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Research Article

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Impact of Carbon Nanotube in the Heat Transfer Applications

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Abstract

The modern industrial development in heating, ventilation, and air-conditioning (HVAC), industrial cooling, automobile cooling, microchip cooling, phase change heat transfer and nuclear reactors has resulted in the urgent need for performance improvement in heating and cooling applications. An efficient heating and cooling system can be achieved by increasing the heat transfer process, which is a significant task in the current scenario of the enormous energy demand. Performance improvements in heating and cooling systems can be carried out through various methods. Because of recent advances in nanotechnology, researchers have tried a new idea of combining nanoparticles with a base fluid to improve the fluid thermophysical properties. The liquid consists of balanced nanoparticle sizes below 100 nm. Nanoparticles might be nanopowder or nanoparticles like MWCNT (Multi-walled carbon nanotube), Al_2O_3, TiO_2, Cu, and SiC. This idea of nanoparticle addition is introduced in the heat transfer application to enlarge the convective heat transfer coefficient and enhance the nanofluid and thermo-physical properties to study the opportunity of improving the system performance.

Keywords

Carbon nanotube, Heat transfer applications, Nanoparticles

Introduction

Heat transfer is crucial in various practical circumstances, such as the automobile industry, HVAC systems, electronic devices, etc. Apart from these, various production procedures, such as industrial cooling, automobile cooling, and nanofluid coolant, use heat transfer. Heat transfer is understood in most applications using heat exchangers, condensers, heat sinks and evaporators. Raising the heat transfer can increase efficiency and reduce the amount of space the system uses. A pump is also used in most heat transfer setups to distribute the working fluid. It is also required to minimize the pumping power. Consequently, improving the heat transfer coefficient with less pumping power intake is the most desired condition [1-3]. Various experimental and theoretical analyses are conducted to improve heat transfer. The design also needs a compact arrangement and less pumping power. Common harms related to applying heat exchangers include fouling, erosion, compactness, cost, and pumping power.

In recent years, the high costs of energy and materials have made people work harder to make more efficient heat exchangers. Increased heat exchanger efficiency through an improved technique may result in significant material cost savings. The heat transfer rate is improved by creating a disturbance in the fluid flow [4-6]. These may knowingly increase pumping power, resulting in high pumping costs. As a result, few methods have been proposed in recent years to achieve the desired heat transfer in the heat exchanger while using low pumping power. The adding of nanoparticles to base fluid named nanofluid stated that it had the extra potential for enlightening convective heat transfer in a heat exchanger.

In recent innovations in the HVAC, electronics and healthcare industries, there is an urgent need for a cooling system with improved performance rather than heating. Heat transfer through a moving fluid, whether laminar, turbulent, or stagnant, is essential in many industrial applications. The heat transfer processes are accelerated to give an efficient cooling system. The heat transfer rate is a significant component in this period of high energy consumption; efforts are being made to increase its efficiency via research and development. Organic and inorganic phase transition materials and heat transfer fluids, including distilled water, ethylene glycol and oil are employed in energy storage systems. These posed significant challenges, such as quickly settling solid particles in the base fluid, obstructing the flow channel and abrasion. The considerable pressure drops these particles produced also restricted their usefulness. Nanofluid refers to a colloidal mixture, a suspension made by combining such as distilled water, ethylene glycol, or oil with nanometer-sized solid particles. Nanofluid exhibits superior stability, excellent thermal conductivity, and improved heat transfer properties with little pressure loss compared to the suspended particles in mm or micro-meter size.

Various heat transfer improvement research studies have gained significant traction in recent years and have been forecast by various research domains. Traditional heat transfer fluid has a substantially lower thermal conductivity, limiting its heat transfer capability. Furthermore, the capabilities of conventional heat transfer fluid and the redesign of heat exchanger have extended their limits [7-9]. A new fluid with excellent thermal conductivity has been established to overcome these issues. The dispersion of 1 - 100 nm-sized nanoparticles in traditional heat transfer fluid, referred to as nanofluid, exhibits significantly higher convective heat transfer than traditional heat transfer fluid.

Modern materials science has made it possible to make nanometer-sized particles with very different mechanical, thermal, electrical, and optical properties than the parent material. Thus, nanofluid technology paired with new heat transfer-related research on the flow of diverse application areas has offered a fresh opportunity to reconsider nanoparticle suspensions. Nanoparticles smaller than 100 nm are suspended in the distilled water to create the nanofluid. The following problems, which have plagued suspension of micro range particles in the distilled water, will be resolved [10-12]. Once the particles settle, they form a coating on the fluid surface, which reduces the fluid ability to conduct heat. When fluid circulation speeds go up, sedimentation is less likely to happen, but heat transfer components and pipelines wear out faster. The cooling channels are narrow; larger particles are more likely to clog them. There is a dramatic drop in fluid pressure [13-15]. An increase in conductivity proportional to particle concentration is realized in the long run. The need for cooling services is a significant problem for many manufacturing sectors.

Even though much research and development have been devoted to the heat transfer demands of industry, breakthroughs in cooling capacity have not occurred. One usual solution is to expand the heat exchanger surface area; however, this might lead to unwieldy or undesired expansions of the heat management system. Base fluids heat transfer capacities must be improved accordingly.

The thermal conductivity of crystalline solids is often higher than that of liquids by three to four orders of magnitude. The fluid thermal conductivity with suspended solid particles is expected to be much greater than that of a fluid with no solid particles. In order to create stable, homogeneous suspensions, crystalline solids with dimensions on the nanometer scale are suspended. The resultant suspensions are called nanofluids because of their higher thermal conductivity compared to the distilled water. The solid has two possible shapes: spherical nanoparticles or nanotubes measuring in the micrometer range. Either a one-step or a two-step process may be used to make nanofluid. Nanofluids have been produced via various processes, including thermal degradation routes, microwave and laser irradiation, chemical reduction, and direct evaporation procedures. The nanofluid thermal conductivity, which includes metals like Ag, Cu, and Au, is more than that of the distilled water. Carbon-based nanostructures are a formidable rival for nanofluid due to more inherent heat conductivity and low densities relative to metal.

The MWCNT is used as a nanoparticle in this research because of its outstanding heat transfer capabilities and base fluid is used as water/ethylene glycol. The nanofluid is anticipated to increase the heat transfer characteristics of the water. The main focus is on preparing nanofluids without allowing nanoparticles to settle. Various nanofluid samples with varying concentrations of surfactants are generated and their stability is examined.

Experimentation

Treatment of nanotubes

Each of the approaches for producing nanotubes has significant limitations. All generate combinations of nanotubes and nanoparticles that clump into more enormous masses. The tubes have broad ranges of lengths, many flaws, and numerous twists. Therefore, the primary concerns are separating them from the useless soot and purifying the tubes. Diverse post-growth procedures have been devised to purify the tubes and eradicate their faults. Using an ultrasonic bath, numerous tubes may be liberated from particles once adhered together. Due to their relatively high weight, the more significant pollutants may be readily removed, for instance, by dispersing the powder in the solvent and then centrifuging it. MWCNT can

be oxidized in a liquid-phase treatment in an acidic environment or by heating the powder in air at 650 °C.

Although nanotubes display excellent qualities in an ultrahigh vacuum environment, samples exposed to air or water vapour exhibit distinct features. Therefore, nanotubes are very susceptible to pollutants such as oxygen adhering to them. They significantly impact electrical characteristics, a significant concern for nanotube-based electronics. This study uses heat transfer enhancement methods in double pipe concentric heat exchanger along with nanofluid. The two-step approach is used to equip the MWCNT nanofluid at 0.2 percent, 0.4 percent, and 0.6 percent volume concentrations. The typical particle size is less than 100 nm, and the nanoparticles are uniformly distributed in distilled water. The Brookfield viscometer is helpful to test the nanofluid viscosity.

Methodology

The following steps are taken to analyse nanofluid convective heat transfer characteristics. The nanofluid passes through a counter-flow heat exchanger. In order to prepare the MWCNT/water nanofluid, a magnetic stirrer and an ultrasonic vibrator are used, and a zeta potential analyser determines nanofluid stability. The substance can be measured with a resistance temperature detector (RTD), and the viscosity of a substance can be measured with a Brookfield viscometer.

In this part, nanofluid preparation using a ball mill, magnetic stirrer, and ultrasonicator is carried out shown in (Figure 1). Then the nanofluid's thermophysical properties are measured viscosity, thermal conductivity, shear stress, density, and specific heat. The measured values are correlated with reference values.

Assumptions

- The cooling setup is assumed to be symmetrical in temperature distribution.
- Steady state.
- Constant material properties (independent of temperature).

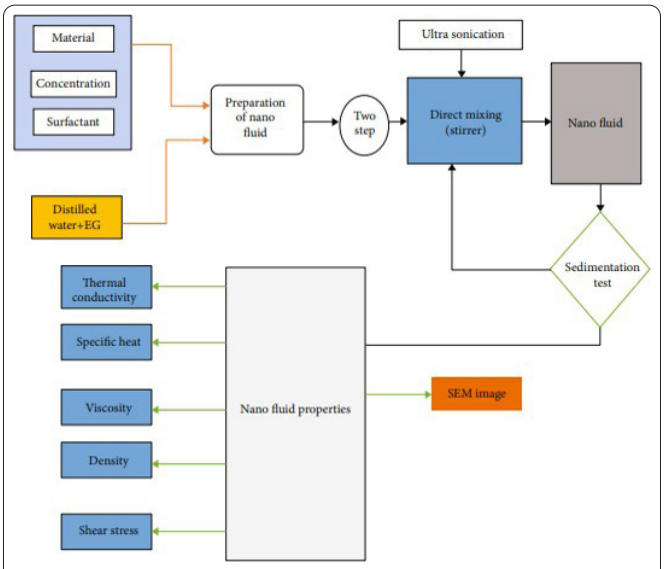

Figure 1: Nanofluid preparation and characterization.

- No internal heat generation.
- One-dimensional conduction.
- Uniform cross-sectional area.
- Uniform convection across the surface area.
- Heat loss is negligible (due to gloss wool insulation.
- The heat transfer due to radiation is neglected.

Preparation of MWCNT nanofluid

The two methods make the stable nanofluid: One-step technique and Two-step technique. One of the most common procedures is termed the direct evaporation one-step method. This approach involves hardening the nanoparticles in a single step after they were previously in the gas phase. This results in the creation of nanofluid. In the procedure that only requires one step; the dispersion in the water is mixed together in a single stage. One-step approaches have the fundamental disadvantage that they need to be more suitable for large manufacturing, limiting their commercialization and restricting their marketability. The one-step process deals with the creation of nanoparticles and their dispersion in water.

In the two-step technique, the nanoparticle for an intended nanofluid is produced in a two-stage process, each using a distinct technique. Inexpensive and highly scalable, this production method has changed the manufacturing technique. Nanoparticle aggregation is a significant downside of the two-step approach. Nanoparticles are created via a two-stage synthesis process. The nanoparticles are mixed into the water in this technique. As a result, the two-stage procedure is often employed.

Preparation of the sample

In the present work, the nanofluid is generated by combining 70% deionized water with 30% EG, sodium dodecylbenzene sulphate (SDBS) used as the surfactant, and MWCNT used as the nanoparticles. The volume concentration of 0.2 percent SDBS, added with MWCNT, is used to make 2 L of nanofluid in each sample. The MWCNT is ball milled for 30 min with 10 mm tungsten carbide balls to ensure proper dispersion of nanoparticles in the deionized water mixture. The mixture is constantly agitated for 30 min and then ultrasonically processed for 45 min under dry circumstances using an ultrasonic processor.

Measuring device

The precision of the measuring instrument is directly proportional to the dependability of the convective heat transfer coefficient. The RTDs are inserted right into the flow of the fluid. The shell side temperature is noted by using a thermocouple. The piezoresistive pressure transmitter is available to monitor nanofluid pressure drop as it passes through the test section. The DPT's output ranges from 4 to 20 mA. A Coriolis mass flow meter, which can measure mass flow rates ranging from 3 to 5 g/s, when a fluid moves through it, the mass flow meters output ranges from 4 to 20 mA

Selection of test section material

Because of the following characteristics, the test section

(heat exchanger) is made of copper material: corrosion resistant, good machinability, malleability, and good thermal conductivity.

Experimental procedure

The two fluids pumped from the constant temperature bath flow through the flow control valve and into the heat exchanger. The flow control valve value adjusts the flow. The water flow rate is checked by rotameter, and that of the nanofluid can be checked by using a measuring jar. A temperature controller maintains the temperature of the constant temperature bath for water and nanofluid with the help of a stirrer. Both tanks are connected to a 1-tonne air conditioning unit to maintain the required temperature. The connections between the data logger and the computer are checked and switched on. After a steady state is attained, the outlet temperatures of the water and the nanofluid are noted using resistance temperature detectors over 30 min at a time interval of 30 s. The pressure drop is noted on the digital pressure transducer. The data is noted every 5 min for 30 min. The readings are tabulated. The procedure is performed on water and nanofluid. The heat transfer between the two fluids is discovered.

In every trial of the tests, the following method is followed: various concentrations of MWCNT are combined with the desired nanofluid volume. Two liters of nanofluid and four liters of water are contained. In both circuits, a chosen temperature is programmed into the temperature controller to maintain the necessary fluid temperature inside the container. Every vessel stirrer motor is activated to guarantee temperature consistency in the nanofluid and the water bath. After turning on the centrifugal pump in both circuits, the needed amount of fluid will begin to flow through the test section, at which point the level of fluid in the vessels will meet the level that was previously calculated. The nanofluid and water can flow at the desired rate by regulating the ball valve in both circuits. A sufficient length of time is provided for the experimental system to attain steady-state conditions. When the test conditions are satisfied, the steady-state condition is validated by measuring temperature homogeneity across all RTDs in the test area. Once the experimental apparatus reaches a steady state (which takes approximately 15 min), for 35 min at 30 s intervals, the temperature of both fluid streams in each section is recorded to ensure the accuracy of the observed data. For each experimental condition, the trials are performed three times to confirm correct findings. As a result, for cooling applications, the nanofluid temperature ranges from 35 °C to 40 °C, while for the shell side (water), the temperature is set at 15 °C to 20 °C. The range of significance for the Reynolds number is between 2,000 to 6,000.

Results and Discussion

The experimental readings are given in below tables with respect to mass flow rate, water temperature, nanofluid temperature, and category of nanofluid concentrations. The convective heat transfer characteristics are crucial to boosting energy-efficient secondary refrigeration loops. In order to undertake the investigation, a convective experimental study

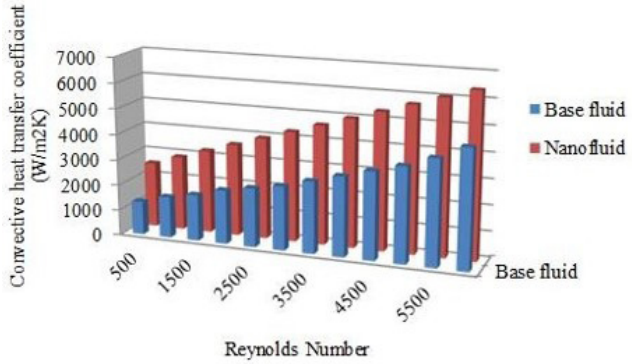

Figure 2: Heat transfer coefficient vs Reynolds number.

is calculated and built up, including a tubular heat exchanger, two thermostatic baths, an RTD, a mass flow meter and pressure monitoring equipment. Consideration is given to the conventional convective heat transfer coefficient, as well as the friction factor for nanofluid. Figure 2 shows the contrast between nanofluid's convective heat transfer coefficients concerning base fluid and nanofluid. The base fluid has a lower heat transfer coefficient compared to the nanofluid, which has a greater heat transfer coefficient. Higher values of the heat transfer coefficient are often seen when suspended particles are present in the fluid combination. This is because the heat transfer coefficient assesses how well heat flows from one fluid to another. As the thickness of the thermal barrier layer is decreased, there is an increase in the amount of heat transferred.

The relationship that exists between the decrease in pressure and the Reynolds number is seen in figure 3. As compared

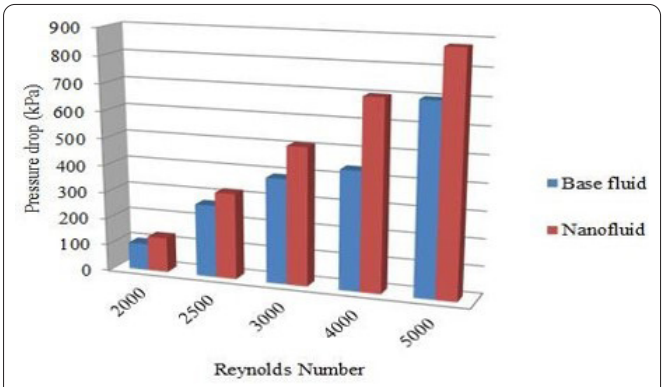

Figure 3: Pressure drop vs Reynolds number.

to the base fluid, the nanofluid has a much higher Reynolds number, which results in a rise in pressure. The viscosity of a nanofluid suspension is much greater compared to the viscosity of the base fluid, which results in an increase in both the needed pumping power and the pressure drop. The effectiveness of a heat exchanger under a range of different Reynolds numbers is analysed in figure 4. When used as a heat transfer fluid, nanofluid contributes to an increase in the heat exchanger's overall efficiency. An increased heat transfer is produced as a result of nanoparticles being introduced into a counter-flow heat exchanger. The base fluid does not absorb as much heat as the nanofluid does.

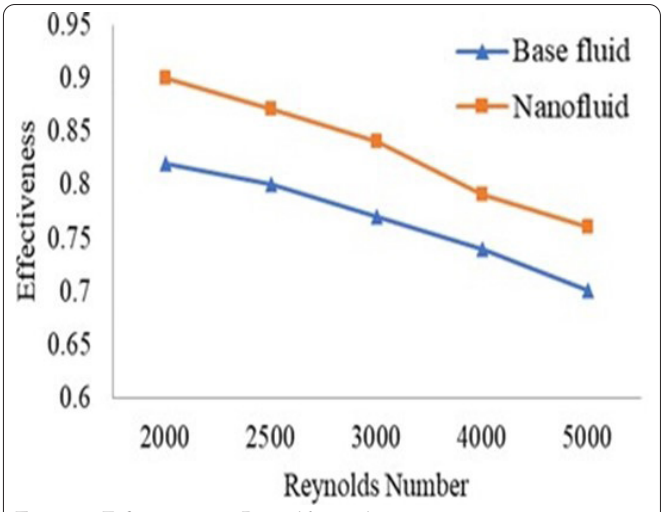

Figure 4: Effectiveness vs Reynolds number.

Conclusion

This chapter described the two-step formulation of MWCNT/water nanofluid. According to the scanning electron microscope analysis of the produced nanoparticles, the particles form agglomerates under airy circumstances, and their shape is near-spherical. To create MWCNT/water nanofluid with varying volume concentrations, an ultrasonic vibrator is used to scatter a suitable quantity of MWCNT nanoparticles in distilled water. This results in the production of MWCNT/water nanofluid. Measurements of zeta potential are used in order to determine the stability of the manufactured nanofluid. The results of this investigation show that the nanoparticles are distributed uniformly throughout the nanofluid, and that the nanofluid is stable. A KD2 Pro thermal properties analyzer is used in order to determine the MWCNT/water nanofluid's thermal conductivity. The viscosity of the nanofluids is determined with the use of a cone and plate viscometer developed by Brookfield.

Acknowledgements

None.

Conflict of Interest

None.

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