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Research Paper

Price-performance evaluation of thermal conductivity enhancement of nanofluids with different particle sizes

Ali Alirezaie [a,*], Mohammad Hadi Hajmohammad [b], Mohammad Reza Hassani Ahangar [c], Mohammad Hemmat Esfe [b]

[a] Department of Mechanical Engineering, Semnan University, Semnan, Iran
[b] Faculty of Mechanical Engineering, Imam Hossein University, Tehran, Iran
[c] Department of Computer Engineering, Imam Hossein University, Tehran, Iran

HIGHLIGHTS

- Comparison between thermal conductivity of MgO and Fe/EG based nanofluid.
- Introduction of a new index for measuring the efficiency of nanofluids.
- Comparison between 2 nanofluids in terms of PPF.
- Proposing a new model to calculate the thermal conductivity of nanofluids.
- Modeling data of nanofluids using artificial neural network.

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ABSTRACT

The nanofluid's thermal conductivity has been one of the most fascinating topics for researchers in this field. So far, a large number of aqueous, non-aqueous and also oleic nanofluids are experimentally studied. These nanofluids have been investigated with different volume fractions, various particle sizes and different production methods. But, the question seems to be very important now is that among available nanofluids, which one can meet our needs better? What particle sizes will work best for a chosen nanoparticle? Whether pure experimental measuring is reliable for using a nanofluid in the industry or not? Two nanofluids of Fe and MgO in Ethylene Glycol base-fluid with various particle sizes have been probed in this research, and the preparation cost of these nanofluids is compared with their thermal performance and proportionate responses are given to above questions. As well, a correlation is provided in order to measure thermal conductivity of nanofluids in terms of thermal conductivity, particle size, temperature and volume fraction of nanoparticles, and the data were compared with the result obtained from a neural network modeling.

1. Introduction

Suspensions whose solid constitutive particles size is smaller than 100 nm are referred to "Nanofluids" [1]. Addition of nanoparticles to fluids increases their transport properties such as thermal conductivity, electrical conductivity and heat transfer. That's why researchers of heat transfer, who have been seeking for a solution to improve heat transfer properties in converting systems and cooling equipment for many years, were attracted to nanofluids and consequently a large numbers of articles and books are published in this area.

The thermal conductivity, to which many studies are dedicated, is one of the most important properties [2–11]. The practical application of this subject can be found in various industrial sectors including transportation, power generation, cooling and heating, air conditioning, chemical and metallurgical sectors [12–14]. The investigation regarding amount of savings, in case of using new technologies, is important to note. In other words, the rate of return on investment, for the use of new technology (hereon nanofluids), should be studied. Conceivability of an idea to be implemented in the industry is related to this issue. Researches pursuing the optimization of products and using them can help the mentioned issue as well. Using "Fluent" software, Abdollahi and Shams [15] have optimized the heat transfer and fluid stream in a rectangular channel. Other studies which are concerned with

* Corresponding author.
E-mail address: Ali.alirezaei68@gmail.com (A. Alirezaie).

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Nomenclature

EG	Ethylene Glycol
nm	nanometer
nf	nanofluid
bf	Base-fluid
k	thermal conductivity
p	particle
T	temperature
R	regression coefficient
d	diameter
C_p	specific heat capacity
exp	experimental
pred	prediction
eff	efficient
MSE	Mean Squared Error
APS	Average Particle Size

Greek symbols

α	thermal diffusivity
ρ	density

experimental data optimization and modeling of nanofluids can also be mentioned [16–22]. Machrafi and Lebon [23] in their research, investigate the thermal conductivity of spherical nanocomposites and proposed a new correlation. Then, they compare their model with theoretical models, Monte Carlo simulation and experimental correlations. They showed that their model has a good agreement with these models in estimating thermal conductivity of nanofluids. More recently, Rostamian et al. [24] have optimized the experimental data of Al_2O_3-water/EG nanofluids' thermal conductivity and viscosity, using NSGA-II-ANN algorithm. These studies show that more than technical viewpoint of each technology, optimization of the cost and Return of Investment (ROI) is one of the needs of industry that should also be considered. In this context, the analytical study of Hemmat Esfe et al. [25], which focused on hybrid nanofluids of SWCNT-MgO in Ethylene Glycol base fluid, can be referred.

Two types of nanofluids – metallic (Fe) and non-metallic (MgO) – have been discussed in the current study. These nanofluids, from the aspect of price and performance, have been examined and compared. To do so, the experimental data of relative thermal conductivity in these nanofluids are obtained and essential studies have been administered. In addition, using two techniques of mathematical modeling and artificial neural networks, the experimental data have been modeled in this study. It is also tried to use all independent variables to find a comprehensive model for mathematical modeling.

2. Experimental data

The experimental data used in this study are extracted from researches of Esfe et al. [8,26]. In the first research, Metallic nanofluids of Fe-EG are produced at six volume fractions and four temperatures. These nanofluids have been prepared at volume fractions of 0.125, 0.25, 0.5, 1, 2, and 3% and tested at temperatures of 26–55 °C. Dimensions of used nanoparticles were in three ranges of 35–45, 65–75 and 95–105 nm. The second research's experimental data are related to MgO-EG nanofluids, at four temperatures and eight volume fractions. These nanofluids are prepared at volume fractions of 0.25, 0.5, 1, 1.5, 2, 3, 4 and 5% and evaluations accomplished at temperature range of 25–55 °C. The nanoparticles utilized in these nanofluids have been in sizes of 20, 40, 50 and 60 nm, respectively. The nanoparticles used in the research have been provided from US Research Nanomaterial Inc. It is noteworthy that MgO nanoparticles with the size of 50 nm had much higher purity, and thus the prepared nanofluid has a higher price. It should also be noted that the nanofluids' thermal conductivity measurement is started at 26 °C in Fe-EG, while it is started at 25 °C in MgO-EG nanofluids; but, both data compared with each other negligibly at 25 °C. Table 1 has represented properties of nanoparticles used in this study.

Table 1
Nanoparticles properties.

Fe	MgO	Property
99.5	99+[a]	Purity (%)
Black	White	Color
Spherical	Polyhedral	Morphology
7.90	3.58	True density (g/cm^3)
80	48	Thermal conductivity ($W\cdot m^{-1}\cdot K^{-1}$)
444	910	Heat capacity ($J\cdot kg^{-1}\cdot K^{-1}$)

After extracting the data, the rate of increment in thermal conductivity of the nanofluid compared to the base fluid – Thermal Conductivity Enhancement (TCE) – is calculated via the following correlation:

$$TCE\ (\%) = \frac{k_{nf} - k_{bf}}{k_{bf}} \times 100 \quad (1)$$

In Fig. 1, the enhancement of thermal conductivity of nanofluids in terms of the solid volume fraction is displayed for a variety of nanoparticles. As seen in these figures, the thermal conductivity enhancement increases with the rise of volume fraction. As it is also observed in both of nanofluid types, the less the nanoparticle sizes, the more increment of thermal conductivity enhancement. As well, it is proved in diagrams of Fig. 1 that the increment of thermal conductivity in Fe nanofluids – with particle sizes of 40 and 70 nm – would be more than MgO nanofluids in nearly all of volume fractions.

3. Results and discussion

The use of any substance in the industry needs to examine the entire aspects, including the scientific, technical and economic aspects. It means that any substance, in addition to the scientific and technical aspects, should be cost-effective in regard to both of the performance and expenses. So, it is necessary to consider an analysis about the fact that using a product is economical or not. This issue is examined in this study. This analysis is provided as the" price-performance analysis". This analysis shows circumstances of the cost as compared with the nanofluids' thermal performance. The resulting thermal conductivity is used in the analysis for the thermal conductivity of nanofluids is a very significant feature, and available to scholars of course, and can be directly related to nanofluids' thermal conductivity coefficient and heat transfer performance. This analysis aims to determine the ratio of cost to relative thermal conductivity of nanofluids and determine nanofluids' efficiency and also compare the efficiency of different nanofluids with each other regarding the heat transfer. Certainly, other factors in each particular case should be taken into account for conducting this analysis, but it can help to correctly choose nanofluids at the first step. In this study, the