

**ANALYSIS OF THERMAL PERFORMANCE OF
COUNTER FLOW DOUBLE PIPE HEAT EXCHANGER
USING SILICON CARBIDE (SiC) NANOFLUID AND
CARBON NANOTUBE (CNT)**

Submitted in partial fulfillment of the requirements for the award of
**Bachelor of Engineering degree in
Mechanical Engineering**

By

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**DEPARTMENT OF MECHANICAL ENGINEERING
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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI -600 119

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Aravind Kumar V N (38150012)** and **Kaushik S (38150049)**, who carried out the project entitled **"Analysis of thermal performance of counter flow double pipe heat exchanger using Silicon carbide (SiC) nanofluid and Carbon nanotube (CNT)"** under my supervision from September 2021 to May 2022.

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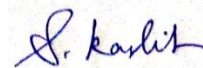
We **Aravind Kumar V N (38150012)** and **Kaushik S (38150049)** declare that the Project Report entitled “**Analysis of thermal performance of counter flow double pipe heat exchanger using Silicon carbide (SiC) nanofluid and Carbon nanotube (CNT)**” done by us under the guidance of **Dr. M.Anish.,M.E.,Ph.D.** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechanical engineering.

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ABSTRACT

A nanofluid is a suspension of nano-sized particles made up of metals, oxides, or carbides with a diameter of less than 100 nanometers suspended in a base fluid such as water, ethylene glycol, or oil. A great number of tests have recently been conducted to evaluate the influence of nanofluid on heat transfer rate augmentation in various heat exchangers. The kind of nanoparticles, size of nanoparticles, shape of nanoparticles, type of base fluid, and concentration of nanoparticles in the base fluid all have a role in heat transfer enhancement utilizing nanofluid. The performance of a double pipe heat exchanger with counter flow arrangements and two types of nanofluid as a cooling fluid was investigated experimentally in this research. With alkaline water as a base fluid, silicon carbide (SiC) and carbon nanotubes (CNT) are employed. The effect of different concentrations of SiC and CNT nanoparticles mixed in water on the heat transfer properties of a double pipe heat exchanger for counter flow arrangement has been investigated in this research. The nanoparticle volume concentration studied for alkaline water and nanofluid was (0.02,0.04,0.06) and flow rate (0.5,1,1.5) In a heat exchanger, hot fluid (water) and cold fluid (Nanofluid) flow at constant intake temperatures of 60 C° and 30 C°, respectively, resulting in two fluids flowing at constant inlet velocity. The results of the experiment revealed that nanofluid absorbs more heat than water at low flow rates, resulting in improved heat exchanger thermal performance due to improved thermal properties of these fluids. It is also shown that when the concentration of nanoparticles increases, the heat transmission rate increases.

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CHAPTER 1

INTRODUCTION

The modern trends in device miniaturization and process intensification have resulted to develop the alternate and effective heat dissipation methods from micro electronics systems and packages. In high-intensity heat fluxes, conventional heat removal technologies have proven to be ineffective. To improve the efficiency of heat transfer systems, many researchers have developed different heat transfer approaches. Researchers are attempting to create nanometer-sized materials following the invention of high-resolution microscopes such as the Scanning Electron Microscope (SEM), Transfer Electron Microscope (TEM), and so on. Nanotechnology has attracted a lot of attention from scientists and engineers during the last few decades. The US government now funds about \$1 billion per year for the National Nanotechnology Initiatives (NNI). The Nano science and Foundation (NSF) predicts the market for nanotechnology related products will exceed 1 trillion in US alone by 2015.

Heat exchangers are widely utilized in a variety of technical applications, including automobile manufacturing, thermal power plants, chemical manufacturing, environmental engineering, waste heat recovery, air conditioning, refrigeration, power generation, and food processing. Several strategies for improving the thermal-hydraulic performance of such devices have been devised, resulting in smaller devices and lower operating costs. These methods can be classified as active methods that require an external power source, such as electrical or acoustic fields or surface vibrations, or passive ways that use particular geometries (fins and baffles) or fluid additives to improve heat transfer. A double pipe heat exchanger is a form of heat exchanger that is made up of concentric pipes that are separated by a mechanical closure. As the name of this heat exchanger represents that it uses two pipes to exchange heat between two fluids. The heated fluid is in one pipe, while the cool fluid is in the other. This heat exchanger is also known as a jacketed u-tube heat exchanger, jacketed tube heat exchanger, hairpin heat exchanger, and pipe-in-pipe heat exchanger. A tiny pipe is encircled by a larger pipe in a twin pipe heat exchanger. One fluid flow inside the

small pipe, while the other flows between the two pipes through the annulus. The heat transmission surface is the tiny pipe's inner wall. In the huge tube, the complete heat transfer process takes place.

The inner pipe acts as a conductive barrier in this way. Fluid flow via the tube side or interior is contained on the exterior side. One technique to improve heat transmission is to add additives to liquids. The primary goal of improving the heat transfer characteristics of liquids is to increase fluid thermal conductivity. The heat transmission between the working fluid and the heated surface is aided by their thermal conductivity. Suspending nano-sized particles with high thermal conductivity in a base fluid with low thermal conductivity is an innovative technique to improve a fluid's thermal conductivity. In recent years, substantial research has demonstrated that nanofluids are superior to traditional fluids as a heat transfer agent. Water, ethylene glycol, propylene glycol, and other common heat transfer fluids are widely used to remove the heat from the mechanical systems. However, these conventional fluids have poor heat transfer properties. Because of these poor heat transfer characteristics, the researchers showed their interest to develop a new kind of heat transfer fluids to enhance the efficiency of the systems. These special kinds of heat transfer fluids are named as "Nano fluids". Nano fluids are a relatively new type of fluid that has nanometre-sized particles suspended in a base fluid such as water, ethylene glycol, propylene glycol, or oil. For his "Advanced fluid programme" project at Argonne National Laboratory, scientist S.U.S. Choi developed a particular sort of fluid in 1993 by dispersing particles with a diameter of 1100nm in the basic fluids (ANL). Although a chief attention while the usage of suspended millimetre- or micrometre-sized debris is that they've the capacity to motive a few critical problems, which includes abrasion, clogging, excessive stress drop, and particle sedimentation, the addition of stable debris into warmness switch media has lengthy been called one of the beneficial strategies for boosting warmness switch. When as compared to the usage of suspended massive debris to enhance warmness transmission, the use of nanoparticles in fluids confirmed higher features in phrases of fluid warmness switch. This is due to the fact that nanoparticles are often utilised at very low quantities and with nanometre-sized particles. These

characteristics prevent deposition in the flow, which might cause the channel to block. On the one hand, new energy-efficient heat transfer equipment sits at the crossroads of a minor increase in heat flux and a massive increase on the other. Many industry activities, including power generation, chemical processes, heating and cooling processes, transportation, microelectronics, and other micro-sized applications, rely on heat transfer fluids such water, minerals, oil, and ethylene glycol. The heat transfer capabilities of these fluids are inferior to those of most solids, which is the principal impediment to high compactness and heat exchanger effectiveness. The basic concept is to take use of solid particles' extremely high thermal conductivities, which can be hundreds of times higher than all other traditional fluids combined. As a result, there is still a pressing need to develop innovative ways for improving the efficient heat transfer properties of conventional fluids. Suspending small solid particles in fluids is an innovative approach to improve the thermal conductivities of common fluids. Slurries can be made with a variety of particles, including metallic, non-metallic, and polymeric particles. Slurries containing suspended particles of the order of micrometres or millimetres, on the other hand, might cause serious issues. In practical applications, the abrasive impact of the particles produces clogging of flow channels, eroding of pipes, and a reduction in momentum transfer, as well as an increase in pressure drop. Furthermore, they have rheological and stability issues. The particles, in particular, have a tendency to settle out of suspension quickly. Despite having better thermal conductivities than traditional heat transfer fluids, the slurries are not suitable for use as heat transfer fluids in practical applications.

Heat exchangers are devices that transfer thermal energy from one fluid to another. Heat exchangers are used in a wide range of industries and applications, including manufacturing, environmental engineering, air-conditioning, refrigeration, power generation, and space applications. The flow pattern and kind of structure are usually used to categorise Heat exchanger. These devices are divided into three categories: double pipe, shell & tube, and plate (compact) Heat exchanger. Within a Heat Exchanger, there are two types of flow routes: parallel flow and counter flow. Both working fluids in the Heat Exchanger flow in the same direction in the parallel flow heat exchanger. The fluids flow in the opposite direction in another arrangement. Numerous

research have looked into how to improve Heat exchanger performance in order to increase productivity. There are two types of approaches for increasing heat transfer rate: passive and active techniques. Because of their poor thermal characteristics, traditional heat transfer fluids play an unfavourable role in heat transfer operations. In light of heat transfer enhancement approaches and based on the fact that solids have a higher thermal conductivity than liquids, additives such as solid particles can change the thermal characteristics of heat transfer fluids, hence increasing the efficiency of heat transfer surfaces. Due to the huge size and high density of the particles, early experiments on suspensions containing millimetre- and micrometre-sized particles encountered the challenge of poor suspension stability. Choi and Eastman proposed adding nanoscale solid particles to conventional heat transfer fluids to improve thermal characteristics and suspension stability in 1995. The extension of nanofluids for engineering applications of heat transmission has received a lot of interest in recent years.

CHAPTER 2

LITERATURE SURVEY

Abbasian Arani et al [1]. investigated heat transfer of TiO_2 /water nanofluids flow in a double pipe counter flow heat exchanger in the volume fraction range from 0.002 and 0.02 and the Reynolds number between 8000 and 51000.

Aghayari et al [2]. observed heat transfer coefficient and Nusselt number of 19% and 24% for 0.3% volume fraction of Al_2O_3 /water nanofluid flow in a double pipe heat exchanger in counter flow direction.

Alkam et al [3]. introduced porous substrates on both sides of the inner cylinder. They discovered that increasing heat exchanger efficiency is vital, especially at large capacity ratios, and that there is a certain thickness of the substrate beyond which no significant improvement in heat exchanger performance occurs.

Allouache et al [4]. performed a thermodynamic analysis on a double pipe heat exchanger with a porous layer. They discovered that when an annular gap is completely filled with a porous media with a high effective thermal conductivity, the rate of entropy development is significantly reduced.

Bahiraei et al [5]. investigated the performance of a water-based Mn–Zn ferrite magnetic nanofluid in a counterflow double-pipe heat exchanger under quadrupole magnetic field using the two-phase Euler–Lagrange method. They looked at the effects of several parameters like as concentration, particle size, magnetic field magnitude, and Reynolds number.

Choi et al [6]. developed high thermal conductivity fluids called as nanofluids, which is prepared by dispersing nanometer sized solid metallic particles in the fluids. The use of nanofluids in double pipe heat exchangers and its convective heat transfer coefficient have been estimated by researchers.

Chun et al [7]. examined the convective heat transfer coefficient of nanofluids made of alumina nanoparticles and transformer oil flowing through a double pipe heat exchanger system in the laminar flow regime. They provided an experimental correlation for an alumina-transformer oil nanofluid system in order to better understand how to improve nanofluid heat transfer.

Clarke et al [8]. numerically investigated the heat transfer mechanism of secondary refrigerant flow in an air chiller U-bends and observed with return bend there is a 20% heat transfer enhancement for up to 20 pipe diameters. Other experimental investigations found that heat transfer may be enhanced immediately downstream of a U-bend.

Darzi et al [9]. estimated heat transfer and pressure drop of Al_2O_3 /water nanofluid in a double pipe heat exchanger at different temperature range of working fluid.

Demir et al [10]. numerically examined the velocity and temperature profiles of water-based TiO_2 and Al_2O_3 nanofluids flowing in a twin pipe heat exchanger. The use of a return bend in a double pipe heat exchanger can improve heat transfer even more.

Dittus et al [11]. proposed the following correlation in which all physical properties are evaluated at the mean bulk temperature: $\text{Nu} = 0.023\text{Re}^{0.8} \text{Pr}^{0.4}$

Duangthongsuk et al [12]. observed heat transfer enhancement of 6-11% at 0.2% volume concentration of TiO_2 /water nanofluid flow in a horizontal double tube counter flow heat exchanger under turbulent flow conditions.

El-Maghlany et al [13]. observed augmentation of effectiveness and the number of transfer units (NTU) of the double pipe heat exchanger using Cu/water nanofluids.

Guo et al [14]. discovered that using a porous material and pulsing flow in an annulus can significantly improve heat transfer while lowering pressure drop.

Hashemi et al [15]. used the Darcy-Brinkman-Forchheimer model to find an analytical solution for forced convection in a micro-annulus filled with a porous media. The outer cylinder was subjected to a steady heat flow, while the inner cylinder was insulated, and vice versa.

Hemmat Esfe et al [16]. estimated convective heat transfer coefficient of MgO /water nanofluid flow in a double pipe heat exchanger at different particle concentrations 0.005, 0.01, 0.015, 0.02 and the nanoparticles diameter of 60, 50, 40 and 20 nm.

Hong et al [17]. noticed increased heat transmission in pipes with return bends, and they came to the conclusion that fluid mixing, hydrodynamic, and thermal development of secondary flows at the U-immediate bend's downstream affected heat transfer.

Huminic et al [18]. numerically investigated heat transfer characteristics of CuO and TiO_2 nanofluids flow in a double-tube helical heat exchanger under laminar flow

conditions and they observed significant enhancement of heat transfer with increase of particle concentration.

Jang et al [19]. predicted Brownian-motion generated nano convection as a significant agent nanoscale process influencing the thermal. The effects of a variety of characteristics on the effective thermal conductivity of nanofluids were included in their model, including the ratio of the thermal conductivity of nanoparticles to that of a base fluid, volume fraction, nanoparticle size, and temperature.

Kahalerras et al [20]. demonstrated that the introduction of porous fins or baffles can significantly improve heat transmission at the expense of a tolerable pressure drop for ideal values of the porous medium qualities.

Kole et al [21]. studied the effect of prolonged sonication on the thermal conductivity of ZnO/ethylene glycol nanofluid. They concluded that the thermophysical properties are affected by the sonication time.

Li et al [22]. proposed cu-water nanofluids moving inside an evenly heated tube had a significantly higher heat transfer coefficient than pure water in laminar and turbulent flow regimes in forced convection. Furthermore, it was revealed that increasing the concentration of nanoparticles improves the heat transfer coefficient.

Lotfi et al [23]. examined the single-phase, mixture, and Eulerian two-phase models. They also evaluated the Nusselt number predictions for a 1% nanoparticle concentration with three correlations and one set of experimental values for the forced convection flow of Al_2O_3 /Water nanofluid with temperature independent features. They also looked into the impact of volume concentration on the temperature of the wall. Their results showed that the Mixture model is more precise than the other two models.

Pak et al [24]. investigated the turbulent forced convection heat transport of Al_2O_3 /water and TiO_2 /water nanofluids inside a circular tube experimentally. It was demonstrated that Al_2O_3 particles have a greater heat transfer enhancement than TiO_2 particles.

Sajadi et al [25]. observed heat transfer enhancement of 22% at 0.25% of TiO_2 -water nanofluid flow in a double pipe heat exchanger in the Reynolds number of 5000.

Sarafraz et. el [26] found heat transfer enhancement of 67% at 1.0% vol. of Ag/50:50% ethylene glycol/water nanofluid flow in a double pipe heat exchanger.

Setia et al [27]. discussed different methods to obtain stable nanofluids, which were

prepared using a two-step method, viz., high shear homogenization, sonication, varying the pH level, and addition of surfactants. They also discussed different methods to evaluate the stability of nanofluids.

Shakiba et al [28]. studied the hydro-thermal characteristics of Fe_3O_4 /water nanofluid at 4.0% volume concentration in a counter flow double pipe heat exchanger using single phase model and control volume technique. Sharma et al [29]. examined the effect of inclusion of strip twisted tape on heat transfer through transition flow of nanofluid and found a better heat transfer than the flow without twisted tapes.

Targui et al [30]. have studied the performance of a twin pipe heat exchanger with porous baffles and pulsing flow numerically. They discovered that when only the flow of the hot fluid pulsates, the highest heat transfer rates are attained. The suspension of metallic nanoparticles in conventional fluids to improve their thermal properties, such as thermal conductivity, is another technique to optimize the operation of thermal systems; these are known as nanofluids.

Timofeeva et al [31]. noted that the Nusselt number is the best parameter to use when comparing experimental and predicted data for the same fluid and heat transfer coefficient in relation to the performance of nanofluids having different thermal conductivities.

Vajjha et al [32]. performed experiments on three nanofluids under constant heat flux boundary conditions and proposed the heat transfer correlation for flow in the turbulent regime similar in form to the well-known Gnielinski's equation for a single-phase fluid. Zarringhalam et al [33]. reported that the thermal performance factor (TPF) determines the acceptability of the nanofluid in practical applications.

CHAPTER 3

EXPERIMENTAL SETUP

Figure 3.1 shows the specifications for double pipe heat exchanger. The outer pipe is manufactured of SS and has an outer diameter of 80.2 mm, an inner diameter of 78.2 mm, and a length of 1.5m, respectively. The inner pipe is also composed of copper, with a 60.2 mm outer diameter, 58.2 mm inner diameter, and 1.6 m length, respectively. Mineral wool cladding with a thickness of 45 mm is used as insulation over the outside pipe. On each pipe, there are valves that can be opened and closed alternately for counter and parallel flow operations. Two independent SS 304 mono-block type centrifugal pumps, one for cold nanofluid and the other for hot water, are provided to circulate cold nanofluid and hot water through pipes. To heat the water, three immersion type heaters, each with a 6-kW capacity, are positioned in the hot water tank. To heat the water, immersion type heaters with a capacity of 6 kW are installed in the hot water tank. To monitor the flow rate of cold nanofluid and hot water from the pipes, two fitzer rotameters in the 0.5–5.0 lpm range are attached. The entrance and outlet temperatures of cold nanofluid and hot water flowing through pipes are measured using J type thermocouples. The temperature is indicated with a digital temperature indicator.

The experimental setup is first tested by running water through the heat exchangers and using the water as a heat exchange fluid. The temperature of the hot and cold fluids at their entrance and outflow is measured, and the overall heat transfer coefficient of water is computed. Following that, the heat is exchanged using the SiC Nano fluid and CNT Nanofluid. The temperature of the hot and cold fluids is measured at the inlet and outlet, and then the overall heat transfer coefficient for SiC and CNT Nano fluid is computed.

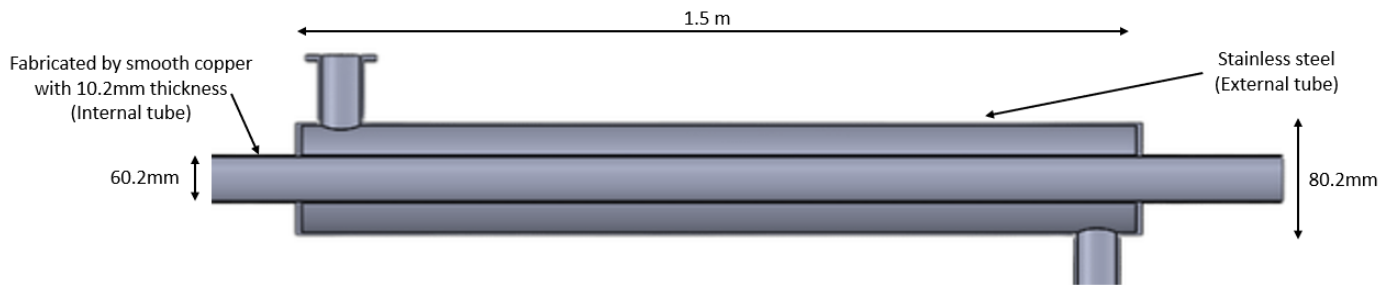


Fig. 3.1: Specifications of double pipe heat exchanger

3.1 EXPERIMENTAL PROCEDURE

- 1) Figure 3.2 shows the flow diagram of a counter flow double pipe heat exchanger.
- 2) Fill one tank with hot water and another with cold nanofluid.
- 3) Heat the water to the required temperature using the immersion type heater installed in the hot water tank.
- 4) Turn on the hot water tank pump with the bypass line valve fully open and the supply valve fully closed to ensure proper mixing of the water in the tank and a consistent temperature.
- 5) Allow hot water to pass through the inner pipe. Using the rotameter, adjust the flow rate to the appropriate value. On the outside pipe side, start the cold nanofluid water supply. Using a rotameter, adjust the flow rate to the appropriate value.
- 6) Observe and record the input and output temperatures of both cold nanofluid and hot water streams after they reach steady state.
- 7) Now we can collect the readings of the heat transfer rate. They are then taken for different levels of concentration of nanofluid and the temperature differences are noted between the different concentration.
- 8) Rotameters are used to record the flow rates of hot water and cold nanofluid.
- 9) Using varied flow rates of cold nonfluid and hot water, repeat the experiment.
- 10) After the experiments are finished, drain the water from tanks.

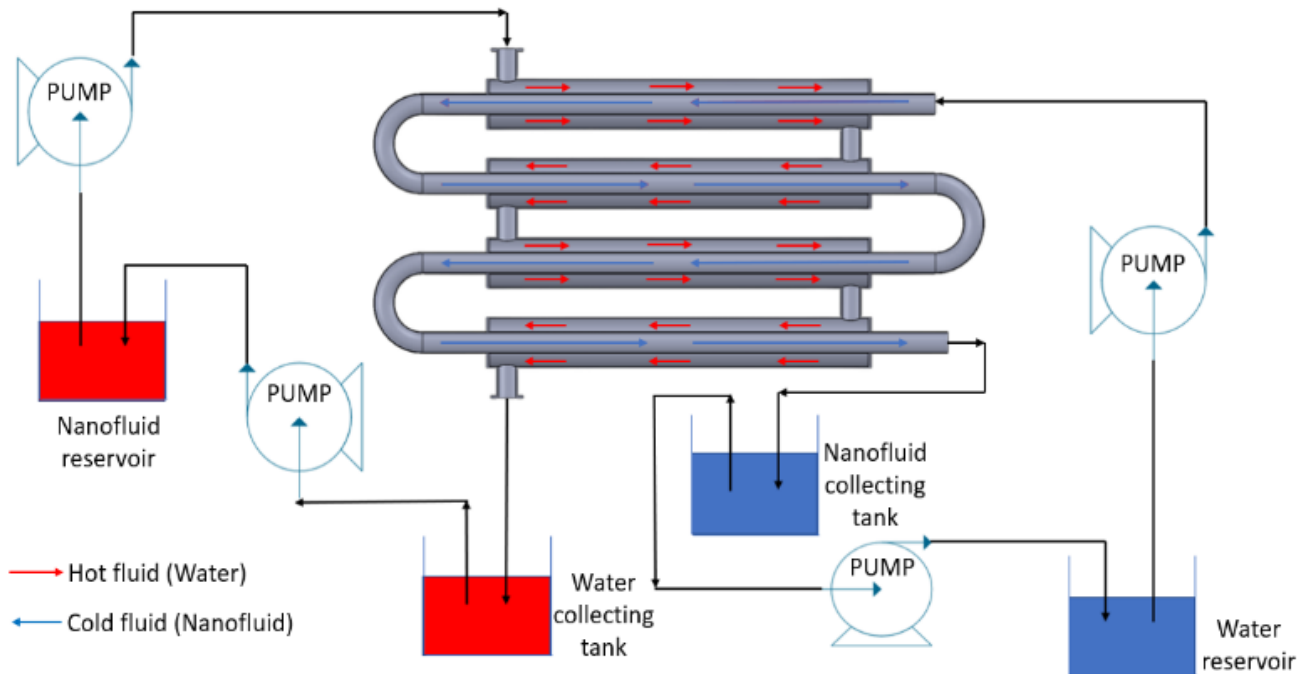


Fig. 3.2: Systematic flow diagram of a counter flow double pipe heat exchanger



Fig. 3.3: Experimental double pipe heat exchanger

Figure 3.3 shows the setup of counter flow double pipe heat exchanger in which experiment was carried out experimentally and analyzed for different levels of concentration of each nanofluids.

3.2 PREPARATION OF NANOFLUID

Nanofluids are a novel type of fluid created by dispersing nanometer-sized materials in a base fluid (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheets, or droplets). Nanofluids, in other terms, are nanoscale colloidal solutions that contain condensed nanomaterials. They are two-phase systems, with one phase (solid phase) in one and the other (liquid phase) in the other (liquid phase). When compared to base fluids like oil or water, nanofluids have better thermophysical properties including thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients. It has shown that it has a wide range of possible applications.

There are certain significant concerns that we must address in a two-phase system. The stability of nanofluids is one of the most pressing challenges, and achieving the appropriate stability of nanofluids remains a major challenge. Nanofluids have gotten a lot of interest in recent years. A wide range of applications is the main driving force behind nanofluids research. Although numerous review articles on the advancement of nanofluid research have been published in recent years, the majority of the reviews focus on experimental and theoretical studies of nanofluid thermophysical characteristics or convective heat transfer.

3.2.1 Two Step Method

The most extensively used approach for preparing nanofluids is the two-step procedure. Chemical or physical processes are employed to make dry powders of nanoparticles, nanofibers, nanotubes, or other nanomaterials utilized in this method. In the second processing stage, the nanosized powder will be distributed into a fluid using intense magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Because nano powder synthesis techniques have previously been scaled up to commercial production levels, the two-step process is the most cost-effective way to create nanofluids on a wide scale. Nanoparticles have a tendency to

agglomerate due to their large surface area and strong surface activity. Surfactants are an important strategy for improving the stability of nanoparticles in fluids. However, the surfactants' functioning at high temperatures is a major concern, particularly in high-temperature applications. Due to the difficulty of producing stable nanofluids using the two-step method, numerous advanced techniques for producing nanofluids, including the one-step method, have been developed. We'll go through the one-step method in depth in the next section.

3.2.2 One Step Method

Eastman et al. developed a one-step physical vapour condensation process to prepare Cu/ethylene glycol nanofluids to decrease nanoparticle aggregation. The one-step method involves creating and distributing particles in a fluid at the same time. Because the drying, storage, transportation, and dispersion of nanoparticles are avoided in this procedure, nanoparticle agglomeration is reduced and fluid stability is improved. The one-step procedures can produce uniformly dispersed nanoparticles that can be suspended in the base fluid for a long time. Another effective approach for preparing nanofluids using various dielectric liquids is the vacuum-SANSS (submerged arc nanoparticle synthesis system).

The diverse morphologies are mostly influenced and determined by the dielectric liquids' thermal conductivity qualities. The morphological shapes of the nanoparticles created are needle-like, polygonal, square, and circular. The approach does a good job of avoiding particle agglomeration. Because the one-step physical technique cannot create nanofluids on a wide scale and has a high cost, the one-step chemical method is fast evolving. Zhu et al. reported a unique one-step chemical approach for preparing copper nanofluids by reducing $CuSO_4 \cdot 5H_2O$ with $H_2PO_2 \cdot H_2O$ in ethylene glycol under microwave irradiation. Copper nanofluids were created that were well-dispersed and stable in suspension. This method was also utilized to create mineral oil-based nanofluids with a narrow size distribution of silver nanoparticles. Korantin may be able to stabilize silver particles by binding to their surfaces via two oxygen atoms and producing a thick layer around them. For nearly a month, the silver nanoparticle suspensions remained steady. With the use of a microwave, stable ethanol-based

nanofluids containing silver nanoparticles may be made in one step. The colloidal silver stabilizer and silver in solution reduction agent employed in this process was polyvinylpyrrolidone (PVP). Phase transfer occurs when silver nanoparticles attach to ODA molecules in the organic phase, either through creation of coordination bonds or weak covalent interaction.

A phase transfer technique has been developed for the production of homogeneous and stable graphene oxide colloids. Graphene oxide nanosheets (GONs) were successfully transferred from water to n-octane after being modified by oleylamine, as indicated in the schematic illustration of the phase transfer process. On the other hand, the one-step solution has several disadvantages. The most important is that residual reactants are left in the nanofluids due to insufficient reaction or stabilization. It's impossible to comprehend the nanoparticle effect without taking into consideration the impurity effect.

Figure 3.4 shows the steps involved in the preparation of nanofluid. This method makes use of nanoparticles that are first in the form of a dry powder. Nano particles are commonly stirred with base fluid using ultrasonic vibrators. When it comes to making nanofluids, agglomeration is a big problem. The use of an ultrasonic vibrator on a regular basis reduces particle aggregation. However, when nanofluids are manufactured in huge quantities, the two-step approach is acknowledged as the most cost-effective way.

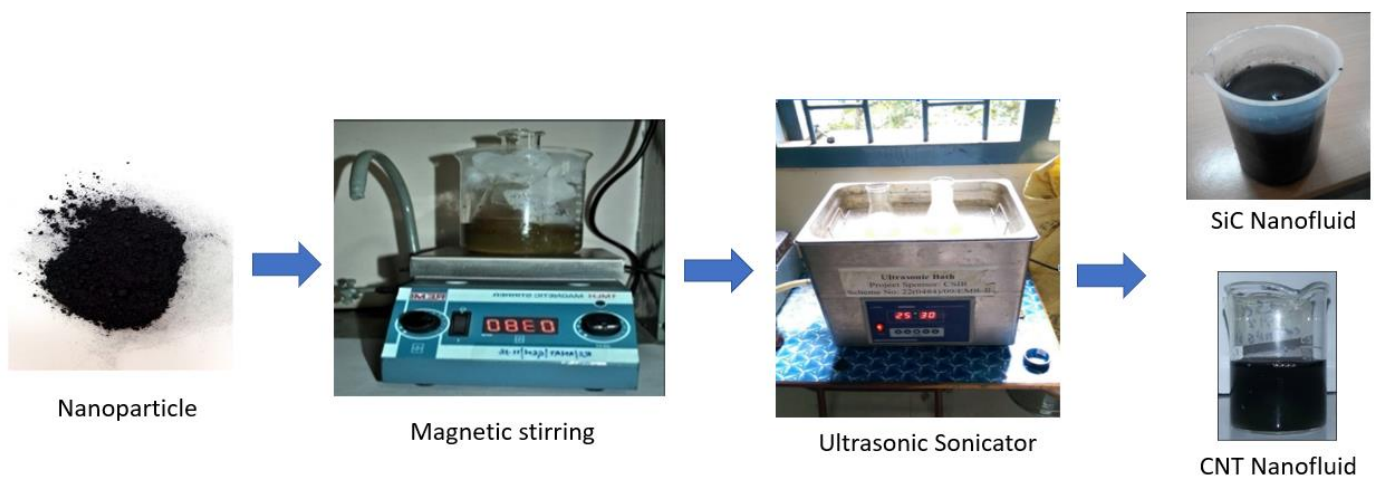


Fig. 3.4: Preparation of nanofluid

3.3 PREPARATION OF SiC NANOFLUID

The two-step method was used to prepare the SiC, water nanofluid. Nanoparticles of less than 50 nm size and with 99% purity were procured. The mass of the nanoparticles for a particular volume concentration was calculated. The SiC nanoparticles were dispersed in the base fluid using a mechanical stirrer. The nanofluid was stirred continuously for about 36 to 48 hours to obtain a stable solution that lasted for approximately 32 to 48 hours for the range of volume concentrations considered in the analysis. The nanofluid preparation, the surfactant=SiC ratio was varied from 1 to 3 at constant SiC concentration i.e., 0.02 wt%, 0.04 wt% and 0.06 wt%.

3.4 PREPARATION OF CNT NANOFLUID

The preparation of CNT nanofluid was done in two steps. With the use of a magnetic stirrer, SDS solution (SDS added to double distilled water) was first made. SDS molecules can unzip CNT nanoparticles, allowing them to scatter easily in polar fluids such as water. The solution was then moved to an ultrasonicator bath, where CNT nanoparticles were introduced. A constant frequency of 40 3 kHz was used to sonicate the ultrasonicator bath. The ultrasonicator bath was kept at a temperature of up to 40 degrees Celsius by circulating cold water. After sonication, the produced CNT nanofluid was given a dynamic condition by centrifuging it at 2000 RPM for 1 hour at a set interval. At constant CNT concentrations of 0.02 wt percent, 0.04 wt percent, and 0.06 wt percent, the surfactant=CNT ratio was changed from 1 to 3 in the nanofluid production. The duration of sonication was also adjusted from 60 to 180 minutes.

3.5 SCANNING ELECTRON MICROSCOPE (SEM) RESULT FOR SiC NANOFLUID AND CNT

The morphology of the SiC nanofluid is seen in Figure 3.5. Following a 3-hour reaction, the resulting as grown sample structures are shown in the figures. Figure shows larger microstructures that appear to be the consequence of a similar reaction between

carbon felt fibres and silicon monoxide vapour. The results displayed are larger in diameter than the original starting material, which is typical of the desired reaction with MWCNTs. The morphology of the materials changed as a result of the SEM photographs.

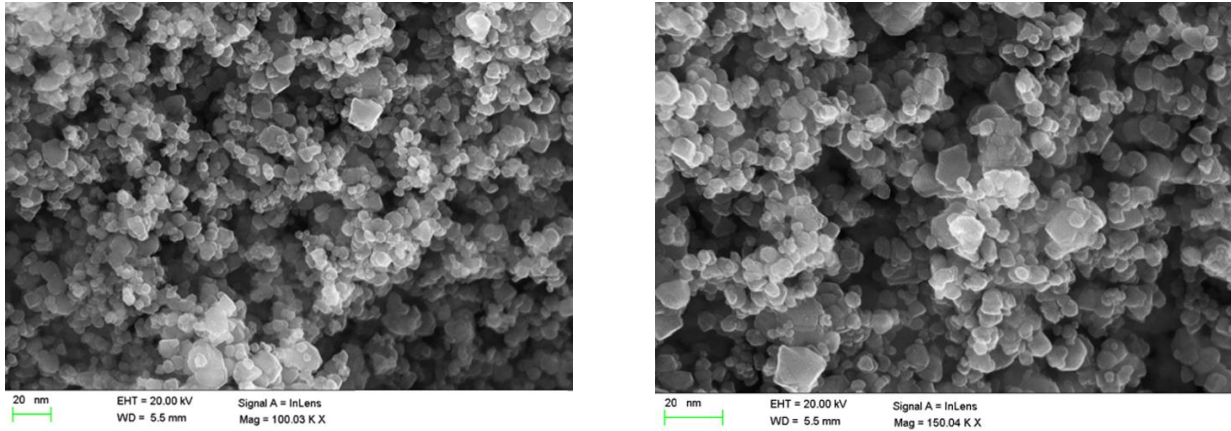


Fig. 3.5: SEM result of SiC nanofluid

Figure 3.6 shows that carbon nanotubes are not evenly dispersed throughout the composite. Figure 3.6 shows many interactions between CNT particles. CNTs have a smaller particle size, which lowers porosity and dislocations, making the CNT composite sample more uniform than SiC nanoparticles.

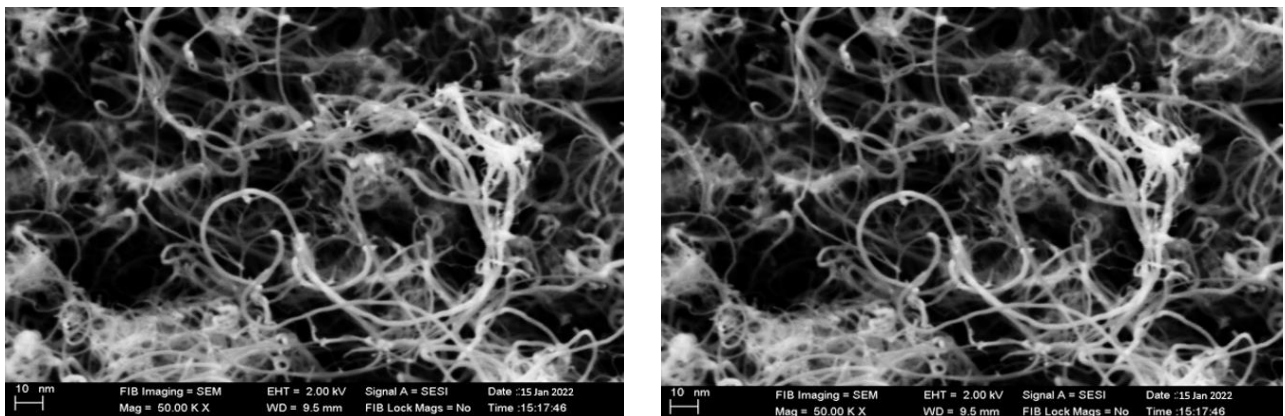


Fig. 3.6: SEM result of CNT

CHAPTER 4

RESULT AND DISCUSSION

4.1 VISCOSITY AND THERMAL CONDUCTIVITY OF THE SiC NANOFLUID AND CNT

Figure 4.1 shows the variations in the viscosity of the SiC nanofluid and CNT with the volume concentration at an operating temperature of 35 degree Celsius. The viscosity of the nanofluid increased with the volume concentration since the number of nanoparticles per unit volume of the fluid increased with an increase in the volume concentration of the nanofluid, thus offering more resistance to the flow. CNT showed better variations of increase in the viscosity compared to that of SiC nanofluid at the operating temperature of 35 degree Celsius.

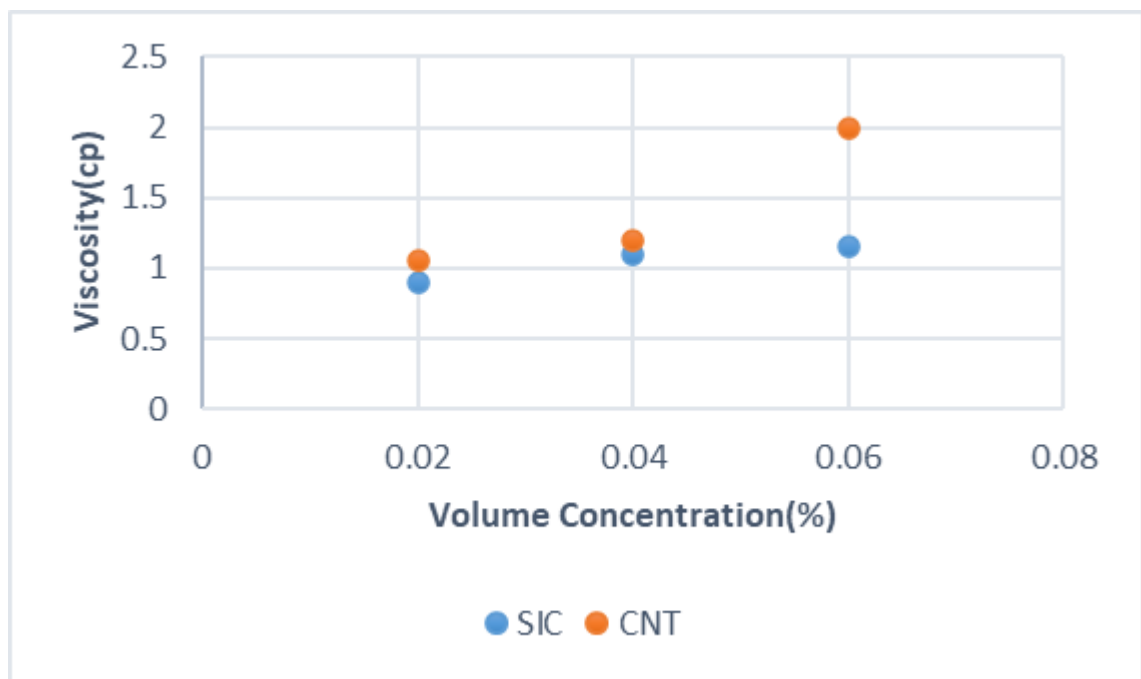


Fig. 4.1: Viscosity of SiC nanofluid and CNT

The thermal conductivity of the CNT had a higher value than that of SiC Nanofluid at all volume concentrations considered in the analysis at the operating temperature of 35 degree Celsius, as shown in Fig. 4.2. The increase in the thermal conductivity of the nanofluid is due to the addition of nanoparticles is attributed to multiple factors, as stated by Machrafi and Lebon (2016), viz., liquid interfacial layering, agglomeration of nanoparticles, and Brownian motion. A maximum enhancement was observed in the thermal conductivity of 0.06% of the CNT. Even at a very low volume concentration of 0.02%, enhancement of 26.74% and 30.72% was obtained in the thermal conductivity of the SiC nanofluid and CNT respectively.

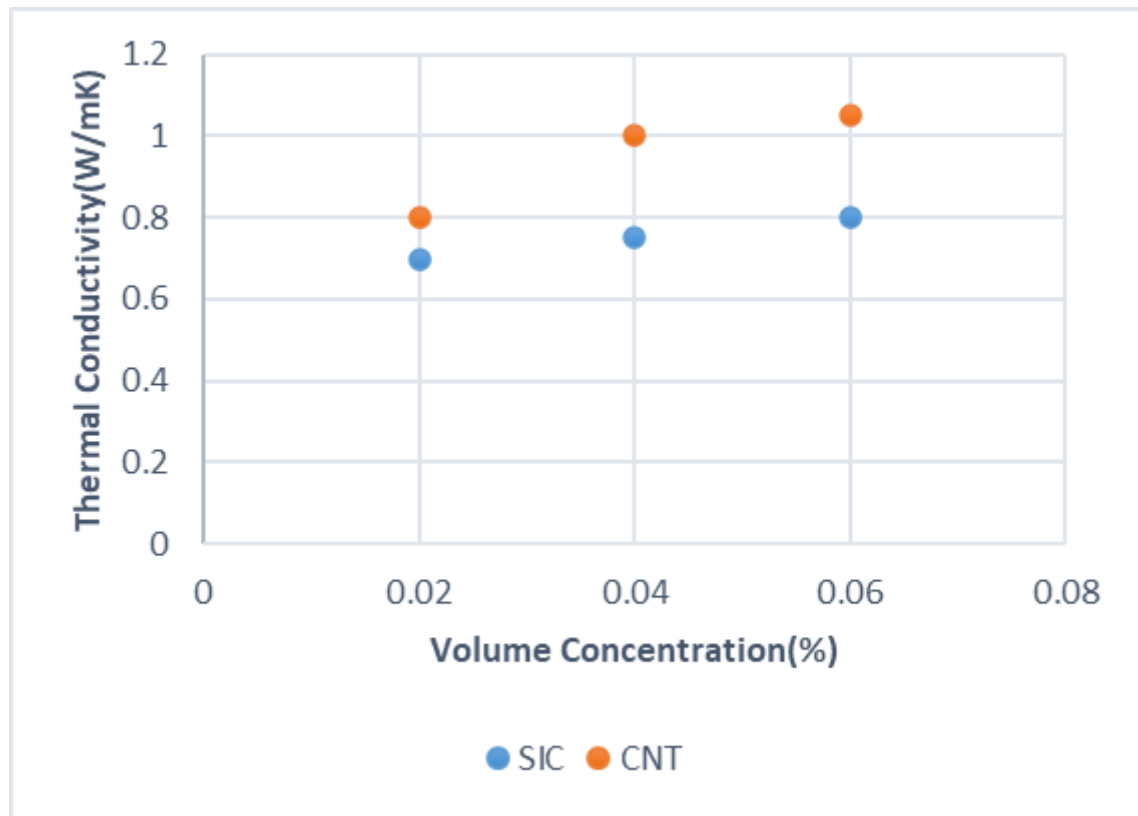


Fig. 4.2: Thermal conductivity of SiC Nanofluid and CNT

4.2 COMPARISON BETWEEN THE EXPERIMENTAL NUSSELT NUMBER AND THE CORRELATIONS

The experimental Nusselt number of the SiC nanofluid and CNT was compared with that of the Dittus [11], Pak et al. [24], Xuan et al. [22], Vajjha et al. [32], and Sharma et al. [29] correlations, given by Eqs. (1) – (5):

$$Nu = 0.023Re^{0.8} Pr^{0.4} \quad (1)$$

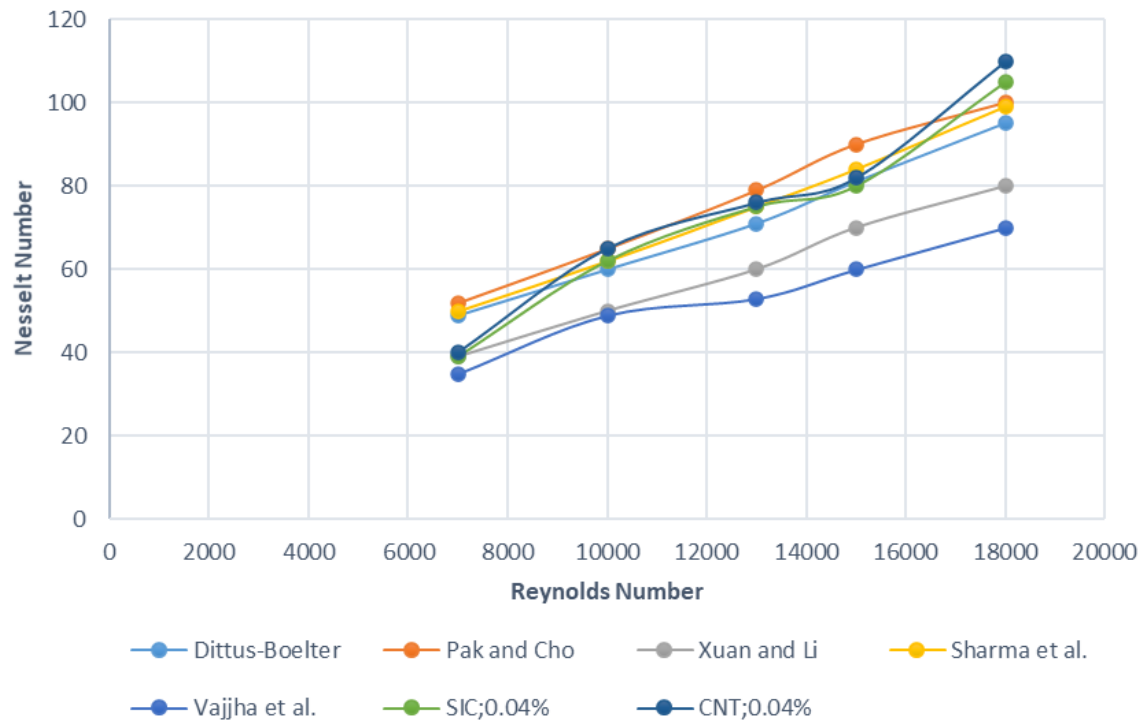
$$Nu = 0.021Re^{0.8} Pr^{0.5} \quad (2)$$

$$Nu = 0.059 (1.0 + 0.76286\phi_p^{0.6886} Pe^{0.001}) Pr_{nf}^{0.9238} \quad (3)$$

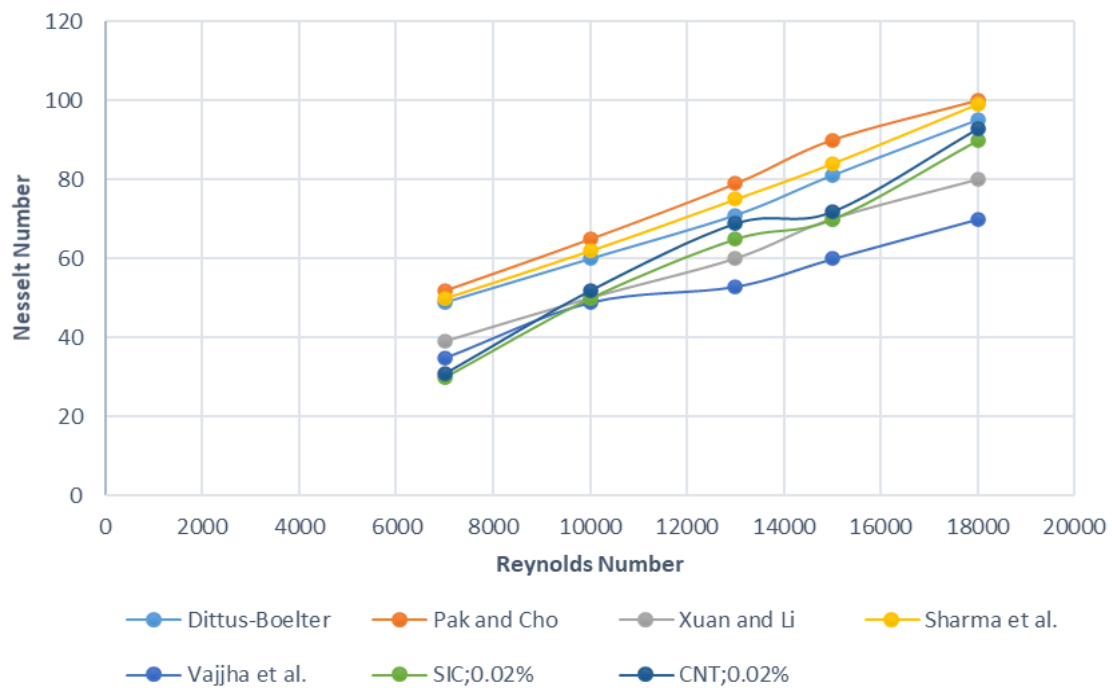
$$Nu = 0.065 (Re^{0.65} - 60.22) (1 + 0.0169\phi^{0.15}) Pr^{0.542} \quad (4)$$

$$Nu = 0.023Re^{0.8} Pr_w^{0.4} (1 + Pr_{nf})^{-0.012} (1 + \phi)^{0.23} \quad (5)$$

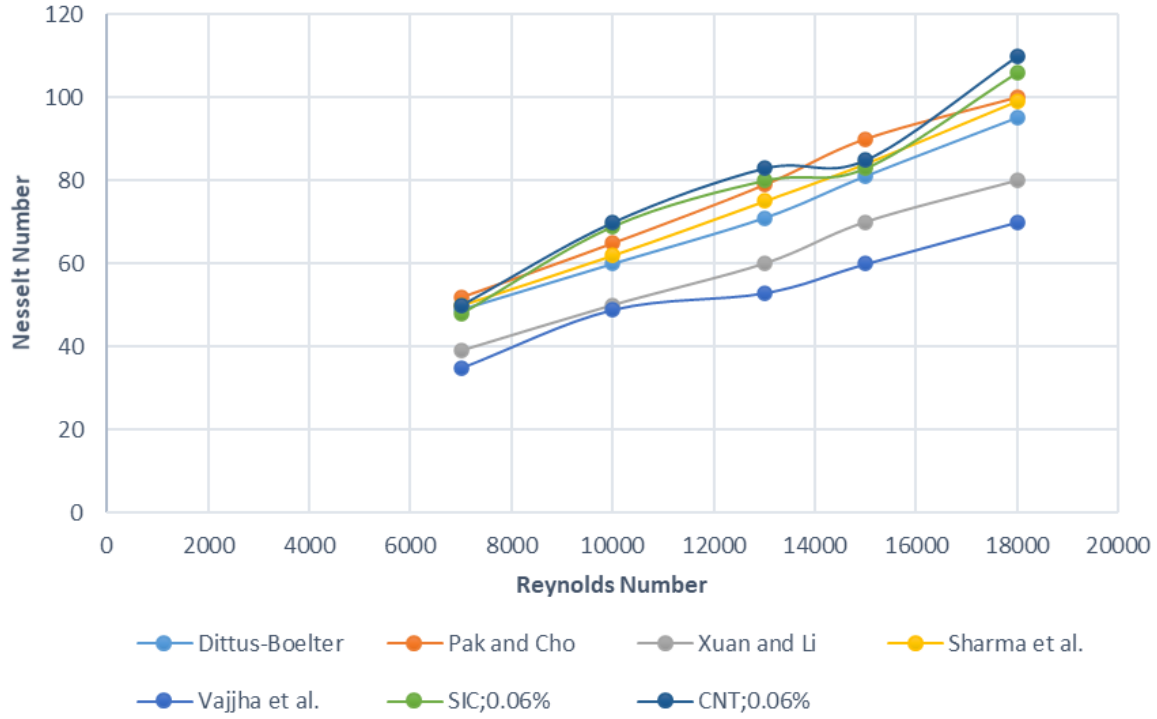
The comparison is presented for volume concentrations of 0.02%, 0.04%, and 0.06% SiC nanofluid and CNT in Figs. 4.3(a)–4.3(c). At the low volume concentration of 0.02%, the Xuan et al. [22] correlation predicted the experimental data with good agreement, while with an increase in the volume concentration, the Sharma et al. [29], Dittus [11], and Pak et al. [24] correlations predicted the experimental data well, with an average deviation of less than 15%. The Vajjha et al. [32] correlation, in general, resulted in a comparatively higher deviation of 23.4%, as shown in Figs. 4.3(a)–4.3(c). The average deviations of the Dittus [11], Pak et al. [24], Xuan et al. [22], and Sharma et al. [29] correlations compared with the experimental data, for the range of volume concentrations considered in the analysis.



(a)



(b)



(c)

Fig. 4.3: Comparison between the experimental Nusselt number and the correlations at 0.02% (a), 0.04%(b) and 0.06% (c)

4.3 COMPARISON BETWEEN THE FRICTION FACTOR AND THE CORRELATIONS

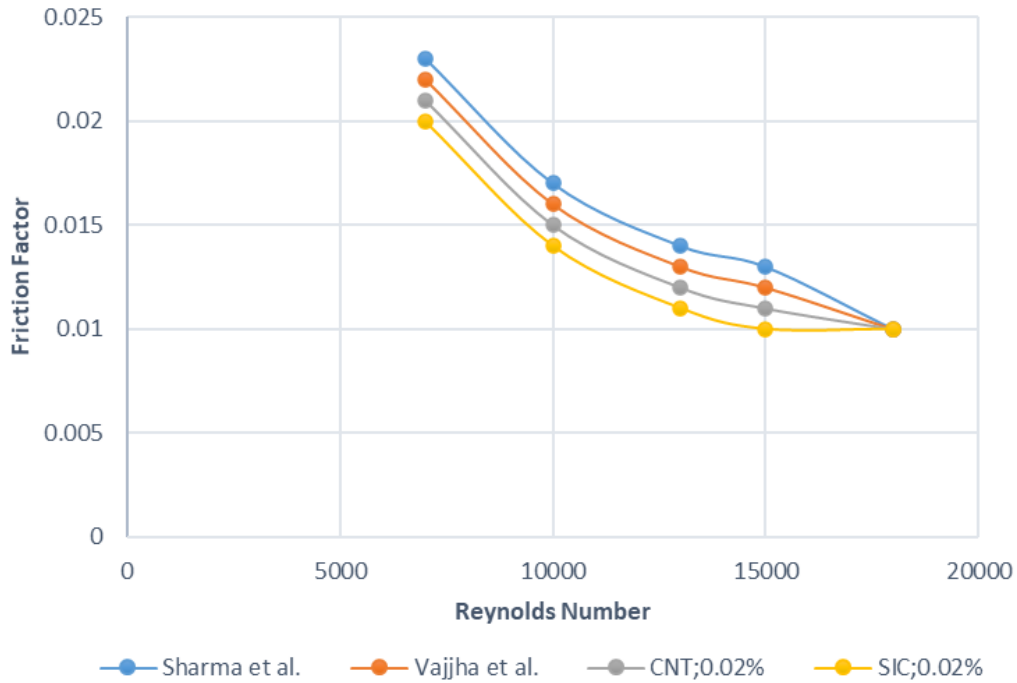
The experimental friction factor of the SiC nanofluid and CNT was compared with that of the Vajjha et al. [32] and Sharma et al. [29] correlations, given by Eqs. (6) and (7), respectively:

$$f_{nf} = f_{bf} [(\rho_{nf}/\rho_{bf})^{0.797} (\mu_{nf}/\mu_{bf})^{0.108}] \quad (6)$$

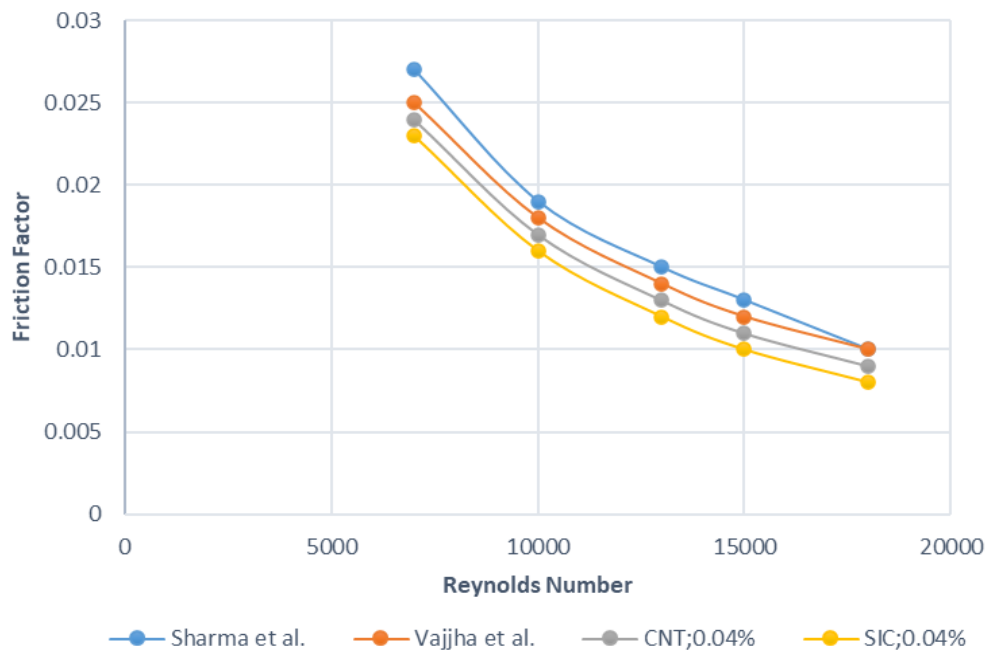
$$f_{nf} = f_{bf} [(\rho_{nf}/\rho_{bf})^{1.3} (\mu_{nf}/\mu_{bf})^{0.3}] \quad (7)$$

Figures 4.4(a)–4.4(c) show the comparison of the experimental friction factor of the 0.02%,0.04%, and 0.06% SiC nanofluid and CNT, respectively. The average deviations of the Vajjha et al. [33] and Sharma et al. [29] correlations with that of the experimental

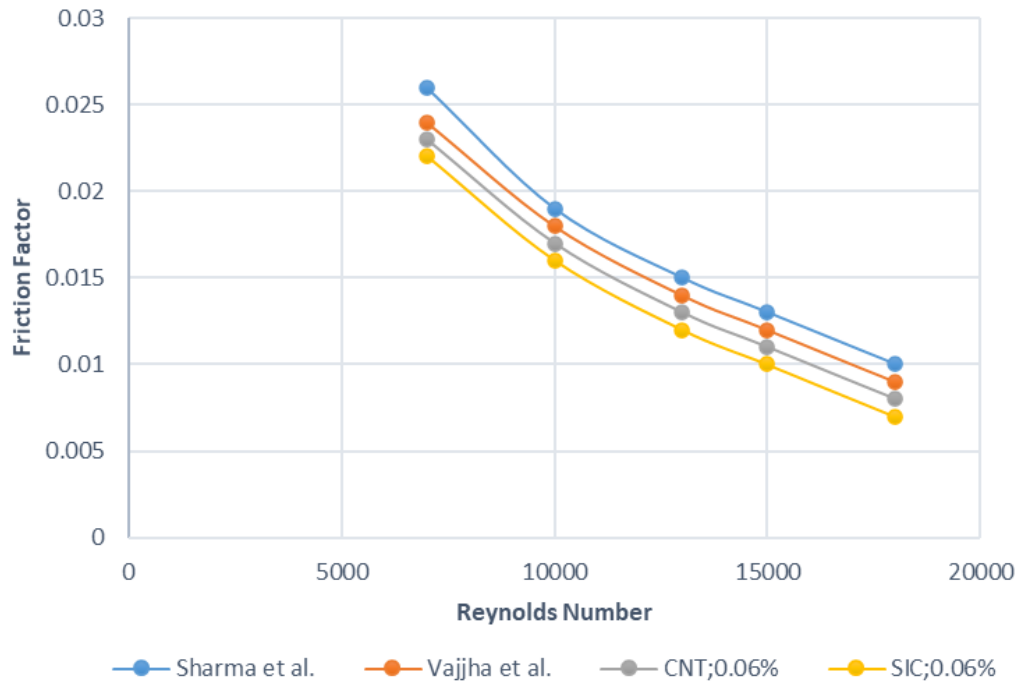
friction factor were observed. This shows that at all of the volume concentrations considered in the analysis, the correlations have predicted the experimental data with good agreement.



(a)



(b)



(c)

Fig. 4.4: Comparison between the experimental friction factor and the correlations at 0.02% (a), 0.04% (b) and 0.06% (c)

4.4 NUSSELT NUMBER AND HEAT TRANSFER COEFFICIENT OF THE SiC AND CNT NANOFLUIDS

Table 4.1 presents the thermophysical properties of the nanofluid. The enhancement in the thermophysical properties of the SiC nanofluid and CNT was reflected in the thermal performance of the heat exchanger. Figure 4.5 shows the variation of the Nusselt number of the SiC nanofluid and CNT with the Reynolds number. For the same flow rate, there was a significant decrease in the value of the Reynolds number of the SiC nanofluid compared to that of the CNT. However, the variation in the Reynolds number with the volume concentration was only marginal due to the very low volume concentrations considered in the analysis. At very low volume concentration of 0.02% of the SiC nanofluid and CNT, the average Nusselt number was observed to decrease

by 8.85%% and 13.92%, respectively. For a volume concentration of 0.04% and upward, the Nusselt number started to increase by a small percentage of 4.94% and was enhanced up to 22.82% for the 0.06% volume concentration. The Nusselt number represents the number of folds by which the heat transfer is enhanced by convection from that by conduction, due to the bulk fluid movement of the fluid. The decrease in the Nusselt number up to the 0.02% volume concentration and the small increase in the Nusselt number from 0.04% of the nanofluid compared to that base fluid is indicates that the dominant mode of heat transfer in the nanofluid is Brownian motion–induced conduction rather than bulk fluid motion–induced convection. In addition, there was also a decrease in the Reynolds number due to an increase in the viscosity, thus decreasing the Nusselt number further, due to convection. Therefore, the Nusselt number serves as a good indicator of heat transfer enhancement in relation to the effect of heat conduction induced by dispersed nanosized particles.

Table 4.1: Enhancement in the viscosity and thermal conductivity of the SiC nanofluid and CNT

Nanofluid	Volume Concentration (%)	Increase in Viscosity (%)	Increase in Thermal Conductivity (%)
SiC	0.02	14.7	29.22
	0.04	23.55	34.10
	0.06	31.40	36.85
CNT	0.02	16.8	30.26
	0.04	25.62	36.30
	0.06	33.45	39.20

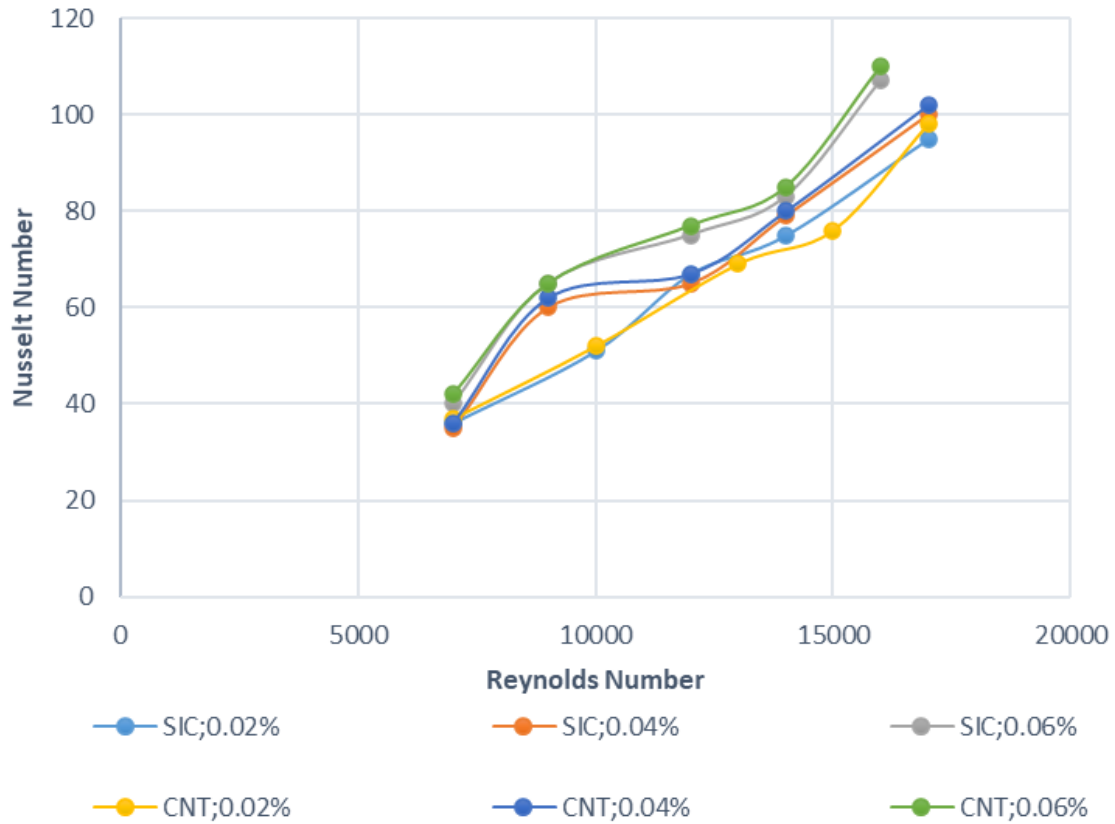


Fig. 4.5: Nusselt number of the SiC nanofluid and CNT

However, due to the variation of the Reynolds number, the representation of the variation of the Nusselt number with the Reynolds number does not appear to be a suitable means of comparing the thermal performance of different nanofluids. Similar observations were reported by Timofeeva et al. (2011). As a result, Timofeeva et al. [31] said that when comparing experimental and anticipated data for the same fluid and heat transfer coefficient in regard to the performance of nanofluids with varied thermal conductivities, the Nusselt number is the optimum metric to use. Figure 4.6 compares the heat transfer coefficients of the SiC nanofluid and CNT at the various flow rates evaluated in the study, demonstrating a constant increase in the heat transfer coefficient with increasing volume concentration and volume flow rate. As a result, the increase in the nanofluid's heat transfer coefficient is attributed to an increase in the heat exchanger's overall heat transfer coefficient as compared to the base fluid.

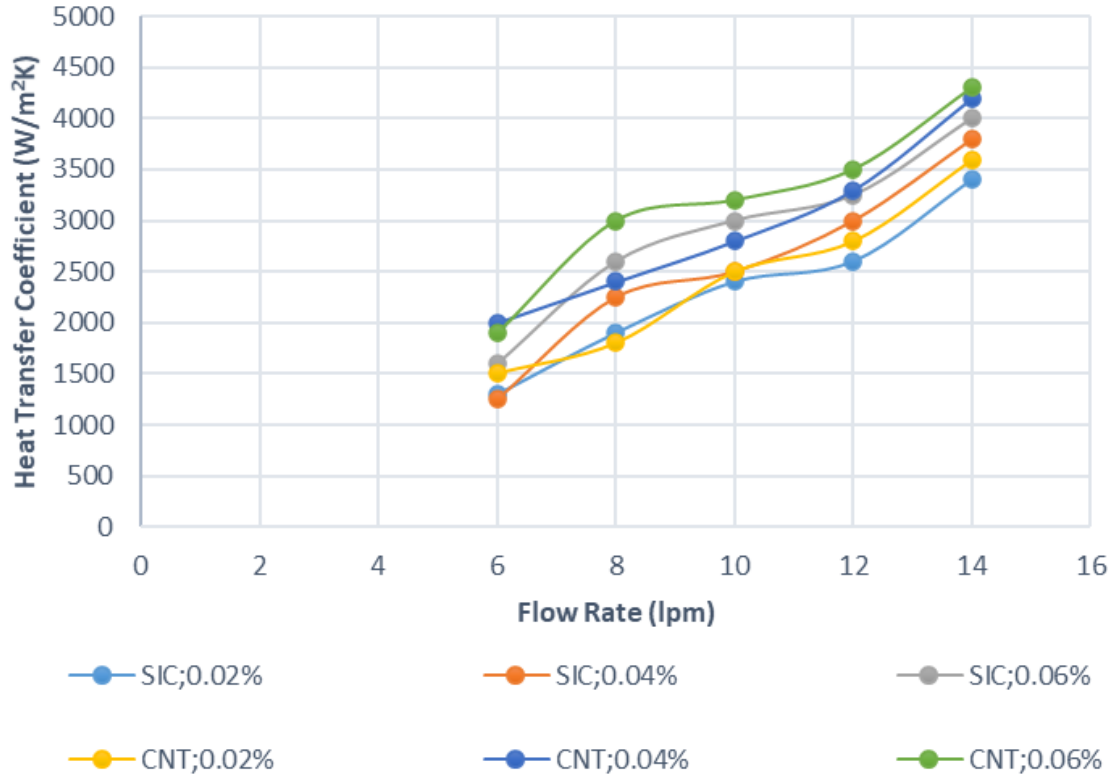


Fig. 4.6: Experimental heat transfer coefficient of the SiC nanofluid and CNT with the flow rate

4.5 FRICTION FACTOR OF THE SiC NANOFLUID AND CNT

The friction factor of the SiC nanofluid and CNT decreased with the Reynolds number, as shown in Fig. 4.7. The friction factor decreased as the rate of shear of the fluid within the boundary layer decreased with an increase in the Reynolds number. Due to a rise in the viscosity of the nanofluid with an increase in the volume concentration, the friction factor of CNT was higher than that of SiC Nanofluid for all of the volume concentrations evaluated in the analysis. However, at higher Reynolds numbers, the friction factor of the nanofluids was found to be nearly the same at all concentrations. This demonstrates that, at higher Reynolds numbers, turbulence, rather than differences in thermophysical characteristics, plays a primary role in determining the friction factor.

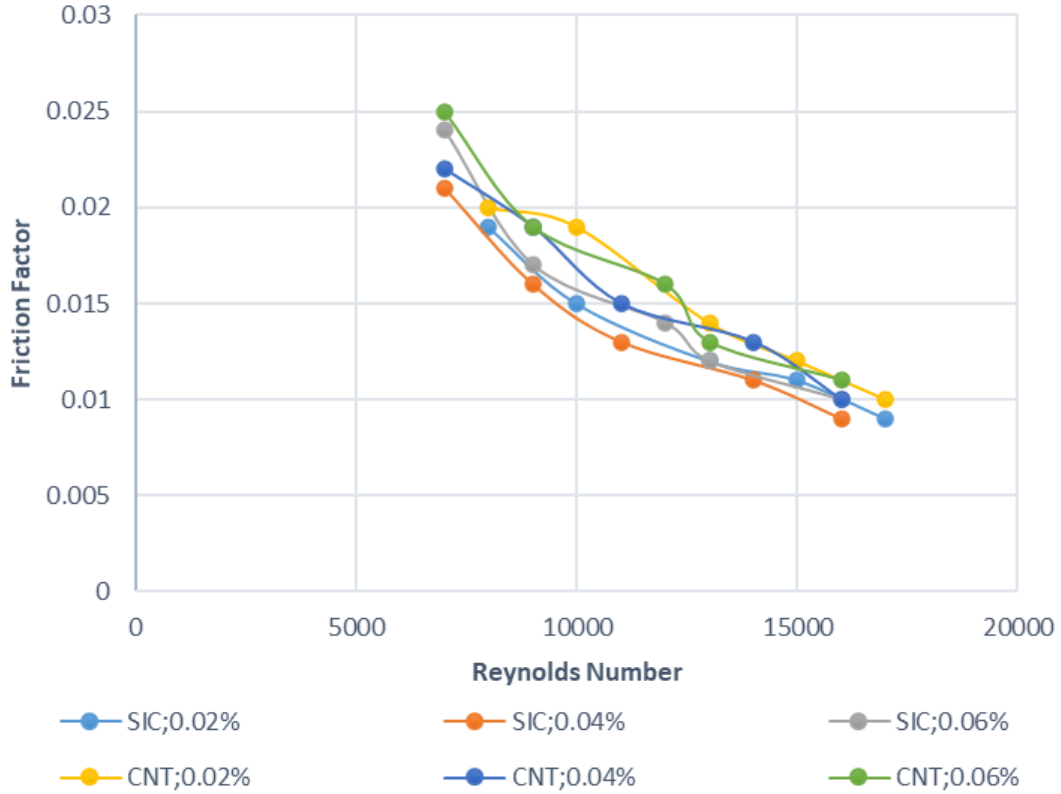


Fig. 4.7: Friction factor of the SiC nanofluid and CNT with the Reynolds number

4.6 PRESSURE DROP OF THE SiC NANOFLUID AND CNT

Figure 4.8 shows the variation of the pressure drop of the nanofluid with the flow rate since the pressure drop is the direct indicator of the pumping power requirement. The pressure drops of the SiC nanofluid and CNT increased with an increase in the volume concentration. To determine the relative effect of the heat transfer enhancement and pressure drop penalty, the thermal performance factor (η) was calculated using Eq. (8):

$$\eta = \frac{Nu_{nf}/Nu_{bf}}{(f_{nf}/f_{bf})^{1/3}} \quad (8)$$

Zarringhalam et al. [24] reported that the thermal performance factor (TPF) determines the acceptability of the nanofluid in practical applications. A TPF of above 1 represents

the usefulness of the working fluid in heat transfer applications with only a marginal pressure drop penalty. Figure 5.1 indicates the TPF of the SiC nanofluid and CNT at the different volume concentrations considered in the analysis. The TPF was observed to increase with an increase in the volume concentration of the nanofluid. For lower volume concentrations, in the range of 0.02% to 0.04%, the TPF was observed to be below 1, while for volume concentrations of 0.06% the TPF was above 1. These results show that the SiC nanofluid and CNT makes a good working fluid for volume concentrations of 0.06%. However, with heat transfer enhancement of 17.47%, even at a low volume concentration of 0.02%, the SiC nanofluid and CNT serves as a good heat transfer fluid.

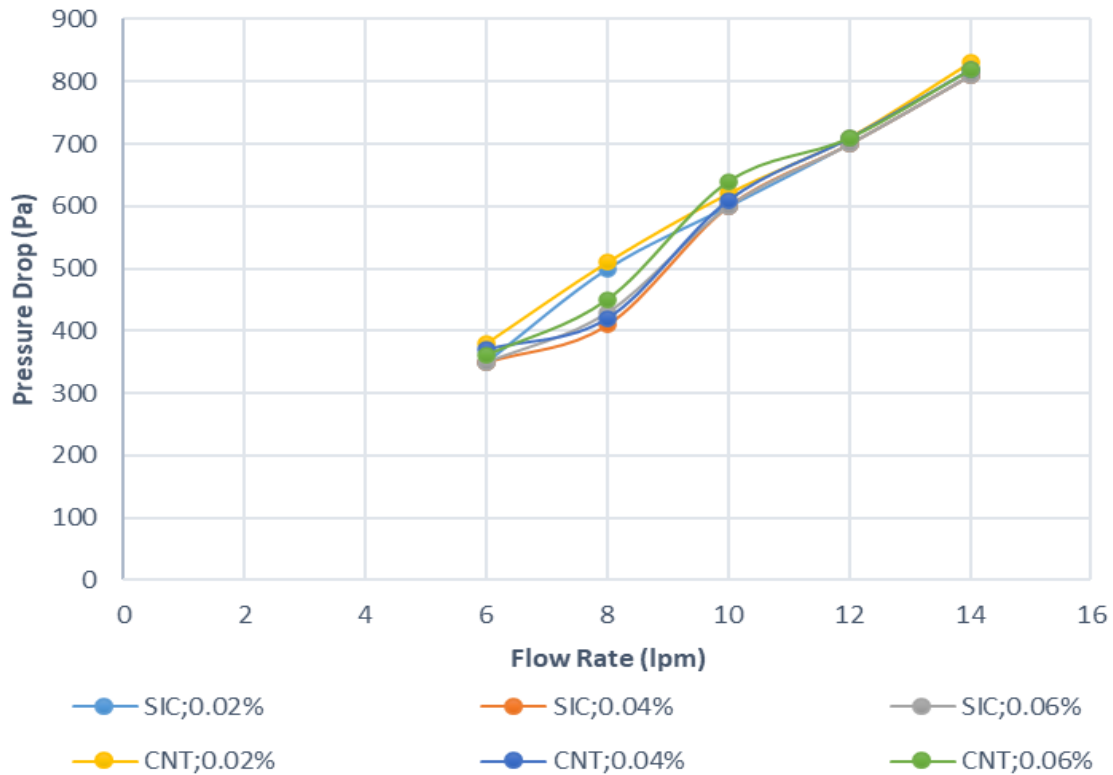


Fig. 4.8: Pressure drop of the SiC nanofluid and CNT with the flow rate

4.7 COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS OF SiC NANOFLUID AND CNT

Figure 4.9 represent the design of double pipe heat exchanger used for CFD analysis. Heat transfer and fluid flow characteristics of SiC and CNT based are studied. The movement nanofluids due to buoyancy force is observed during occurrence of natural convection inside the considered geometry. Contours for temperature distribution are shown in Fig. 4.10 and Fig. 4.11 for SiC Nanofluid and CNT respectively. Thermal stratification in this slice model can be observed.

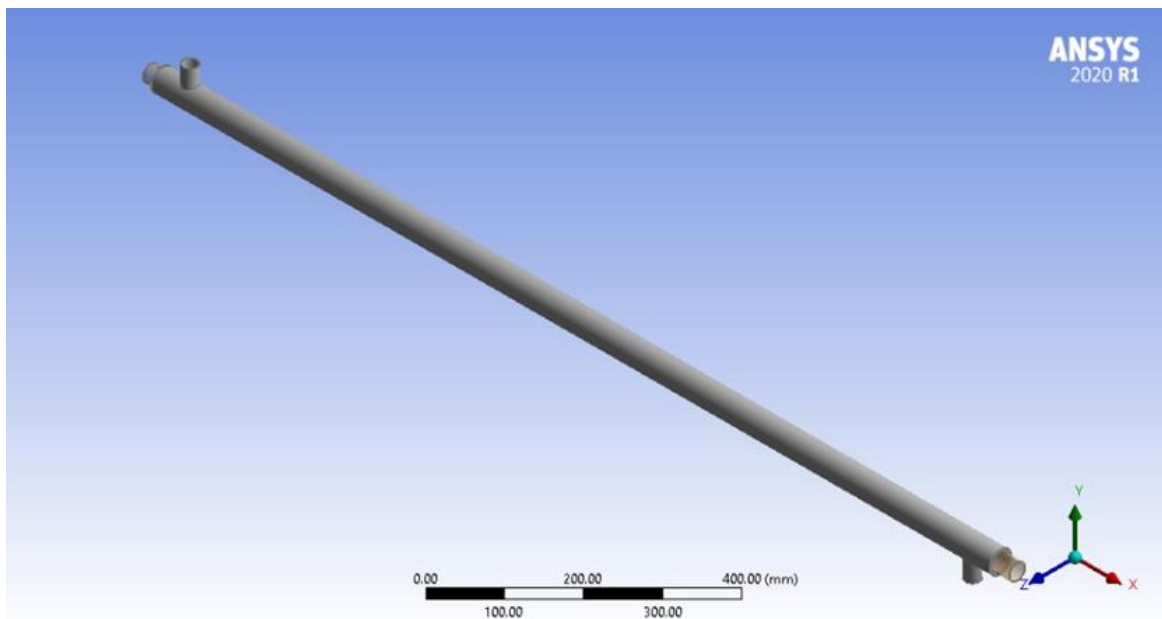
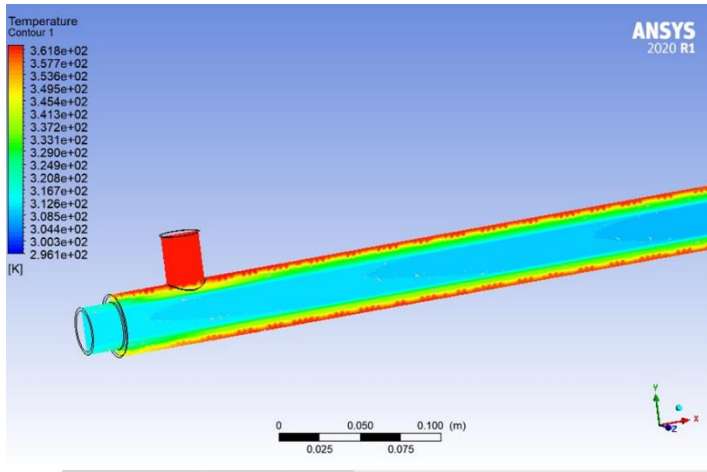
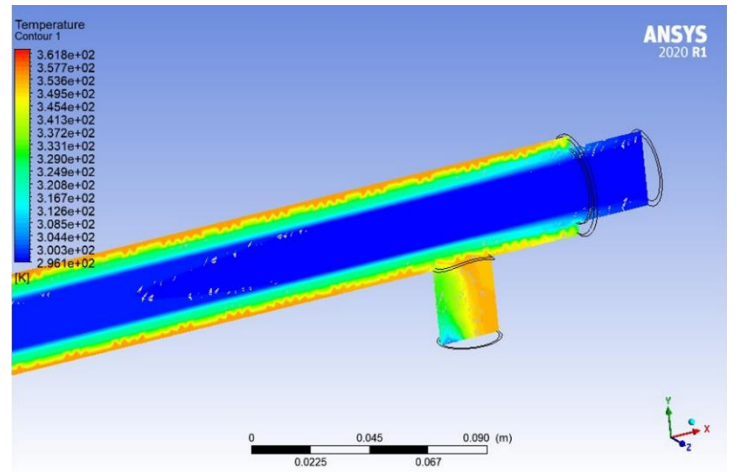


Fig. 4.9: Design of double pipe heat exchanger

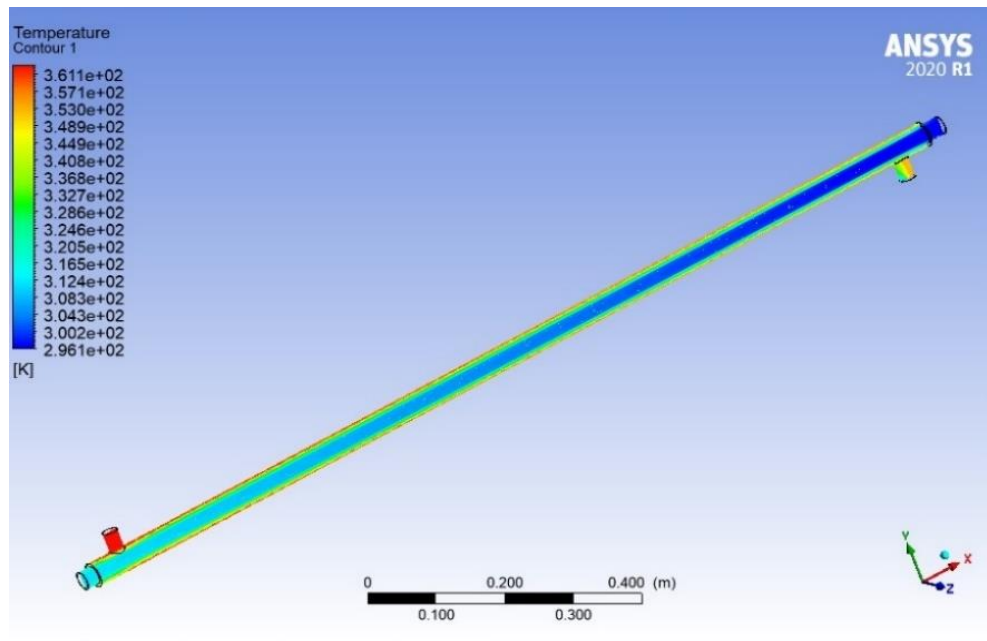
SiC nanofluid and CNT are both passed through the inner tube separately with an inlet temperature of 23 degree Celsius and at a constant velocity of 1m/s. Hot fluid is passed through the outer tube with an inlet temperature of 90 degree Celsius and at a constant velocity of 1m/s. Considerable amount of temperature drop is observed to the hot fluid with an outlet temperature of 72 degree Celsius when cold SiC nanofluid is passed through the model. Temperature of hot fluid at the right of the geometry is relatively lower than other sections. Similarly, rise in temperature of SiC nanofluid can be observed with an outlet temperature of 43 degree Celsius as shown in Fig. 4.10.



(a)



(b)



(c)

Fig. 4.10: Temperature contours of SiC nanofluid at left (a), right (b) and full section of geometry (c)

CNT exhibit slight improvement in flow patterns. Due to high density of fluid, buoyancy and velocity are affected that could be the reason for low rate of natural convection in SiC nanofluid. SiC has high density but low thermal conductivity as compared to CNT.

CNT based nanofluids are less affected due to low density as compared to SiC nanofluids. The CNT based fluid movements and directions due to natural convection in different parts of the slice model is shown in Fig.4.11. The obtained outlet temperature of CNT and Hot fluid are 48 degrees Celsius and 68 degrees Celsius respectively.

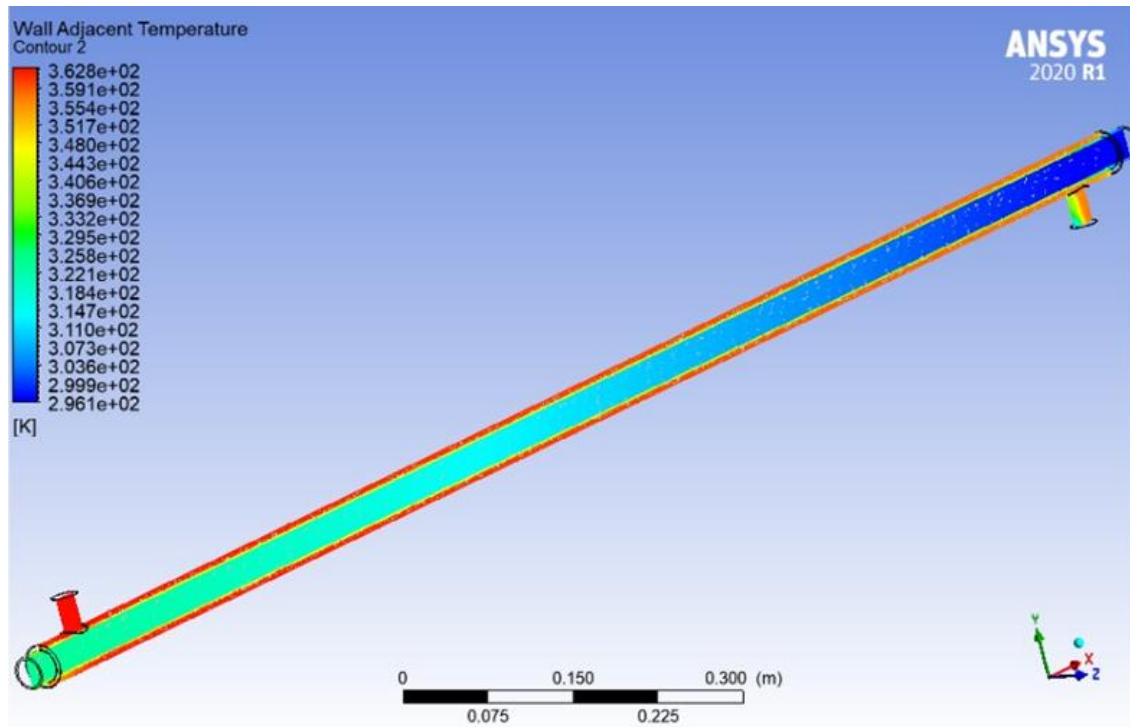


Fig. 4.11: Temperature contour of CNT

Figure 4.12 (a) and (b) shows the pressure contour distribution of SiC nanofluid at left and right section of the heat exchanger and similarly, Fig. 4.12 shows the pressure contour for CNT. By comparing these two we can observe and conclude that CNT shows higher pressure difference from inlet to outlet of the geometry. Fluid flow rates, pipe surface friction, the number of heat exchanger runs, bulk density, and viscosity all affect the pressure differential. If there are deposits, they lower the available surface area and raise the pressure differential, resulting in insufficient flow.

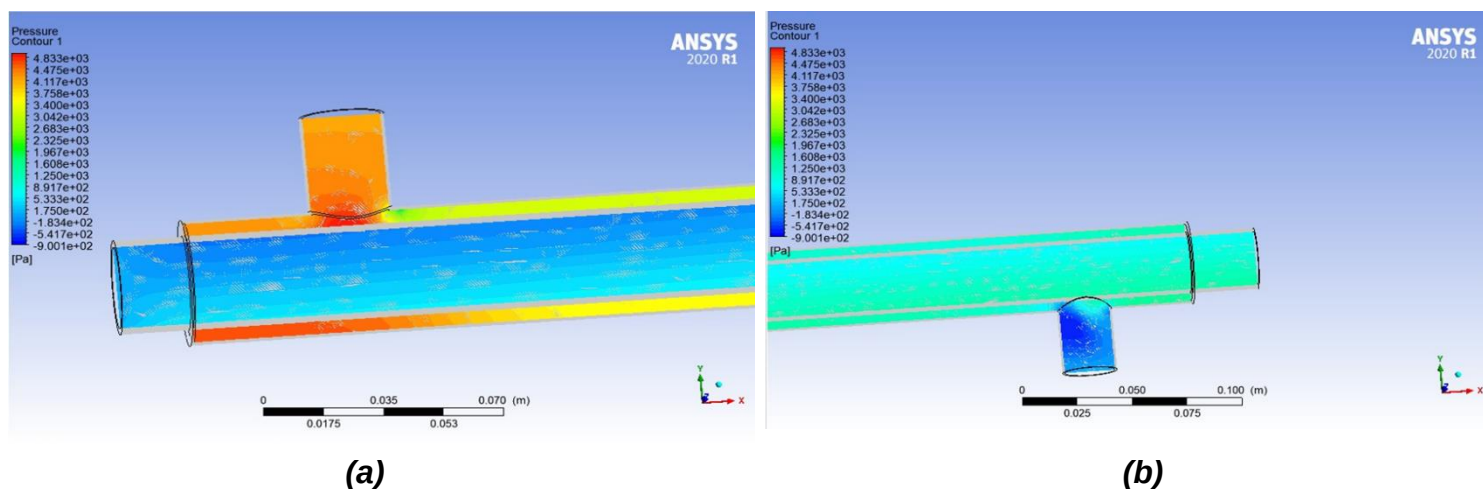


Fig. 4.12: Pressure contours of SiC nanofluid at left (a) and right (b) section of geometry

Experimental study aimed at achieving better control of the deposition patterns of carbon nanotubes (CNTs) is presented. The deposition patterns on the substrate were controlled for process times and carrier gas flow rates. In order to investigate the reaction mechanism and production rate for the growth of CNTs in catalyst CVD, computational fluid dynamics (CFD) model was developed in this study. Then the computational model was integrated with the dynamic model to optimize the process parameters formulating a correlation between turbulence, deposition rate for the growth of carbon nanotubes and parameters as process time and carrier gas flow rate. Scanning electron microscopes (SEM) are used to characterize carbon nanotubes products. The CNTs deposition profiles inside a chemical vapor deposition reactor are strongly dependent on the reaction temperatures, process time, feed gas flow rates, carrier gas flow rates and reactor geometry. Obtaining and optimizations of the simulation parameters propose generate a high degree of purity in the samples. This type of optimization becomes more and more difficult with an increasing number of design parameters. The advent of computing power reaching at relatively low cost has spurred the development of numerical models.

The CNTs deposition profiles inside a chemical vapor deposition reactor are strongly dependent on the reaction temperatures, process time, feed gas flow rates, carrier gas flow rates and reactor geometry. Obtaining and optimizations of the simulation parameters propose generate a high degree of purity in the samples. This type of optimization becomes more and more difficult with an increasing number of design parameters. The advent of computing power reaching at relatively low cost has spurred the development of numerical models. The distribution of pressure can be observed in the Figure 4.13. The influence of turbulence in the second furnace has a relation with purity of CNTs. With lower turbulence there are better results with groups of aligned CNTs such as shown in Figure 4.13. It can be obtained better results. This means less impurity and larger nanotubes with lower velocity of flow as observed.

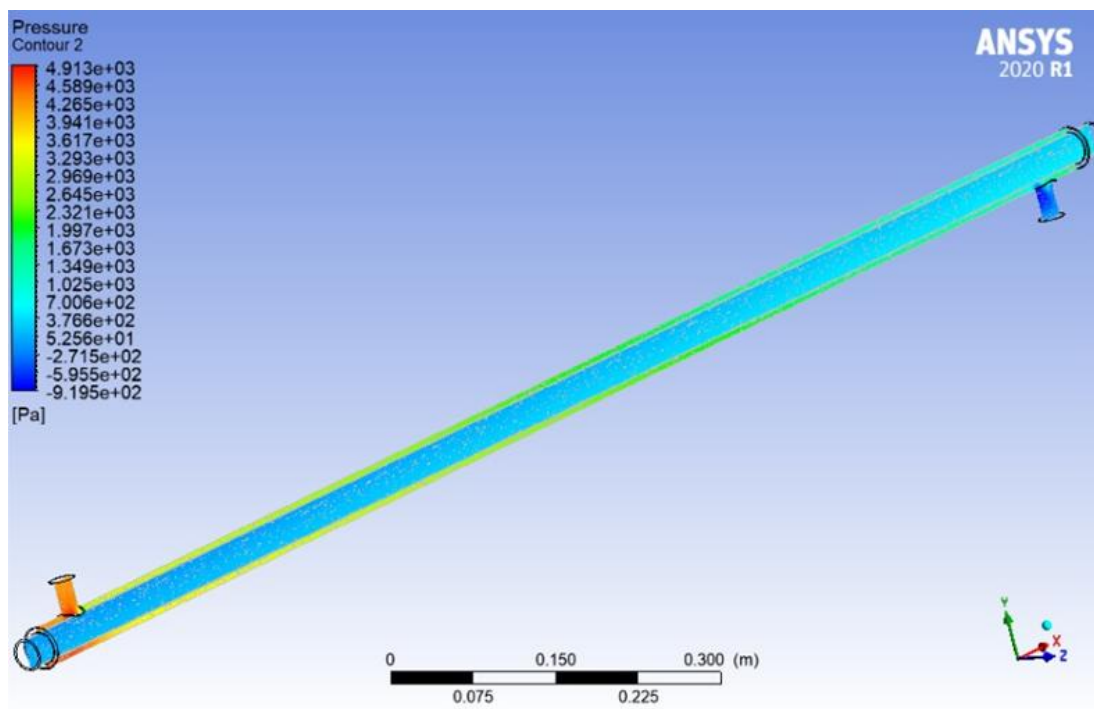


Fig. 4.13: Pressure contours of CNT

CHAPTER 5

CONCLUSION

Figure 5.1 shows the thermal performance factor of SiC nanofluid and CNT for various concentrations. The heat transfer and flow aspects of the SiC nanofluid and CNT were experimentally analyzed in a DPHE for very low volume concentrations in the range of 0.02%–0.06% at the operating temperature of 35°C. The following inferences can be drawn from the analysis:



Fig. 5.1: Thermal performance factor of the SiC nanofluid and CNT

- At very low volume concentrations of up to 0.06%, significant enhancement of the thermophysical properties is observed for the SiC nanofluid and CNT.
- The correlations available in the literature for the Nusselt number and friction factor of nanofluids have predicted the experimental data with good agreement; in particular, the Sharma et al. and Vajjha et al. correlations.

- For the volume concentrations of the SiC nanofluid and CNT considered in the analysis, the enhancement in the heat transfer was predominantly due to Brownian motion–induced heat conduction compared to that of bulk fluid motion–induced convection.
- An average enhancement of 55.29% in the heat transfer coefficient was obtained with the 0.06% SiC nanofluid and 66.34% with the CNT, thus presenting the excellent heat transfer aspects of the CNT nanofluid as a working fluid, even at low volume concentrations of less than 0.1%.
- For the volume concentrations considered in the analysis, the maximum thermal performance factor obtained was 1.148 for a volume concentration of 0.06% of the SiC and 2.243 for CNT at a Reynolds number of 9000.
- CNT exhibit better temperature and pressure distribution contours than SiC nanofluid due to low density and higher thermal conductivity.

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