Нанофлюїди є перспективними теплоносіями, застосування яких сприяє підвищенню загальної ефективності енергетичних систем. Основною перепоною на шляху практичного застосування нанотеплоносіїв на основі водних розчинів пропіленгліколю є відсутність точних даних з їхніх теплофізичних властивостей. В роботі виконано експериментальне дослідження (методом адіабатної калориметрії) теплоємності та параметрів фазових перетворень тверда фаза – рідина пропіленгліколю та теплоносія на основі водного розчину пропіленгліколю. Виконано експериментальне дослідження теплоємності рідкої фази теплоносія на основі водного розчину пропіленгліколю з домішками наночастинок Al_2O_3 (до 2,01 мас. %) в інтервалі температур 235…338 K та пропіленгліколю з домішками наночастинок Al_2O_3 (1,03 мас. %) у інтервалі температур 268…335 K.

Виконано зіставлення температурної залежності ефективної теплоємності теплоносіїв зі зміною їхньої внутрішньої структури. Показано, що додавання води до пропіленгліколю збільшує температуру і теплоту фазового переходу тверда фаза – рідина (теплота фазового переходу пропіленгліколю складає 37,85 Дж·г$^{-1}$, теплоносія пропіленгліколь/вода (54/46 мас. %) – 77,97 Дж·г$^{-1}$). Показано, що домішки наночастинок Al_2O_3, як в пропіленгліколі, так і в теплоносії на основі водного розчину пропіленгліколю, сприяють зменшенню теплоємності рідини. Теплоємність зменшується приблизно пропорційно зростанню концентрації наночастинок. Ефект зменшення теплоємності проявляється у більшій мірі при високих температурах (на 3,9 % при 265 K та на 5,0 % при 325 K для нанотеплоносія з концентрацією наночастинок Al_2O_3 2,01 мас. %).

Отримані результати покращать якість проектування теплообмінного обладнання з застосуванням нанотеплоносіїв. Результати є корисними для розробки методів прогнозування питомої теплоємності нанофлюїдів

Ключові слова: теплоносій, пропіленгліколь, наночастинки, калоричні властивості, теплоємність, фазовий перехід, температура плавлення, адіабатний калориметр

UDC 621.564.36+536.6
DOI: 10.15587/1729-4061.2020.200126

AN EXPERIMENTAL STUDY OF Al_2O_3 NANOPARTICLES INFLUENCE ON CALORIC PROPERTIES OF PROPYLENE GLYCOL BASED COOLANTS

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Received date 10.03.2020
Accepted date 30.03.2020
Published date 30.04.2020

1. Introduction

Currently, nanofluids are considered to be promising coolants for use in heat transfer equipment in various fields, such as refrigeration systems, solar energy systems, energy conversion systems, and the like. Numerous experimental studies have shown that the presence of nanoparticles can lead to increased thermal conductivity and intensification of heat transfer [1–11]. Therefore, the introduction of a new generation of coolants into practice is quite promising and will help reduce the overall dimensions of heat exchange equipment and increase the efficiency of the entire energy system.

Water solutions of propylene glycol have been widely used as coolants due to their low freezing temperature and non-toxicity. The disadvantage of such coolants is their high viscosity [12]. The use of nanoparticles to increase the thermal conductivity of aqueous propylene glycol solutions further increases the viscosity of the nanocoolant. To compensate the negative effect of nanoparticles on the viscosity of the coolants, ethanol can be included in their composition [13, 14].

Thus, it can be stated that the new generation of composite nanocoolants containing nanoparticles and additives for viscosity reduction is quite promising for introduction into the modern industry. However, the main obstacle to their practical application is the lack of accurate data on thermophysical properties.

2. Literature review and problem statement

Review works [1, 2] show prospects of application of nanofluids based on water, oils and ethylene glycol for increasing the heat transfer coefficient in various heat exchange equipment. Several papers show the possibilities of enhancing the heat transfer in the flow of propylene glycol aqueous solutions with nanoparticles [3–5]. The study [3] reports the increase of convection heat transfer coefficient up to 15.3 % at 0.75 wt. % of graphene nanoparticles in propylene glycol/water mixture (30/70 wt. %). The thermophysical properties of nanofluid based on the aqueous solution of propylene glycol with sand (SiO_2) addition (2 vol. %) for solar energy collection were obtained and analyzed in the experimental work [4]. The use of 2 vol. % sand/propylene glycol/water nanofluid resulted in the growth of heat transfer and solar energy collection by 16.5 %. The result of [5] evidenced the increase in the mean convective Nusselt number (about 25 % and 20 % correspondingly compared to the base coolant) by adding Al_2O_3 nanoparticles both of 0.53 and 1.03 wt. % concentrations in the aqueous solution of propylene glycol. Nevertheless, [3] does not contain an experimental investigation of thermophysical properties including heat capacity, and the results presented in [4, 5] reflect only some thermophysical properties which were obtained experimentally. However, the paper [6] justifies that conclusions on the possibility of nanofluids application as coolants can be obtained only with the availability of qualitative experimental data on both the heat transfer coefficients and their thermophysical properties.

The review work [1] showed a deficiency in studies devoted to the experimental investigation of the nanofluids heat capacity in comparison with their thermal conductivity and viscosity, but emphasized the prospects of propylene glycol based nanofluids.

The review of research on nanofluids heat capacity performed in [7] does not reveal any work on the heat capacity of nanofluids based on propylene glycol and its aqueous solutions.

Experimental studies on the viscosity, electrical and thermal conductivity of ethylene glycol and propylene glycol based fluids with β-SiC nanoparticles addition are presented in [8]. The paper does not study heat capacity, although this property is important for modeling the coefficient of heat transfer during the flow of the studied coolant.

The review [2] provides information on works that experimentally investigated the viscosity and thermal conductivity of nanofluids based on aqueous propylene glycol solutions. It is noted that the study of heat capacity is not given sufficient attention and it is proposed to calculate it by the additivity rule, which contradicts their own experience of modeling heat capacity [9].

Experimental data on the heat capacity for five different nanofluids containing Al_2O_3, ZnO, CuO, TiO_2 and SiO_2 nanoparticles, which were dispersed in a propylene glycol/water base fluid (60/40 wt. %) are presented in [10]. It is shown that the heat capacity is not an unambiguous function of the mass fraction of nanoparticles. Heat capacity of nanofluid containing 2 wt. % of Al_2O_3 nanoparticles decreased by about 27 % at 243 K and about 19 % at 363 K compared to the heat capacity of the base fluid. There was a slight decrease in the specific heat while increasing the concentration of nanoparticles from 0.5 to 2 wt. %, and a significant decrease in the concentration range from 0 to 0.5 wt. %. The results obtained are rather illogical and contradict the data [7, 9], where it is shown that the heat capacity of nanofluids based on water and organic matter decreases in proportion to the increase in the mass fraction of nanoparticles in them, and also the physical justification of this trend is provided.

In [11], hybrid nanofluids containing ZnO nanoparticles and encapsulated paraffin wax in aqueous propylene glycol solution were created and investigated. It is shown that the presence of paraffin wax mass fraction (4–16 wt. %) and ZnO nanoparticle volumetric fraction (0–2 vol. %) can increase the specific heat by up to 18.7 % compared to the heat capacity of the aqueous propylene glycol solution. The study [11] does not allow to make a clear conclusion about the effect of ZnO nanoparticles on the heat capacity, since it is paraffin wax particles that significantly influence the change in the heat capacity of aqueous propylene glycol solutions.

The review above has shown that today, in the field of research of thermophysical properties of nanofluids, works devoted to the study of thermal conductivity and viscosity prevail [1, 2, 8]. There are quite a few papers devoted to the study of the heat capacity of nanofluids based on an aqueous solution of propylene glycol, and these are controversial [2, 5, 7, 10, 11]. An experimental study of the caloric properties of propylene glycol based nanofluids will allow us to evaluate the effect of nanoparticles on the heat capacity and to identify the main trend in the concentration dependence of the heat capacity of nanofluids. And the study of the parameters of phase transitions in propylene glycol-based coolants will justify the feasibility of introducing nanoparticles into their composition to create new substances with phase transformations for thermal accumulators.

3. The aim and objectives of the study

The aim of the present work is an experimental study of the caloric properties of nanofluids based on aqueous solutions of propylene glycol, promising as coolants for various applications.

To achieve the aim, the following objectives were set:

– to perform the experimental study of heat capacity of propylene glycol, multicomponent coolants and nanocoolants;

– to perform an analysis of the temperature dependence of the heat capacity of propylene glycol and propylene glycol based multicomponent coolant and to determine the parameters of the solid – liquid phase transition;

– to investigate the effect of Al_2O_3 nanoparticles on the heat capacity of the liquid phase of propylene glycol and propylene glycol based multicomponent coolant.

4. Method of experimental investigation of the caloric properties of propylene glycol, multicomponent coolants and nanocoolants

4. 1. Objects of study of caloric properties

The objects of the study are:

– propylene glycol (designated as PG in the text and figures);

– propylene glycol with the content 1.05 wt. % of Al_2O_3 nanoparticles (designated as PG+1.05 % Al_2O_3 in the text and figures);

– XHT-40 industrial coolant of propylene glycol/water (54.00/46.00 wt. %) with doping agents (designated as Coolant1 in the text and figures);

– nanocoolant of propylene glycol/water/ethanol/Al_2O_3 nanoparticles (48.00/46.15/4.82/1.03 wt. %) (designated as Coolant2+1.03 % Al_2O_3 in the text and figures);

– nanocoolant of propylene glycol/water/ ethanol/Al_2O_3 nanoparticles (47.56/45.67/4.76/2.01 wt. %) (designated as Coolant2+2.01 % Al_2O_3 in the text and figures).

Additionally, the data obtained from [5] on the heat capacity of propylene glycol/water/ethanol (48.60/46.52/4.88 wt. %) coolant (designated as Coolant2 in the text and figures) were used to correctly interpret the effects obtained in the study.

To prepare the objects of the study, the following were used:

– distillate water;

– propylene glycol (CAS# 57-55-6) with purity 99.5 wt. %;

– ethanol (CAS# 64-17-5) with purity 96.3 vol. % (the water content was taken into account when calculating the coolant composition);

– α-Al_2O_3 nanoparticles (CAS# 1344-28-1) with an average powder size of 10±5 nm (data provided by the Wenzhou Jingcheng Chemical Co manufacturer).

For the preparation of nanocoolants, a two-stage method was used, by which nanoparticles in the form of powder were mixed up with a portion of the base liquid and underwent dispersion (for 24 hours). The dispersion process took place in a bead mill (glass bulb filled with ZrO_2 balls, 2 mm in diameter, and with approximately 100 sm^3 of liquid containing nanoparticles). Additionally, after each 3–4 hours, the nanofluid was exposed to ultrasonic treatment for 30 min. For this purpose, the Codison CD 4800 ultrasonic bath with the frequency of 42 kHz and power of 0.07 kW was used. The obtained nanofluid with the high mass fraction of nanoparticles was diluted to the required composition before putting into the calorimeter of the experimental setup. The nanofluids were prepared without using surfactants, since their impurities may influence the thermophysical properties of the object under study.

The mass fraction of components in multicomponent solutions was determined by the gravimetric method using the AND GR-300 analytical balance (with uncertainty 0.5 mg).

The results of the study of the colloidal stability of propylene glycol/water/ethanol/Al_2O_3 nanoparticles are presented in [5].

Similar studies have been performed for nanofluids propylene glycol/Al_2O_3 nanoparticles. The data obtained in [5] indicate the colloidal stability of the tested nanofluid samples. This result is important because it shows that the studied nanofluids might be used in industrial heat exchangers with the forced circulation of nanocoolant without changing its dispersive composition over time.

4. 2. Experimental method

Measurements of the two-phase isochoric heat capacity for all objects of the study were conducted by a monotonic heating method. The scheme of a low-temperature adiabatic calorimeter and details of the performed experiment are reported in the work performed [15]. The technique of experimental data processing is presented in [9].

5. Experimental study of propylene glycol, multicomponent coolants, and nanocoolants caloric properties

5. 1. Results of the experimental study

Temperature dependences of the effective (taking into account structural phase transitions) heat capacity for propylene glycol and Coolant1 are presented in Fig. 1, 2. The rate of temperature variation did not exceed 0.15 $K \cdot min^{-1}$. The temperature range, which covers the phase transition region of solid phase – liquid was chosen because of the promising use of the objects under study as working media for thermal accumulators with phase transition. Data on the phase transition parameters are necessary for estimating the expediency of utilizing these matters in the mentioned systems.

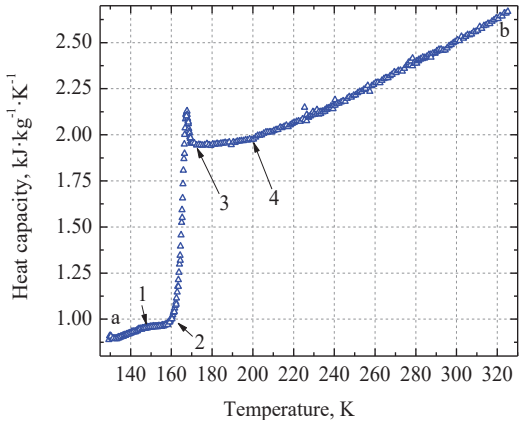

Fig. 1. Temperature dependence of the PG effective heat capacity (designation of alphanumeric and numeric notations is given in the text)

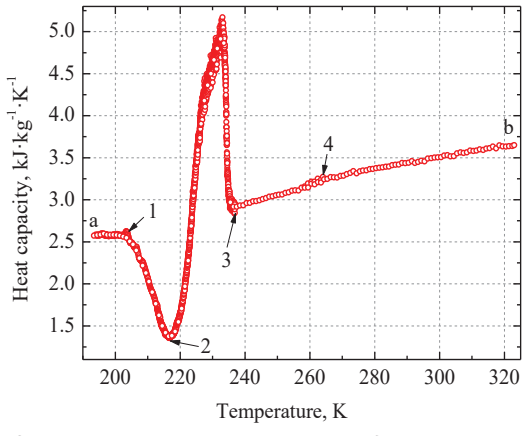

Fig. 2. Temperature dependence of the Coolant1 effective heat capacity(designation of alphanumeric and numerical notations is given in the text)

Experimental data on the isobaric heat capacity of propylene glycol (Fig. 1) were fitted by the following equations:

– solid crystal phase in the temperature range from 132.43 to 149.22 K (region a–1):

$$c_P = 372.04 + 3.933 \cdot T; \quad (1)$$

– structured state in the temperature range from 175.37 to 198.38 K (region 3–4):

$$c_P = 1725.6 + 1.237 \cdot T; \quad (2)$$

– liquid phase in the temperature range from 198.38 to 325.1 K (region 4–*b*):

$$c_P = 1555.1 + 0.0106 \cdot T^2, \quad (3)$$

were c_P is the heat capacity of the object under study, J·kg^{-1}·K^{-1}; T is temperature, K.

Experimental data on the isobaric heat capacity of Coolant1 (Fig. 2) were fitted by the following equations:

– metastable phase in the temperature range from 193.46 to 202.44 K (region *a*–1):

$$c_P = 2505.8 + 0.365 \cdot T; \quad (4)$$

– structured state in the temperature range from 236.49 to 265.42 K (region 3–4):

$$c_P = 49.911 + 12.05 \cdot T; \quad (5)$$

– liquid phase in the temperature range from 265.42 to 323.0 K (region 4–*b*):

$$c_P = \left(67.533 - \frac{7.444 \cdot 10^5}{T^2}\right)^2, \quad (6)$$

where c_P is the heat capacity of the object under study, J·kg^{-1}·K^{-1}; T is temperature, K.

The relative deviations (Eq. (7)) of the obtained experimental data from those calculated by the Eqs. (1)–(6) are shown in Fig. 3.

$$dev = 100 \cdot \left(\frac{c_p^{fit} - c_p^{eEp}}{c_p^{eEp}}\right), \quad (7)$$

where c_p^{fit} and c_p^{eEp} are heat capacity values of the objects under study, calculated by the fitted equations and obtained experimentally, correspondingly, J·kg^{-1}·K^{-1}.

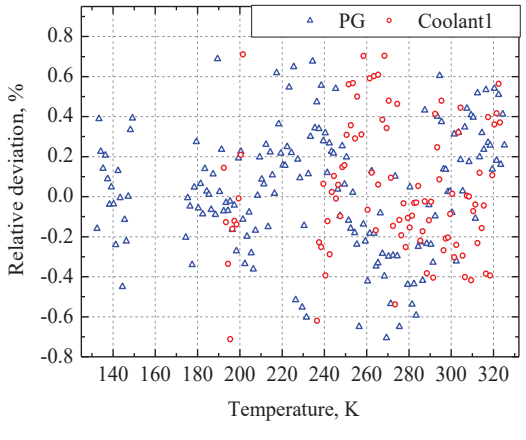

Fig. 3. Relative deviations (Eq. (7)) of the obtained experimental data on the heat capacity of PG and Coolant1 from those calculated by Eqs. (1)–(6)

The study of the heat capacity of the objects with nanoparticle admixtures was performed in the temperature range, which corresponds to the scope of their application as coolants (only in the liquid phase). The results of studying the influence of Al_2O_3 nanoparticles on the heat capacity of propylene glycol liquid phase and propylene glycol/water/ethanol solutions are shown in Fig. 4, 5. Additionally, Fig. 4, 5 present the results of calculating the heat capacity by the fitted equations:

– PG+1.05 %Al_2O_3:

$$c_P = 1567.2 + 0.0101 \cdot T^2; \quad (8)$$

– Coolant2+1.03 %Al_2O_3:

$$c_P = \left(66.334 - \frac{7.11 \cdot 10^5}{T^2}\right)^2; \quad (9)$$

– Coolant2+2.01 %Al_2O_3:

$$c_P = \left(65.724 - \frac{7.003 \cdot 10^5}{T^2}\right)^2, \quad (10)$$

where c_P is the heat capacity of the object under study, J·kg^{-1}·K^{-1}; T is temperature, K.

Since Coolant2 is a base fluid for nanofluids Coolant2+1.03 % Al_2O_3 and Coolant2+2.01 % Al_2O_3, the additional temperature dependence of the heat capacity for Coolant2 is presented in Fig. 5.

Relative deviations (Eq. (7)) of the obtained experimental data from those calculated by Eqs. (8)–(10) are presented in Fig. 6.

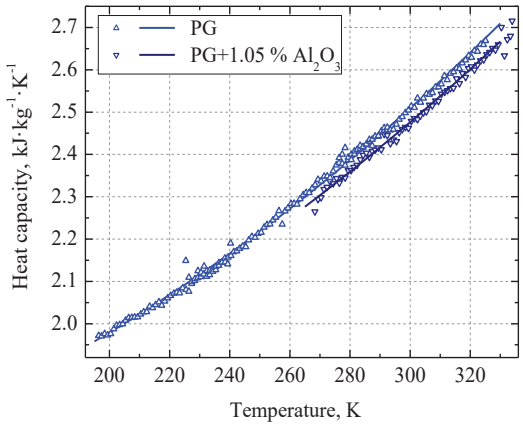

Fig. 4. Temperature dependence of the heat capacity of PG+1.05 %Al_2O_3 in comparison with pure PG

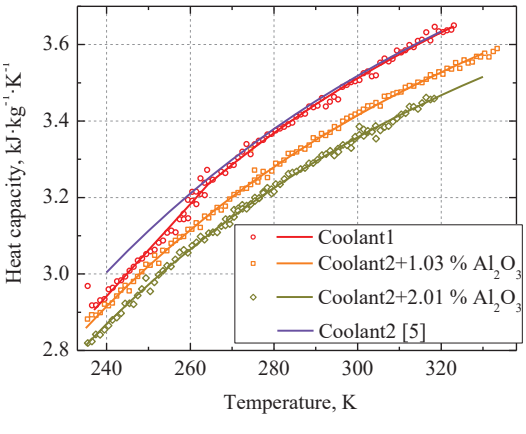

Fig. 5. Temperature dependence of the heat capacity of Coolant2+1.03 %Al_2O_3 and Coolant2+2.01 %Al_2O_3 in comparison with coolants without Al_2O_3 nanoparticles

Eqs. (8)–(10) qualitatively describe the obtained experimental data on the studied nanofluids heat capacity – Fig. 6.

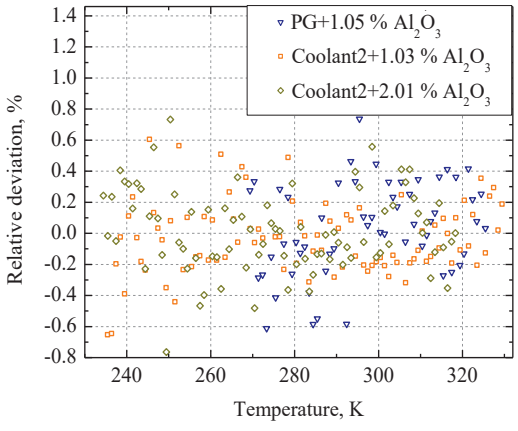

Fig. 6. Relative deviations (Eq. (7)) of the obtained experimental data on the heat capacity of nanofluids PG+1.05 % Al_2O_3, Coolant2+1.03 % Al_2O_3 and Coolant2+2.01 % Al_2O_3 from those calculated by Eqs. (8)–(10)

5. 2. Uncertainty analysis

The uncertainty analysis was carried out in accordance with the recommendations for estimation and expression of uncertainty [16]. Both uncertainty components were considered: type A «random» and type B «systematic». Extended uncertainty was estimated with a coverage factor of $k=2$ at a confidence level of 0.95 %.

The performed analysis shows that the expanded uncertainty of the experimental data obtained is: for PG – 20.7 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ (0.78 %), for Coolant1 – 19.5 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ (0.65 %), for PG+1.05 %Al_2O_3 – 19.4 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ (0.71 %), for Coolant2+ +1.03 %Al_2O_3 – 15.4 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ (0.52 %), for Coolant2+ +2.01 %Al_2O_3 – 17.6 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ (0.51 %).

6. Analysis of temperature dependence of heat capacity of propylene glycol and propylene glycol based coolant

From the analysis of Fig. 1, 2, the following can be concluded.

The phase transition lines for PG and Coolant1 are complex, differ significantly from each other in parameters and consist of the number of regions.

In the temperature dependence of the effective heat capacity of propylene glycol, the following regions can be distinguished (Fig. 1):

– region (a–1) – heating of the sample in the crystalline state from 132.43 K to 149.22 K (heat capacity increases);

– region (1–2) – in the temperature range from 149.22 to 156.25 K, the destruction of the crystalline state with a slight consumption of part of the energy for the implementation of the blurred phase transition begins, while the sample remains in the solid phase (heat capacity increases, but with lower rate than in region (a–1));

– region (2–3) – in the temperature range from 156.25 K to 175.37 K, melting of the sample is observed (significant increase in effective heat capacity). The sample transits into liquid phase with a high degree of residual structuring of propylene glycol. Analysis of the obtained data shows that the heat of this phase transition is 37.85 $J{\cdot}g^{-1}$;

– region (3–4) – in the temperature range from 175.37 K to 198.38 K, gradual destruction of the propylene glycol structured state is observed. At the same time, part of energy goes to sample heating;

– region (4–b) – heating of the sample in the liquid phase.

In the temperature dependence of the effective heat capacity of Coolant2, the following regions can be distinguished (Fig. 2):

– region (a–1) – from the temperature of 193.46 K to 202.44 K – the state of supercooled liquid;

– region (1–2) – from the temperature of 202.44 K to 216.78 K, the sample crystallization is observed;

– region (2–3) – from the temperature of 216.78 K to 236.49 K, sample melting is observed. Analysis of the obtained data shows that the heat of this phase transition is 77.97 $J{\cdot}g^{-1}$. This value is significantly greater than the propylene glycol heat of melting (by almost two times);

– in region (3–4) – from the temperature of 236.49 K to 265.42 K, further destruction of the sample liquid phase structure is observed. It should be noted that portion of the supplied energy going to the destruction of the liquid structure of Coolant 1 sample increases, compared to the similar thermodynamic state of propylene glycol. Therefore, the slope of the temperature dependence of the effective heat capacity is higher. This effect is probably due to the presence of water in the Coolant1 sample, which promotes the formation of structurally stable density fluctuations in the liquid phase, the destruction of which requires an additional supply of energy;

– region (4–b) – heating of the sample in the liquid phase.

As can be seen from Fig. 4, 5, the presence of both water and ethanol in propylene glycol contributes to the significant increase in propylene glycol heat capacity. At the same time, the concave shape of the temperature dependence of heat capacity usually observed for normal substances has changed to the convex shape dependence. This effect is explained by the enhancement of the molecules association in the objects under study because of the effect of highly polar substances additives (dipole moments of molecules are: 1.80 D for water, 1.70 D for ethanol, 3.63 D for propylene glycol [17]). The presence of strong hydrogen bonds in aqueous solutions contributes to greater association of molecules in them in comparison with pure propylene glycol. As the temperature increases, part of supplied energy goes for the destruction of associated molecular complexes (dimers, trimers, etc.) in the propylene glycol/water and propylene glycol/water/ethanol solutions. The convexity of the temperature dependence of the samples heat capacity is mitigated.

7. Analysis of Al_2O_3 nanoparticles influence on the heat capacity of the liquid phase of propylene glycol and propylene glycol based coolant

From the analysis of Fig. 4, 5, it can be concluded that additives of Al_2O_3 nanoparticles both in propylene glycol and in propylene glycol/water/ethanol solutions contribute to the reduction of the heat capacity of liquids.

To estimate the effect of Al_2O_3 additions on the heat capacity of the propylene glycol/water/ethanol coolant, a concentration dependence was constructed at different temperatures – Fig. 7. The authors used previously obtained data on the heat capacity of such systems in the temperature range from 265 to 325 K:

– propylene glycol/water/ethanol (48.60/46.52/4.88 wt. %) coolant (Coolant2);

– propylene glycol/water/ethanol/Al_2O_3 nanoparticles nanocoolant (48.24/46.38/4.85/0.53 wt. %).

Heat capacity can be calculated by Eq. (11) with the following coefficients: $A=0.00010815$, $B=0.053257$ for coolant without nanoparticles; $A=0.000096026$, $B=0.057539$ for coolant containing 0.53 wt. % of Al_2O_3.

$$c_p=\left(A+B/T\right)^{-1}, \quad (11)$$

where c_p is the heat capacity of the object under study, $J\cdot kg^{-1}\cdot K^{-1}$; T is temperature, K.

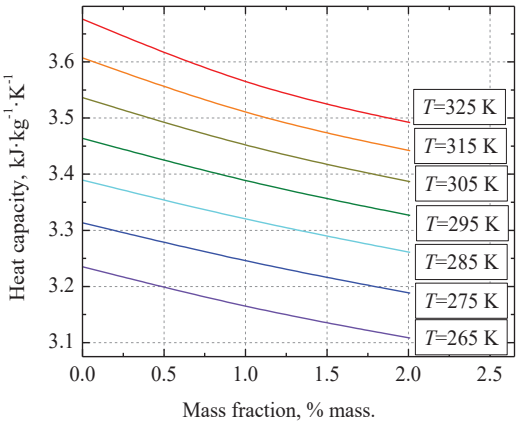

Fig. 7. Concentration dependence of propylene glycol/water/ethanol/Al_2O_3 nanoparticles nanocoolant heat capacity

Fig. 7 implies that the heat capacity dependence on the nanoparticles mass fraction is nearly linear. Moreover, the effect of reducing the heat capacity is manifested more at high temperatures.

8. Discussion of the results of studying the caloric properties of propylene glycol based coolants and nanocoolants

The qualitative data on caloric properties of the important for industrial application coolants based on aqueous solutions of propylene glycol and containing nanoparticles have been obtained by performing the measurement using the adiabatic calorimeter method. The obtained data are considerably valuable for two reasons:

– the results are valuable for developing industrial heat exchangers utilizing nanocoolants;

– the results can be used for predicting the specific heat capacity of propylene glycol based nanofluids containing Al_2O_3 nanoparticles additives.

To study the effect of nanoparticles on heat capacity, the most promising for the industrial application range of Al_2O_3 nanoparticles mass fractions – up to 2 wt. % was chosen. Propylene glycol fraction in industrial coolants varies widely, which is not considered in this study. It should be noted that the trend of nanoparticles effect on heat capacity is expected to be close for coolants with various propylene glycol fractions. Confirmation of this hypothesis requires further verification. Additional study of the effect of different promising nanoparticles (for instance, TiO_2) on the heat capacity of propylene glycol based coolants is required.

The effect of nanoparticles on the parameters of phase transition is not investigated in this study. It is this area of research that needs further development to evaluate the prospects of using nanofluids based on aqueous propylene glycol solutions in phase transitional thermal accumulators.

9. Conclusions

1. Experimental study of the heat capacity and parameters of solid phase – liquid phase transitions for propylene glycol and industrial coolants based on aqueous solutions of propylene glycol in the temperature range from 132 to 325 K and from 193 to 323 K, respectively, has been performed.

The experimental study of the effect of Al_2O_3 nanoparticles (at the mass fractions up to 2.01 wt. %) on the heat capacity of the liquid phase of propylene glycol/water/ethanol coolant in the temperature range from 235 to 338 K, as well as Al_2O_3 nanoparticles (at the mass fractions of 1.03 wt. %) on the heat capacity of the liquid phase of propylene glycol in the temperature range from 268 to 335 K is performed.

2. The heat value of the solid phase – liquid phase transition is 37.85 $J\cdot g^{-1}$ for propylene glycol, 77.97 $J\cdot g^{-1}$ for propylene glycol/water coolant. It is shown that the presence of water in propylene glycol contributes to the increase in both temperature and heat of the solid phase – liquid phase transition. Addition of water in propylene glycol affects the ability to form the associates in solutions that break down while temperature increases. For this reason, the temperature dependence of the heat capacity of the propylene glycol/water coolant has a convex shape.

3. It is shown that the presence of Al_2O_3 nanoparticles both in propylene glycol and propylene glycol/water solutions and propylene glycol/water/ethanol contributes to the decrease of heat capacity. Heat capacity decreases nearly proportional to the increase in the nanoparticles mass fraction. The effect of heat capacity decrease is more significant at high temperatures (by 3.9 % at 265 K and by 5.0 % at 325 K for nanocoolant containing 2.01 wt. % of Al_2O_3 nanoparticles).

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