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Influence of Adding Various Nanoparticles with Base Fluid Flow on Heat Transfer Enhancement: A Comprehensive Study

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Abstract: Many industrial and engineering applications have low thermal conductivity affecting heating or cooling processes, so we are going to improve the heat transfer process for these applications using small particles of nanometer size such as metal, oxide, carbide, etc. dispersed in the basic fluid of the application, these particles are called nanofluids. This paper reviews the varying factors affecting the thermal conductivity of various nanomaterials under different conditions. All the authors focused on the thermal conductivity of nanoparticles to increase the heat transfer process, whereby increasing the percentage of nanoparticles, the thermal conductivity increases, and therefore the performance and efficiency of thermal systems increases. The size, shape, collision, aggregation, porous layer, melting point of nanoparticles, etc. are all parameters that affect the thermal conductivity of the nanomaterial, and their control determines the behavior of its increase or decrease. The use of nanofluid is a new and influential technology to improve heat transfer for the next generation.

Keywords: Fluid Flow, CFD, Heat Transfer, Nanofluid, Thermal Conductivity

1. Introduction

Nanoparticles are metal particles with a small size nanometer contained in a nanofluid mixed with water, ethylene glycol, and oil as examples of the basic fluid with a coefficient of convective heat transfer and low conductivity compared to a nanofluid made of metals, carbides, oxides or carbon nanotubes.

There are two techniques for preparing nanofluid to improve heat transfer, the first is called the one-step and two-step method. The production of nanoparticles in the first step and their dispersion by the main fluid is the second step. Using the Internet gas condensation technique to mass-produce nanofluid is another processing technique. The shape of the mass during the preparation of nanoparticles is one of the drawbacks of the first two-step technique. The requirements for nanofluid can be summarise as follow.

- The minimum pressure value decreases due to the molecular size of the nanofluid.
- Increased heat transfer rate due to the high thermal conductivity of nanoparticles.
- The advantages of using nanofluids in heat exchangers are that they are lightweight and small.
- Mixing the nanofluid with the basic fluid changes its thermophysical properties.
- The large surface volume causes an increase in the heat transfer rate of the main fluid.
- To achieve a heating or cooling system using a nanofluid is best suited.

1.1 Uses of Nanofluid

The nanofluid flows through small passages to improve efficiency and is therefore used in welding equipment, high heat flow devices, heat exchangers, and also in car engines for cooling. Common uses of nanofluid for some engineering industrial applications are as follows:

- Cooling in engine types.
- Transmission and engine oils for vehicles
- Cooling in electronic and electrical devices
- Nuclear cooling systems
- The use of solar energy for water heating
- In general lubrication and drilling operations
- Thermal storage systems
- Applications of Biomedical
- Flue gas recovery of exhaust boiler

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2. Previous Literature

Dongdong Li et al. [1] an experimental study to investigate the flow and heat transfer properties of a pipe using distilled water as the working fluid. Addition of concentrations (0.1% to 2%) with a volume of (30 nm) of nanofluid particles (CuO) with distilled water to improve its thermophysical properties. The results of the study showed the temperature of the nanofluid is lower for start-up and the start-up time of the evaporation section of the tube is short compared to distilled water. The heat transfer performance of distilled water improved in the condenser and evaporation section of the pipe. The heat transfer coefficient increased by (29.4 %) and (125%) at the concentration of the mass of nanoparticles by (0.5%) with the addition of nanofluid compared to the tube with distilled water and the input power ranges (15 – 45 Watts). The results also indicated that when using nanofluid particles at a concentration of (1%) gave the best improvement of the heat transfer process in the tube.

Byung-Hee Chun et al. [2] an experimental study explores increasing the heat transfer rate by adding alumina particles with transformer oil used as a working fluid in a single-phase laminar flow double-tube heat exchanger system. Although the thermal conductivity of alumina is not high compared to other nanomaterials, it gave a noticeable increase in the rate of heat transfer of the base fluid. By increasing the mass concentration of alumina nanoparticles, the thermal conductivity increases, thereby giving good thermal properties to raise the heat transfer rate of the system. An experimental Association of alumina oil and transducers has been proposed to understand the enhanced heat transfer of nanofluids.

A. M. Elfaghi and M. S. M. Hisyammudden [3] numerical modeling by using the Ansys Fluent program for analyzing the use of titanium oxide (TiO2) at a concentration of (0.5%) by adding it with water in a circular tube to improve the thermophysical properties of single-phase turbulent flow for the Reynolds number range (7000-16000) of the tube wall shed with constant and continuous heat flux. According to the numerical results, the efficiency of heat transfer (represented by the Nusselt number) gradually increases with increasing the Reynolds number, so the use of nanoparticles significantly improves the heat transfer of the convection tube compared to the empty tube (without nanoparticles). Two models of turbulent flow were used, the first (k-epsilon) and the second (k-omega). the superiority of the first model in terms of accuracy of results and analysis was noted.

Abdulhafid MA Elfaghi and Musfirah Mustaffa [4] numerical analysis using commercial code to improve the flow properties of the fluid inside a tube used with a regular thermal overflow. Nanoparticles (Al2O3) with different volume concentrations (0.5,1, and 2 %) were used to add them to the base fluid (water) to increase heat transfer. Several parameters have been studied, including the heat transfer coefficient, Nusselt number, and friction factor of the nanofluid as a function against the Reynolds number. The results of the study indicated that (11.8%) nanofluids have better thermal performance than the basic fluid. As the concentrations of the nanomaterial increase, the Reynolds number increases and is accompanied by an increase in heat transfer (Nusselt number). A comparison of the results of the study with previous studies in the same field showed a good convergence.

Reza Aghayari et al. [5] an experimental study to predict the effect of adding Al2O3 nanoparticles with a volume of (20nm) and a concentration of (0.1-0.3%) with stable single-phase fluid flow in a double-tube heat exchanger. Various parameters of heat transfer (Nusselt number change) have been studied, including the temperature and concentration of the nanofluid. There is an accepted agreement to compare the results of the study with the correct theoretical data based on quasi-empirical equations. The experimental results showed a significant increase up to (19%) and (24%) for the coefficient of heat transfer by forced convection and the Nusselt number, respectively. It is also observed that as the concentration of nanoparticles increases and the operating temperature, the heat transfer coefficient of the system increases.

M. R. Sohel et al. [6] experimental investigation of thermal performance of a microchannel using nanofluid instead of pure water with a range of fractional sizes (0.1-0.25%). The different flow rates of the coolant on the overall thermal performance were checked. The working ranges are for the flow rate (0.5 -1.25 L/min) and for the Reynolds number range (395-989). Thermal performance improved by using nanofluid instead of pure distilled water, this is what the experimental results showed. Also, the coefficient of heat transfer by forced convection improved higher than (18%) successfully.

Shung-Weng Kang et al. [7] an experimental study employing nanoparticles (Ag) with a molecular size (10 nm) with the basic fluid (pure water) of a horizontal tube with a heated wall. Because of this, the nanofluid's improved thermal performance has demonstrated its potential to replace traditional pure water in grooved heat pipes. The results also indicated the temperature distribution of the surface of the tube gradually decreasing towards the axis of fluid flow and with different concentrations of nanoparticles.

Khalid Faisal Sultan et al. [8] experimental evaluation of increased heat transfer of a car radiator by using aluminum and copper nanoparticles with sizes (50 nm) and (30 Nm), respectively, by mixing them with pure distilled water. Various parameters have been studied, including the temperature at which the nanofluid enters, the friction factor and the Reynolds number, as they affect the heat transfer process. The results gave an indication that the number of nucleates gradually increases by increasing the Reynolds number, by increasing the concentrations of nanoparticles and also by increasing the degree of entry of the nanomaterial. Improved heat transfer using copper gave an advantage over aluminum. The findings also showed that employing nanofluid as the working fluid improves heat transfer efficiency, which boosts vehicle engine performance and lowers fuel consumption. Additionally, because of the size of the nanoparticles and the thermal conductivity of the copper, the thermal conductivity of the nanofluids copper was higher than that of the nanofluids aluminum.

N. K. Chavda [9] experimental evaluation of the improvement of the heat transfer properties of a double-tube heat exchanger by changing the concentrations (0.002% to 0.004 %) of nanoparticles (CuO) mixed with water. The study's total heat transfer coefficient increases as the volume concentration of nanoparticles relative to water increases, a finding that is also supported by theoretical predictions.

K. N. Shukla et al. [10] an experimental study to improve the thermal performance of a tube with a length (400 mm) and a diameter (19.5 mm) by adding three different types of nanoparticles (silver, copper, and de-ionized) was tested at different ranges of heat input (100-250 W). Using nanofluids, the results of the study showed the thermal efficiency of the tube improved by (14 %) compared to the tube with the basic fluid only. Additionally, it was discovered that a rise in the metal content of copper-water nanofluids improved the heat pipe's thermal efficiency.

J. Choi, and Y. Zhang [11] numerical study of heat transfer in a curved return tube in which nanoparticles (Al2O3) were used with the basic fluid with single-phase laminar flow to increase the rate of heat transfer. The finite element method was used to perform numerical analysis. The numerical results showed an increase in the Nusselt number rate (heat transfer rate) by increasing the Reynolds number and the Prandtl number, and also the heat transfer process increased as a result of increasing the specific heat of the nanomaterial. The numerical results of the curved tube were compared and gave the best improvement against the straight tube, as well as exploring empirical relationships of the rate of the Nusselt number against the Dean and Prandtl number.

S. H. Anilkumar and G. Jilani [12] examined the improvement of heat transmission and the flow properties of the (Al2O3-Water) nanofluid utilizing a microchannel heat sink. The test section's dimensions are (5x5 mm), and (50W) of heat is applied. When there is a high concentration of nanofluid and a high Reynolds number, heat transmission is improved because the wall temperature drops and the pressure drop increases.

M. Rostamani et al. [13] numerical analysis of the optimization of heat transfer of a two-dimensional rectangular channel with turbulent single-phase flow and with a water-factor fluid. Three different nanoparticles were used, including copper oxide, alumina oxide and titanium oxide in variable volume ratios. All thermophysical properties of nanomaterials are temperature dependent except for viscosity obtained from experimental data. The results indicated improved heat transfer of the channel by increasing the volume ratio. Copper oxide gave the best enhancement of heat transfer compared to other used nanofluids.

T. Menlik et al. [14] an experimental investigation of how the addition of MgO nanoparticles affects the flow and heat transfer properties of a pipe with a diameter of 13 mm, a length of 1 M and a wall thickness of 2 mm. The nanomaterial is equipped with a volume ratio (44.5 ml). In order to cool the system, three distinct cooling water flow rates (5, 7.5, and 10 g/s) were employed in the condenser during the trials, along with three distinct heating power levels (200 W, 300 Wand, and 400 W). The improvement ratio changed in response to changes in heat loads and condenser cooling water flow rates.

A. M. Elfaghi et al. [15] numerical simulation of computational fluid dynamics using the ANSYS program to improve the coefficient of heat transfer by forced convection of a circular tube with turbulent flow for the Reynolds number range (6000 to 12000) by mixing nanoparticles represented by alumina oxide with the basic fluid (distilled water). Several parameters studied as a function against the Reynolds number are the heat transfer coefficient, the Nusselt number, the friction factor, the surface temperature and the fractional volume fractions (0.5, 1, 2 %). The results recorded the mixing of nanoparticles with water higher the best improvement of the heat transfer coefficient compared to the placement of distilled water alone in the tube. Heat transfer (Nusselt number) gradually increased by increasing the fluid velocity (Reynolds number) and increasing the fractional volume ratios of the nanofluid.

3. Discussions

Many authors in their experimental and numerical research papers use nanoparticles (Al2O3, ZnO, TiO2, Ag, ZrO2, SiC, CuO, and diamond) in various engineering and industrial applications as a technique to improve the heat transfer process (represented by increasing the Nusselt number) and thus increase the performance and efficiency of thermal systems. Many discussed the use of the most common nanoparticles (CuO and Al2O3) causing increased thermal conductivity of the basic fluid. To enhance the thermal conductivity of nanoparticles an important ultrasonic mixing is used.

4. Conclusions

1. Increased concentrations in nanoparticles increase the rate of heat transfer.
2. In nanofluids the Nusselt number (heat transfer rate) increases by increasing the Reynolds number as a result of directly proportional.
3. The microarray of the nanoparticles suffers from poor stability but increases the heat transfer rate of the system.
4. The main influencing factor of the nanofluid is increasing the heat transfer rate due to the aggregation and collision of various particles.
5. The pressure in the nanofluid decreases with an increase in the percentage concentration of nanoparticles.
6. The spherical shape of the particles in nanomaterials significantly increases the rate of heat transfer when mixed with the basic fluid compared to other shapes of molecules.

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7. Nanomaterials added with spiral tubes significantly improve the heat transfer rate compared to plain tubes with a circular cross-section.
8. The decrease in the value of pressure in inclined tubes filled with nanofluid is higher compared to horizontal tubes.

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