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INVESTIGATION OF THE HEAT CAPACITIES OF NANOFLUIDS BASED ON NANOPARTICLES OF Al_2O_3, TiO_2 AND CuO BY THE ADDITIVE METHOD

Abstract: *This study investigates the thermal properties of nanofluids, with a particular focus on their heat capacity when various nanoparticles are integrated into a base fluid. Nanofluids, which are composed of nanoparticles dispersed within a base fluid, are of significant interest due to their enhanced thermal characteristics compared to traditional fluids. The research employs the additive method, a widely used technique for estimating the effective heat capacity of nanofluids. This method posits that the total heat capacity of a nanofluid can be approximated by summing the contributions of each component according to its volume or mass fraction. This research represents the effect of nanopartilces concentration (1wt.%, 3 wt.%, 5 wt.%) on effective heat capacity of TiO2 based nanofluid. The analysis reveals that key factors influencing the heat capacity of a nanofluid, as determined by the additive method, include the heat capacities of the individual components and the concentration of the nanoparticles. Specifically, the greater the disparity in heat capacities between the base fluid and the nanoparticles, and the higher the nanoparticle concentration, the more the nanofluid's heat capacity shifts toward that of the nanoparticles. The calculations in this study indicate that the most significant decrease in heat capacity occurs in a nanofluid containing 5 wt.%* Al_2O_3 *nanoparticles with water as the base fluid. Conversely, the smallest reduction is observed in a nanofluid with 1 wt.%* Al_2O_3 *nanoparticles in a 50% aqueous ethylene glycol solution.*

Key words: *nanofluid, specific heat capacity, thermophysical properties, nanoparticles, heat transfer.*

Introduction

Nanofluids, which are engineered colloidal suspensions of nanoparticles with dimensions typically below 100 nm (including metals, metal oxides, carbides, or carbon nanotubes), have garnered significant research interest due to their superior thermal properties compared to traditional heat transfer fluids. These properties make nanofluids promising candidates for enhancing thermal management systems across a range of applications, such as heat exchangers, electronic cooling systems, and thermal energy storage [1-5].

The base fluids used in nanofluids play a crucial role in determining their overall thermal performance. Common base fluids include water, ethylene glycol, oils, and a variety of organic solvents [6-10]. Water is often favored for its high specific heat capacity, excellent thermal conductivity, and low cost. However, its relatively high freezing point and corrosiveness can limit its application in certain environments. Ethylene glycol, either in pure form or as a water mixture, is widely utilized in automotive cooling systems due to its lower freezing point and ability to reduce corrosion, despite its lower thermal conductivity compared to water.

Oils, including mineral and synthetic oils, are frequently employed as base fluids in high-temperature applications due to their high boiling points and chemical stability. However, its relatively low thermal conductivity and high viscosity can limit their effectiveness. Organic solvents, such as alcohols or acetone, are sometimes used in specialized applications where specific chemical compatibility or low viscosity is required.

Incorporating nanoparticles into these base fluids significantly alters their thermophysical properties. The effective heat capacity of nanofluids is not merely a straightforward combination of the base fluid and nanoparticle properties but is influenced by complex interactions, including particle-fluid interactions, particle size and shape, and the concentration of nanoparticles. These factors must be carefully optimized to tailor the nanofluid for specific applications, ensuring enhanced thermal performance while maintaining stability and minimizing any adverse effects on the system components.

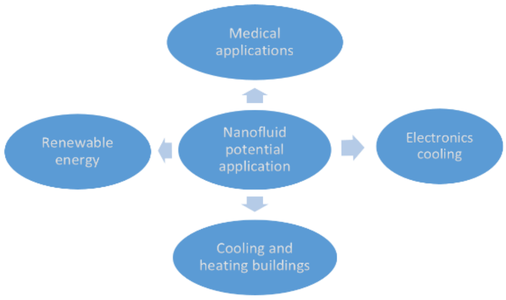


Figure 1 – Potential applications of nanofluids in various fields of industry and economics

Methodology

In this research, the effective heat capacity of nanofluids is determined using the additive method, which assumes that the total heat capacity of the nanofluid can be derived by summing the contributions of the individual components-namely, the base fluid and the nanoparticles-based on their respective volume or mass fractions. The research focuses on three types of nanoparticles: aluminum oxide (Al2O3), titanium oxide (TiO2), and copper oxide (CuO). These nanoparticles are dispersed in two different base fluids: water and a 50:50 mixture of ethylene glycol and water (EG:W). The thermophysical properties, including heat capacity and thermal conductivity, of nanoparticles like Al_2O_3, TiO_2, and CuO, as well as liquids such as water and aqueous ethylene glycol solution, are detailed in references [11, 12].

For a nanofluid consisting of a base fluid and dispersed nanoparticles, the effective heat capacity C_{nf} can be calculated using the following equation:

$$Cp_{nf} = wt \cdot Cp_{np} + (1 - wt) \cdot Cp_{bf} \quad (1)$$

Where wt – weight concentration of nanopartlices, C_{np} – nanoparticles specific heat capacity (kJ/kg·K), C_{bf} – base fluid specific heat capacity (kJ/kg·K).

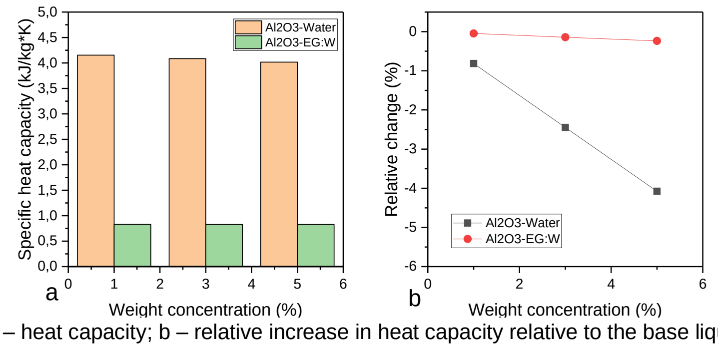
The relative change in specific heat capacity Cp_r was determined by comparing the nanofluid to base fluid (water or 50% aqueous ethylene glycol solution). This comparison was calculated using the following formula:

$$Cp_r = \frac{(Cp_{nf} - Cp_{bf})}{Cp_{bf}} \cdot 100\%, \quad (2)$$

Results

In this research, the heat capacity of a nanofluid was calculated using the additive method for three different types of nanoparticles: aluminum oxide (Al_2O_3), titanium oxide (TiO_2), and copper oxide (CuO). The base fluids used were distilled water and a 50:50 mixture of ethylene glycol and water (EG:W) at 20°C. The isobaric heat capacity of water at 20°C is 4.187 kJ/kg·K, while that of the 50% ethylene glycol solution at the same temperature is 0.830 kJ/kg·K.

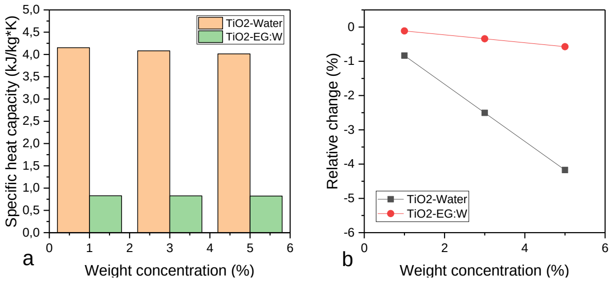
The results indicate that the concentration of nanoparticles significantly influences the heat capacity of the nanofluid. Specifically, in the Al_2O_3-water-based nanofluid, an increase in nanoparticle concentration from 1 wt.% to 5 wt.% resulted in a decrease in heat capacity from 4.153 kJ/kg·K to 4.005 kJ/kg·K, corresponding to a reduction of 0.8% at 1 wt.% and 4.1% at 5 wt.%. In contrast, the ethylene glycol-water solution exhibited a more consistent decrease in heat capacity, with the maximum reduction observed at 5 wt.% being approximately 0.24 % (fig.2).



a – heat capacity; b – relative increase in heat capacity relative to the base liquid

Figure 2 – Nanofluid based on Al_2O_3 nanoparticles

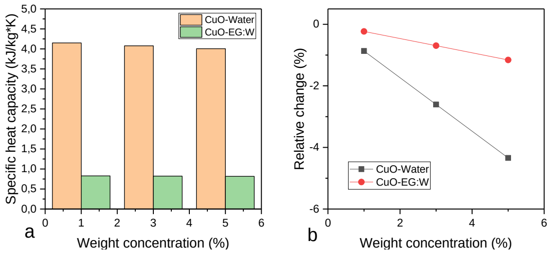
A comparable reduction in heat capacity is observed with TiO_2 nanoparticles. In comparison to Al_2O_3, the TiO_2-water nanofluid at 5 wt.% exhibits a reduction in heat capacity by 4,2%. Additionally, the heat capacity of the 5 wt.% TiO_2-EG:W nanofluid shows a 0.34% greater decrease than that of Al_2O_3 (fig.3).



a – heat capacity; b – relative increase in heat capacity relative to the base liquid

Figure 3 – Nanofluid based on TiO_2 nanoparticles

For nanofluids based on CuO nanoparticles, the calculations indicate the most significant decrease in heat capacity for both types of base fluids, particularly in the EG:W mixture. Specifically, the heat capacity of the CuO-EG:W nanofluid decreases from 0.827 kJ/(kg·K) to 0.816 kJ/(kg·K), representing a percentage reduction ranging from 0.2% to 1.16% (fig.4).



a – heat capacity; b – relative increase in heat capacity relative to the base liquid

Figure 4 – Nanofluid based on CuO nanoparticles

Conclusion

This research investigates the impact of varying nanoparticle concentrations (1 wt%, 3 wt%, and 5 wt%) on the effective heat capacity of a TiO2-based nanofluid, using two different base liquids. The substantial reduction in the heat capacity of nanofluids containing all three types of water-based nanoparticles can be largely attributed to the significant differences in the heat capacities of the individual components. In contrast, when using an EG:W mixture as the base fluid, these differences are less pronounced, resulting in a maximum decrease in heat capacity of only about 1.2 %, even with a nanoparticle concentration of 5 wt.%. While the additive method has limitations, it remains a valuable tool for providing an initial approximation of nanofluid heat capacity and is commonly employed in the study and application of nanofluids. However, this method does not account for several critical factors, such as nanoparticle interactions, non-uniform distribution within the fluid, and nanoscale effects that can significantly influence thermal behavior.

References

1. Choi S. Developments and applications of non-Newtonian flows, 1995: Presented at the 1995 ASME International Mechanical Engineering Congress and Exposition, ... 12-17, 1995, San Francisco, California.
2. Elcock D. Potential impacts of nanotechnology on energy transmission applications and needs / D. Elcock // Argonne National Lab.(ANL), Argonne, IL (United States). – 2007. https://doi.org/10.2172/924389.
3. Manna I. Synthesis, characterization and application of nanofluid – an overview / I. Manna // Journal of the Indian Institute of Science. – 2009. – T. 89, № 1. – C. 21-33.
4. Nanofluid research and applications: A review / J. Li et al // International Communications in Heat and Mass Transfer. – 2021. – T. 127. – C. 105543.
5. Sharma A.K. Progress of nanofluid application in machining: a review / A.K. Sharma, A.K. Tiwari, A.R. Dixit // Materials and Manufacturing Processes. – 2015. – T. 30, № 7. – C. 813-828.

6. Abu-Nada E. Effect of nanofluid variable properties on natural convection in enclosures filled with a CuO–EG–water nanofluid / E. Abu-Nada, A.J. Chamkha // International Journal of Thermal Sciences. – 2010. – Т. 49, № 12. – С. 2339-2352.
7. Thermal conductivity of Cu/TiO2–water/EG hybrid nanofluid: Experimental data and modeling using artificial neural network and correlation / M.H. Esfe et al // International communications in heat and mass transfer. – 2015. – Т. 66. – С. 100-104.
8. Effect of Al2O3 – Cu/water hybrid nanofluid in heat transfer / S. Suresh et al // Experimental Thermal and Fluid Science. – 2012. – Т. 38. – С. 54-60.
9. The effect of alumina/water nanofluid particle size on thermal conductivity / T.P. Teng et al // Applied Thermal Engineering. – 2010. – Т. 30, № 14-15. – С. 2213-2218.
10. Heat transfer enhancement of a radiator with mass-producing nanofluids (EG/water-based Al2O3 nanofluids) for cooling a 100 kW high power system / T.J. Choi et al // Applied Thermal Engineering. – 2020. – Т. 180. – С. 115780.
11. Sarkar J. A critical review on convective heat transfer correlations of nanofluids / J. Sarkar // Renewable and sustainable energy reviews. – 2011. – Т. 15, № 6. – С. 3271-3277.
12. Ethylene Glycol. Thermal Properties of Ethylene Glycol [Electronic resource]. URL: https://www.engineeringtoolbox.com/ethylene-glycol-d_146.html (date of application: 30.08.2024).

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ИССЛЕДОВАНИЕ ТЕПЛОЕМКОСТЕЙ НАНОЖИДКОСТЕЙ НА БАЗЕ НАНОЧАСТИЦ Al_2O_3, TiO_2 и CuO АДДИТИВНЫМ МЕТОДОМ

В этом исследовании изучаются теплофизические свойства наножидкостей, уделяя особое внимание их теплоемкости. Наножидкости, состоящие из наночастиц, диспергированных в базовой жидкости, представляют значительный интерес из-за их улучшенных тепловых характеристик по сравнению с традиционными жидкостями. В исследовании используется аддитивный метод – широко используемый метод оценки эффективной теплоемкости наножидкостей. Этот метод подразумевает, что общую теплоемкость наножидкости можно аппроксимировать путем суммирования вкладов каждого компонента в соответствии с его объемом или массовой долей. Данное исследование представляет влияние концентрации наночастиц (1 мас.%, 3 мас.%, 5 мас.%) на эффективную теплоемкость наножидкости на основе TiO2. Анализ показывает, что ключевыми факторами, влияющими на теплоемкость наножидкости, определенную аддитивным методом, являются теплоемкость отдельных компонентов и концентрация наночастиц. В частности, чем больше разница в теплоемкостях между базовой жидкостью и наночастицами и чем выше концентрация наночастиц, тем больше теплоемкость наножидкости смещается в сторону теплоемкости наночастиц. Расчеты в данной работе показывают, что наиболее существенное снижение теплоемкости происходит в наножидкости, содержащей 5 мас.% наночастиц Al2O3, с водой в качестве базовой жидкости. Напротив, наименьшее снижение наблюдается в наножидкости с 1 масс.% наночастиц Al2O3 в 50% водном растворе этиленгликоля.
Ключевые слова: *наножидкость, удельная теплоемкость, теплофизические свойства, наночастицы, теплообмен.*

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Al2O3, TiO2 ЖӘНЕ CuO НАНОБӨЛШЕКТЕР НЕГІЗІНДЕГІ НАНОСҰЙЫҚТЫҚТАРДЫҢ ЖЫЛУ СЫЙЫМДЫЛЫҒЫН АДДИТИВТІК ӘДІС АРҚЫЛЫ ЗЕРТТЕУ

Бұл зерттеуде наносұйықтықтардың жылу сыйымдылығына ерекше назар аудара отырып, олардың жылуфизикалық қасиеттері зерттеледі. Сұйықтықта дисперсті нанобөлшектерден тұратын наносұйықтықтар дәстүрлі сұйықтықпен салыстырғанда жылулық көрсеткіштерінің жақсаруына байланысты қызығушылық тудырады. Зерттеуде наносұйықтықтардың тиімді жылу сыйымдылығын бағалаудың кең ауқымды қолданылатын аддитивті әдіс пайдаланады. Бұл әдіс наносұйықтықтың жалпы жылу сыйымдылығын оның көлеміне немесе массалық бөліктеріне сәйкес әрбір компоненттің үлестерін қосу арқылы жуықтауға болады деп болжайды. Бұл зерттеу *нанобөлшек концентрациясының (мас. 1%, 3 масса%, 5 масса%) TiO_2 негізіндегі наносұйықтықтың тиімді жылу сыйымдылығына әсерін көрсетеді. Талдау көрсеткендей, аддитивті әдіспен анықталатын наносұйықтықтың жылу сыйымдылығына әсер ететін негізгі факторлар жеке компоненттердің жылу сыйымдылығы және нанобөлшектердің концентрациясы болып табылады. Атап айтқанда, негізгі сұйықтық пен нанобөлшектердің арасындағы жылу сыйымдылықтарының айырмашылығы және нанобөлшектердің концентрациясы неғұрлым жоғары болса, нанобөлшектердің жылу сыйымдылығы соғұрлым нанобөлшектердің жылу сыйымдылығына қарай ығысады. Бұл жұмыстағы есептеулер жылу сыйымдылығының ең елеулі төмендеуі құрамында 5 масс. % Al_2O_3 нанобөлшектері бар наносұйықтықта, негізгі сұйықтық ретінде – су. Керісінше, ең аз төмендеу 50% сулы этиленгликоль ерітіндісіндегі 1 масс.% Al_2O_3 нанобөлшектері бар наносұйықтықта байқалады.*

Түйін сөздер: *наносұйықтық, меншікті жылу сыйымдылығы, жылуфизикалық қасиеттер, нанобөлшектер, жылу алмасу.*

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