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Research Article

Experimental Analysis of Heat Transfer by Using Nanofluid and Impact of Thermophysical Properties

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The scope of the project is to analyse the heat transfer behaviours by using shell and tube heat exchangers and measurements of various thermophysical properties of carbon nanotube nanofluid. The nanofluid is created using different volume fractions at different operation temperatures. The research focuses on theoretical and experimental research on CNT nanofluids, with the goal of improving thermophysical parameters such as thermal conductivity, specific heat, and viscosity. The thermophysical characteristics of CNTs were investigated using this theoretical method. Various tests were carried out to investigate the thermophysical qualities, and they were found to have an impact. The improved characteristics of carbon nanotubes (CNTs) have the potential to save energy and reduce CO_2, NO_2, and SO_2 emissions in industrial settings. Improving heat exchange performance in the thermal sector would result in a high heat-to-power conversion efficiency. Nanofluids can considerably enhance critical heat flux (CHF) in heat transfer systems.

1. Introduction

The majority of scientists think that facilitating contamination and worldwide climate change, primarily as a result of excessive carbon dioxide emissions, poses a threat to the environment. Because manufacturing is one of the most power-intensive sectors, a change toward increased energy-efficiency in manufacturing, particularly in manufacturing, is essential. Using thermal systems to reduce energy consumption and emissions is a new issue. Many approaches for improving heat transfer have been implemented over the last decade [1–3]. This can be accomplished by reducing the thickness of the thermal limit. At the heat transfer wall, there will be a velocity gradient, interrupting fluid flow and raising velocity from laminar to turbulent flows, thus raising the heated wall's extended surface and modifying the surface and fluid thermophysical characteristics [4].

In the process sector, heat transfer procedures are quite frequent to transmit a large quantity of thermal energy from one fluid to another for various purposes. Water is the most popular heat transfer fluid (HTF) owing to its more specific heat, ease of use, and affordability. Traditional heat transfer fluids, such as water, include minor thermal conductivity, the most important thermophysical attribute, resulting in reduced efficiency of heat transfer [5]. The adding of nanoparticles extremely thermal conductive materials, particularly at the nanoscale, produces nanofluid (NF), which has emerged as an effective HTF over the past two decades and has been studied in an extensive variety of applications [6, 7].

The heat transfer quality of traditional effective fluid is a concern. The production of well-organized and compacted thermal systems, particularly heat exchangers, is a major challenge. They are commonly used in the thermal industry. Nanofluids are now well recognised as demanding resources by virtue of their potential applications in heat exchangers, convective systems, energy, solar collectors, and electronic devices [8, 9]. Due to their prospective applications, they have also become a global study focus. Nanofluid consumes superior thermal conductivity than the base fluid, which increases dramatically as the concentration of nanomaterials increases. These advantages are also influenced by the type of nanoparticles [10]. Fluids that are commonly used with carbon-based nanomaterials are also of great interest due to their unique properties and excellent thermal characteristics intrinsically.

The various strategies were designed to improve the nanofluid heat transfer coefficient with the goal of creating a compact system that was low in cost and efficient in energy use. Since Mukesh Kumar et al. [11–13], the use of suspensions rather than traditional heat transfer liquids has been recommended because solids have higher thermal conductivities than liquids. Although using suspensions to contain microparticles will pose significant challenges, such as particle corrosion of transport equipment, high pumping power constraints, and sedimentation, Mondragon et al. describe a suspension containing nanoparticles in the fluid as a suspension containing nanoparticles in the fluid. In addition, when compared to typical suspension, fluid conveyance has negligible corrosion effects and requires little pumping power [14]. Furthermore, it is referred to as nanofluid since it has a high heat conductivity when compared to base fluid and conventional suspension [15]. The nanofluid contains a minor amount of metals, such as Cu, as well as nonmetals, such as Al_2O_3, SiC, and CuO nanoparticles. Pay special attention to the CNT's unusual arrangement and exceptional thermal characteristics [16–18].

Nanofluid has been extensively employed as excellent performances in heat transfer fluid with variety of application due to its greater performance compared to base fluid [19–21]. Heat transfer during various heat exchanger like shell and tube heat exchanger, solar collectors, heat pipe, for energy storage, and many other applications is among the most common uses for NF [22–25]. Because of their superior thermophysical qualities, nanofluid has a significant possible use in favour of recovering waste heat and increasing the energy effectiveness of many operations [26–28].

2. Treatment of Nanofluid

2.1. Purification. The treatment of the nanofluid is shown in Figure 1, for understanding easily. The creation of the nanofluid can be done in two ways, with the two-step process being more convenient and being employed by many researchers. The nanotube comes in a wide variety of lengths, flaws, and twists. As a result, the main concern is how to separate them as garbage stain and sanitise the tube. Various postenlargement therapies have evolved to clean the tube and remove flaws. In an ultrasonicator, the materials can be treated to release the tubes from the particles that have bound them all together.

2.2. Stability. The nanofluid is said to be stable when the concentration of scattered nanoparticles remains constant throughout time. The pictures of the nanofluid test tube should be taken every day to determine the sedimentation rate (stability test) are shown in Table 1.

Although nanotubes show perfect uniqueness, the samples are taken under unusual settings, such as when they are exposed to air or water, confirming that they are distinct. As a result, impurities like O_2 clinging to the nanotubes made them extremely vulnerable. The lubricated nanotube stain is repeatedly distributed in ethanol, where it may be preserved without causing damage to the tubes. It is worth noting that the nanotubes are stable, preserving their structure even when contaminated.

2.3. Effect of Sonication Time. The carbon nanotube nanofluid is affected by ultrasonication in two ways. Though the optimum time had reached more ultrasonication outcomes than before, which was more than the break rate of nanotubes and reduced the aspect ratio of carbon nanotubes, ultrasonication aids in the formation of superior dispersions under the ideal processing time. With a 140 W and 20 kHz ultrasonicator, the most favourable ultrasonication time was up to 35 minutes at 1 wt percent MWCNT. The nanofluid viscosity is increased by sonication time until it reaches its maximum value, after which it declines. The declustering of the carbon nanotube bundle was linked to the early ascent, which led to the production of enhanced dispersal. Due to the increased breakage rate of carbon nanotubes, the latter reduces viscosity, resulting in a shorter nanotube and poor dispersion of carbon nanotubes. With a 35-minute ultrasonication time, the maximum thermal conductivity enhancement is observed, but this decreases with additional sonication.

3. Experimental Setup

The experimental apparatus is schematically depicted in Figure 2, which includes an experiment section, water loop, nanofluid loop, and data monitoring system.

The test unit is 2 m length and a tube in tube heat exchanger with a counter flow arrangement in which the nanofluid flows from beginning to end of the inside copper tube with inside diameter of 10 mm and water flow is taken by the shell side with outside diameter of 25 mm. The experiment part remains separated to five equal length sections, and the whole unit is wrapped in insulating material. On the inner side of a wooden box packed with the help of glass wool, the insulated test part is placed. To display the bulk temperatures of nanofluid, RTDs remain directly placed where the fluid flows at the entrance and outflow of each section. The following approach is used to calculate the convective heat transfer coefficients of nanofluids flowing inside the tube using the measured data. Using the nanofluid inlet as reference, the length of each segment is calculated.

4. Measurement of Thermophysical Properties

4.1. Density Measurement. The addition of solid nanoparticles, which have a higher density, results in NF having a higher density than BF. The density is determined using

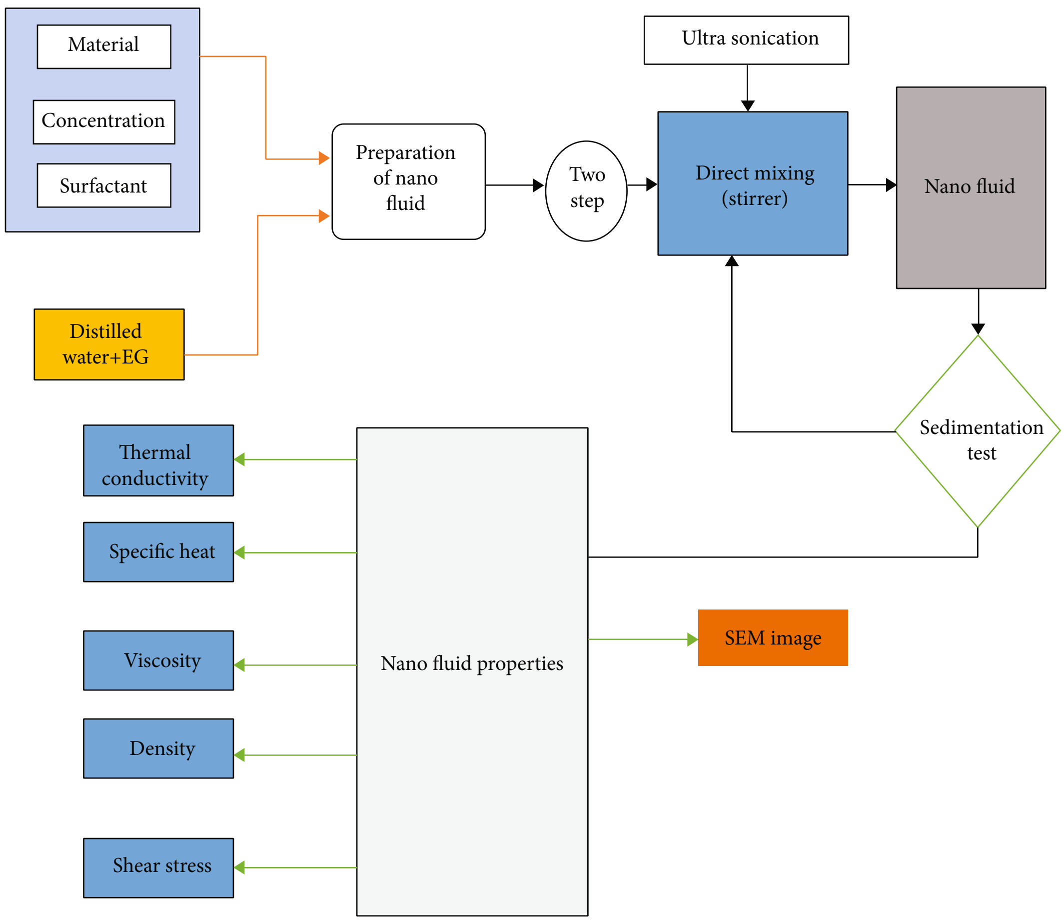

FIGURE 1: Treatment of nanofluid.

the volumetric flask method, in which a known amount of nanofluid is placed in a conventional volumetric flask of a given volume and the mass of the flask containing nanofluid is measured using a highly valuable electronic balance (M_2). Using the same electronic balance, the empty flask mass (M_1) is measured first. The difference between M_2 and M_1 yields the precise nanofluid mass for a given volume. As a result, the density of nanofluid is determined utilising

$$\rho_{nf} = (M_2 - M_1)/V_{fl}, \quad (1)$$

where,
ρ_{nf}: Density of the nanofluid,
M_2: Flask mask with nanofluid,
M_1: Mass of empty flask,
V_{fl}: Volume of the flask.

The density measurements arrangement is exposed in the Figure 3.

The empty flask was initially kept in the electronic balance machine without water to set the zero reading in the electronic balance machine. The nanofluid concentrations are then put into the flask and kept in an electronic balance machine, where the values are recorded. This is useful for determining density measurements for varied nanofluid concentrations. The electronic balance machine's specifications are as follows: BL 220H, 220 g capacity, 0.001 g readability, and digital model. The Pak and Cho correlations were used to compare the density values. The Pak and Cho correlations are calculated as follows:

$$\rho = \Phi\rho_p + (1 - \Phi)\rho_f, \quad (2)$$

where,
ρ: Density of the nanofluid,
Φ: Fraction of volume,
ρ_f: Base fluid density,
ρ_p: Nanoparticle density.

4.2. Specific Heat. The heat transfer rate is very much influenced by the specific heat; hence, the situation requires analysis of the consequence of CNT in the base fluid. The specific heat capacity remains essentially the quantity of an energy needed to increase the temperature of unit mass substance by 1° Celsius, represented in metric units as J/g·K. The heating or cooling ability of the fluid per unit raises or decreases the temperature determined by the specific heat capacity of the nanofluid as a characteristic of heat transfer fluid, in which just the creation of the fluid flow rate and the specific heat capacity in J/K, by means of superior heat

Table 1: Stability test.

Illustrate	Description	Time in Hrs	Remarks
	Water +0.15 volume % of CNT	1	CNT is settled
	Water with 0.20% Cetyl pyridinum chloride +0.15 volume % of CNT	2.15	CNT is settled
	Water with 0.20% Cetyl dimethyl benzyl-ammonia chloride +0.15 volume % of CNT	2.30	CNT is settled
	Water with 0.20% benzyl trimethyl ammonia chloride +0.15 volume % of CNT	6	CNT is settled
	Water with 0.20% SDBS+0.15 volume % of CNT	24	CNT is not settled

capability with superior heat transfer fluid. As a result, as specific heat capacity increases, heat capacity decreases, necessitating low HTF flows for given heating or cooling jobs, lowering pumping power requirements.

A differential scanning calorimeter with a nitrogen chilling facility is used to test the nanofluid specific heat. A known mass of nanofluid is placed in a pan, and the solution is heated and cooled at a rate of 50 degrees Celsius per

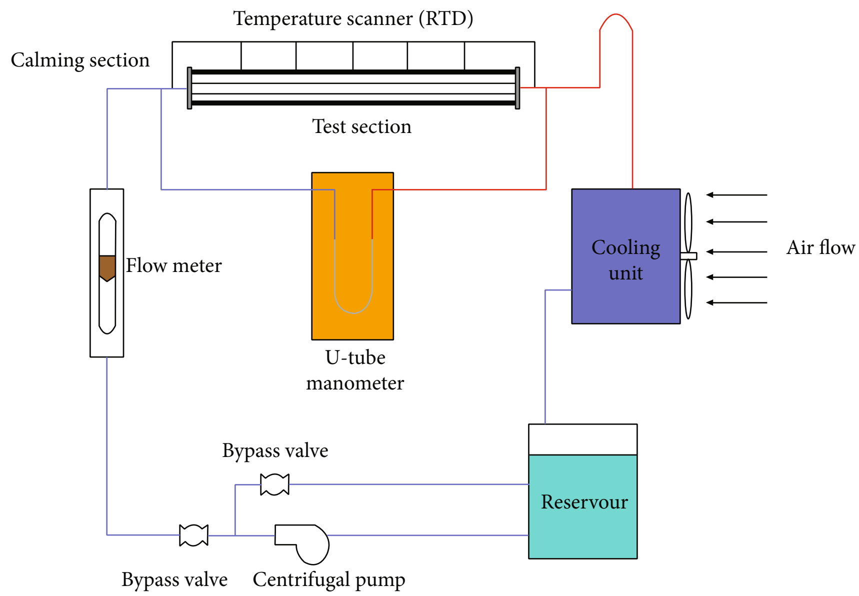

FIGURE 2: Experimental Setup.

FIGURE 3: Flask with 0.15 vol %.

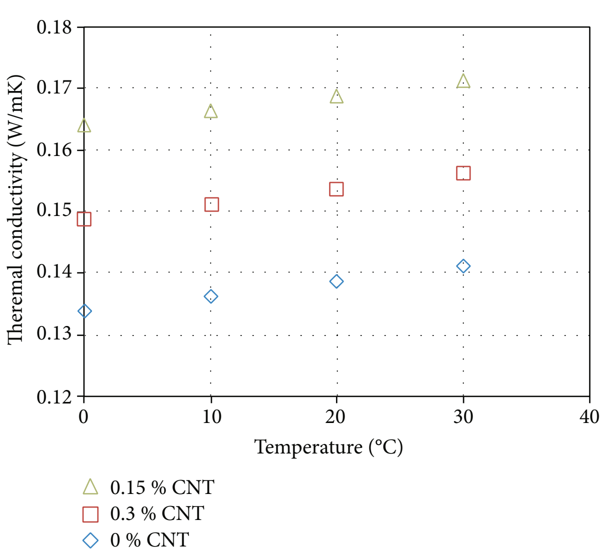

FIGURE 4: Temperature versus specific heat.

minute. $Cp = Q/(mn_f \Delta T)$ is the formula for finding nanofluid specific heat established on results of the heating rate and heat flow.

The results show in Figure 4, as how the specific heat of nanofluids varies with temperature. It should be noted that the specific heat of a nanofluid is proportional to its temperature. Incorporating carbon nanotubes (CNTs) into water increases the specific heat of a nanofluid. It is due to an increase in nonconsistent intermolecular forces between the CNT and the fluid, which require more energy to rise in temperature than water.

4.3. Thermal Conductivity. The most essential property of NF is its increased thermal conductivity, with high thermal conductive NPs added specifically to boost BF's thermal conductivity. Thermodynamic conductivity is an important feature in heat transfer applications. To determine the effective thermal conductivity of propanol-based CNT, a variety of correlations are available in the open literature. The system is set up in this paper, and it is utilised to determine the effective thermal conductivities of nanofluids. It was chosen because the majority of experimental results correlate well with projected values using this model, which takes into account both liquid and CNT form and size.

The variant of thermal conductivities of nanofluid at different temperatures is depicted in Figure 5. The outcome shows that nanofluid thermal conductivities increase with the addition of carbon nanotube in the water. The framework displays that the thermal conductivity of nanofluid is the function of the different temperature.

4.4. Viscosity. In heat transfer application, the pumping power is a vital aspect by the way it depends on the viscosity of HTF. Viscosity is simply the fluid's resistance to flow as a result of interlayer or fluid or surface contact. Alike to the density, viscosities have dual negative effect on the pressure

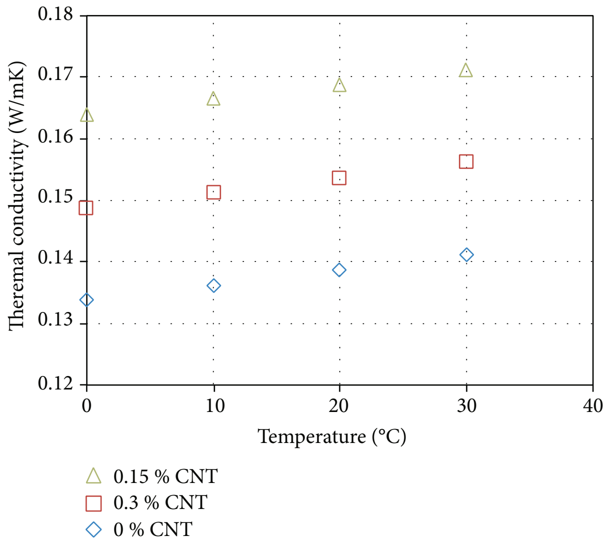

Figure 5: Temperature versus thermal conductivity.

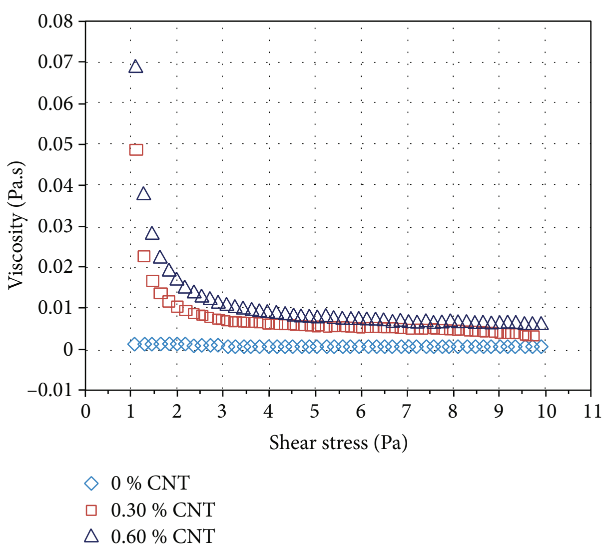

Figure 6: Viscosity versus shear stress.

drop and the amount of pumping power needed. Because of nanoparticles/surface collision and previous interlayer resistances and interfacial forces, the occurrence of nanoparticle in water, i.e., creating nanofluid, increases friction at fluid/surface contact. As a result, the NF"s viscosity is increased in comparison to the BF as a result of these interfacial resistances. To take use of the nanofluid's good effects, it is necessary to compute the increased pumping power caused by the addition of carbon nanotubes to the water-based base fluid. It is required to determine the viscosity of the nanofluid at different temperatures.

Experimentally, the viscosity of CNT nanofluid was estimated at various concentrations of 0.15 and 0.3 at 25°C. Figure 6 depicts the relationship between nanofluid viscosities and shear stresses. It is clearly seen that nanofluid viscosity drops as shear stress increases from 0 to 3 N m-2, indicating that the nanofluid performs non-Newtonian at low shear stress.

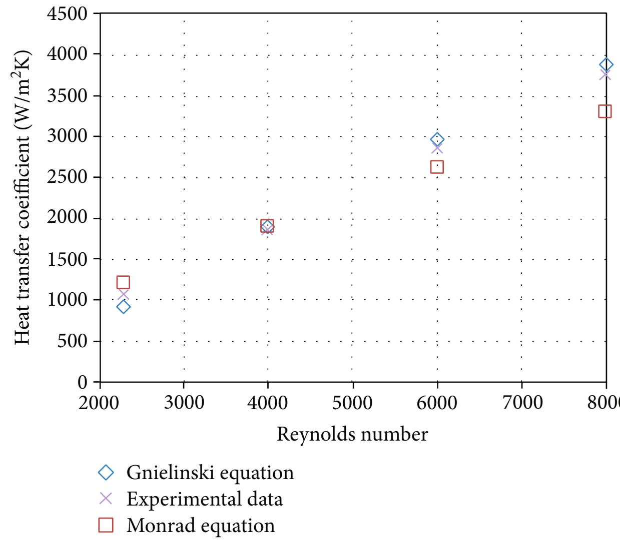

Figure 7: Comparison of measured HTC for water and those calculated from the Gnielinski equation and Monrad equation.

4.5. Comparison of Measured HTC for Water and Those Calculated from the Gnielinski Equation and Monrad Equation. Figure 7 compares the measured HTC of the base fluid flow from end to end tube to that of predicated values using the Gnielinski equation and Monrad equation at various flow conditions ($Re > 2200$). The water flows from end to end of the tube at 10°C, and in the annulus fluid it is at 25°C. It is understood from the graph that the investigational values match those obtained from the correlations. Having established confidence, the experiment is conducted with base fluid and a heat transfer fluid on tube side and water on annular side.

5. Conclusion

Nanofluid has recently been developed as a high-efficiency heat transfer fluid with excellent thermophysical characteristics. To progress the thermophysical property of commonly used fluid, a variety of nanostructures, specifically nanoparticles, have been introduced. In this work, the effective thermophysical properties of the carbon nanotube have been discussed and subsequent conclusion has been attained. The thermal performance of system can be considerably enhanced by adding of CNT in base fluid (water). The following conclusion is drawn from the results of the thermal conductivity, viscosity, and shear stress of CNT nanofluid: the viscosity of nanofluid increases as the concentration of the nanofluid increases, and the nanofluid is appropriate when the operating temperature is greater than 45°C with superior concentration. As the temperature rises, the thermal conductivity of the nanofluid increases. Carbon nanotubes have an advantage in the nanofluid because they conserve energy, reduce emissions, and improve convective heat transfer and efficiency.

Nomenclature

Φ: Concentration (%)
k: Thermal conductivity ($W\,m^{-1}\,K^{-1}$)
h: Convective heat coefficient ($W\,m^{-2}\,K$)
Cp: Specific heat ($Jkg^{-1}\,K^{-1}$)
ρ: Density ($kg\,m^{-3}$)
Re: Reynolds number
T: Temperature (°C)
m: Mass flow rate ($kg\,s^{-1}$)
ΔT: Change in temperature

Special characters

CNT: Carbon nanotube
CHF: Critical heat flux
HTF: Heat transfer fluid
BF: Base fluid
NF: Nanofluid
MWCNT: Multiwalled carbon nanotube
RTD: Resistance temperature detector

Subscripts

n_f: Nanofluid
b_f: Base fluid
n_p: Nanoparticle

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

It was performed as a part of the Employment Hawassa University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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