EXPERIMENTAL INVESTIGATION OF LAMINAR FORCED CONVECTION OF NANOFLUID IN HEAT EXCHANGE EQUIPMENT

D V Guzei[1,2], A V Minakov[1,2], M I Pryazhnikov[1,2]

[1] *Siberian Federal University, Krasnoyarsk, Russia*
[2] *Kutateladze Institute of Thermophysics, SB RAS, Novosibirsk, Russia*
E-mail: gudimas@yandex.ru

Abstract. The laminar forced convection in a recuperative heat exchanger operating with nanofluids with MgO nanoparticles was investigated experimentally. In the experiments, nanoparticle concentration varied in the range from 2.5 to 12 wt. %. The nanoparticle size equalled 50 nm. The viscosity and thermal conductivity coefficients of the nanosuspensions were experimentally determined. The dependence of the average heat transfer coefficient and pressure drop on the Reynolds number for nanofluids was obtained.

1. Introduction

The intensification of heat exchange devices is a basic problem in the creation of various thermal systems and technologies. In all machines, equipment and technologies there is a need for intensive heat dissipation. Heat exchange equipment of various kinds is used for this. The urgency of this problem is determined by the necessity to increase the intensity of heat exchangers and to reduce energy costs as well as to achieve maximum compactness with minimum material consumption. The work aims at studying the effect of the nanoscale particles addition on heat exchange in heat exchange equipment. The results of this study will help to answer the question about the feasibility of using nanofluids in industrial heat exchangers.

2. Experimental investigation

Experimental study of forced laminar convection of propanol-based nanofluids with nanoparticles of magnesium oxide (MgO) was carried out in recuperative heat exchanger. In the experiments, Nanoparticle concentration varied in the range from 2.5 to 12 wt.%. The nanoparticle size equalled 50 nm. The experiments were carried out on the recuperative heat exchanger of the "pipe-in-pipe" type. The hot heat carrier from the heater was supplied through the flowmeter to the external circuit of the working area by means of a pump. The inner diameter of the outer pipe was d_3=0.021 m. After passing the working section the hot coolant returned to the heater. Coolant flow was regulated by rotameters. In the experiment, the flow rate in the external circuit was constant G_2=0.05 kg/s. The water temperature at the inlet to the circuit was 30°C. The investigated nanosuspension was used as a cold coolant in the internal circuit. The flow rate of nanosuspension was controlled by a wing flowmeter. The inner pipe of the working section had the following dimensions: inner diameter d_1=0.01 m, outer diameter d_2=0.012 m, and length l=1 m. The suspension from the collecting tank was fed into the inner circuit, cooled by a thermostat after passing the working section and returned to the collecting tank. In the experiments, the temperature of the cold coolant at the inlet to the working area was equal to 23°C. The experimental setup was equipped with thermocouples for measuring the temperatures of the heat carriers at the inlet and outlet of both circuits. The scheme of the experimental setup is shown in Figure 1.

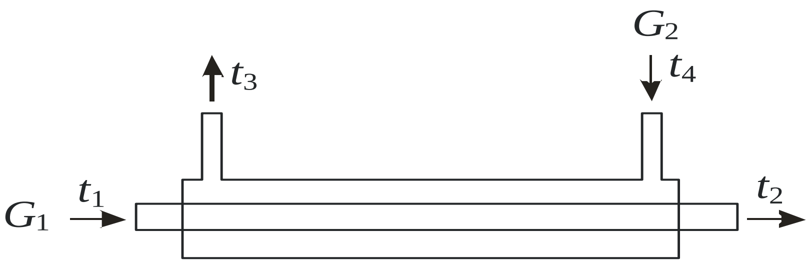


Figure 1. The diagram of experimental setup.

The experimental setup was tested on pure liquids (distilled water and isopropyl alcohol) in the range of Reynolds number from 600 to 8000. The obtained data were compared with known empirical correlations. The experimental dependence of the mean heat transfer coefficient on the Reynolds number in the laminar flow regime for pure isopropanol was compared with the Sieder and Tate correlation [1]. The experimental dependence of the average heat transfer coefficient on the Reynolds number for distilled water was compared with the Mikheev correlation [2]. The results of the comparison are shown in Figure 2. The discrepancy between the experimental data and the theoretical dependencies did not exceed 5%.

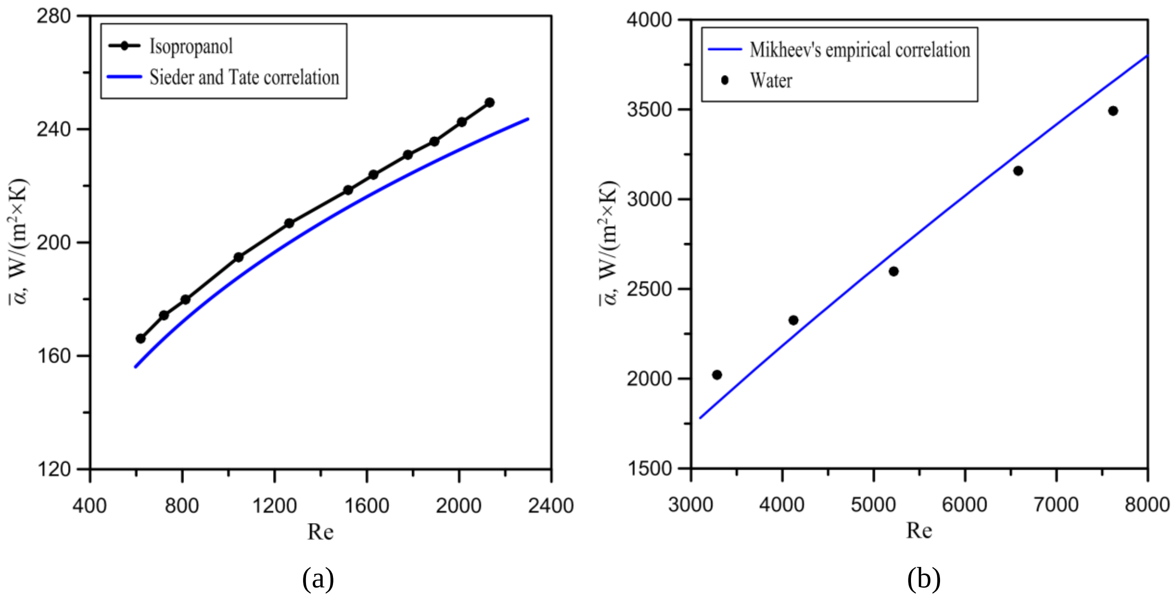


Figure 2. Testing of experimental setup.

The suspensions were prepared by a two-step method. Initially the required mass of particles was added to the base fluid and mechanically mixed. After that the suspension was treated with ultrasound using the USTD "Wave". Surfactants were not added to the nanofluid. Particle size distribution in suspensions was measured by acoustic and electroacoustic spectrometer DT1202 (Dispersion Technologies) [3]. During the measurements we have obtained the bimodal distribution of the average particle sizes in the suspension equal to: 61 and 318 nm. Fig. 3 shows the particle size distribution by mass in the suspension as an example.

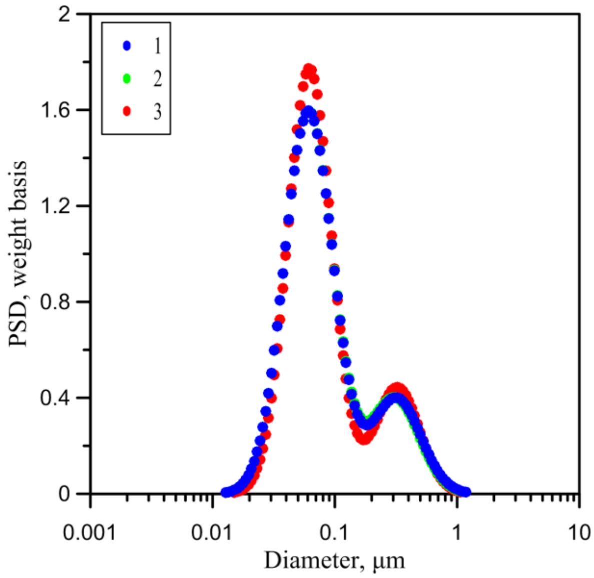
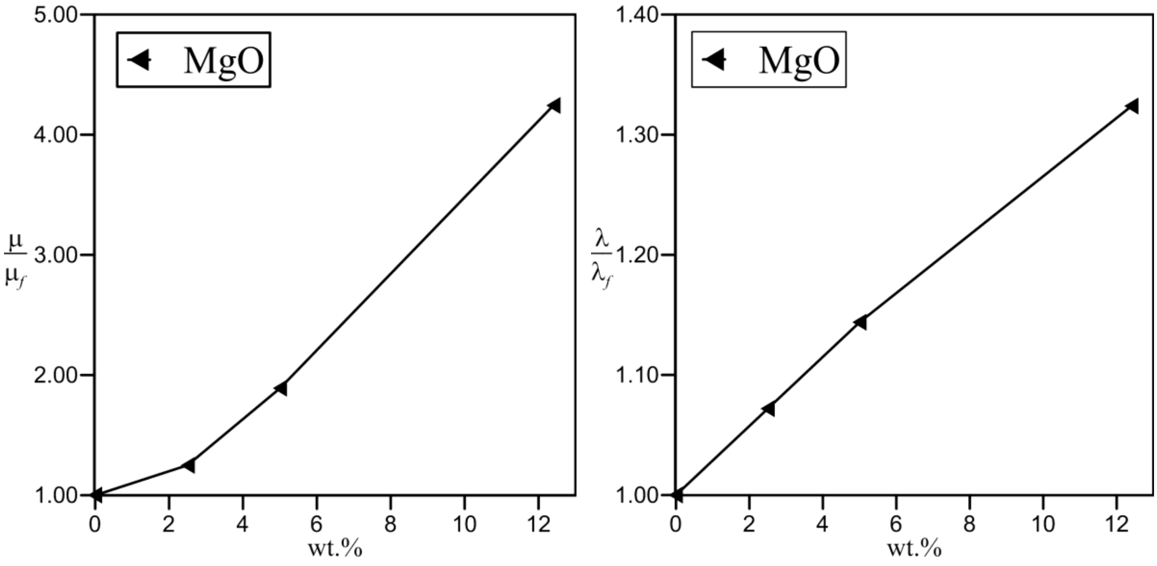


Figure 3. The distribution of particle sizes by weight in suspension.

The systematic study of heat transfer of nanofluids requires knowledge of their thermophysical properties, namely, viscosity and thermal conductivity. The viscosity of the considered nanofluids was measured by means of rotational viscometers DV2T and OFITE-900. The measurements were conducted within the range of shear rates from 10 to 200s^{-1} at a temperature of 25°C. The measurement accuracy of the viscosity coefficient was about 1%. The thermal conductivity of nanofluid was measured by a nonstationary hot wire method. A detailed description of the installation and its testing is given in [4, 5]. The measurement accuracy of the thermal conductivity did not exceed 2–3%.

The viscosity and thermal conductivity coefficients of the nanosuspensions were experimentally determined. The viscosity increased by 25 % relative to pure isopropanol at a particle mass concentration of 2.5 %. The viscosity coefficient increased with rise in the concentration of magnesium oxide particles. The viscosity coefficient increased 4 times compared to the base fluid (isopropanol) at a mass concentration of 12 %. The thermal conductivity coefficient of the nanofluid increased with the nanoparticles concentration. Mass concentration of 2.5 % increased the thermal conductivity coefficient by 7 %, while 12 % concentration increased the thermal conductivity coefficient by 20 %. Dependences of thermophysical properties on the mass concentration of particles are shown in figure 4.

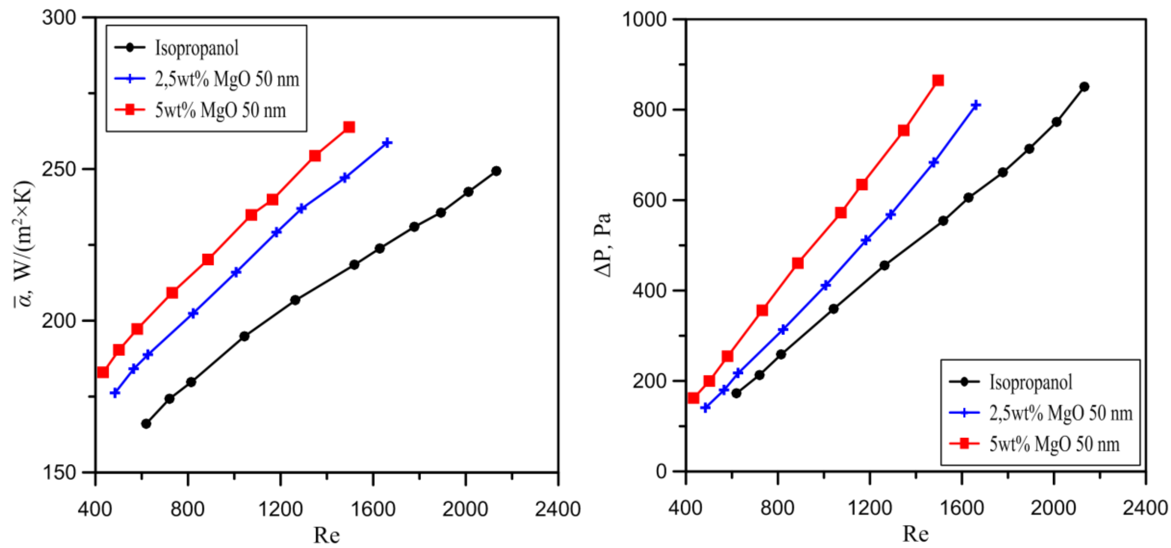


(a) (b)

Figure 4. Thermophysical properties of suspensions.

4. Result and Discussion

The integrated experimental study of heat transfer processes in suspensions with nanosized particles in a shell-and-tube heat exchanger were carried out. Isopropyl alcohol was used as the base fluid. The mass concentration of nanoparticles ranged from 2 to 12%. The dependences of the average heat transfer coefficient on the Reynolds number were obtained. The addition of 5 mass percent of magnesium oxide nanoparticles intensified heat transfer by 18% at a constant Reynolds number. The average heat transfer coefficient decreases monotonically to the values for pure isopropanol, as the concentration of nanoparticles decreases (Figure 5(a)). In the course of the work it was obtained that the dependences of the pressure drop on the Reynolds number at different mass concentrations of nanoparticles. The addition of nanoparticles leads to an increase in the pressure drop required to pump the suspension. The pressure drop increases at a constant Reynolds number by 20% for 2.5% of the particles by mass, and 1.55 times for 5% concentration (Figure 5(b)).



(a) (b)

Figure 5. The dependence of the average heat transfer coefficient (a) and the pressure drop (b) on the Reynolds number for different concentrations of nanoparticles.

To evaluate the efficiency of using nanofluid as a coolant in the heat exchanger, the dependence of the quantity of heat, removed by the nanosuspension, on the pressure drop spent on its pumping has been derived. With a constant pressure drop of the isopropanol-based nanofluid the addition of 2.5 wt% magnesium oxide particles provides a 3% increase in the quantity of heat from the external circuit of the heat exchanger compared to pure isopropanol (Figure 6). The quantity of heat increases by 6% compared to pure isopropanol at a constant pressure drop with an increase in the mass concentration of particles up to 5%.

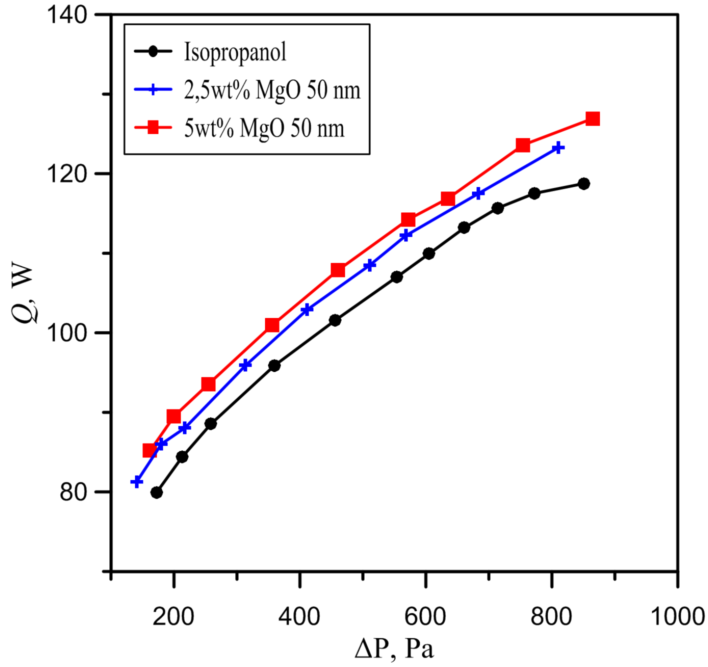


Figure 6. The dependence of the heat flux on the pressure drop, spent on pumping nanofluid.

5. Conclusions

The experimental results show that small additives of nanosized particles (5 wt.%) make it possible to intensify heat transfer in a heat exchanger at a laminar flow regime. Therefore, the addition of nanoparticles to the coolant will increase the efficiency of heat exchange equipment without changing the design. Numerical simulation of heat transfer processes in a regenerative heat exchanger using nanofluids as a heat carrier will be carried out to determine the optimal concentration and material of nanoparticles. The experimental data obtained in this work will be used as data for verification of a numerical model.

Acknowledgments

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