heat flow effect.

As a result of the experimental study, the local temperature change of the conductor flux surface has been shown.

CONCLUSIONS

The compounds based on liquid crystal nanoparticles, namely cholesteryloleate and hexyloxybenzoic acid, were more effective in observing the heat flux.

The above method can be applied to effectively determine the flow direction in the case of opaque conductor walls.

Compounding of nanoparticles leads to a change in the viscosity of liquid crystals.

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CONTRIBUTION OF THE AUTHORS

Rezida G. Rakhmatullina – scientific guidance; development of research methodology; drawing up a plan of experimental work; conducting experimental work; processing the results of the experiment; writing the source text; conclusions of the article.

Nestor Njiya – identifying dependencies; analysis and processing of the results; writing the draf.

Alexei A. Rusinov – collection of materials.

Albina R. Maskova – development of research methodology; scientific text editing; revision of the text.

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