UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

HEAT TRANSFER PERFORMANCE OF DOUBLE PIPE HEAT EXCHANGER USING Al_2O_3/WATER AND TiO_2/WATER NANOFLUIDS

Master Thesis

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Institute of Science and Technology

Mechanical and Aeronautical Engineering Department

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STATEMENT OF NON-PLAGIARISM PAGE

I hereby declare that all the information in this study I presented as my Master's Thesis, called "**Heat Transfer Performance of Double Pipe Heat Exchanger Using Al_2O_3/Water and TiO_2/Water Nanofluids**" has been presented in accordance with the academic rules and ethical conduct. I also declare and certify on my honor that I have fully cited and referenced all the sources I made use of in this present study.

Mohanad AL-SAMMARRAIE

14.12.2018

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December 2017 Mohanad Nazar AL-SAMMARRAI

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ABSTRACT

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The modern heat transfer science ends to use small and more effective devices by developing heat transfer methods/ in order to get best results. Double pipe heat exchanger (DPHE) is considered to be one of the most important types of exchangers of heat which was used in various industrial fields. In order to increase the efficiency of such heat exchangers, many researchers have proposed different heat transfer techniques. One of these techniques is replacing the base fluid with another kind of fluid which has better heat specifications, called the nanofluids.

The main aim of this study is to investigate experimentally the effect of adding Al_2O_3 and TiO_2 nanoparticles to deionized water as a base fluid on the horizontal counter flow double pipe heat exchanger's performance under turbulent flow conditions. The test rig consists of a hot liquid loop, cold liquid loop and the test section of double pipe heat exchanger with 0.8m length. The inner tube is made out of copper with a diameter of 16mm. The outer tube is made of iron with a diameter of 36mm. The hot water flows through the outer tube and the cold liquid (nanofluids) flow through the inner tube. Several experiments were conducted under current nanofluid volume concentrations (0.1, 0.2 and 0.3%) and under several flow rate ranges (2.5, 3, 3.5, 4 and 4.5 LPM) at the cold loop (nanofluids) and constant flow rate at (7 LPM) at the hot loop (pure water). When comparing the experimental results of

TiO_2/water, pure water, and Al_2O_3/water, we can observe, that the values of Nusselt number, Reynolds number, heat transfer coefficient and the overall heat transfer coefficient were increased when the rate of mass flow was increased, furthermore, they were increased directly with an increase of volume concentration (0.1, 0.2 and 0.3%) of nanofluids. Finally, it was declared that all the values of the properties which were mentioned in above were better in Al_2O_3/water (distilled water) nanofluids than in TiO_2/water (distilled water) nanofluids and water, respectively.

Keywords: Double pipe heat exchanger (DPHE), Al_2O_3/water and TiO_2/water Nanofluids, Nusselt Number, Heat Transfer Coefficient, Overall Heat Transfer Coefficient.

ÖZET

Al_2O_3/SU VE TiO_2/SU NANOAKIŞKANLARININ KULLANILDIĞI ÇİFT BORULU ISI EŞANJÖRÜNÜN ISI AKTARIM PERFORMANSI

AL-SAMMARRAIE, Mohanad
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Modern ısı aktarımı bilimi, en iyi sonuçları elde etmek adına ısı aktarım metotlarını geliştirerek daha küçük ve daha etkili cihazları kullanmayı maksat edinmektedir. Çift borulu ısı eşanjörü, muhtelif endüstriyel alanlarda kullanılan en önemli ısı eşanjörlerinden biri olarak ele alınmaktadır. Bu türdeki ısı eşanjörlerinin verimliliğini artırmak amacıyla birçok araştırmacı farklı ısı aktarım tekniklerini önermiş bulunmaktadır. Bu tekniklerden biri de; ana akışkanı, daha iyi bir ısı spesifikasyonlarına sahip olan nanoakışkanlar olarak adlandırılan başka bir tür akışkan ile değiştirmektir.

Bu çalışmanın esas amacı, türbülanslı akım altında yatay ters akışlı çift borulu ısı eşanjörünün performansındaki bir ana akışkanı olarak deiyonize suya Al_2O_3 ve TiO_2 nanopartiküllerinin etkisinin deneysel olarak araştırılmasıdır. Test donanımı, bir sıcak sıvı kavisinden, soğuk su kavisinden ve 0.8 uzunluklu çift borulu ısı eşanjörünün test kısmından meydana gelmektedir. İç boru, 16 mm çaplı sahip bir bakırdan imal edilmiştir. Dış boru, 36 mm çaplı demirden imal edilmiştir. Sıcak su, dış boru üzerinden ve soğuk su (nanoakışkanlar) da iç boru üzerinden akar. Soğuk kavis (nanoakışkanlar) ve sıcak kavis (saf su)'deki sabit akış oranında (7 LPM) mevcut nanoakışkan hacmi konsantrasyonları (% 0.1, 0.2 ve 0.3) altında ciddi akış oranı aralıkları (2.5, 3, 3.5, 4 ve 4.5 LPM) altında birkaç deney gerçekleştirilmiştir.

TiO_2/su, saf su ve Al_2O_3/suyun deneysel sonuçlarını kıyasladığımızda; Nusselt sayısı, Reynolds sayısı, ısı aktarım katsayısı ve genel ısı aktarımı katsayısı değerlerinin, kütle akış oranının arttığında artmış olduğu ve hatta bunların nanoakışkanların (% 0.1, 0.2 ve 0.3)'lik bir hacim artışıyla direkt olarak artmış olduğunu gözlemleyebilmekteyiz. Sonuç olarak; yukarıda belirtilen özelliklerin tüm değerlerinin, sırasıyla Al_2O_3/sudaki (distile su) nanoakışkanlarında, TiO_2/sudaki (distile su) nanoakışkanları ve sudan daha iyi olduğu tanımlanmıştır.

Anahtar Sözcükler: Çift borulu ısı eşanjörü, Al_2O_3/su ve TiO_2/su Nanoakışkanları, Nusselt Sayısı, Isı Aktarım Katsayısı, Genel Isı Aktarım Katsayısı

NOMENCLATURE AND SUBSCRIPTS

1. NOMENCLANTURE

$Q_{\cdot bf}$	:	The total heat transfer of base fluid (water)
$m^{\circ}{}_{\cdot bf}$	:	Mass flow rate of baes fluid, L/s
$C_{p.bf}$	:	The specific heat of water (base fluid), J/kg K
$T_{bf.out}$	:	Outlet temperature of base fluid, °C
$T_{bf.in}$	:	Inlet temperature of base fluid, °C
T_{ave}	:	Average temperature, °C
V	:	Inside mean velocity, m/s
ρ	:	Density, kg/m^3
d_i	:	Tube inner diameter, m
V°	:	Volume flow rate, m^3/s
A_c	:	Cross section area, m^2
A_s	:	Surface area, m^2
L	:	Length, m
D	:	Tube diameter, m
Re	:	Reynolds number
υ	:	Kinematic viscosity, m^2/s
Nu	:	Nusselt number
μ_{bf}	:	The dynamic viscosity of water (base fluid), kg/m.s
k_{bf}	:	Thermal conductivity of base fluid (water), W/m.k
Pr	:	Prandtl number
h	:	The heat transfer coefficient, W/m^2 k
U_i	:	Overall heat transfer coefficient, W/m^2 k
ΔT_{lm}	:	Logarithmic mean temperature difference °C

$\mathbf{Q_{nf}}$	:	The heat transfer rate of the nanofluid, W
$\mathbf{m^{\circ}_{nf}}$	:	The mass flow rate of nanofluid, L/s
$\mathbf{T_{i.nf}}$	:	Inlet temperature of nanofluid, °C
$\mathbf{T_{o.nf}}$	:	Outlet temperature of nanofluid, °C
$\mathbf{T_{c1}}$	:	Inlet temperature of cold fluid (nanofluid), °C
$\mathbf{T_{c2}}$	:	Outlet temperature of cold fluid (nanofluid), °C
$\mathbf{T_{h1}}$	:	Inlet temperature of hot fluid (water), °C
$\mathbf{T_{h2}}$	:	Outlet temperature of hot fluid (water), °C
$\mathbf{C_{p.nf}}$	:	The specific heat of nanofluid, J/kg
$\boldsymbol{\rho_{nf}}$	:	The density of nanofluid, kg/m^3
$\boldsymbol{\phi}$	:	Volume concentration of nanofluid
$\boldsymbol{\rho_{bf}}$	:	The density of base fluid (water), kg/m^3
$\boldsymbol{\rho_{np}}$	:	The density of nanoparticles, kg/m^3
$\mathbf{C_{p.np}}$	:	The specific heat of nanoparticles, J/kg K
$\mathbf{Re_{nf}}$	:	Reynolds number of nanofluid
$\boldsymbol{\mu_{nf}}$	:	Dynamic viscosity of nanofluids, kg/m.s
$\mathbf{Pr_{nf}}$	:	Prandtl number of nanofluid
$\mathbf{k_{nf}}$	:	The thermal conductivity of nanofluids, W/m.k
$\mathbf{Nu_{nf}}$	:	Nusselt number of nanofluid
$\mathbf{h_{i.nf}}$	:	The heat transfer coefficient of nanofluids, W/m^2. k

2. SUBSCRIPTS

n(in) **:** nanofluid inlet

n(out) **:** nanofluid outlet

b.f. **:** base fluid

n.p. **:** nanoparticles

n.f. **:** nanofluid

CHAPTER ONE

INTRODUCTION

This chapter aims to introduce some important background information about heat transfer field, heat exchangers and their types as well as the recognition of nanotechnology, nanoparticles, and nanofluids and their effect on heat transfer.

1.1 Motivation

There is a potential quest for more efficient, new heat transfer devices with higher power output and small size systems [1]. Based on this fact, scientists and engineers are inventing new approaches/techniques/technologies to save energy and meet the increasing world's demand for energy. Heat base fluids including water, ethylene glycol, and minerals oil play a critical function in many industrial methods, inclusive of power technology, chemical tactics, cooling and heating techniques, microelectronics, and transportation. These fluids still suffer from low heat transfer effectiveness in various applications. Thusly, a vital necessity nevertheless exists to develop new methods to be able to improve the powerful heat transfer behaviors of the generally used fluids.

An innovative manner of improving the thermal conductivities of conventional fluids is adding small particles to the fluids [2]. These particles may be made from metals, metal oxides, and non-steel materials. But, slurries having suspended particles of the order of a micrometer or maybe millimeter may purpose some extreme troubles. The abrasive movement of the particles causes eroding of pipelines, blockage of waft channels and a discount of their momentum transfer which will increase the pressure drop in some applications [2]. This is in addition to the tendency of particles to settle speedily out of the suspension. Despite the fact that these slurries contain higher thermal conductivities than ones used as traditional heat transfer fluids, they are still not suitable to be applied as warmth switch fluids for realistic applications. Therefore, to overcome the above obstacles and to further enhance the heat transfer performance, it is important to find new, effective, and convenient approaches. One of the most effective approaches is to replace the base fluid (water) with a higher thermal conductivity fluid containing solid nanoparticles in nanoscale known as nanofluids [2].

1.1 Heat Transfer

Heat transfer is considered as a branch of thermal engineering that focuses on conversion, generation, usage, and exchanging heat between physical systems. Heat can be transferred by a different mechanism such as radiation, convection, conduction, and energy transfer by changing of phase. Heat transfer plays a critical role in various industrial applications such as automotive industry, power plants, thermal management of electrical and electronic systems, and petroleum refinery [3]. In most of these disciplines, heat transfer is done through some units of heat transfer or apparatuses such as evaporators, heat exchangers, condensers, heat sinks among others. Engineers focus on heightening the thermal efficiency of these devices or units to meet the requirements of manufacturing compact, lightweight, and efficient devices with saving energy [4].

1.2 Heat Exchangers

A heat exchanger is a medium that transfers heat energy from a (hot to cold) fluid without mixing them together. Heat exchangers are utilized in many engineering processes, chemical, and electrochemical plants, air conditioning, space heating, refrigeration, and power stations [3-4]. There are diverse types of heat exchangers such as double pipe heat exchanger and plate heat exchanger as shown in Fig. (1.1a and 1.1b). The Double pipe heat exchanger is the simplest and cheapest exchangers for both design and maintenance utilized in the industry, which makes it a good choice for small industries. However, it suffers from a low efficiency associated with the high space required in large scales, has resulted in a great potential of finding an approach or technology that enhances its thermal efficiency [5].

One of these approaches is to introduce nanoparticles of materials with high thermal conductivity to the base fluid. The resulted fluid can be called nanofluid. Recently, there is a great trend in using nanofluids in most applications, and one of these applications is the double pipe heat exchangers. Engineering and science of nanotechnology have brought about a significant and clear evolution in the Technological and scientific developments in nanoparticles, nanostructured, materials, nanodevices, and systems [1].

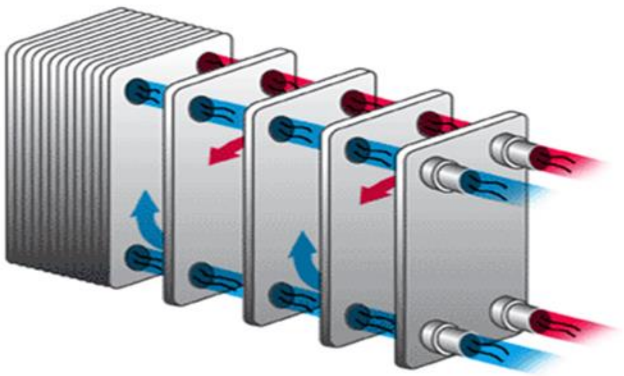


Figure 1.1a: plate heat exchanger.

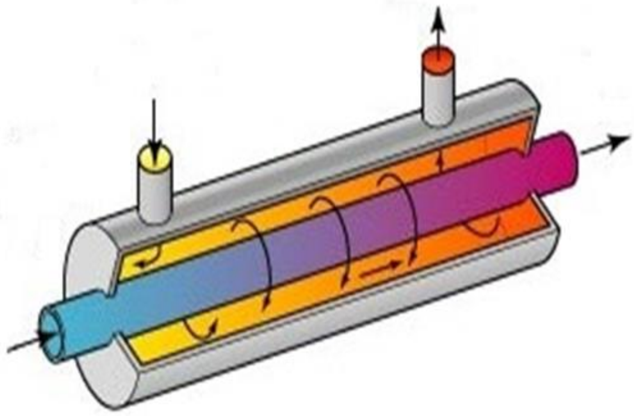


Figure 1.1b: Double Pipe Heat Exchanger.

Figure 1.1: Heat transfer exchangers (a) plate heat exchanger and (b) double pipe heat exchanger.

1.4 Nanotechnology

The National Nanotechnology Initiative (NNI) provides a definition for the nanotechnology which is: "Nanotechnology is the information and control of count at dimensions of roughly 1 to 100 nanometers, where unique phenomena allow novel applications. Encompassing nanoscale science, nanotechnology involves imaging, engineering, and technology, modeling, measuring, and manipulating remember at this duration scale [5-6]." The nanostructured materials can be nanoparticles, nanowires, nanotubes, nanorods, nanoporous materials, and many other structures. In this study, we will focus on the nanoparticles for the nanofluid preparation [6].

At the Nano level, the biological, chemical and physical properties of materials differ invaluable and fundamental aspects of the characteristics of individual molecules and atoms or bulk matter [5]. The Nanotechnology research and development (R&D) is steered towards understanding improved devices, materials, and systems which take advantage of these novel properties as well as creating them.

1.4.1 Nanoparticles

Nanoparticles are ultra-small objects with dimensions measured in nanometers (nm) between 1 and 100 nm in size. Nanoparticles are typically considered as zero-dime national materials with no dimension more than 100 nm. There is a great scientific interest in using the nanoparticles and they are considered as a link connecting bulk materials and molecular or atomic structures. At the Nano level, the properties which rely on size are often noticed, while a bulk material must contain constant physical characteristics that do not rely on its size. Thus, the change occurring in the characteristics of materials happens due to their size reaching more to the nanoscale as well as the surface percentage relative to the volume percentage of a material becoming more substantial. For the case of bulk materials having a size of more than one micrometer (or single micron), the surface percentage is inconsequential relative to the volume of the material bulk. The characteristics of nanoparticles that are interesting and often unexpected are thus mostly because of the large material surface area, which governs the contributions created by the small material bulk [6].

1.4.2 Nanofluid Technology and Applications

A Nanofluid is a mix of particles of nano-size with a base fluid as shown in Fig. (1.2). Conventional nanoparticles are made of carbides, oxides or metals, while base fluids could be oil, ethylene glycol or water. The nanofluid exhibits diverse thermophysical properties than that of the base fluid. Generally, nanofluids have higher thermal conductivity than base fluids, which in turn, increases the rate of heat transfer [7]. For example, when the aluminum or titanium or copper oxide nanoparticles is mixed with base fluid, the resulted fluid has better thermophysical properties than base fluid. The amount of mixing nanoparticles with the base fluid depends on the application of the equation (3.1) [22]. The Concentration and size of the nanoparticles in base fluids are vital in enhancing the heat transfer in the heat exchangers. In recent times, numerous research works have been conducted to understand and describe the effects of adding the nanoparticles to the base fluids on the efficiency of heat exchangers [7].

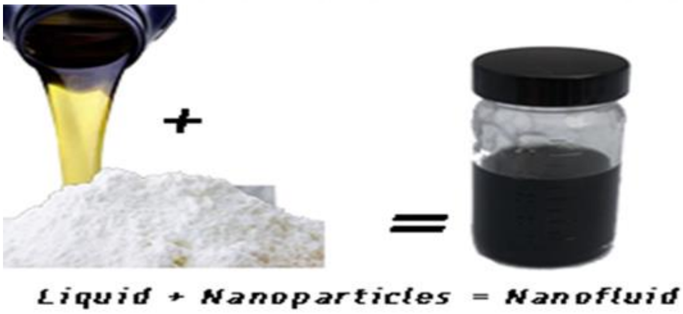


Figure 1.2: A mixture of nanoparticles with a base fluid is known as nanofluid.

1.5 The Objective of this thesis

The contemporary inclinations of miniaturizing devices and intensifying processes have caused developing alternate and more effective methods of heat dissipation from microelectronics packages and systems. The typical methods of heat removal have been seen to be rather ineffective when used in high intensities of fluxes of heat. Various researchers proposed different techniques of heat transfer in order to increase and enhance the efficiency of the heat transfer systems. One of these techniques is to replace the base fluid with nanofluid. Hence, the novelty of this study is to investigate experimentally the effect of adding TiO_2 and Al_2O_3 nanoparticles to the distilled water as a base fluid on the performance of a horizontal counter flow double pipe heat exchanger under turbulent flow conditions. Several experiments were conducted under current nanofluid concentrations (0.1-0.3%) and under several flow rate ranges (2.5, 3, 3.5, 4 and 4.5 LPM). The experiments will be carried out on a number of nanofluid systems; varying the type and concentration of nanoparticles. Finally, the effect of flow rate of the nanofluid on the heat transfer rate, the overall heat transfer coefficient, the heat transfer coefficient and the Nusselt number are studied.

In addition, and at the same time period and the same experimental system has studied the investigation experimentally the effect of adding TiO_2 and Al_2O_3 nanoparticles to the distilled water as a base fluid on the performance of a horizontal counter flow shell and tube heat exchanger under turbulent flow conditions, by the researcher Raed ABDULLAH (2017) [32]. Where several experiments were conducted under same current nanofluid concentrations (0.1-0.3%), but under different several flow rate ranges (5, 5.5, 6, 6.5 and 7 LPM). Fig. (3.1) and Fig. (3.2) illustrate a schematic of the experimental setup used to investigate heat transfer characteristics in a (double pipe heat exchanger) and (shell and tube heat exchanger).

1.6 Thesis Outline

The outline of the thesis will base follows: Chapter 2 gives a detailed description of the up to date literature related to the studies centered on the research of the overall performance of double pipe heat exchanger the usage of nanofluids. In chapter 3, the components of the experimental setup of the double pipe heat exchanger as well as the experimental procedure used in this study are described in details. The results of the proposed nanofluids flow in the double pipe heat exchanger are discussed in chapter 4 and compared to the results of the base water. Finally, summary and conclusions of this work and future work are presented in chapter 5.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a detailed description of the literature related to the experimental and theoretical studies focused on the performance investigation of a double pipe heat exchanger using nanofluids. The focus will be on Al_2O_3 and TiO_2 nanofluids as they are considered the working fluids in this study.

2.1 Experimental Studies

In a study performed by Weerapun Duangthongsuk et al. (2009) [8] the forced convective heat transfer and flow characteristic TiO_2/water nanofluids, as well as the base fluid (water), were investigated experimentally in a horizontal double pipe heat exchanger with a counterflow under turbulent flow conditions. The TiO_2/water nanofluid contains TiO_2 nanoparticles with 21 nm in diameter and their volume concentration was 0.2%. When compared to the base fluid, the outcomes showed that the nanofluid exhibited 6-11% higher convective heat transfer coefficient. In addition, it was found that increasing the mass flow rate of the hot water and nanofluid and decreasing the nanofluid temperature results in an increase in the heat transfer coefficient of the nanofluid, while there is no effect of the hot fluid temperature. Finally, the friction factor and the drop in pressure for both the water and the nanofluid were found to be the same, implying that the nanofluid requires no more power of pump to be introduced in the double pipe heat exchanger.

The authors in reference [8] also the effect of the different TiO_2 particle concentrations on the convective heat transfer coefficient in a horizontal double pipe heat exchanger. The TiO_2 particles have a diameter of 21 nm and the particle volume concentration was varied between 0.2-2%. It was found that this nanofluid exhibited a higher heat transfer coefficient than the heat transfer coefficient of the base fluid and it increases alongside any increase in particle concentration and Reynolds number as shown in fig. (2.1). At 1% volume concentration of TiO_2 nanoparticles, the nanofluid has higher heat transfer coefficient than water by 26%, while, at higher concentration (2%), the water showed 14% higher heat transfer coefficient than the nanofluid. Alternatively, increasing the Reynolds number results increasing the pressure drop, while the particle concentrations have a small impact on the heat transfer coefficient. Finally, the author propped new correlations between heat transfer and friction factor used to predict friction factor and the Nusselt number for the TiO_2/water nanofluid. Most of the data vary between ±10% of the suggested equation. Such equations are true within the range of Reynolds number between 3,000-18,000 and concentrations of particle volume in the range of 0 and 1.0 vol.% for the Nusselt number and lastly, friction factor between 0 and 2.0 vol. % [9].

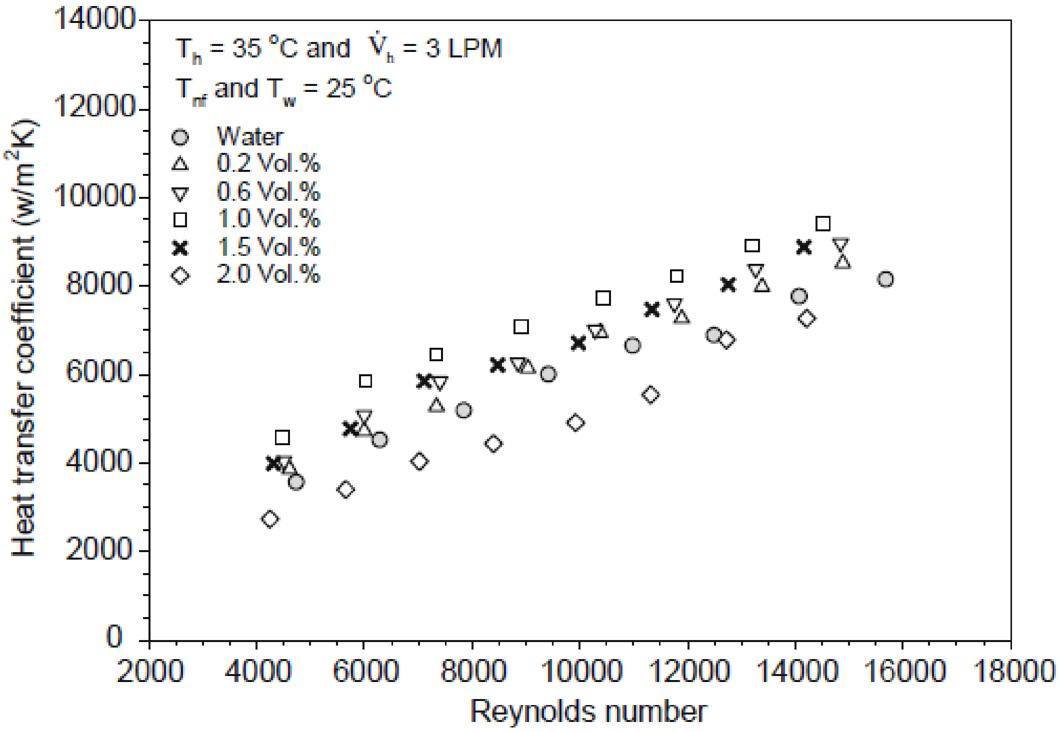


Figure 2.1: Experimental heat transfer coefficient for water and TiO_2/water nanofluids versus Reynolds number at various volume concentration [9].

M. Akhtari et al. (2013) [10] studied the performance of heat transfer for the shell and tube heat exchanger and double pipe heat exchanger using Al_2O_3/water nanofluid under laminar flow conditions numerically and experimentally. The effect of the following parameters: nanofluid temperature, cold and hot flow rates of volume and particle concentration on heat transfer properties all were examined. The results revealed that increasing the particle concentrations, the hot and cold volume flow rates, and the inlet temperature of the nanofluid, in turn, increases the heat transfer performance for both tube and shell heat exchanger and double pipe heat exchanger. Compared with pure water, the results indicated that the heat transfer coefficients of nanofluid in the double pipe and shell and tube heat exchangers are higher than those of water by 13.2% and 21.3%, respectively. Moreover, a direct comparison between the heat transfer coefficient of the nanofluid showed that the performance of heat transfer in a shell and tube heat exchanger is higher than that of the double pipe heat exchanger by roughly 26.2% as shown in fig. (2.2). The authors used the computational fluid dynamics (CFD) to create a simulation for the performance of the nanofluid in both shell and tube heat exchanger and double pipe heat exchanger. The numerical results of the nanofluid heat transfer coefficients showed a positive agreement with the experimental results and findings.

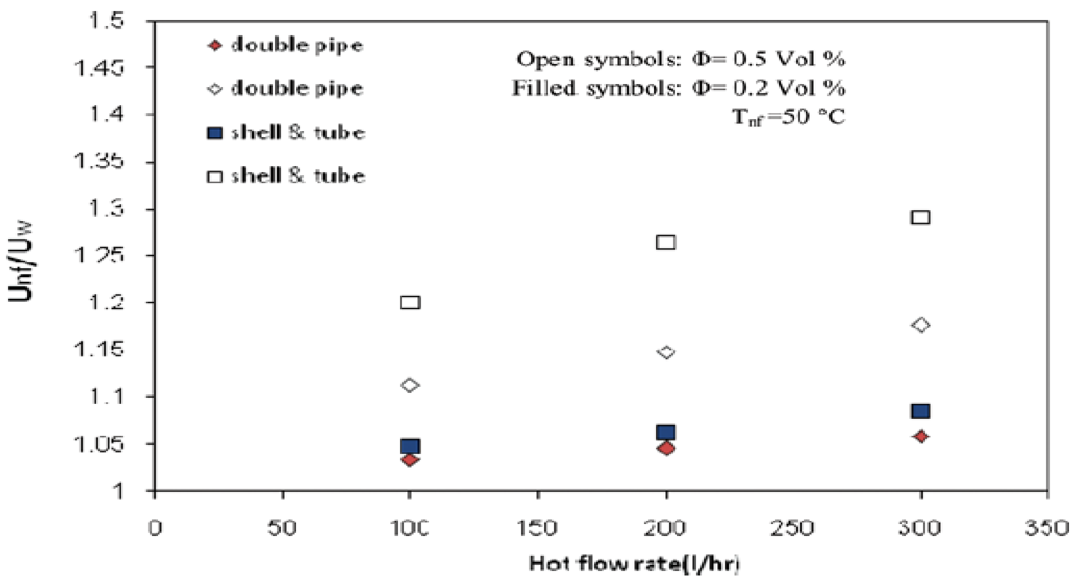


Figure 2.2: Comparison of heat transfer coefficient between the double pipe and shell and tube heat exchangers [10].

In another study, the effect of adding the aluminum oxide (Al_2O_3) nanoparticles to a base fluid in a double pipe heat exchanger with the counter turbulent flow, on heat transfer coefficient and the Nusselt number, were investigated [11]. In this study, the nanoparticle diameter was 20 nm and the volume concentration was varied (0.1-0.3%). The experimental results demonstrated a remarkable increase in heat transfer coefficient and Nusselt number up to 19 and 24 %, respectively as shown in figures (2.3), (2.4). Furthermore, it was noted that as the operating temperature and the nanoparticles concentration increase, the heat transfer coefficient also increases.

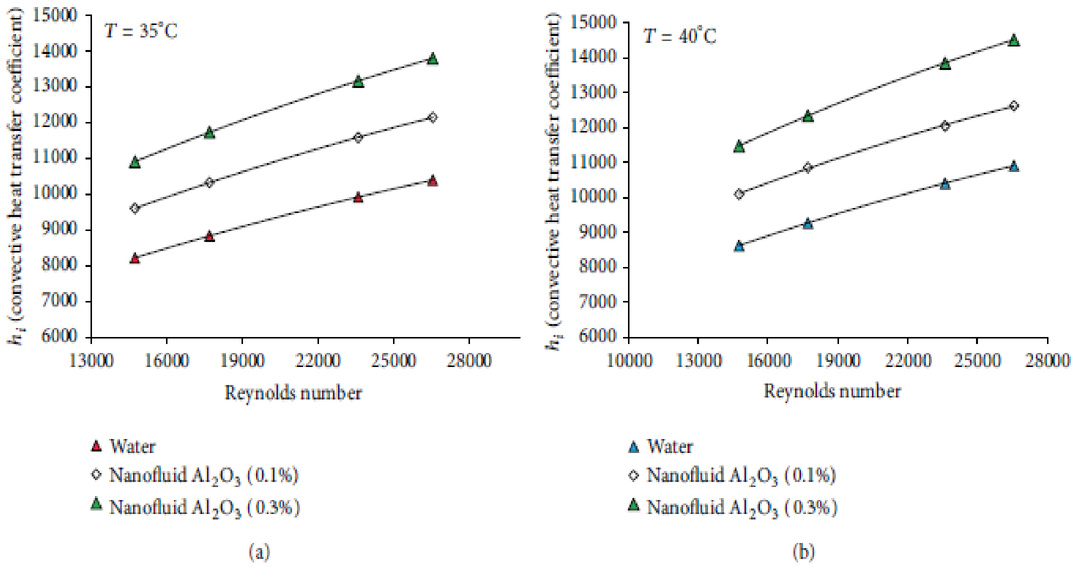


Figure 2.3: Convective heat transfer coefficient of γ-Al_2O_3/water nanofluid versus Reynolds number for different volume concentrations (T =35∘C, 40∘C) [11].

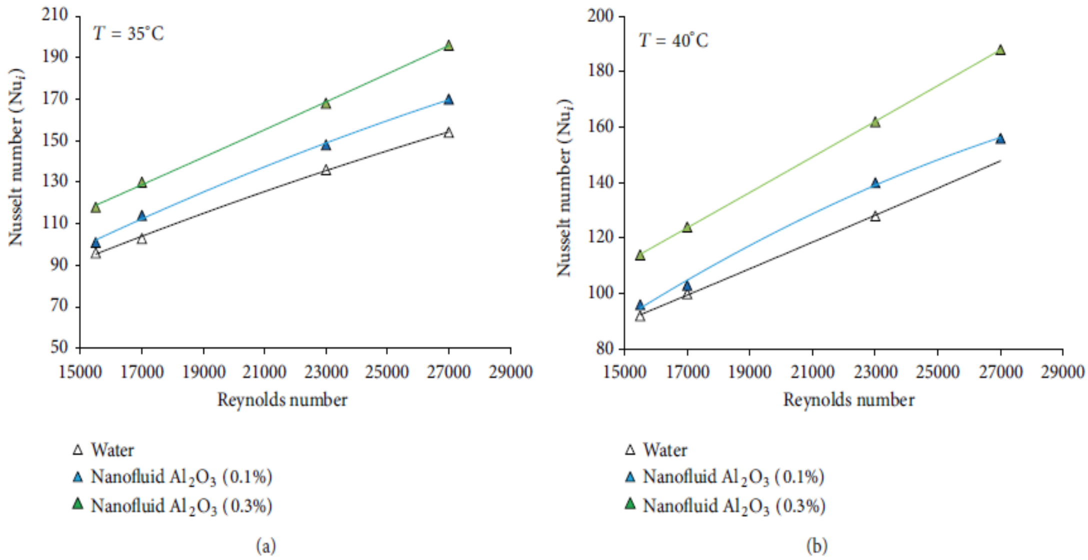


Figure 2.4: Nusselt number of γ-Al_2O_3/water nanofluid versus Reynolds number for different volume concentrations (35∘C, 40∘C) [11].

Heydar Maddah et al. (2014) [12] an experimental study of the use of nanofluid Al_2O_3/water in horizontal double pipe heat exchanger equipped with twisted bands under turbulent flow conditions. Given the same operating conditions, what has been evaluated when the effect of a different geometrical progression ratio (GPR) of variation is the new modified twisted bands and the variable concentration of nanofluid on the heat transfer performance of the double pipe heat exchanger. These experiments were conducted with the Reynolds number range from 5000 to 21,000 and the concentration of nanoparticle size varied in the range of 0.2-0.9%. The length of the pitch of the proposed twisted bands and then proportions of evolution changed with fluctuations in relation to the ratio of geometric evolution (GPR) ingress (IGPR > 1) or reducer (RGPR < 1). Compared with the tube with typically twisted tapes (GPR = 1) and nanofluid, using reducer geometrical ratio twists (RGPR) together with nanofluids, this will tend to increase heat transfer and friction factor by 12% to 52% and 5% to 28%, respectively. The properties of the friction factor and the rate of heat transfer were explored by changing the concentration of volume, the proportion of engineering progress, and the rate of evolution. It has been found that there is a significant effect of the rate of geometric progression with a bar on the heat transfer agent and the friction factor. Based on the rate of engineering development, the results showed that the heat transfer rate and the friction factor in the double pipe heat exchanger with the twisted and nano tape were 1.03 to 4 and 1.4 to 2.8 times respectively, which is higher than in a normal tube. Based on the current experimental results, experimental associations of thermal performance, friction factor and number of Nusselt have been developed under turbulent conditions and compared with the available links shown in the literature. Fig. (2.5) is presented the effect of modified twisted tapes on friction factor characteristics at several nanoparticle concentration and GPR, and Fig. (2.6) is presented the variation of thermal performance actor with Reynolds number.

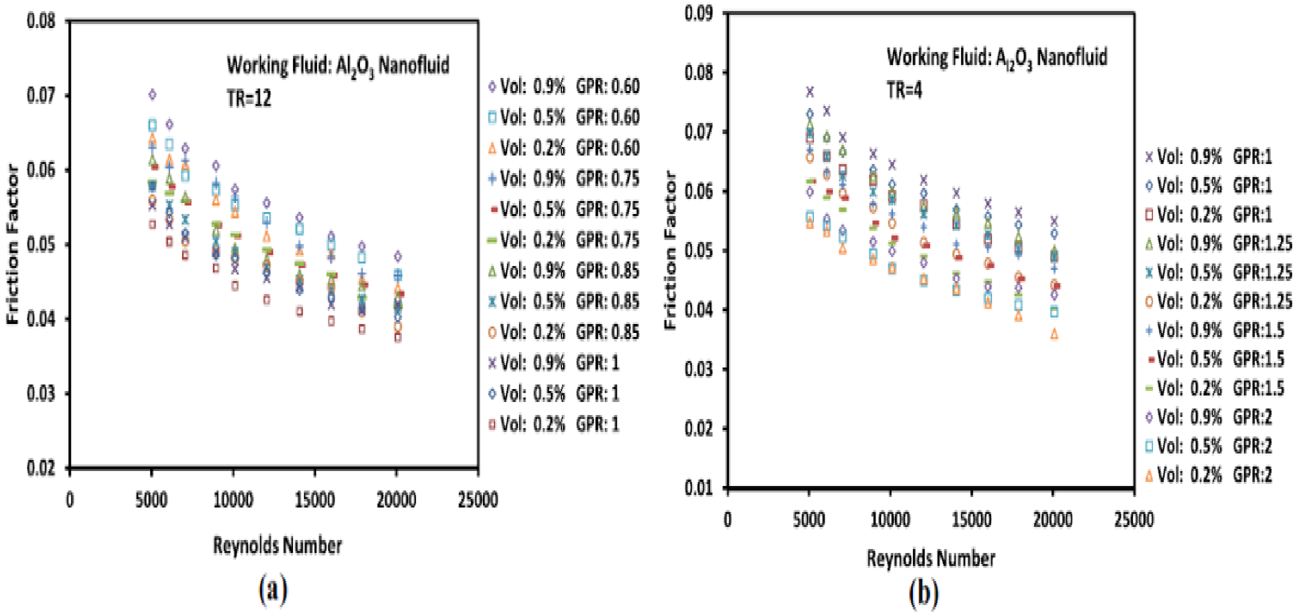


Figure 2.5: The effect of geometrical progression ratio on friction factor (a) RGPR (b) IGPR [12].

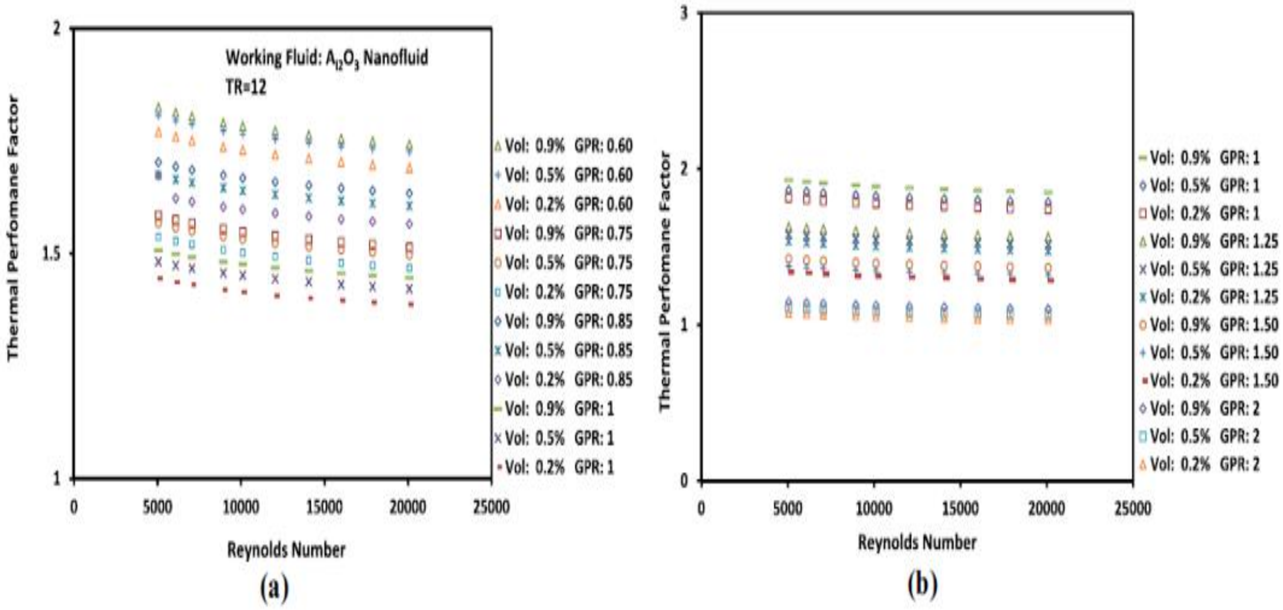


Figure 2.6: The variations of thermal enhancement index with Reynolds number for (a) RGPR (b) IGPR [12].

An experimental study was done by P.V. Durga Prasad et al. (2014) [13] of the performance of heat transfer under turbulent flow conditions and friction factor of Alumina (Al_2O_3)/water nanofluid flow through a heat exchanger related to a concentric U-Bend compound with a helical and non-helical tape in the inner tube. During these experiments, the Reynolds of number varied in the range between 3000 and 30,000 with 0.01%, 0.03% of the volume concentrations of the Al_2O_3 particle size and the insertion of spiral tape from p/d = 5, 10, 15 and 20. Results indicate that the Nusselt of number Increases along with increased Reynolds and Prandtl numbers. The enhanced thermal conductivity of the base fluid was found with the addition of Al_2O_3 nanoparticles added to enhance heat transfer. The Nusselt number of entire pipes for 0.03% volume concentrations of nanofluid with helical tape inserts of p/d = 5 shows an enhancement of 32.91%, as compared to water as shown in fig. (2.7). In addition, the friction factor increased by 1.38 times compared with baseline water. This is consistent with the fact that the increased concentration of nanoparticle size and the elevation ratio of the inclusion results in an increase in lower pressure in the inner tube. The author produced experimental links to the friction factor and Nusselt number as functions for Prandtl number, Reynolds number, height ratio, and volume concentration.

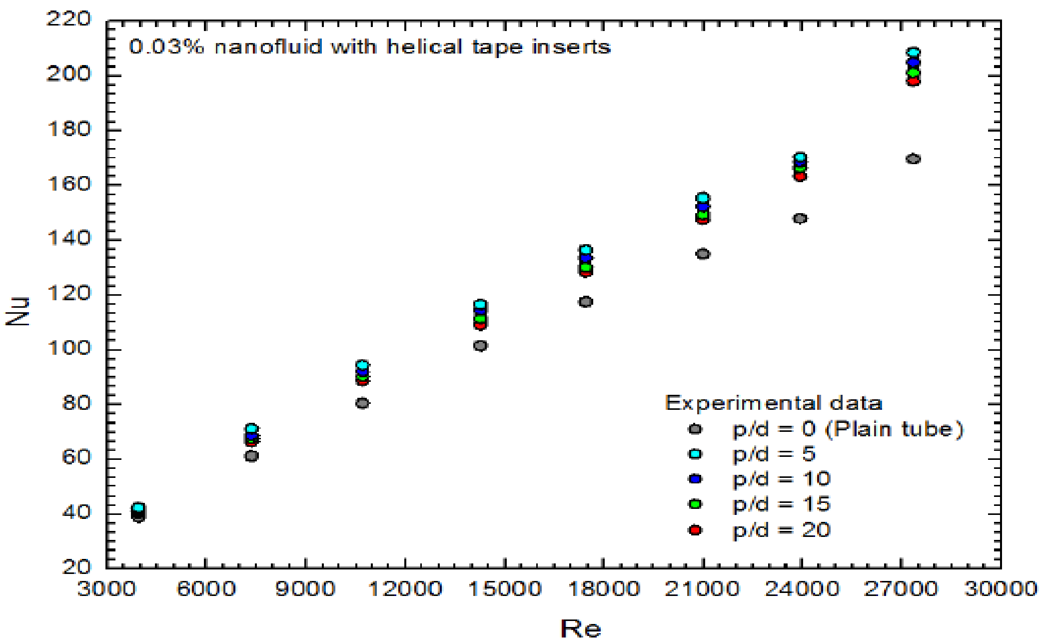


Figure 2.7: Experimental Nusselt number of 0.03% nanofluid in a tube with helical tape inserts [13].

In another study, Reza et al. (2015) [14] A double-flow flow flux is used as a heat exchanger to investigate the heat transfer of aluminum oxide nanoparticles/water nanofluid. The volume concentration of nanoparticles ranged from (0.1-0.3%) and the diameter of nanoparticles was about 20 nanometers. Nanofluid showed a slight improvement in heat transfer of about 12% compared to base fluid (water).

P.V. Durga Prasad et al. (2015) [15] carried out an experimental work on evaluating the heat transfer coefficients and friction factors of Al_2O_3/water based nanofluid in a double pipe U-tube heat exchanger with trapezoidal-cut twisted tape insert. The experiments were performed under turbulent flow regime with particle volume concentration of 0.01% and 0.03%, twist ratios ranging between 5 and 20, flow rates ranging from 0.0333 kg/s to 0.2667 kg/s, and Reynolds number in the range 3000<Re<30000. About 34.24% enhancement in the Nusselt number of entire pipe for 0.03% concentrations of nanofluid with trapezoidal-cut twisted tape inserts of H/D = 5 was reported. In addition to that, it was found that the friction factor of entire pipes for 0.03% concentration of nanofluid with trapezoidal-cut twisted tape inserts of H/D=5 was increased by 1.29 times as compared to water. Figure (2.8) shown the results indicated that as the nanoparticles volume concentration increases, the heat transfer coefficient and friction factor were enhanced.

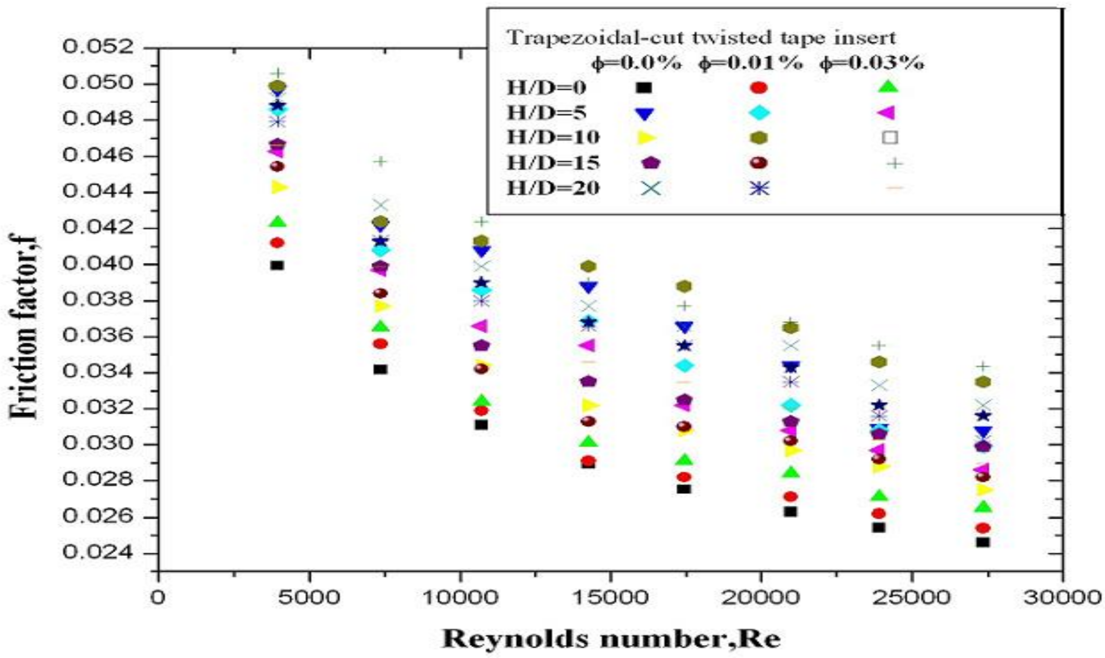


Figure 2.8: Comparison of friction factor of nanofluid in a tube with trapezoidal-cut twisted tape inserts [15].

2.2 Numerical Studies

Ali Mahrooghi et al. (2015) [16] performed a numerical investigation of the forced convective flow and heat transfer of Al_2O_3 /Water nanofluid by single and two-phase (volume of fluid) models. The outer tube contains the hot water, while the nanofluid flows within the inner tube of the sinusoidal double tube and the isothermally concentric circular heat exchangers. In order provide a simulation for the nanofluid-forced convection of 2% and 3% volume concentrations, the single and two-phase models were utilized. The ANSYS Fluent 15.0 was utilized to simulate the turbulence by the renormalization group k-ε model. Results revealed that as the volume concentrations of the nanoparticles increases, the overall heat transfer coefficient increases. The highest overall rates of heat transfer coefficient were assessed for each concentration and shape corresponding to the highest flow rate of the tubular heat exchanger. In the 3% volume concentration of nanoparticles, the maximum overall heat transfer coefficient is 220% in the inner tube of the sinuses concentric double tube heat exchanger corresponding to the 10LPM flow rate as shown in fig. (2.9). There was an increase in low nanofluid pressure along the inner tube of a circular heat exchanger and a circular tube of 3% and 5% for concentrations of 2% and 3%, respectively. There was a good agreement between simulation results and Rohit S. Khidkar published empirical data [17] as shown in Fig. (2.10).

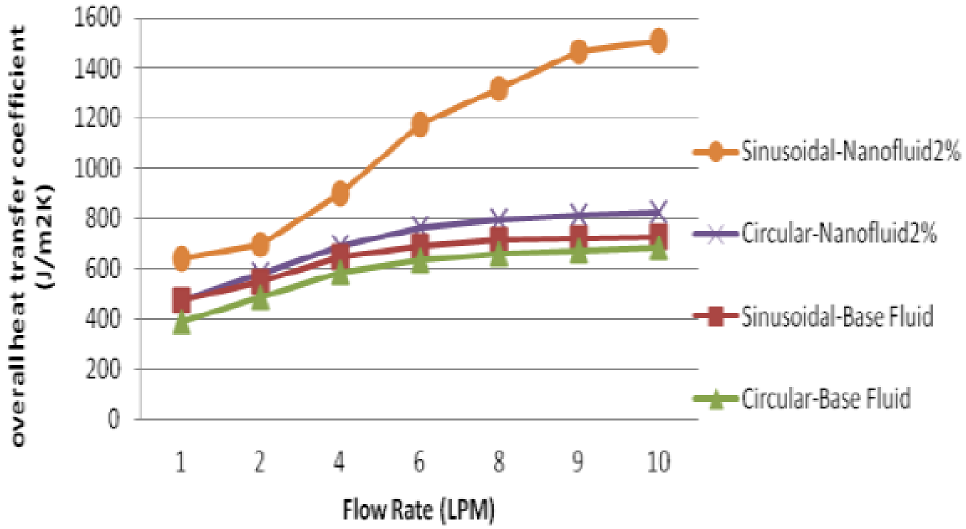


Figure 2.9: The overall heat transfer coefficient nanofluid enhancement in comparison to pure water flow in circular and sinusoidal double tube heat exchanger [16].

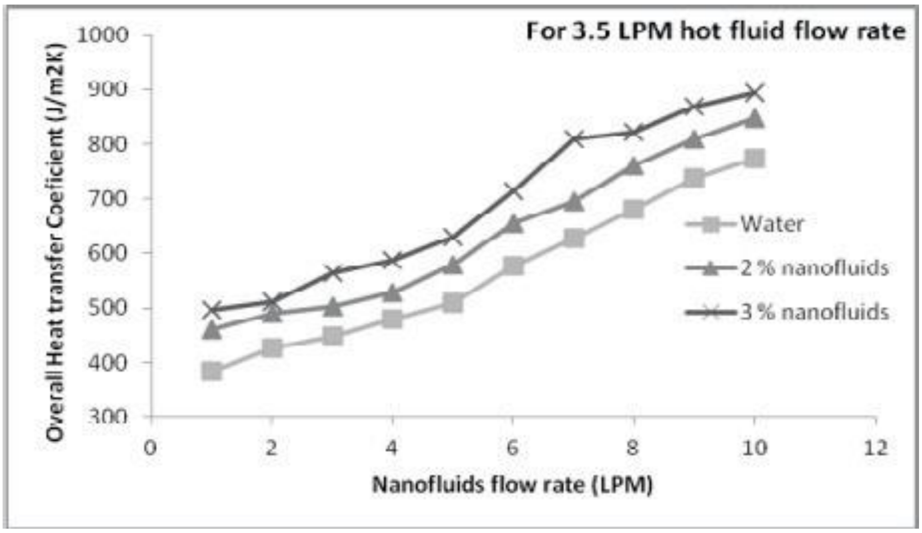


Figure 2.10: Overall heat transfer coefficient against nanofluids flow rate for 3.5 LPM of hot fluids flow rate [17].

In another study, Ch. Venkata Anvesh et al. (2016) [18] computational fluid dynamics (CFD) simulators were performed to study the heat transfer efficiency of Al_2O_3/ water nano-fluid with concentrations of 0.1%, 0.2% and 0.3% in a (DPHE). In general, the results confirmed the positive effect of using nano-fluid on heat transfer efficiency in double pipe heat exchanger.

More recently, Hussein Talal Dhaiban (2016) [19] for a numerical study of nanostructure flow Al_2O_3/water nano-fluids with a nanoparticle concentration of 1%, 2%, 3%, and 4% and a wide range of Reynolds number (3000-7500). The length of one meter, anti-flow double pipe heat exchanger was considered as a test section with cold and hot liquid rings. The inner and outer tube are made of fine copper with diameter 15 and 50 mm, respectively. The cold nanofluid flows inside the inner tube and the hot liquid flows through the outer tube. The outer tube was thermally insulated through which the hot fluid flows at a constant velocity (0.5 m/s), while the cold nanofluid was introduced inside the cold loop at a uniform velocity of 0.2, 0.3, 0.4 and 0.5 m/s. It is reported that as the particle concentration and the number of Reynolds increased, the Nusselt and the heat transfer coefficient was enhanced. For example, in the Reynolds number of 7100 particles part of 4%, the numerical results showed that the maximum improvement in the Nusselt number and heat transfer coefficient is about 9.5% and 13.5%, respectively as shown in fig. (2.11). Finally, in particle size portions of 1%, 2%, and 3%, nanoparticles showed good compatibility with experimental links available in the literature [20]; however, a slight deviation was observed in volume fractions of 4%.

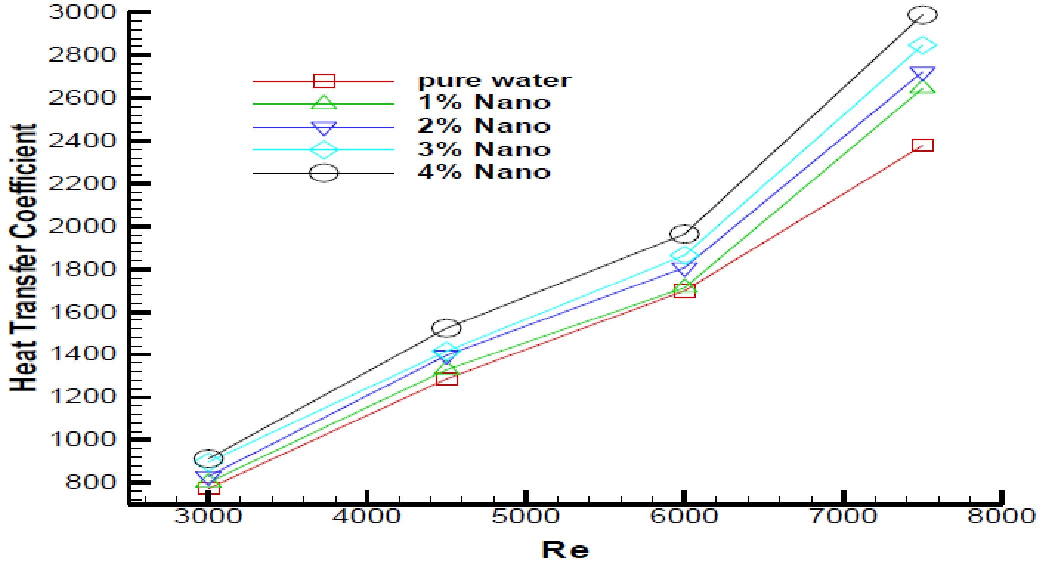


Figure 2.11: Heat transfer coefficient of nanofluids a DI water at various particles volume fractions and Reynolds numbers [19].

2.3 Conclusion Remarks

Based on a review of the literature above, it is clear that most researchers have chosen one particular nanofluid few studies have proposed two or more specific nanofluids, which would improve the thermal conductivity of the base fluid and this will be positively reflected on the heat transfer coefficient in a double tube heat exchanger. We can note that most researchers have used the volume concentrations of nanoparticles less than 1%, which was most of their studies within the experimental work depending on the dispersion of a low volume (<1%) fraction of solid nanoparticles in traditional base fluid drastically increases the thermal conductivity than that of base fluid Chopkar et al. [21], [22]. Lee et al. [23] demonstrated a maximum increase in the thermal conductivity increases maximum 20% when CuO nanoparticles were suspended in ethylene glycol. Suspending copper nanoparticles mean diameter size less than 10 nm, Eastman et al. [24] were able to increase the thermal conductivity of ethylene glycol up to 40%. Pak and Cho [25] under turbulent flow conditions. The results showed that the Nusselt number of nanofluids increased with increasing Reynolds number and the volume concentration. However, they still found that the convective heat transfer coefficient of the nanofluids with 3 vol. % nanoparticles were 12% lower than that of pure water in a given condition. And that some researchers used the volume concentrations of nanoparticles higher than 1%, which were their numerical studies, but their results were not compared with experimental work. Hence, more in-depth investigation and fair comparison between two or more than two different nanofluids types are required to have a better understanding of the role of the nanofluid types, nanoparticle size and volume concentration, and the nanofluid flow rates.

This study is concerned with performing a comparison of two kinds of nanofluids (TiO_2/water nanofluid and Al_2O_3/water nanofluid) with the base fluid on heat transfer performance of a double pipe heat exchanger. The Al_2O_3 is one of the most common nanoparticles used in the preparation of the nanofluids for heat transfer applications due to its low cost, availability, and unlike many metal oxide nanoparticles; it is not susceptible to surface oxidation and is much easier to incorporate in the base fluid [26]. On the other hand, it was observed that there are limited studies utilizing TiO_2 nanoparticles in the nanofluid preparation for heat transfer application. Therefore, we proposed carrying out an experimental comparison between these kinds of the nanofluids to evaluate the forced convective heat transfer in a double pipe heat exchanger.

CHAPTER THREE

EXPERIMENTAL WORK

This chapter's aim is to present the experimental work of using the nanofluids instead of the base fluid (water) to improve heat transfer in a double pipe heat exchanger. The following sections provide a detailed information about the experimental set-up, measuring and auxiliary devices, the nanofluid preparation, the experimental procedure, and finally the theoretical analysis.

3.1 The Experimental Setup

Fig. (3.1) and Fig. (3.2) illustrate a schematic of the experimental setup used to investigate heat transfer characteristics in a double pipe heat exchanger. While Figure (3.1) shows the experimental setup, which consists of a double pipe heat exchanger with counterflow pattern, a heating unit to heat the water, two flow loops, a unit for cooling used to cool down the nanofluid and a device to measure temperature. The cold loop carries the nanofluid that introduces inside the inner pipe, while the water flows inside the outer pipe. In each flow loop, there is a pump, a flow meter, a bypass valve, a reservoir and two tanks to store the fluids. To measure the inlet and outlet temperatures of the cold and hot fluids, four k -type thermocouples were utilized. In order to minimize the heat loss, the experimental setup was completely insulated.

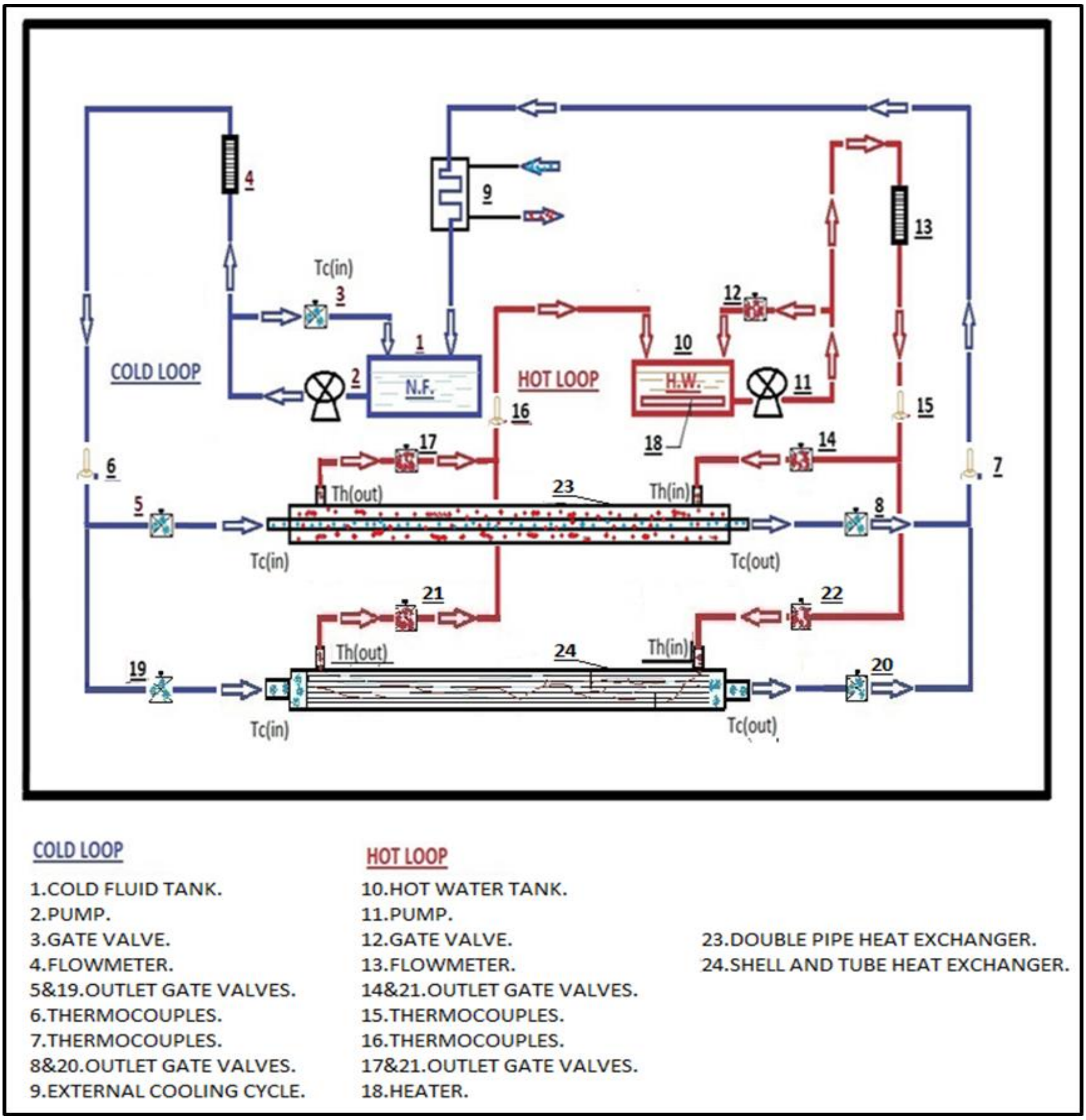
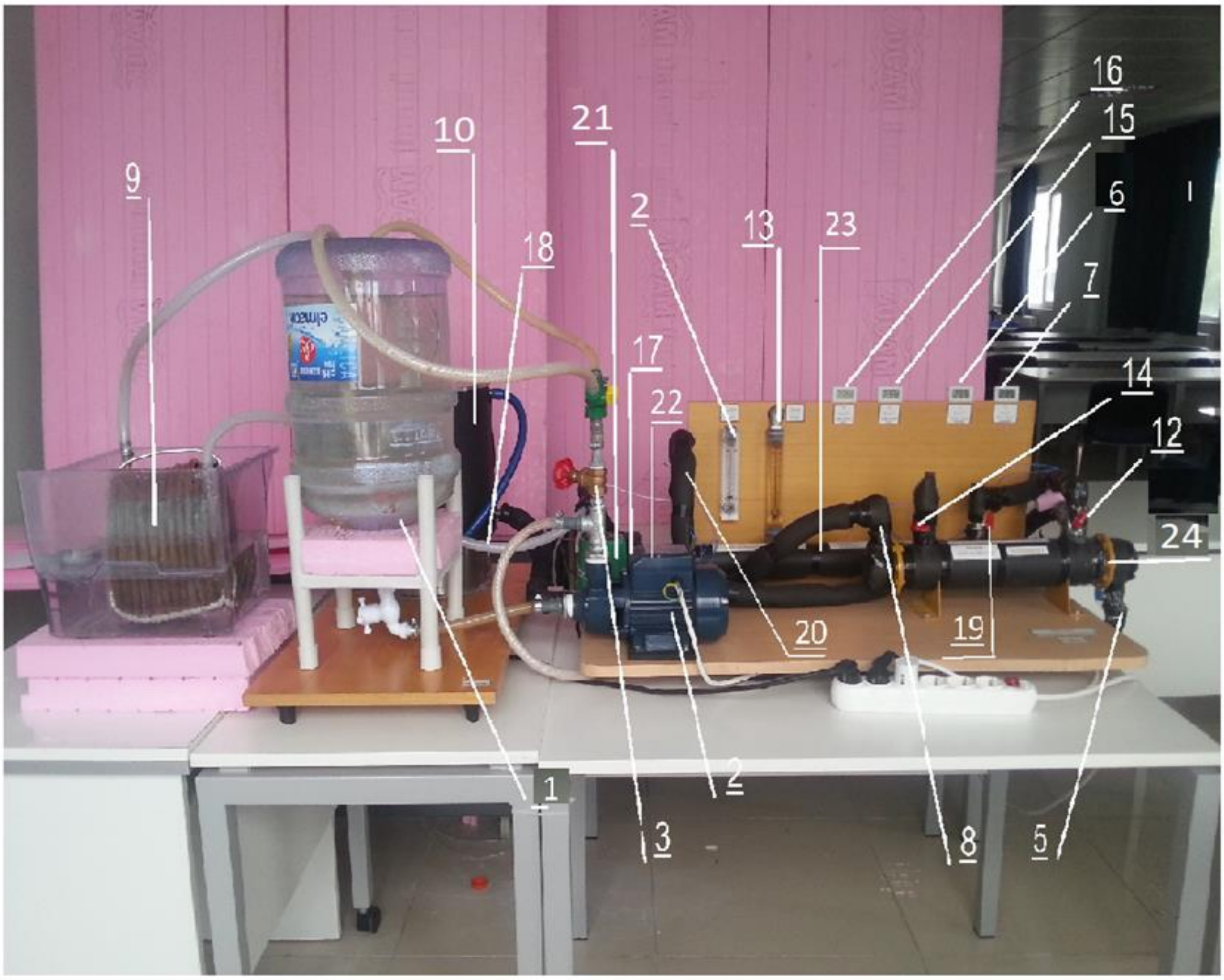


Figure 3.1: The schematic of experimental setup.



COLD LOOP

1.COLD FLUID TANK.
2.PUMP.
3.GATE VALVE.
4.FLOWMETER.
5&19.INLET VALVES.
6.THERMOCOUPLES.
7.THERMOCOUPLES.
8&20.OUTLET VALVES.
9.EXTERNAL COOLING CYCLE.

HOT LOOP

10.HOT WATER TANK.
11.PUMP.
12.GATE VALVE.
13.FLOWMETER.
14&22.INLET VALVES.
15.THERMOCOUPLES.
16.THERMOCOUPLES.
17&21.OUTLET VALVES.
18.HEATER.

23.DOUBLE PIPE HEAT EXCHANGER.
24.SHELL AND TUBE HEAT EXCHANGER.

Figure 3.2: The Experimental set-up.

3.1.1 The Double Pipe Heat Exchanger

The double pipe heat exchanger is comprised of two pipes which are shown in Fig. (3.3) and Fig. (3.4). The inner pipe is made out of a copper tube with 12mm inner diameter, 16mm outer diameter, 2mm of thickness, and 1 m in length, while the outer pipe is made of an iron tube with 36mm inner diameter, 42mm outer diameter, 3mm in thickness, and length of 0.8m. Table (1) contains the specifications of the double pipe heat exchanger.

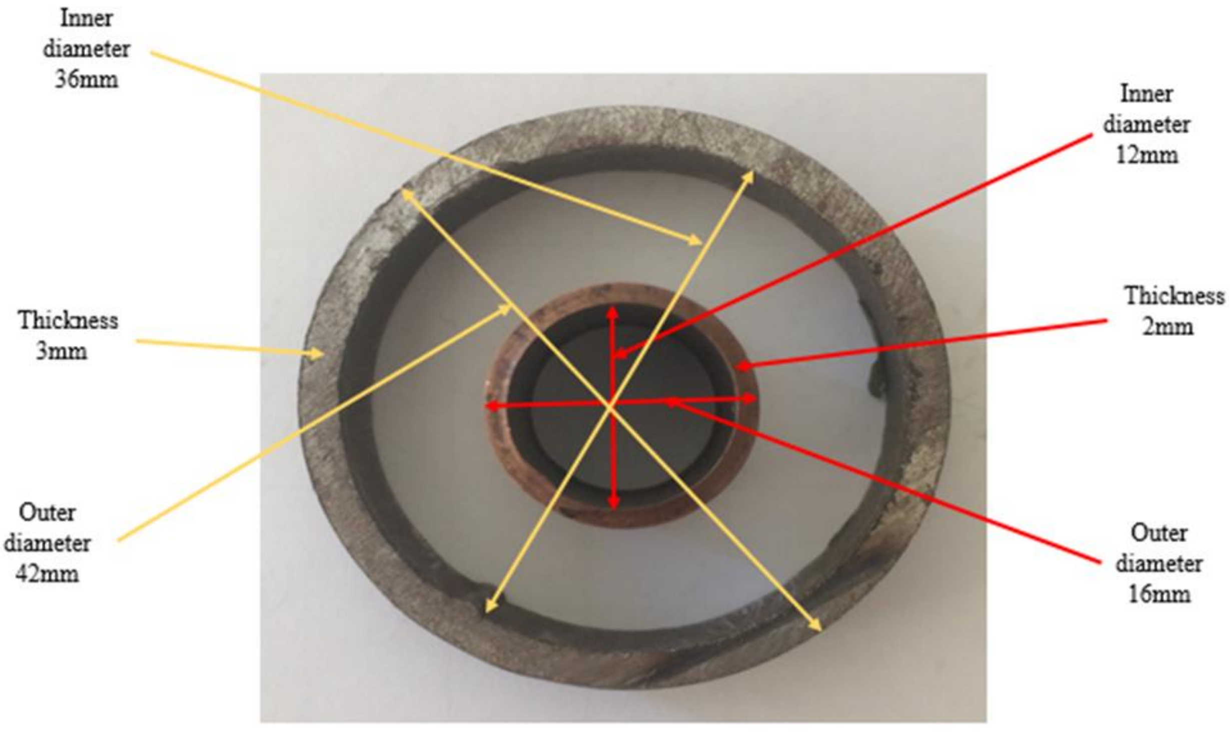


Figure 3.3: Cross section of double pipe heat exchanger.

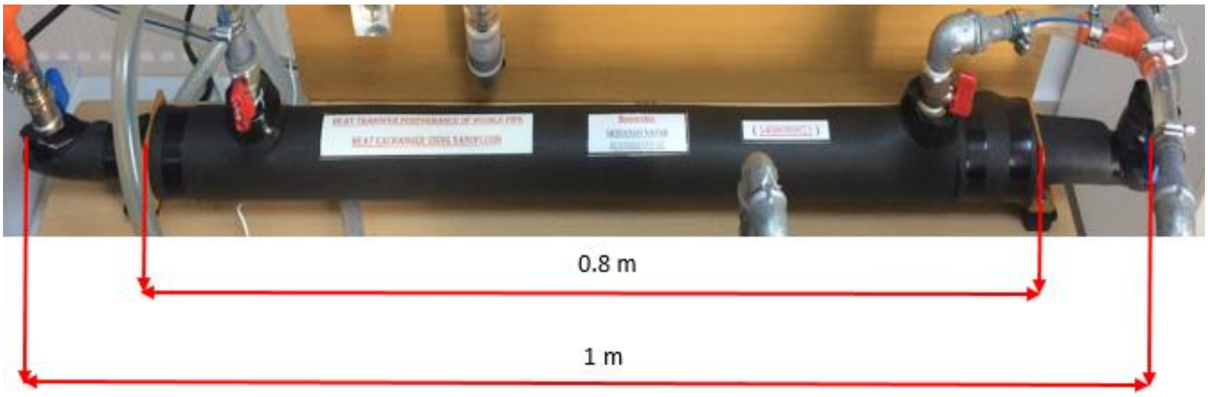


Figure 3.4: Side-view of the double pipe heat exchanger**.**

Table 3.1: The specification of the double pipe heat exchanger components.

Component	Dimension	Remarks
Inner pipe	L= 1m L_{test}= 0.8m D_i= 12mm D_o= 16mm Thickness= 2mm	(The cross section area Ac= 0.000144 m^2) Metal: copper
Outer pipe	L= 0.8m L_{test}= 0.8m D_i= 36mm D_o= 42mm Thickness= 3mm	(The cross section area Ac area=0.0004 m^2) Metal: Iron

3.1.2 Insulation

To minimize the heat loss, a thermal insulation material made of (PVC and Nitrile Rubber (nbr)) was used. The thermal insulator has a thickness of 1 cm, the thermal conductivity of 0.034w / m. K (with the temperature range of [(-38° C) to (180° C)]. The insulator was utilized to insulate the double pipe heat exchanger, the storage tanks, and the inlet and outlet pipes connected to the double pipe heat exchanger as shown in Fig. (3.5).

Figure 3.5: The insulation of the double pipe heat exchanger, storage tanks, and the inlet and outlet pipes connected to the double pipe heat exchanger.

3.1.3 Pumps

There are two pumps included in the experimental setup. Fig. (3.6) shows the pump with single speed work, the frequency of (50 Hz), the voltage of (220 V) and heat resistant. On the other hand, the cold fluid pump is with single speed work, the frequency of (50 Hz) and voltage of (220 V) as shown in Fig. (3.7). Therese pumps were used to maintain a continuous flow through the cold and hot loops at a constant rate of flow through the heat exchanger experimental setup.

Figure 3.6: The hot water Pump.

Figure 3.7: The cold fluid Pump.

3.1.4 Storage Tanks

There are two tanks for the cold and hot loops in the experimental setup. Figure (3.8) shows the storage tank of hot water. This tank has a capacity of 15-liter which is made of stainless steel to keep hot liquids (water).The heating tank is equipped with 2 kW electric heater to heat up the water. Figure (3.9) shows the storage tank of cold fluid, which is made from plastics with a 20-liter capacity.

Figure 3.8: The hot water tank.

Figure 3.9: The cold fluid tank

3.2 The Measuring Devices

3.2.1 Thermocouples and Temperature Recorder Device

Hot and cold temperatures for entry and exit from hot water and cold liquids are measured using k-type thermocouples inserted directly into the inlet flow and heat exchanger flow outlet. Readings of the thermocouples were recorded by a temperature recorder [(Thermocouple Thermometers)-(model HT-9815)-(made in China)], which has 4 channels as shown in Fig. (3.10).

Product Specifications:-

1- Temperature range:- ($-200^{\circ}C \sim 1372^{\circ}C$) ($-328^{\circ}F \sim 2501^{\circ}F$)

2- Accuracy:- $>100^{\circ}C$ ($-148^{\circ}F$): $\pm 1\ ^{\circ}C$ ($\pm 1\ ^{\circ}F$)

$< 100^{\circ}C$ ($-148^{\circ}F$): $\pm 2\ ^{\circ}C$ ($\pm 3.6\ ^{\circ}F$)

3- Type K temperature resolution: $< 1000^{\circ}C$: $< 0.1^{\circ}C$/ ˚F/K

$> 1000^{\circ}C$: $< 1^{\circ}C$/ ˚F/K

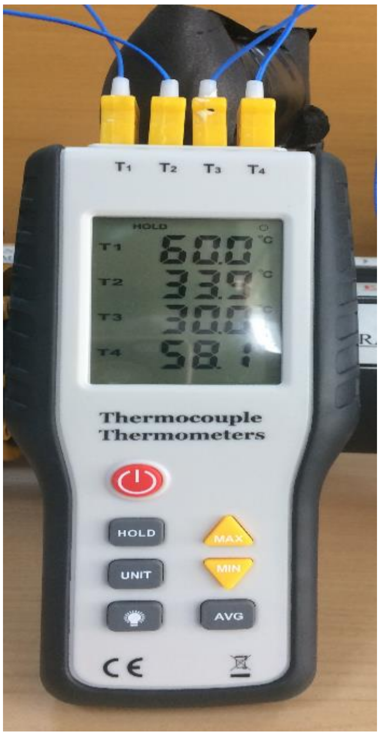


Figure 3.10: Temperature Recorder.

3.2.2 Flowmeters

There are two flowmeters for the cold and hot loops in the experimental setup. The flow meter is shown in Fig. (3.11) was utilized to measure the rate of flow of hot water flowing inside the hot loop in the experiments setup. The flow meter range is 1.8 - 18 Lpm with an accuracy of ±5%. Figure (3.12) shows the flow meter of the cold loop with a flow rate range of (0.5 – 8) Lpm and an accuracy of ±5%.

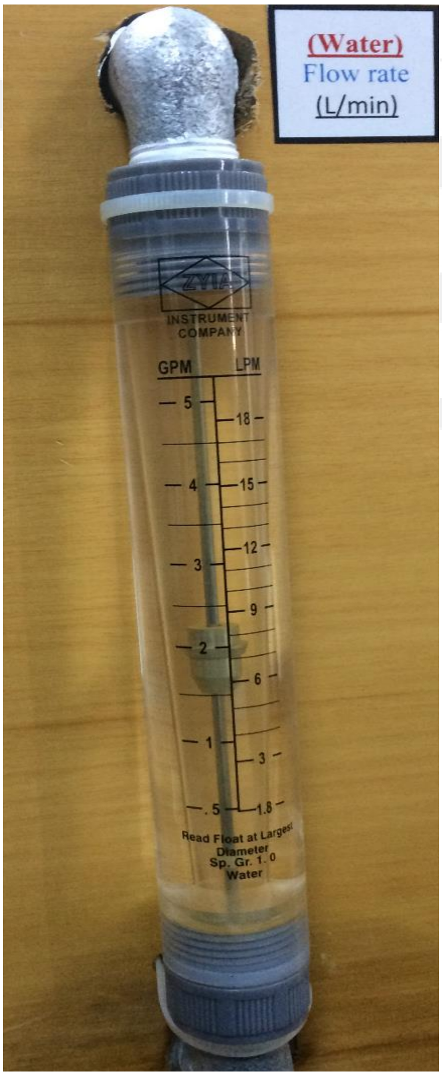


Figure 3.11: The flowmeter for a hot loop.

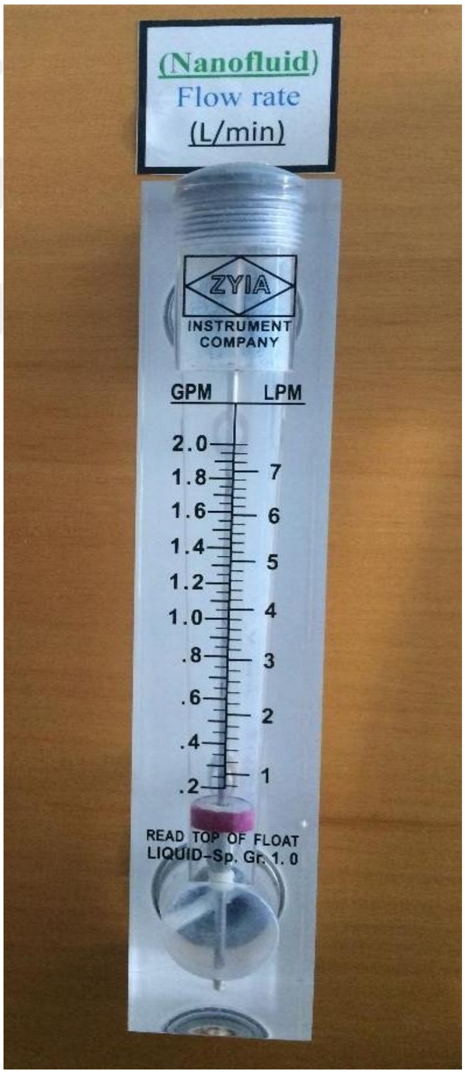


Figure 3.12: The flowmeter for a cold loop.

3.3 The Calibration of Measuring Devices

Before the experiments began, all measuring devices were calibrated as depicted in the following sections:

3.3.1 Calibration of Thermocouples and Thermometers

All thermocouples were calibrated by connecting one end of the thermocouple to the digital thermometer and the other end of de-ionized water in order to check the temperature which records at the boiling point. The water was placed in a bowl, then a heat source was focused on the bowl when the water began to boil, thermocouples were submerged in the boiling water for the purpose of measuring the temperature of water in boiling state. As known, the boiling degree of de-ionized water is (100°C), and the thermometers record (100°C) in this state. That's mean that the thermometers recorded right temperature. Finally, this method was used to calibrate the thermometers in the good and easy way.

3.3.2 Calibration of Flow Meter

The flow meter utilized to measure the rate of flow of liquids is calibrated using a graded glass cylinder and stopwatch. Volume flow rates of (2.5, 3, 3.5, 4 and 4.5 liters per minutes) were used in calibrating the flow meter. A volume of water is accumulated in the graded cylinder after passing throw the flow meter (which reads 1 L/m), during a known period of time recorded by the watch (60 seconds), then the volume flow rate gives by dividing the volume by time.

3.4 Nanofluid

There are two types of nanofluids were used in the experiments. The first one is Titanium Oxide (TiO_2/water nanofluid), and another one is Aluminum Oxide (Al_2O_3/water nanofluid). These nanofluids were prepared in the Nanografi Company (Nano Technology Computer Manufacturing and Consulting LTD. /Middle East Technical University, Ankara). The properties of these Nano-powders are recorded in Table (3.2).

Table 3.2: Properties of Aluminum oxide (Al_2O_3) and Titanium oxide (TiO_2) Nano-powders.

No.	Technical properties	Al_2O_3	TiO_2
1	Purity %	99.99	99.99
2	Average particle size (nm)	28	25-45
3	Specific surface area (m^2/g)	150	50
4	True density (g/cm^3)	3900	4500
5	Color	white	white
6	Morphology	nearly spherical	nearly spherical
7	Elemental Analysis	Ca: <25pp Fe: <80pp Cr: <4ppm Na : <70pp Mn : <3pp Co: <2pp	Al : 0.003 Ca: 0.005 Si: 0.003 S : 0.005 Mg : 0.01 W: 0.01

The nanofluids were purchased from the Nanografi Company with high nanoparticles concentration (Al_2O_3 in Water, gamma, 22% by weight, 28nm in diameter) and (TiO_2 in Water, Rutile, 22% by weight, 25-45nm in diameter) as shown in Fig. (3.13).

Figure 3.13: (Al_2O_3 in Water, gamma, 22 % by weight, 28nm in diameter) and (TiO_2 in Water, Rutile, 22% by weight, 25-45nm in diameter).

In order to reach to the required concentrations (0.1, 0.2 and 0.3% by volume) for these nanofluids, the equation (3.1) was used to know the volume of water that must be added to get the required concentration [27]:

$$\text{Vol }\%(\phi) = \frac{\text{volume of nanopowder (Vn.p.)}}{\text{volume of water(Vw)+volume of nanopowder (Vn.p.)}} \qquad (3.1)$$

Where:

Ø: volume concentration of nanofluid.
$V_{n.p:}$ (mass of nanopowder / density of nanopowder)
V_w: (mass of water /density of water)

In order to dilute the concentrated nanofluids, the calculated amount of distilled water from Eq. (3.1) is added to the concentrated nanofluid. This mixture was blended for one and half hour in a closed cycle of the nanofluid reservoir and water pump as shown in Fig. (3.14).

Figure 3.14: The nanofluid mixing cycle.

3.5 Experimental Procedure

Before starting the experiments, the following preparations were carried out as follows:

1- Fill the hot loop tank with deionized water.
2- Fill the cold loop tank with deionized water.
3- The pump is connected to the hot loop tank from one side and the other side is connected to the flow meter, then to the heat exchanger.
4- The pump is connected to the cold loop tank from one side and the other side is connected to the flow meter, then to the heat exchanger.
5- Check all valves of the system.
6- Run the system pumps to ensure that the water enters the system and returns back to the tanks.
7- Run the heater of the hot loop tank.
8- The thermocouples were connected to temperature recorder device for measuring the temperatures at different points during experiments.

At this stage, the experimental setup is ready to proceed with the following experiments:

3.5.1 The Base Water Experiments

Flowing through the outer tube is hot water and cold water flows through the inner tube in DPHE with counter flow pattern. The outer pipe is thermally insulated and the cold fluid enters the heat exchanger at different flow rates (2.5, 3, 3.5, 4 and 4.5 L/min) with an inlet temperature (30˚C). While the hot liquid flows in the inner tubes at a constant flow rate of (7 L/min) at an inlet temperature of (60˚C). The temperature of the inlet and outlet currents of both hot and cold liquids was recorded [at steady states]. To get a fair comparison, it should be noted that all the experiments were performed under the same experimental conditions with changing the fluid type, nanoparticles concentration, and the fluid flow rate.

3.5.2 The TiO_2/water Nanofluids Experiments

During these experiments, Hot water flows through external tubes and the cold fluid (TiO_2/water nanofluids) flows inside the inner pipe of the double pipe heat exchanger under counter flow pattern. The nanofluid was pumped into the heat exchanger at different flow rates (2.5, 3, 3.5, 4 and 4.5 lit/min) at 30˚C inlet temperature. On another side, the hot fluid (water) flows in the inner pipe at a constant flow rate of (7 lit/min) at an inlet temperature of (60˚C). The concentrations of nanoparticle size from nanofluid ranged within (0.1-0.3%).

3.5.3 The Al_2O_3/water nanofluids experiments

During these experiments, Hot water flows through external tubes and the cold fluid (Al_2O_3/water nanofluids) flows inside the inner pipe of the double pipe heat exchanger under counter flow pattern. The nanofluid was pumped into the heat exchanger at different flow rates (2.5, 3, 3.5, 4 and 4.5 lit/min) at 30˚C inlet temperature. On another side, the hot fluid (water) flows in the inner pipe at a constant flow rate of (7 lit/min) at an inlet temperature of (60˚C). The concentrations of nanoparticle size from nanofluid ranged within (0.1-0.3%).

The results of Al_2O_3/water nanofluid and TiO_2/water nanofluid were compared with each other and with respect to the results of the base fluid (water).

The summary of the experiments was shown in the schematic shown in Fig. (3.15).

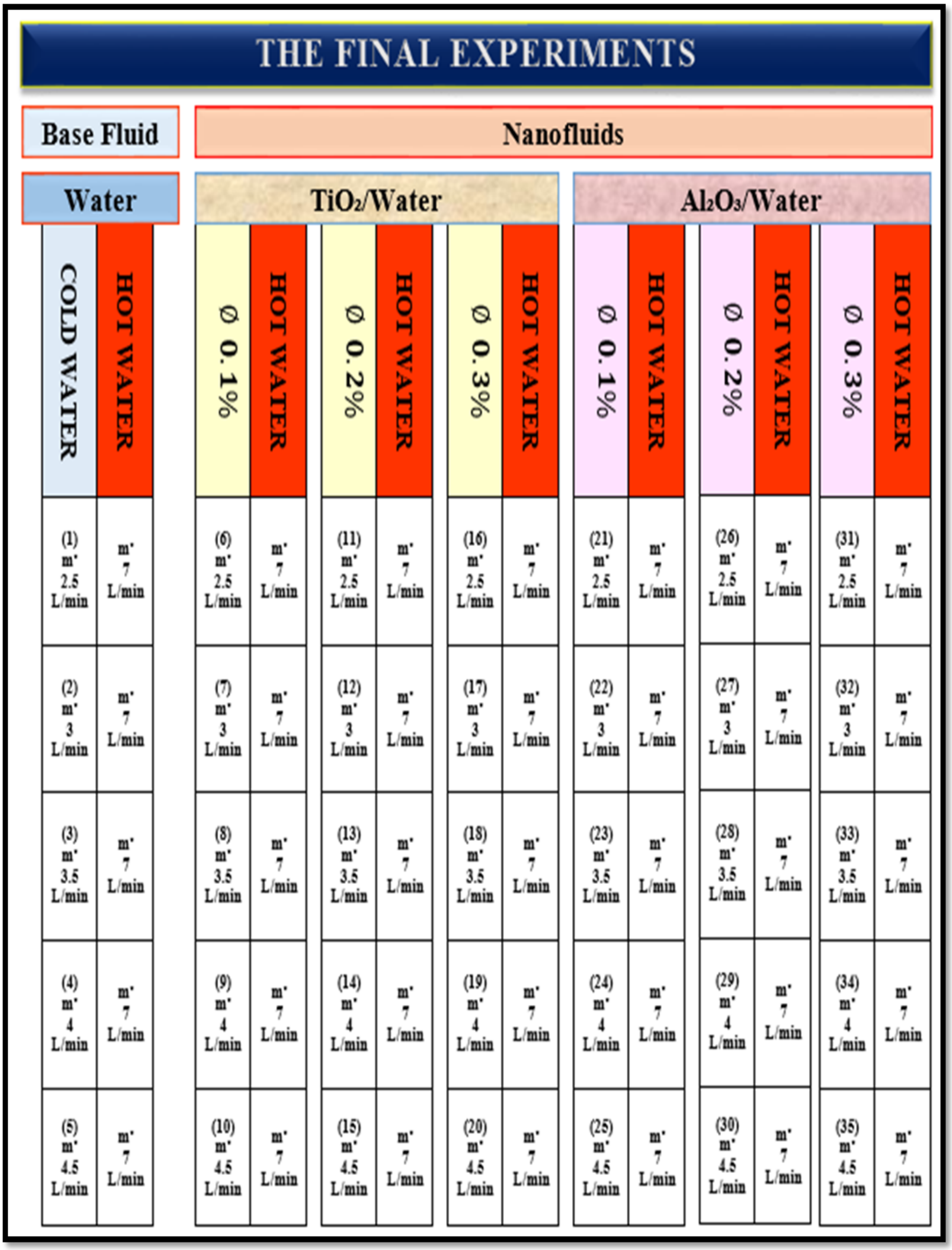


Figure 3.15: The chart of the experiments.

3.6 Theoretical Analysis

The total heat transfer of the double pipe heat exchanger for water can be calculated by the following equation:

$$Q_b = m^{\circ}{}_b \times C_{p.b} \times (T_{b.out} - T_{b.in}) \tag{3-2}$$

Where:

$C_{p.b}$, specific heat base fluid, J/kg K

$m^{\circ}{}_b$, mass flow rate of base fluid, L/s

$T_{b.out}$, outlet temperature of base fluid, °C

$T_{b.in}$, inlet temperature of base fluid, °C

The properties of water are determined at average temperature, which is:

$$T_{ave} = \frac{(T_{out} + T_{in})}{2} \tag{3-3}$$

Where:

T_{ave} , average temperature, °C

The water velocity inside the double pipe heat exchanger can be expressed by:

$$V = \frac{V^{\circ}}{A_c} \tag{3-4}$$

$$V^{\circ} = \frac{m^{\circ}}{\rho} \tag{3-4-a}$$

$$A_c = \frac{\pi}{4}\, d_{in}^2 \qquad (3\text{-}4\text{-}b)$$

$$A_s = \pi D L \qquad (3\text{-}4\text{-}c)$$

Where:

ρ Density, kg/m^3

d_i Tube inner diameter, m

V° Volume flow rate

V Inside velocity, m/s

A_c Cross section area, m^2

A_s Surface area, m^2

The Reynolds number is defined as:

$$R_e = \frac{\rho\, V_{in}\, d_i}{\mu} \qquad (3\text{-}5)$$

$$\mu = \upsilon\ x\ \rho \qquad (3\text{-}5\text{-}a)$$

Where:

V_{in} : The mean velocity, m/s

d_i : Tube inner diameter, m

υ : The kinematic viscosity, m^2/s

μ : The dynamic viscosity (kg/m.s)

The Nusselt number is calculated by:

$$Nu = \frac{h\,D}{K} \tag{3-6}$$

Where:

h : The heat transfer coefficient, W/m^2 k

K : The conductivity, W/m.k

For water, the Nusselt number is calculated by [28]:

$$Nu = 0.012(Re^{0.8} - 280)Pr^{n} \tag{3-7}$$

In this equation, the properties were evaluated at the temperature of the common liquids, and the exponent *n* has the following values:

n = (0.4 for heating or 0.3 for cooling) of the fluid

For: 1.5< Pr < 500, 3000< Re< 10^6

The overall heat transfer coefficient for nanofluids and water is expressed by the following equation:-

$$U_{\mathrm{i}} = \frac{Q_{nf}}{A_s\,\Delta T_{lm}} \tag{3-8}$$

Where:

ΔT_{lm} The logarithmic mean temperature difference °C:

$$\Delta T_{lm} = \frac{(T_{h2}-T_{c2})-(T_{h1}-T_{c1})}{L_n\frac{(T_{h2}-T_{c2})}{(T_{h1}-T_{c1})}} \quad (3\text{-}8\text{-}a)$$

The physical thermal properties of nanofluid were calculated based on the average temperature. The heat transfer rate of nanofluid is:

$$Q_{nf} = m^{\circ}_{nf} \cdot C_{p.nf}(T_{o.nf} - T_{i.nf}) \quad (3\text{-}9)$$

Where:

$C_{p.nf}$: The specific heat of nanofluid, J/kg K

m°_{nf} : The mass flow rate of nanofluid, L/s

$T_{o.nf}$: Outlet temperature of nanofluid, °C

$T_{i.nf}$: Inlet temperature of nanofluid, °C

The equation that is appropriate for using nanofluid density [21-29]:

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \quad (3\text{-}10)$$

Where:

ρ_{nf}: The density of nanofluid, kg/m^3

ϕ : The volume concentration of nanofluid.

ρ_{bf}: The density of base fluid (water), kg/m^3

ρ_{np}: The density of nanoparticles, kg/m^3

Also, the specific heat of nanofluid can be determined by the following equation [6]:

$$C_{p,nf} = \frac{(1-\phi)\rho_{bf}C_{p.bf}+\phi\rho_p C_{np}}{\rho_{nf}} \qquad (3\text{-}10\text{-}a)$$

The viscosity of nanofluids is computed by using the general Einstein's formula [20-30]

$$\mu_{nf} = \mu_{bf}(1 + 2.5\,\emptyset\,) \qquad (3\text{-}11)$$

By Maxwell's model, the effective thermal conductivity (k_{nf}) of the nanofluids can be assessed as follows [19-31]:

$$k_{nf} = k_{bf}\left[\frac{k_{np}+2k_{bf}-2\phi(k_{bf}-k_{np})}{k_{np}+2k_{bf}+\phi(k_{bf}-k_{np})}\right] \qquad (3\text{-}12)$$

Table 3.3: Thermal properties of base fluids and nanoparticles.

No.	Property	Al_2O_3 (nanoparticle)	TiO_2 (nanoparticle)	Water (base fluid)
1	$c_p [J.kg^{-1}.k^{-1}]$ (Specific heat)	895	689.36	4178
2	$\rho [kg.m^{-3}]$ (Density)	3900	4500	996
3	$k[W.m^{-1}.K^{-1}]$ (Thermal conductivity)	36	8.4	0.617
4	$d_p (nm)$ (Dimeter of nanoparticles)	28	25-45	-

The calculated thermophysical properties of the nanofluids were listed in Table (3.3). The Reynolds and Prandtl numbers are calculated by considering the nanofluid properties as follows:

$$Re_{nf} = \frac{\rho_{nf}\, u_{nf}\, D_{h.nf}}{\mu_{nf}} \tag{3-13}$$

$$Pr_{nf} = \frac{C_{p_{nf}}\, \mu_{nf}}{K_{nf}} \tag{3-14}$$

The following equation was used to calculate the Nusselt number and to predict the heat transfer performance of the nanofluid [9]:

$$Nu_{nf} = 0.074 {Re_{nf}}^{0.707} {Pr_{nf}}^{0.385} \emptyset^{0.074} \tag{3-15}$$

$$Nu_{nf} = \frac{h_{i.nf}\, d_i}{K_{nf}} \tag{3-16}$$

The heat transfer coefficient for nanofluids is expressed by the equation seen below:

$$h_{i.nf} = \frac{Nu_{nf}\, K_{nf}}{d_i} \tag{3-17}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

Experimental heat transfer results from proposed nanofluids (TiO_2/water and Al_2O_3/water), as well as the results of base fluid in the double pipe heat exchanger, were presented and discussed in this chapter. The results of these fluids are evaluated based on the effect of varying volume concentrations of 0.1, 0.2 and 0.3% of each type of nanofluids, and flow rates of (2.5, 3, 3.5, 4 and 4.5 L/min) for each concentration of the proposed nanofluids on the heat exchanger performance. The double pipe heat exchanger performance is expressed by the difference of the flowed fluids in the heat exchanger. The parameters of heat transfer, heat transfer coefficient, overall heat transfer coefficient, specific heat, the logarithmic mean temperature, thermal conductivity, density, dynamic viscosity, kinematic viscosity, Nusselt number, Reynolds number, and Prandtl number were calculated according to the equations which were related with these situations. Finally, the results of all experiments were analyzed to create a comparison among these experiments.

4.1 Preparation and assembly of the test apparatus

In order to conduct this study, a new experimental system must be manufactured, because there is no such device in the university for these types of experiments. The first step is to manufacture a double tube heat exchanger. In mid-April 2017, a double pipe heat exchanger was manufactured according to the thesis requirements in a specialized workshop. Subsequently, all other equipment and accessories were purchased from component markets that specialized in the sale of these types of equipment. The assembling of the test system happened in the laboratory of the aerodynamic department of the University of Turkish aeronautical association institute of science and technology in Ankara under eyes of Assist Prof. Dr. Mohamed

Salem Elmnefi "the supervisor of this thesis". The system was obtained from mid-April to the end of June 2017. In this period, the proposed nanofluid was prepared in a nongraphic laboratory of the Middle East University in Ankara, Turkey.

4.2 Experimental Results

4.2.1 Base fluid (water) Experimental Results

The first experiment on the base fluid (water) as a cooling fluid was carried out on 12 July 2017, in flow rates of (2.5, 3, 3.5, 4 and 4.5 L/min) and inlet temperature of 30 ˚C for the cold fluid, and 7 L/m and inlet temperature of 60 ˚C for the hot water of the hot loop. Table (4.1) presents the temperatures which measured by thermocouples and the flow rates which measured by the flowmeters for both the cold and hot fluid. The experiment is repeated twice for each flow rate to get accurate results.

Table 4.1: The three tests of the base fluid (water)

Date 12 July 2017	Cold Water							
No	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	2.5	30.0	33.6	33.7	33.7	33.67	0.0577	0.0333
2	3	30.0	33.5	33.6	33.6	33.57	0.0577	0.0333
3	3.5	30.0	33.5	33.5	33.6	33.53	0.0577	0.0333
4	4	30.0	33.3	33.4	33.4	33.37	0.0577	0.0333
5	4.5	30.0	33.3	33.3	33.4	33.33	0.0577	0.0333

4.2.2 TiO_2/Water Nanofluids Experimental Results

The following test on the TiO_2 water nanofluid with TiO_2 nanoparticles of 0.1% was added to the double pipe heat exchanger rather than cold water to study its effect on the overall heat exchanger performance. This experiment was executed on 19 July 2017, and repeated for 2 times for the same nanofluid, but for concentrations of (0.2 and 0.3%) at the identical situations cited previously on 26 July and 02 August 2017, respectively. Tables (4.2), (4.3) and (4.4) present the temperatures which measured by using thermocouples and the flow rate which measured by the flow meters for each of the cold fluid (nanofluid) and hot fluid (water) for these experiments. The experiment is repeated twice for each flow rate to get accurate results.

Table 4.2: The three tests of the TiO_2/water nanofluid with TiO_2 nanoparticles of 0.1%.

Date 19 July 2017	TiO_2 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	0.1	2.5	30.0	33.9	34.0	34.0	33.97	0.0577	0.0333
2	0.1	3	30.0	33.8	33.7	33.8	33.77	0.0577	0.0333
3	0.1	3.5	30.0	33.6	33.7	33.7	33.67	0.0577	0.0333
4	0.1	4	30.0	33.6	33.6	33.7	33.63	0.0577	0.0333
5	0.1	4.5	30.0	33.5	33.4	33.5	33.47	0.0577	0.0333

Table 4.3: The three tests of the TiO_2/water nanofluid with TiO_2 nanoparticles of 0.2%.

Date 26 July 2017	TiO_2 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	0.2	2.5	30.0	34.2	34.3	34.3	34.27	0.0577	0.0333
2	0.2	3	30.0	33.9	34.0	34.0	33.97	0.0577	0.0333
3	0.2	3.5	30.0	33.9	33.9	33.9	33.9	0.0577	0.0333
4	0.2	4	30.0	33.8	33.7	33.8	33.77	0.0577	0.0333
5	0.2	4.5	30.0	33.6	33.7	33.7	33.67	0.0577	0.0333

Table 4.4: The three tests of the TiO_2/water nanofluid with TiO_2 nanoparticles of 0.3%.

Date 02 August 2017	TiO_2 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviati on	Stander Error
1	0.3	2.5	30.0	34.5	34.6	34.6	34.57	0.0577	0.0333
2	0.3	3	30.0	34.3	34.4	34.4	34.37	0.0577	0.0333
3	0.3	3.5	30.0	34.2	34.2	34.2	34.2	0.0	0.0
4	0.3	4	30.0	34.0	33.9	34.0	33.97	0.0577	0.0333
5	0.3	4.5	30.0	33.8	33.8	33.9	33.83	0.0577	0.0333

4.2.3 Al_2O_3/Water Nanofluids Experimental Results

On the other hand, another three experiments were carried out on the Al_2O_3/water nanofluids instead of TiO_2/water nanofluids which used in the previous experiments, and with concentrations of 0.1, 0.2 and 0.3% at the same initial conditions mentioned in all previous experiments. These experiments were performed on 10, 16 and 27 August 2017, respectively. Tables (4.5), (4.6) and (4.7) present the temperatures which measured by thermocouples and the flow rates which measured by the flow meters for both of the cold fluid (nanofluid) and hot fluid (water) for these experiments. The experiment is repeated twice for each flow rate to get accurate results.

Table 4.5: The three tests of the Al_2O_3/water nanofluid with Al_2O_3 nanoparticles of 0.1%.

Date 10 August 2017	Al_2O_3 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	0.1	2.5	30.0	34.4	34.5	34.5	34.47	0.0577	0.0333
2	0.1	3	30.0	34.3	34.2	34.3	34.27	0.0577	0.0333
3	0.1	3.5	30.0	34.1	34.1	34.2	34.13	0.0577	0.0333
4	0.1	4	30.0	34.0	34.0	34.1	34.03	0.0577	0.0333
5	0.1	4.5	30.0	33.9	33.8	33.9	33.87	0.0577	0.0333

Table 4.6: The three tests of the Al_2O_3/water nanofluid with Al_2O_3 nanoparticles of 0.2%.

Date 16 August 2017	Al_2O_3 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	0.2	2.5	30.0	34.7	34.7	34.8	34.73	0.0577	0.0333
2	0.2	3	30.0	34.3	34.4	34.4	34.37	0.0577	0.0333
3	0.2	3.5	30.0	34.3	34.3	34.3	34.3	0.0	0.0
4	0.2	4	30.0	34.1	34.2	34.2	34.17	0.0577	0.0333
5	0.2	4.5	30.0	34.0	34.1	34.1	34.07	0.0577	0.0333

Table 4.7: The three tests of the Al_2O_3/water nanofluid with Al_2O_3 nanoparticles of 0.3%.

Date 27 August 2017	Al_2O_3 Nanofluid								
No	Concentration Ø(%) (N.P.)	Flow Rate L/min	T3 Tc in (°C)	T4 Tc out Test 1 (°C)	T4 Tc out Test 2 (°C)	T4 Tc out Test 3 (°C)	T4 Tc out Average (°C)	Stander Deviation	Stander Error
1	0.3	2.5	30.0	34.9	34.9	35.0	34.93	0.0577	0.0333
2	0.3	3	30.0	34.6	34.7	34.7	34.67	0.0577	0.0333
3	0.3	3.5	30.0	34.4	34.5	34.5	34.47	0.0577	0.0333
4	0.3	4	30.0	34.3	34.4	34.4	34.37	0.0577	0.0333
5	0.3	4.5	30.0	34.2	34.3	34.3	34.27	0.0577	0.0333

4.2.4 Errors in the Experiment

Before starting the error estimation of the current experimental results, let us first consider some important terms shall be considered, that is commonly used in error analysis. These terms are especially crucial for understanding the uncertainty analysis of the experimental results**:**

4.2.4.1 Personal Errors

This error is caused by the focus of the person who is experimenting on the close readings and neglect of the extreme readings, and to count accuracy when taking a reading, such as the direction of his glance when reading the meter, or a defect in his eyes.

4.2.4.2 Random Errors

Random Error is an error that does not appear regularly in all data (and is often observed indirectly) and has nothing to do with any of the variables. The random error usually has a normal distribution function. Such as temperature change, light intensity, air movement, electrical voltage, vibrations in the equipment or internal friction in the device. The causes of random errors are not always easy to identify or to do something about. Since they are random, they are just as likely to give a measured value that is high as it is low. Because of this, it is possible to analyze random errors statistically, and to be more confident of a result based on multiple measurements.

4.2.4.3 Systematic Errors

A systematic error is an error that will occur consistently in only one direction each time the experiment is performed, i.e., the value of the measurement will always be greater (or lesser) than the real value. Systematic errors most commonly arise from defects in the instrumentation or from using improper measuring techniques. For example, measuring a distance using the worn end of a meter stick, using an instrument that is not calibrated, or incorrectly neglecting the effects of viscosity, air resistance, and friction, are all factors that can result in a systematic shift of the experimental outcome.

4.2.5 Standard Deviation

The standard deviation is a measure of the dispersion, or scatter, of the data [33]. The standard deviation is often denoted by the Greek letter sigma, σ. The variance is σ². For a finite number of measurements, xi, the standard deviation is given by:

$$\sigma = \left[\frac{1}{n-1}\sum_{i-1}^{n}(Xi-\bar{X})^2\right]^{\frac{1}{2}} \tag{4-1}$$

Where:

$\bar{X}$: Mean temperature

n : Number of the tests.

4.2.5 Standard Errors

The standard error provides an estimate of the precision of a parameter (such as a mean, proportion, odds ratio, etc) and is used when one wants to make inferences about data from a sample (eg, the sort of sample in a given study) to some relevant matters [34]. The standard error of the sample mean depends on both the standard deviation and the sample size, by the simple relation:

$$SE = \frac{\sigma}{\sqrt{n}} \tag{4-2}$$

Tables (4.1) for the three test of the base fluid (water), (4.2, 4.3 and 4.4) for the three tests of the TiO_2/water nanofluid with TiO_2 nanoparticles of (0.1%, 0.2% and 0.3%) respectively and (4.5, 4.6 and 4.7) for the three tests of the Al_2O_3/water nanofluid with Al_2O_3 nanoparticles of (0.1%, 0.2% and 0.3%) respectively, showing the values of both standard deviation and standard error, which are reliable in determining the percentage of errors in the tests. The standard deviation tells us something about how close our measurements are to the mean. If σ is small, that means random errors are small, and the precision of the measurements is high. This can be seen by examining the formula for σ. The standard error is always smaller than the standard deviation, this can be seen in all the tables above.

Figures (4.1), (4.2) and (4.3) show the standard error of (5) systematic samples (n=3) from temperatures for (water, TiO_2 0.1%, 0.2% and 0.3% nanofluids and Al_2O_3 0.1%, 0.2%, and 0.3% nanofluids).

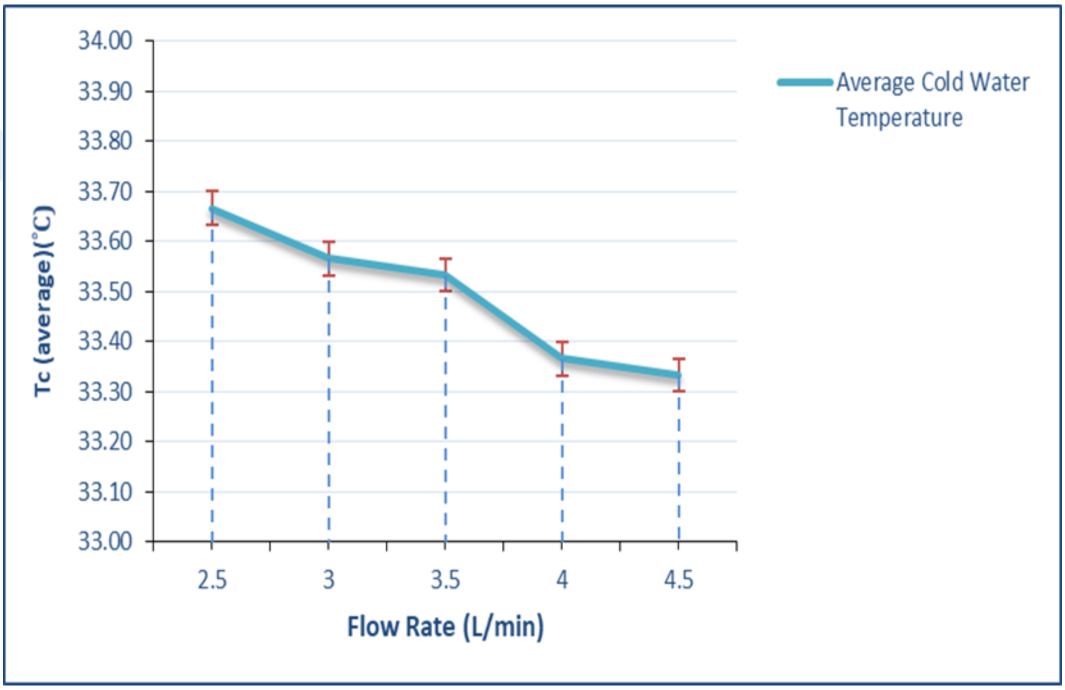


Figure 4.1: The standard error of (5) systematic samples (n=3) from temperatures for water.

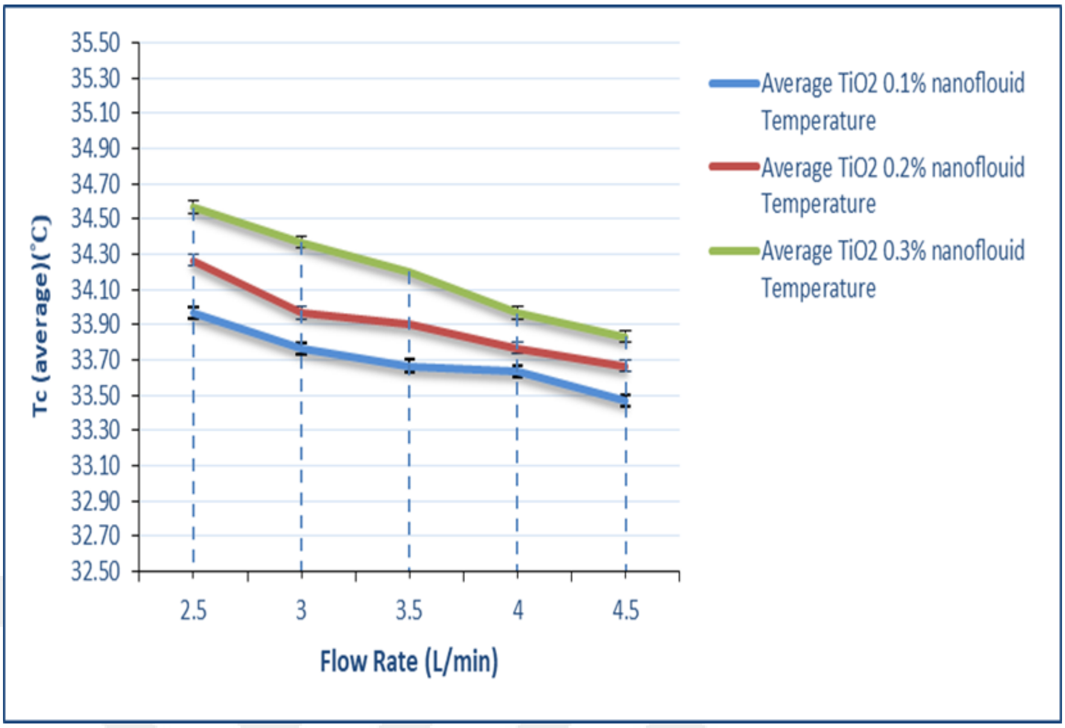


Figure 4.2: The standard error of (5) systematic samples (n=3) from temperatures for (TiO_2 0.1%, 0.2% and 0.3% nanofluids).

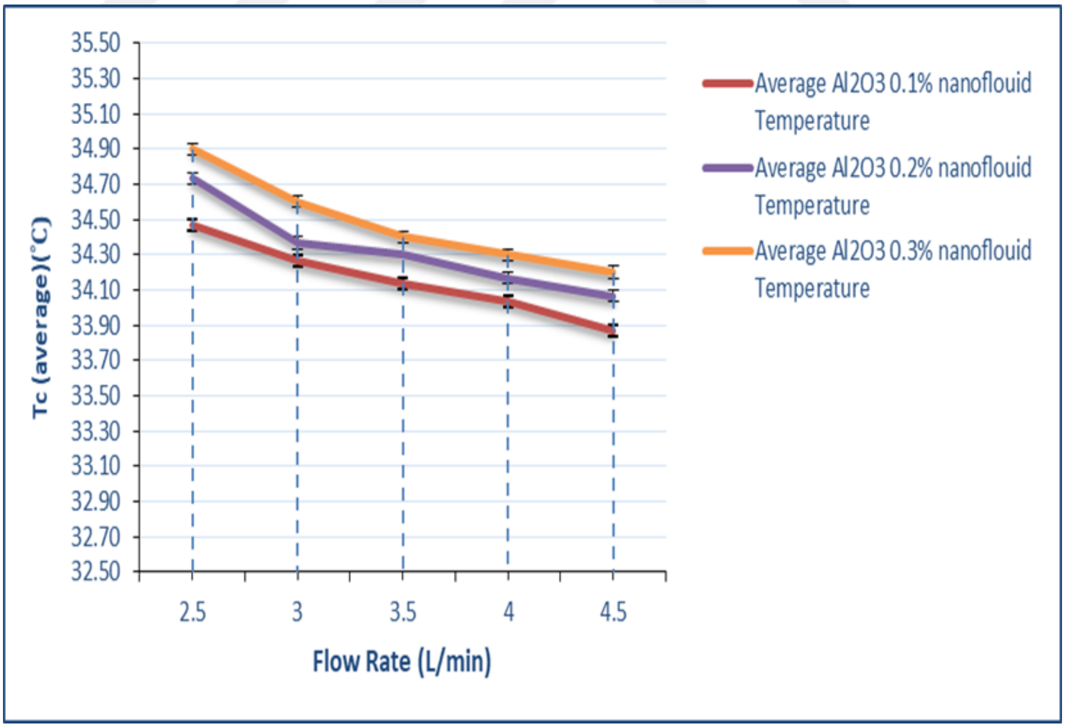


Figure 4.3: The standard error of (5) systematic samples (n=3) from temperatures for (Al_2O_3 0.1%, 0.2%, and 0.3% nanofluids).

4.3 The performance results of the double pipe heat exchanger

4.3.1 The effect double pipe heat exchanger geometric

The heat transfer is carried out in the heat exchanger specifically in the (double pipe heat exchanger) through the surface area of the liquid. The surface area of the heat exchanger is one of the most important factors that control the rate of heat transfer from hot liquid to the cold fluid. If the amount of heat to be transferred from hot liquid to cold fluid is large, this requires a heat exchanger with a large surface area (the surface area of the heat exchanger is large). The heat exchanger surface area can be increased by increasing the number and length of the heat exchanger piping with the diameter of the exchanger pipes.

There are many factors that have a significant and direct impact on the thermal performance of heat exchangers, which must be considered in the design and operation of these exchanges, including the following:

- Mass flow rate of fluid.
- Surface area of heat exchange.
- Thermal conductivity.
- The heat transfer coefficient.
- Hot and cold temperatures of fluids.
- The specific heat of the fluid.

A primary advantage of a double pipe heat exchanger is that it can be operated in a true counterflow pattern, which is the most efficient flow pattern compared to the parallel flow pattern. That is, it will give the highest heat transfer, overall heat transfer coefficient, heat transfer coefficient and Nusselt number for the double pipe heat exchanger design. Also, double pipe heat exchangers can handle high pressures and temperatures well. When they are operating in true counterflow.

4.3.2 Heat transfer versus mass flow rate

The figure (4.4) shows the rate of heat transfer performed according to the flow rate of the nanofluids, which is the ratio of TiO_2/water and Al_2O_3/water nanofluids heat transfer rate to the heat transfer rate of distilled water. They have used the volume concentrations 0.1% for TiO_2/water and Al_2O_3/water nanofluids at flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min). The addition of nanoparticles to distilled water has led to an increase in the rate of heat transfer. The effect of adding Al_2O_3 nanoparticles to the base fluid has yielded better results than the effect of adding TiO_2 nanoparticles to base fluids.

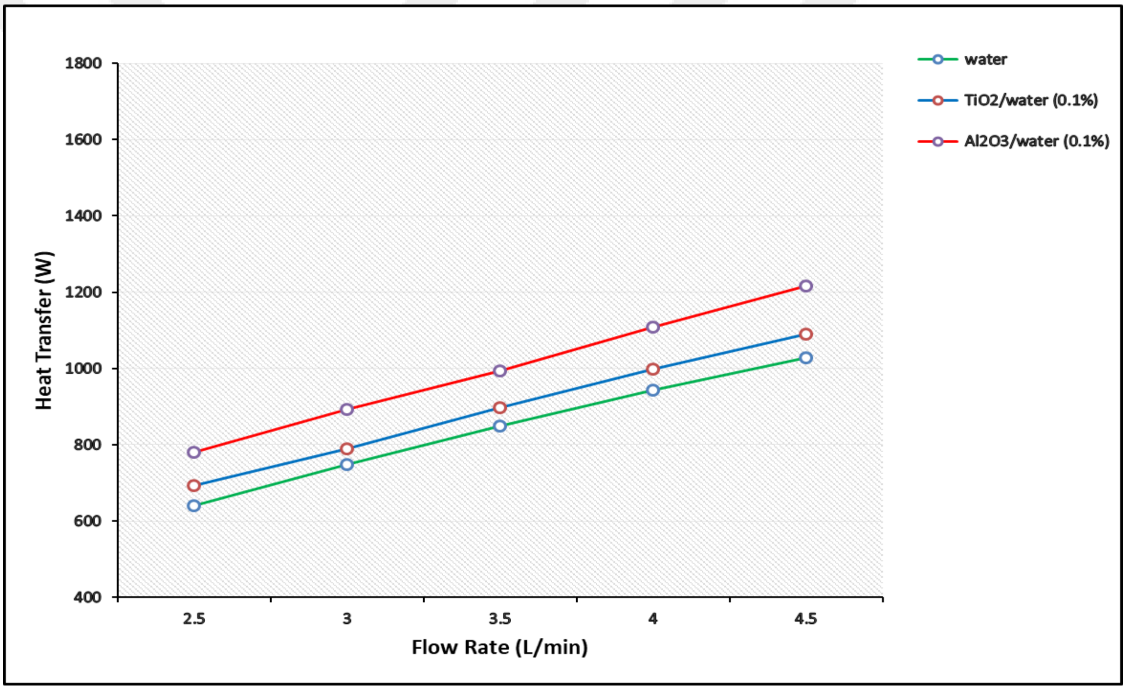


Figure 4.4: The relation between heat transfer with mass flow rate for (Water, TiO_2 0.1% & Al_2O_3 0.1%).

The rate of heat transfer performed according to the flow rate of the nanofluids as shown in figure (4.5), which is the ratio of TiO_2/water and Al_2O_3/water nanofluids heat transfer rate to the heat transfer rate of distilled water. They have used the volume concentrations 0.2% for TiO_2/water and Al_2O_3/water nanofluids at flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min). The addition of nanoparticles to distilled water has led to an increase in the rate of heat transfer. The effect of adding Al_2O_3 nanoparticles to the base fluid has yielded better results than the effect of adding TiO_2 nanoparticles to base fluids.

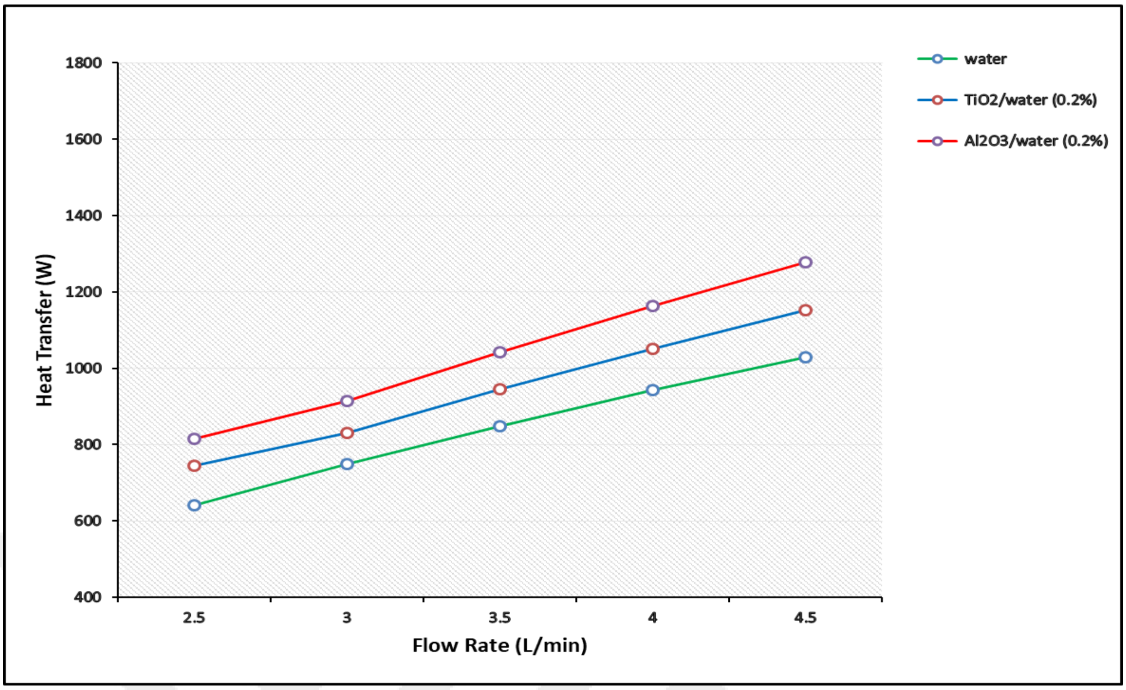


Figure 4.5: The relation between heat transfer with mass flow rate for (Water, TiO_2 0.2% &Al_2O_3 0.2%).

The best heat transfer rate happened for TiO_2/water and Al_2O_3/water nanofluids in the concentration of 0.3 % for each of nanofluids in flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min). Furthermore, the heat transfer rate of Al_2O_3/water nanofluid was better than TiO_2/water nanofluid and water respectively, as shown in figure (4.6).

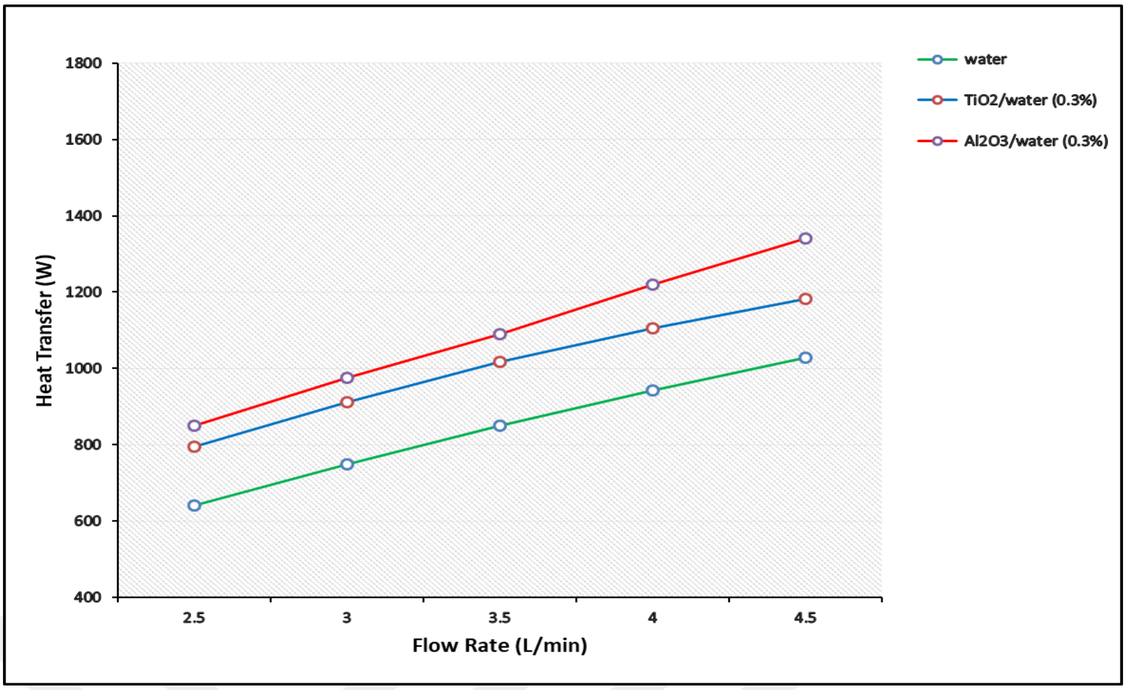


Figure 4.6: The relation between heat transfer with mass flow rate for (Water, TiO_2 0.3%&Al_2O_3 0.3%).

Figure (4.7) shows the comparison among water and Al_2O_3/water nanofluids in concentrations of (0.1, 0.2 and 0.3%) according to the flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

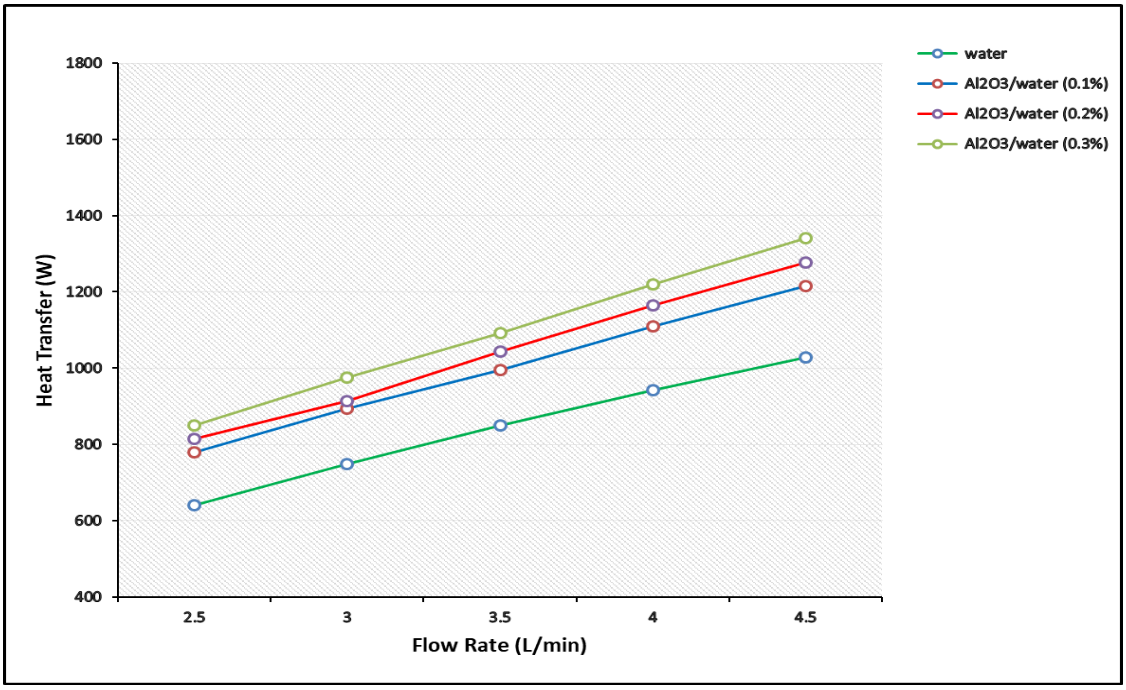


Figure 4.7: The relation between heat transfer with mass flow rate for (Water& Al_2O_3 0.1, 0.2 & 0.3%).

And the figure (4.8) shows the comparison among water and TiO_2/water nanofluids in concentrations of (0.1, 0.2 and 0.3%) according to the flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

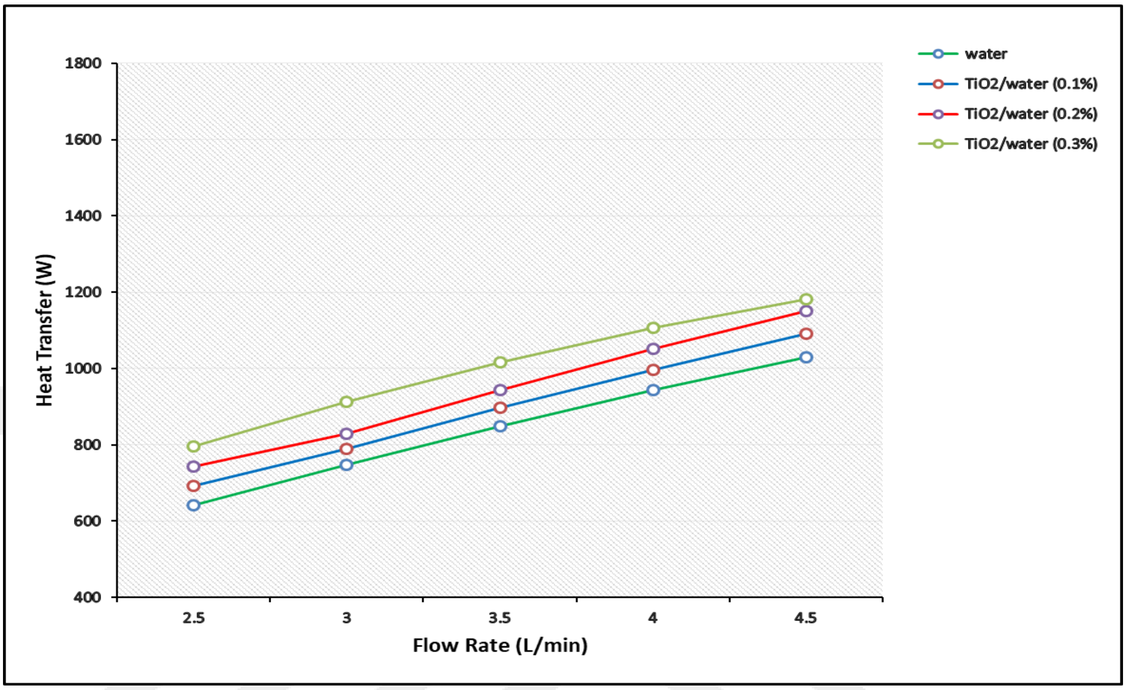


Figure 4.8: The relation between heat transfer with mass flow rate for (Water, TiO_2 0.1, 0.2&0.3%).

The results displayed that the rate of heat transfer of nanofluid is better than that of water and increases with the concentration of the size of nanoparticles to a certain mass flow rate, and it also increases with a flow rate of nanofluid rate of the same concentration of the volume of nanoparticles.

4.3.3 Overall heat transfer coefficient versus mass flow rate

In figure (4.9) can see a comparison between the overall heat transfer coefficient for the volume concentration of 0.1% for both TiO_2/water and Al_2O_3/water nanofluids to the water at flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

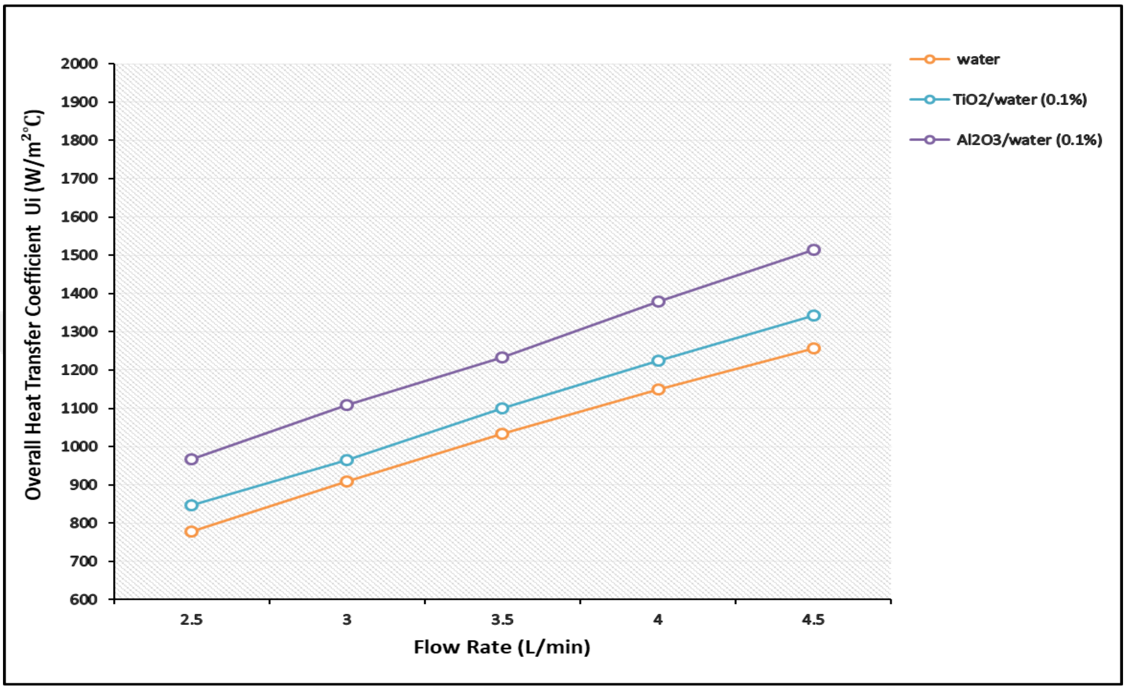


Figure 4.9: The relation between overall heat transfer coefficient with mass flow rate for (Water, TiO_2 0.1% & Al_2O_3 0.1%).

In figure (4.10) can see the impact of adding nanoparticles to water on the overall heat transfer coefficient for the volume concentration of 0.2% for both TiO_2/water and Al_2O_3/water nanofluids according to the flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

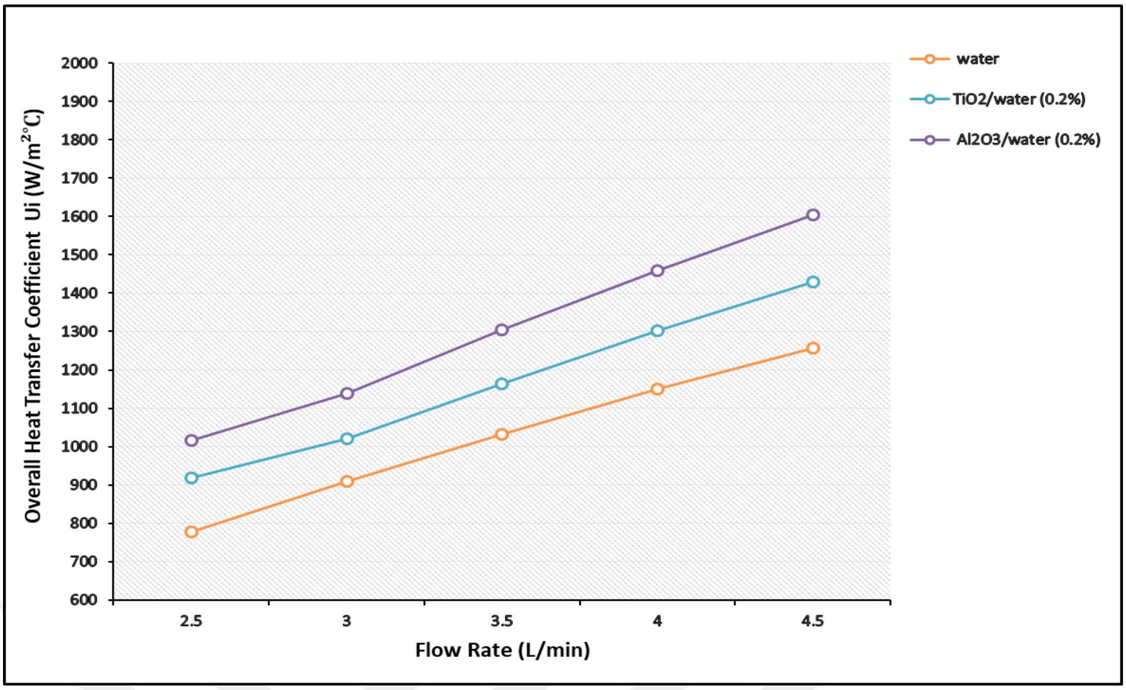


Figure 4.10: The relation between overall heat transfer coefficient with mass flow rate for (Water, TiO_2 0.2%&Al_2O_3 0.2%).

The comparison of overall heat transfer coefficient for TiO_2/water and Al_2O_3/water nanofluids in volume concentration of 0.3% and water according to the flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min) as shown in figure (4.11).

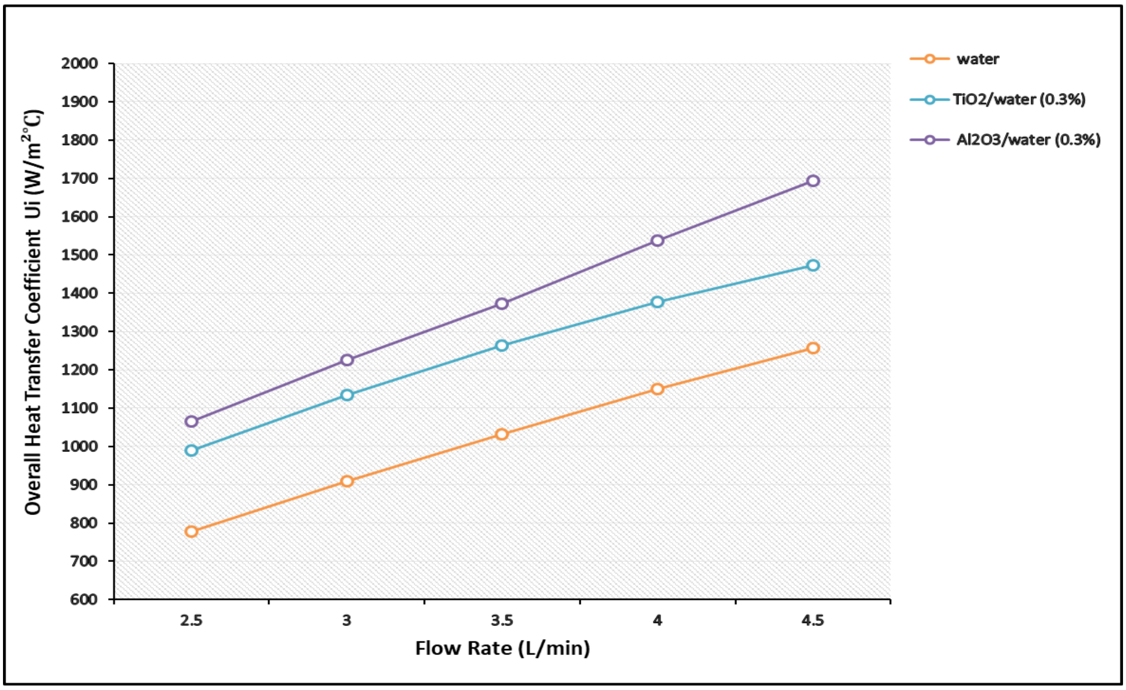


Figure 4.11: The relation between overall heat transfer coefficient with mass flow rate for (Water, TiO_2 0.3%&Al_2O_3 0.3%).

Figure (4.12) illustrates a comparison of the overall heat transfer coefficient of the water and nanofluids of Al_2O_3/water in volume concentrations of (0.1, 0.2 and 0.3%) at a flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

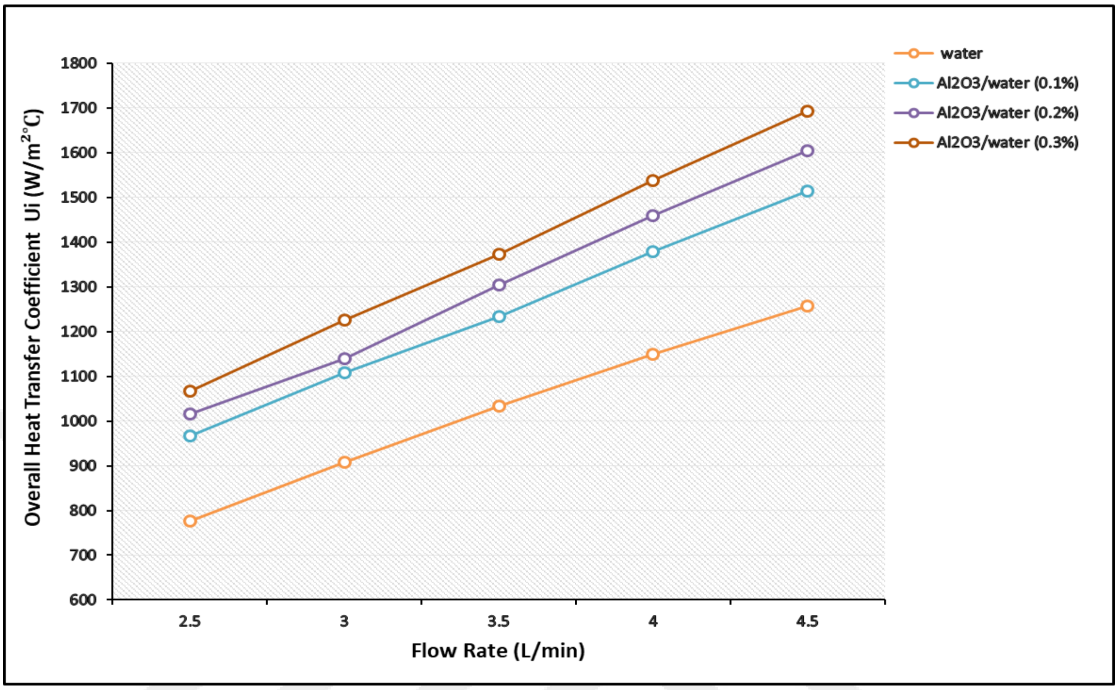


Figure 4.12: The relation between overall heat transfer coefficient with mass flow rate for (Water&Al_2O_3 0.1, 0.2 &0.3%).

The overall heat transfer coefficient of water and nanofluids of TiO_2\water in concentrations of (0.1, 0.2 and 0.3%) were compared as in figure (4.13) at a flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min).

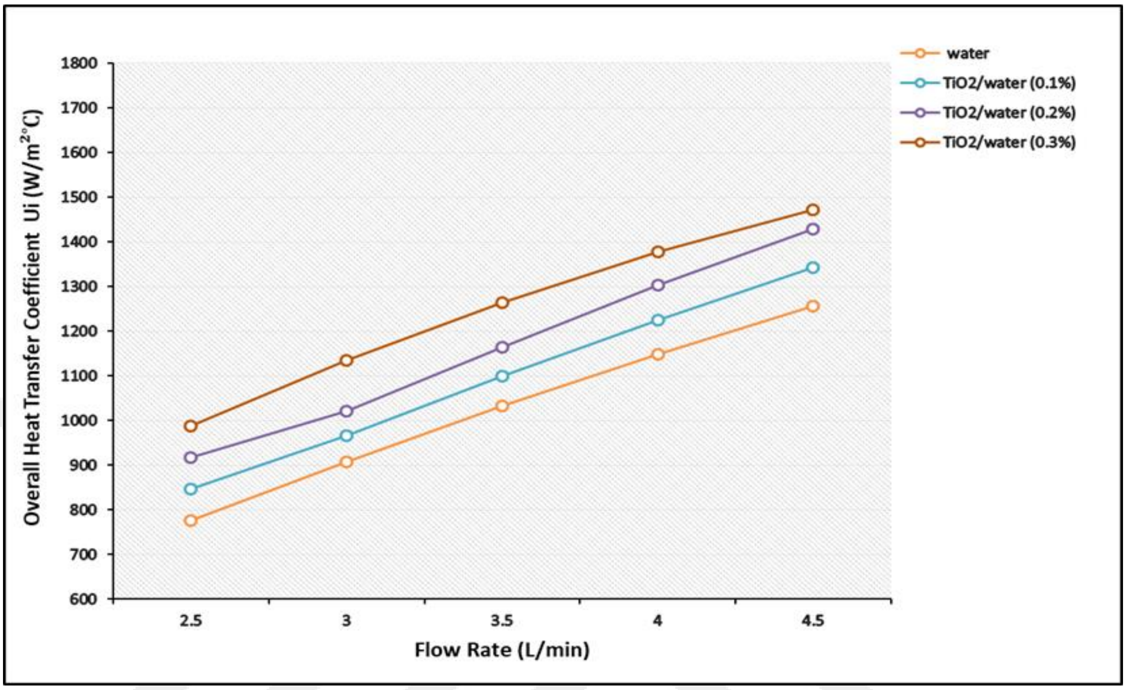


Figure 4.13: The relation between overall heat transfer coefficient with mass flow rate for (Water&TiO_2 0.1, 0.2 &0.3%).

From the figures (4.9), (4.10), (4.11), (4.12) and (4.13), it was cleared that overall heat transfer coefficient of the Nano-fluid is greater than overall heat transfer coefficient of distilled water. And for the nanofluids, the value of the overall heat transfer coefficient increased directly with increasing of particle volume concentration of nanofluid. Farther more, the overall heat transfer coefficient in a given concentration for Al_2O_3/water nanofluid is greater overall heat transfer coefficient of TiO_2/water nanofluid in same concentration value, and the best value of overall heat transfer coefficient was recorded in a concentration of 0.3% of Al_2O_3/water nanofluid.

4.3.4 Heat transfer coefficient versus mass flow rate

The comparison of the value of heat transfer coefficient among water, TiO_2/water, and Al_2O_3/water nanofluids is shown in Figures (4.14), (4.15) and (4.16) for concentrations of (0.1, 0.2 and 0.3%) for nanofluids, respectively.

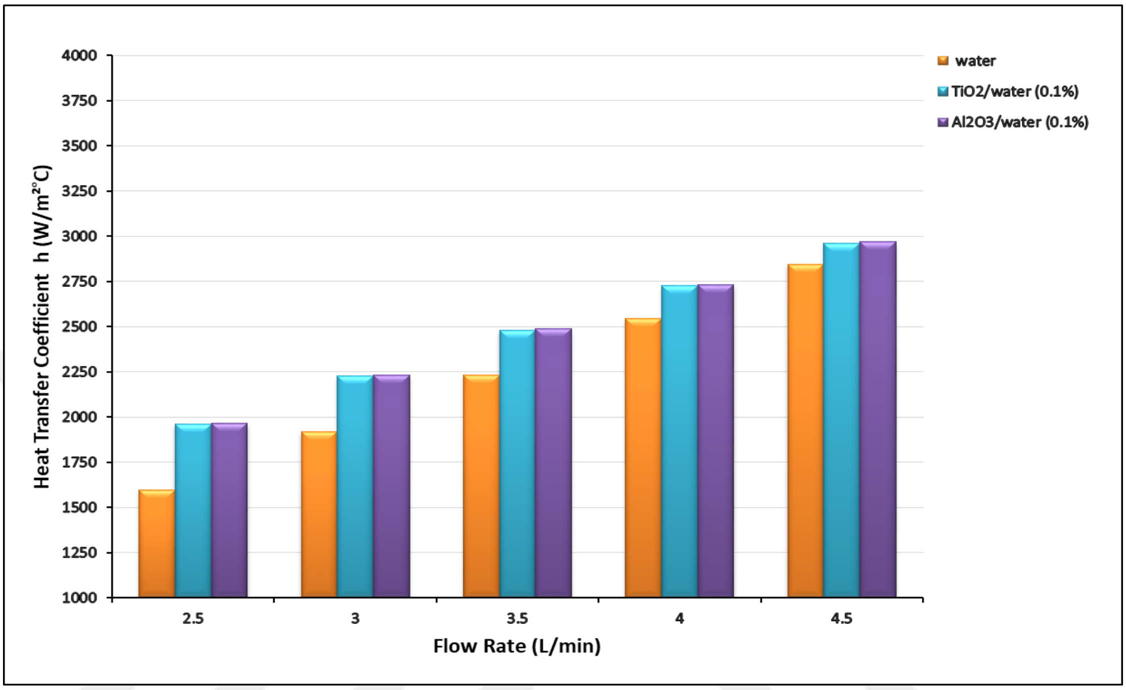


Figure 4.14: The relation between heat transfer coefficient with mass flow rate for (Water, TiO_2 0.1% & Al_2O_3 0.1%).

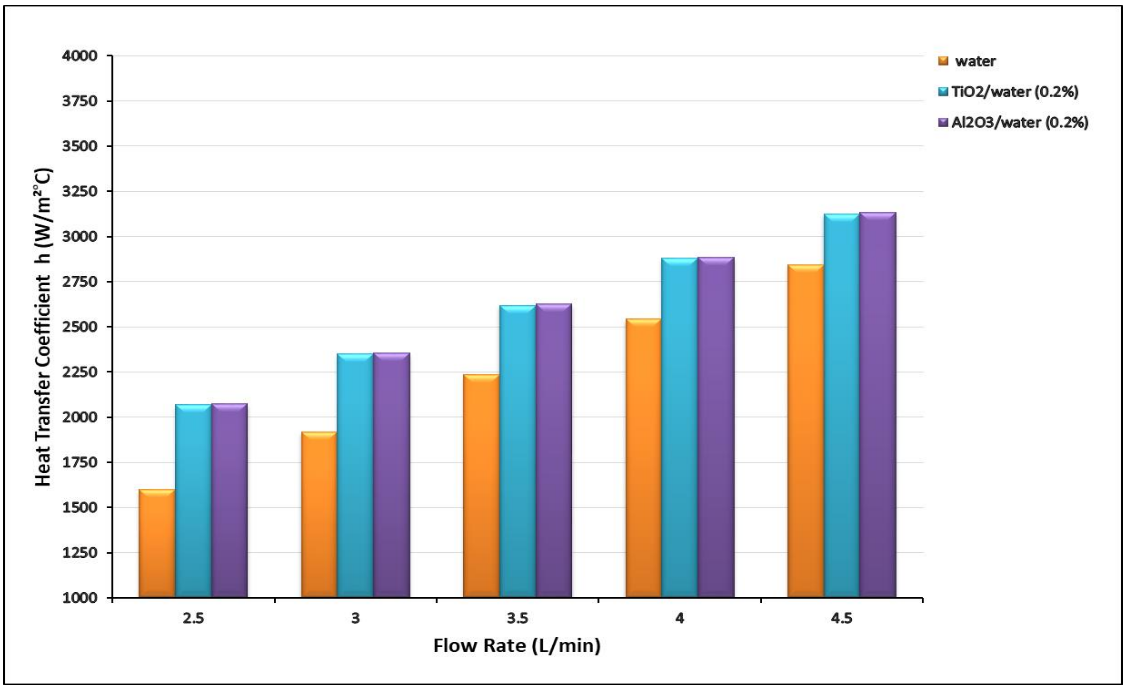


Figure 4.15: The relation between heat transfer coefficient with mass flow rate for (Water, TiO_2 0.2% & Al_2O_3 0.2%).

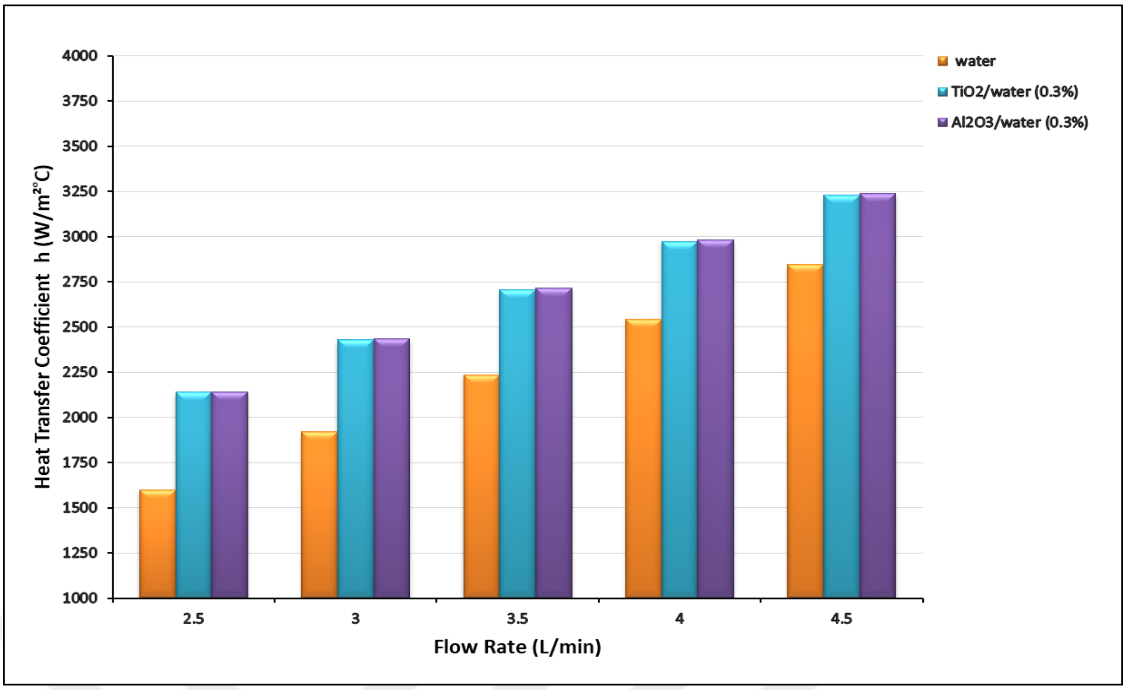


Figure 4.16: The relation between heat transfer coefficient with mass flow rate for (Water, TiO_2 0.3% & Al_2O_3 0.3%).

The comparison of the value of heat transfer coefficient among water and Al_2O_3/water nanofluids in concentrations of (0.1, 0.2 and 0.3%) is shown in figure (4.17).

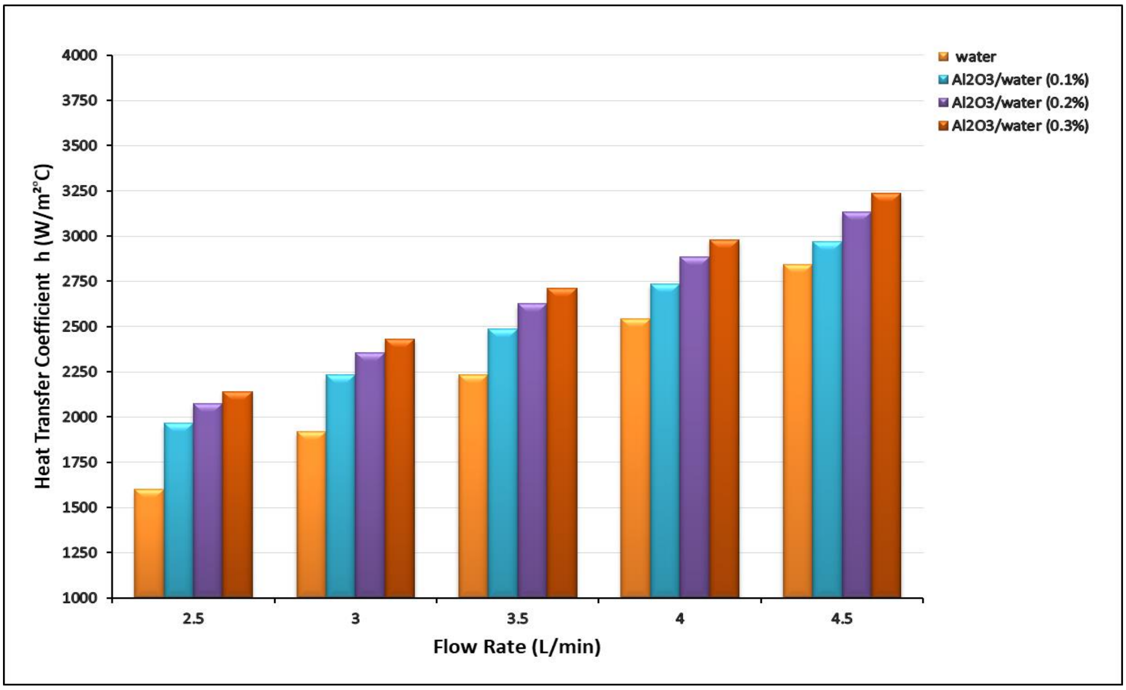


Figure 4.17: The relation between heat transfer coefficient with mass flow rate for (Water, Al_2O_3 0.1, 0.2&0.3%).

The comparison of the value of heat transfer coefficient among water and TiO_2/water nanofluids in concentrations of (0.1, 0.2 and 0.3%) is shown in figure (4.18).

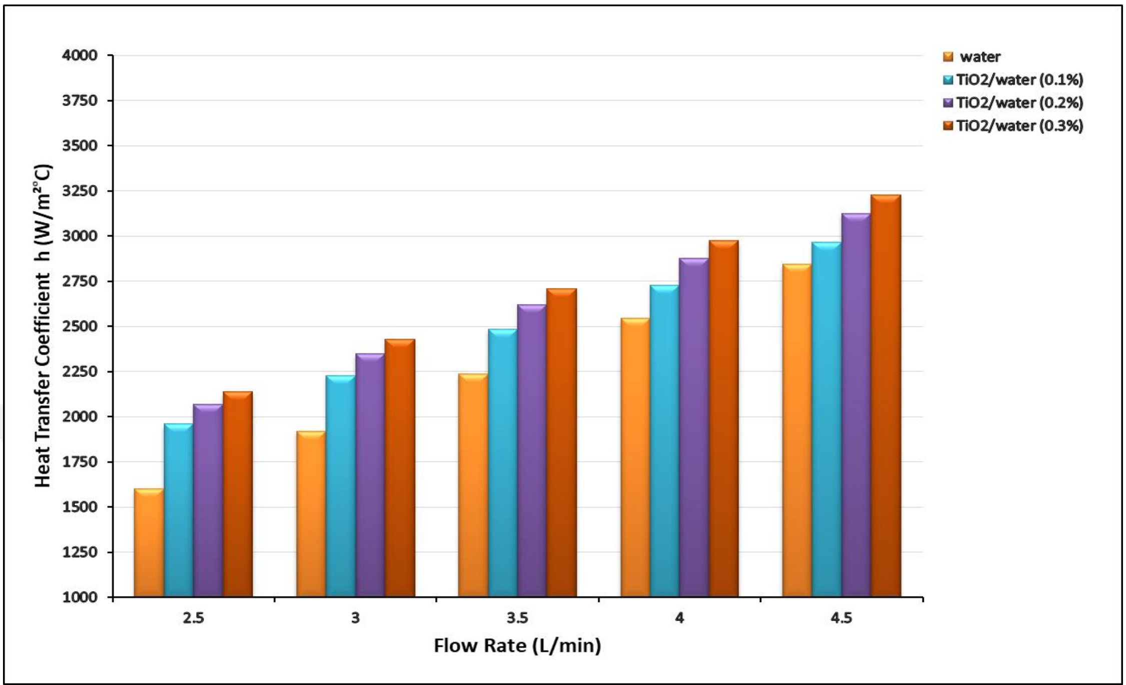


Figure 4.18: The relation between heat transfer coefficient with mass flow rate for (Water, TiO_2 0.1, 0.2&0.3%).

Figures (4.14), (4.15), (4.16), (4.17) and (4.18), showed that the enhancement of heat transfer coefficient is directly proportional to the increase in the concentration of nanofluids, and its value in nanofluids is higher than its value in the water. Farther more, the value of the heat transfer coefficient in Al_2O_3/water nanofluids is higher than TiO_2/water nanofluid and water respectively. And it is directly proportional to the increase in mass flow rate.

4.3.5 Nusselt number versus mass flow rate

Figures (4.19), (4.20) and (4.21) showed Nusselt number enhancement ratio, which is the ratio of TiO_2/water and Al_2O_3/water nanofluids Nusselt number to the Nusselt number of pure water, for different concentrations of nanoparticles of (0.1, 0.2 and 0.3%), in the various mass flow rate of (2.5, 3, 3.5, 4 and 4.5 L\min). It was clear that adding nanoparticles to base fluid increased the value of Nusselt number for both kinds of nanofluid, and it is a little bit better in TiO_2/water than Al_2O_3/water because of the difference in viscosity for each of them.

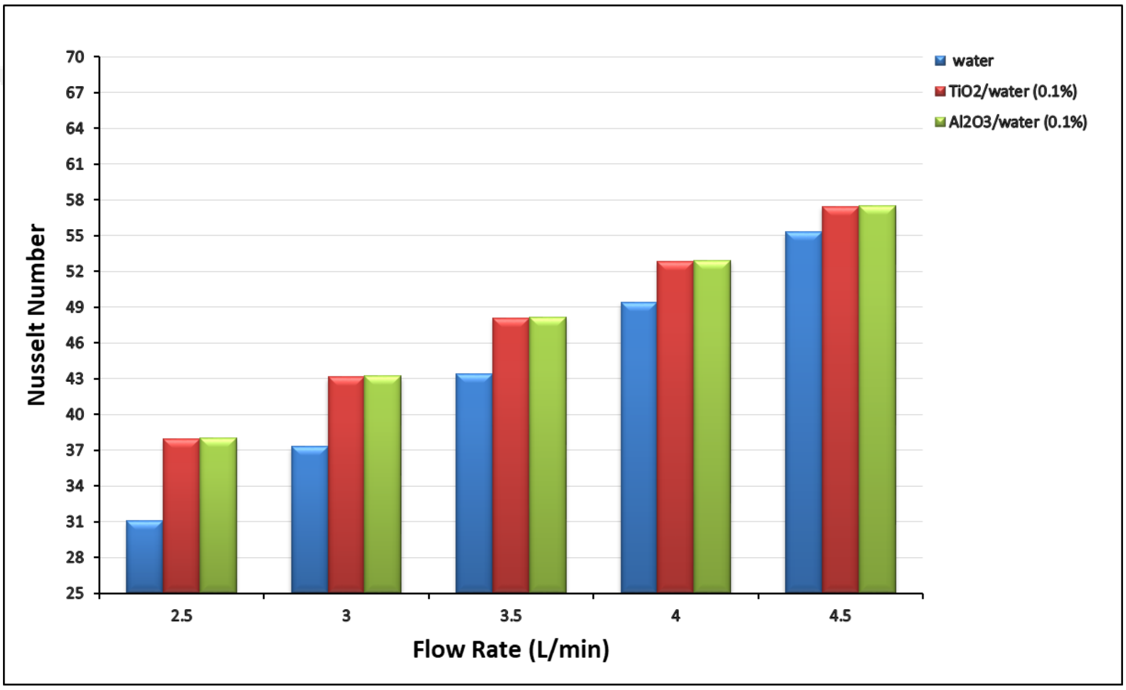


Figure 4.19: The relation between the Nusselt number with mass flow rate for (Water, TiO_2 0.1% & Al_2O_3 0.1%).

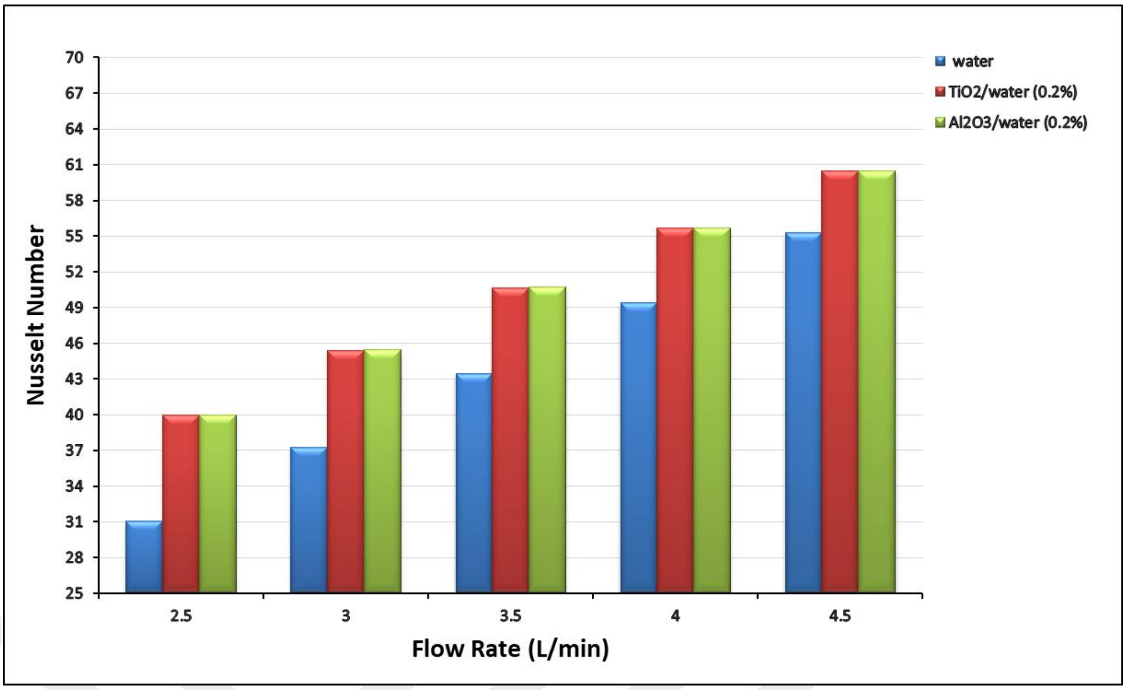


Figure 4.20: The relation between the Nusselt number with mass flow rate for (Water, TiO_2 0.2% & Al_2O_3 0.2%).

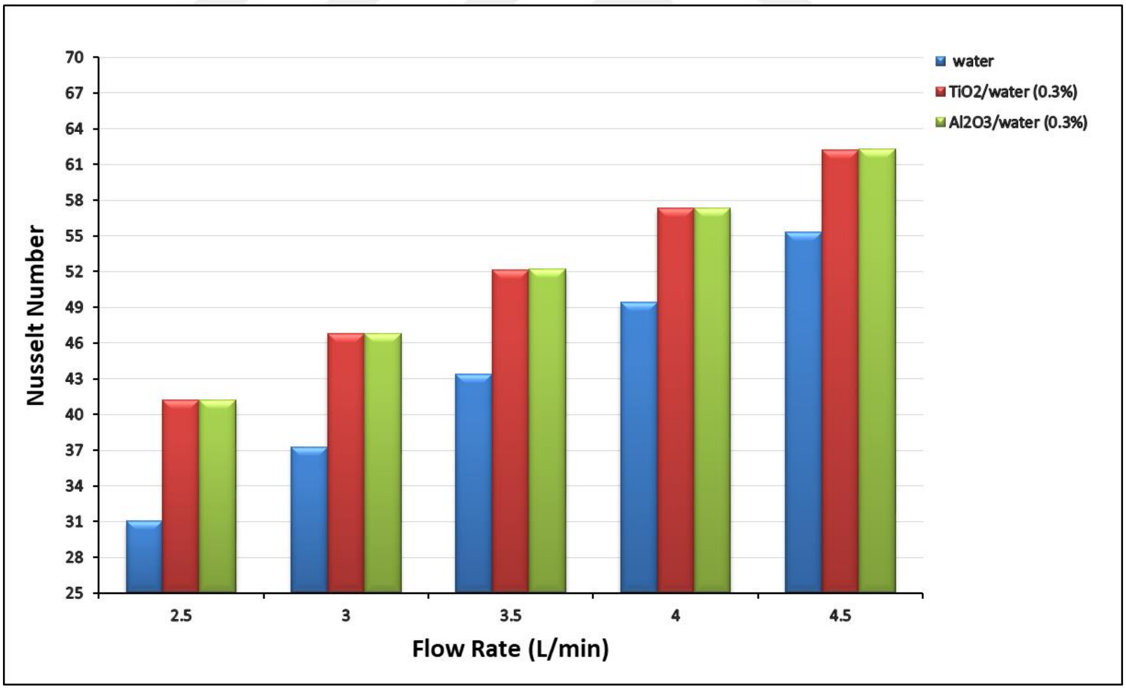


Figure 4.21: The relation between the Nusselt number with mass flow rate for (Water, TiO_2 0.3% & Al_2O_3 0.3%).

The figure (4.22) shows the relationship of Nusselt number for TiO_2/water in concentrations of (0.1, 0.2 and 0.3%) and pure water at mass flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min).

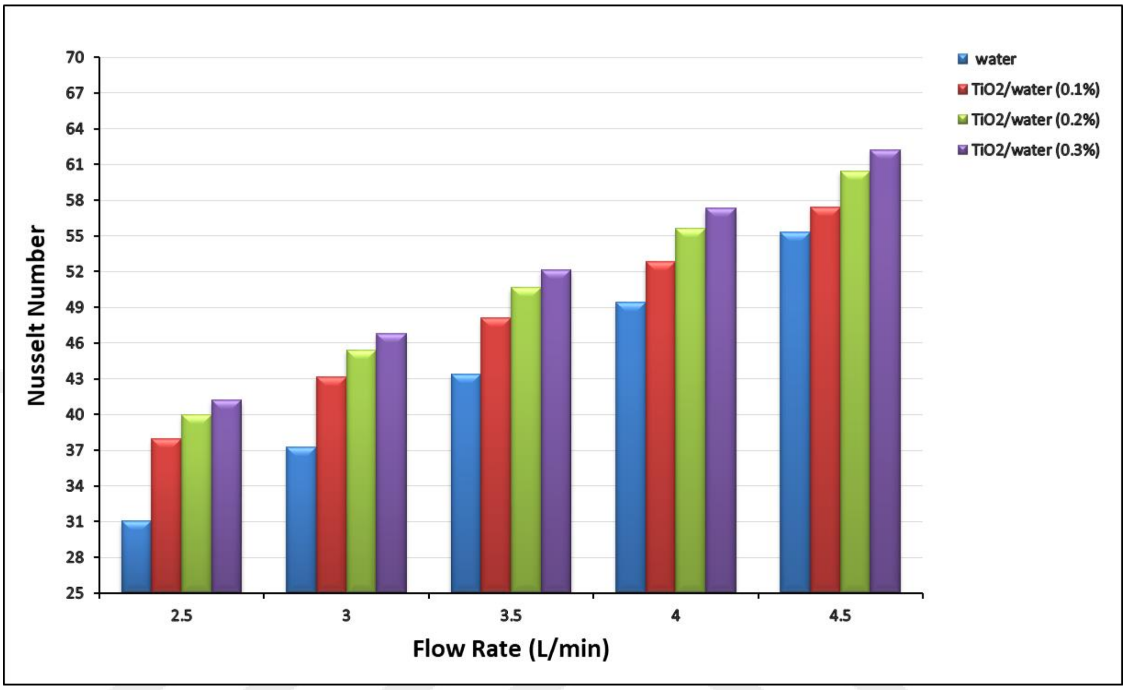


Figure 4.22: The relation between the Nusselt number with mass flow rate for (Water & TiO_2 0.1, 0.2&0.3%).

The figure (4.23) shows the relationship of Nusselt number for Al_2O_3/water in concentrations of (0.1, 0.2 and 0.3%) and pure water at mass flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min).

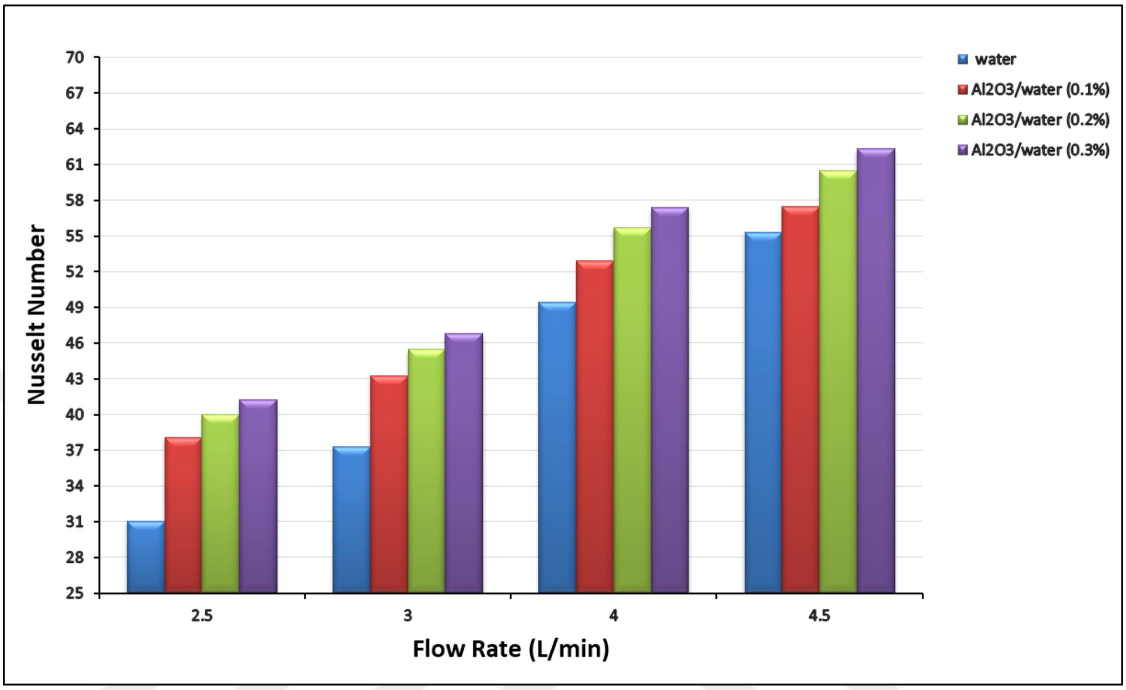


Figure 4.23: The relation between the Nusselt number with mass flow rate for (Water & Al_2O_3 0.1, 0.2&0.3%).

The above has shown an increase Nusselt number when the mass flow rate has increased and is increasing with increased concentration of nanofluids. In addition, the Nusselt number in the Al_2O_3/water is greater than the Nusselt number of TiO_2/water, and the highest value in the 0.3% concentration of Al_2O_3/water.

4.3.6 Reynolds number versus mass flow rate

To determine the ratios for Reynolds number for the mass flow rates of (2.5, 3, 3.5, 4 and 4.5 L/min) for water and nanofluids of Al_2O_3/water and TiO_2/water at (0.1, 0.2 and 0.3%) respectively. The figures (4.24), (4.25) and (4.26) were shown that the Reynolds number of nanofluids was higher than water and increased slightly with increased concentration of nanofluids according to the variable value in viscosity because of the effect of adding nanoparticles.

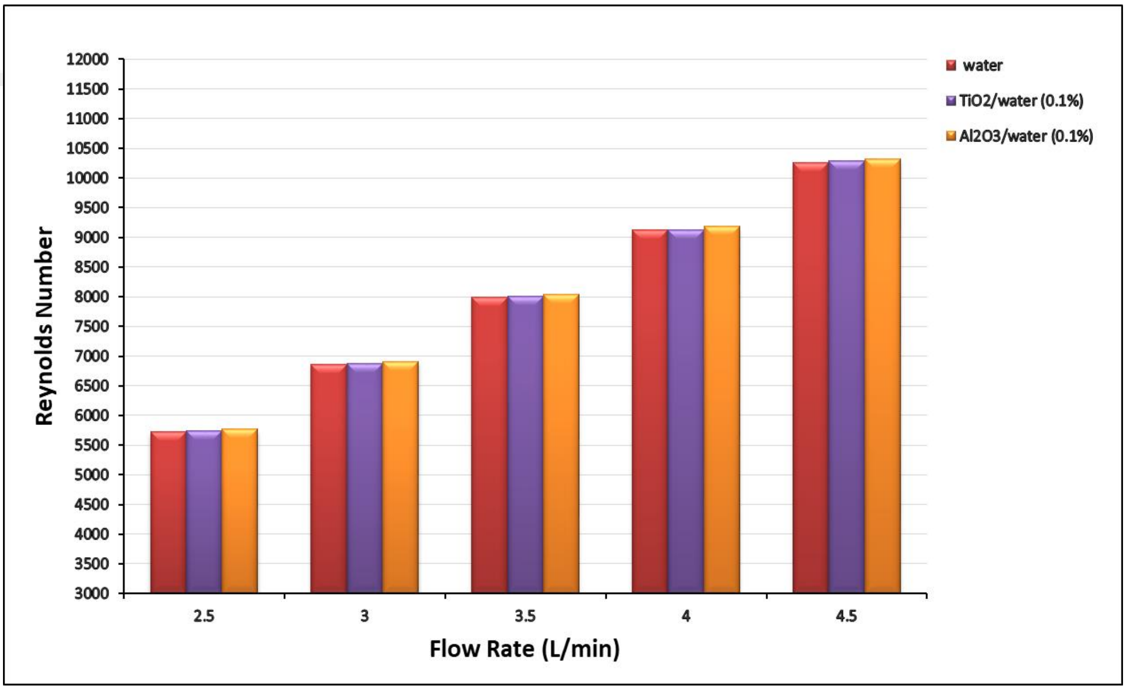


Figure 4.24: The relation between Reynolds number with mass flow rate for (Water, TiO_2 0.1% & Al_2O_3 0.1%).

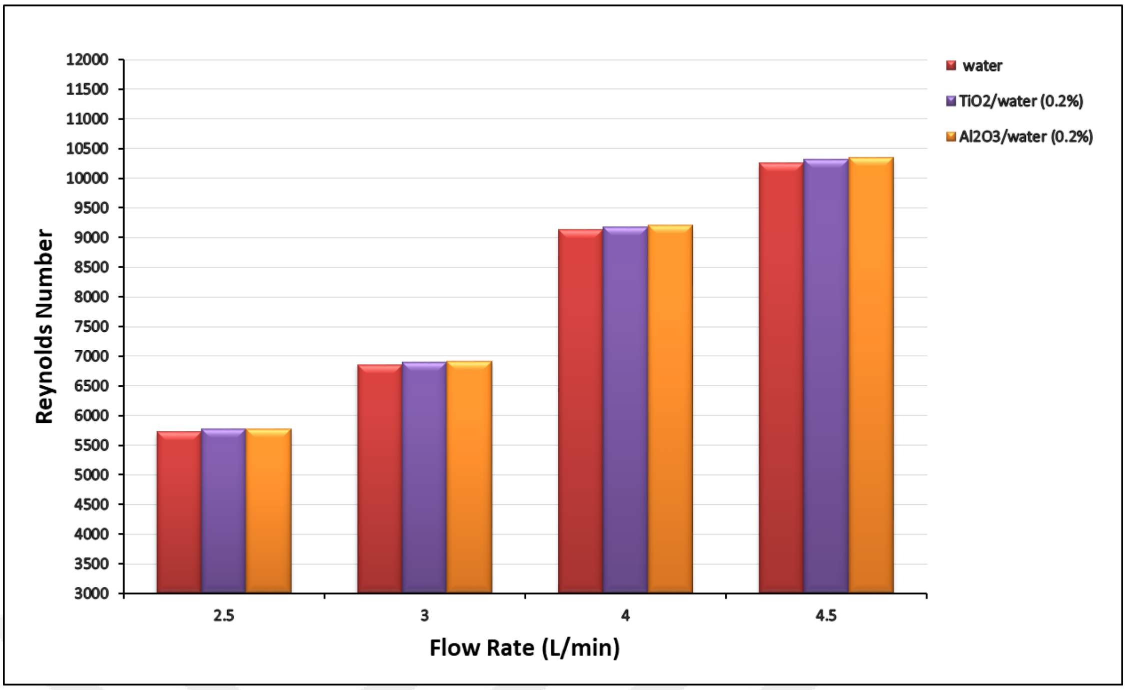


Figure 4.25: The relation between Reynolds number with mass flow rate for (Water, TiO_2 0.2% & Al_2O_3 0.2%).

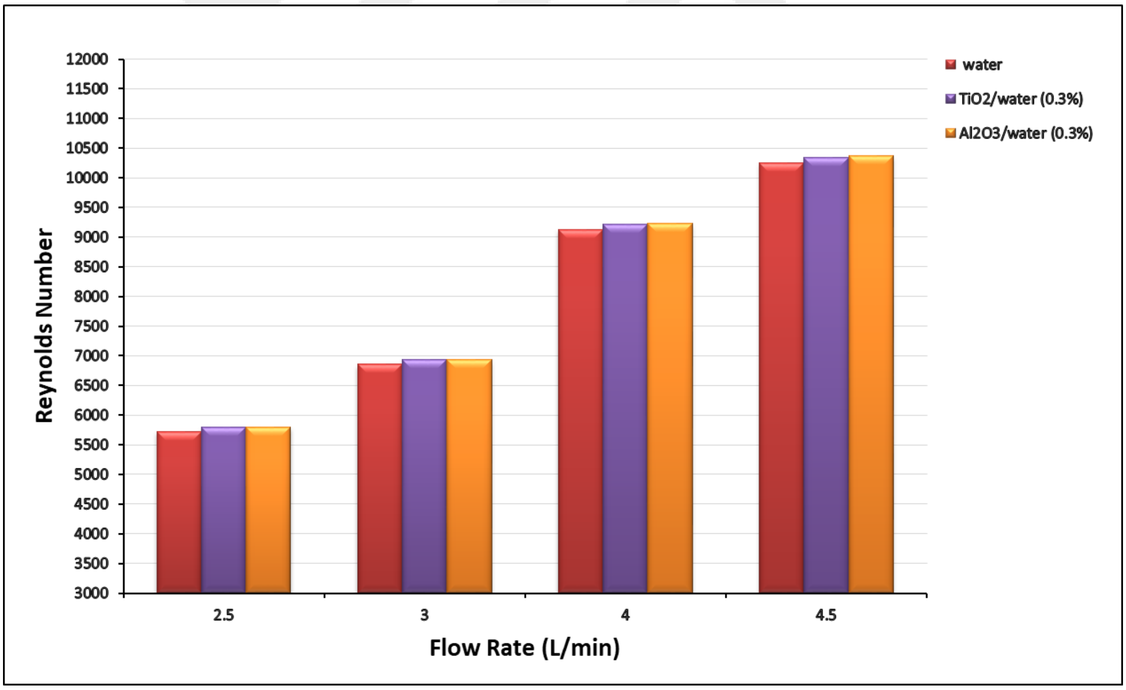


Figure 4.26: The relation between Reynolds number with mass flow rate for (Water, TiO_2 0.3% & Al_2O_3 0.3%).

The figure (4.27) shows that nanoparticles of TiO_2 in water at concentrations of (0.1, 0.2% and 0.3%) were compared to pure water for the Reynolds number at flow rates value of (2.5, 3, 3.5, 4 and 4.5 L\min). And the figure (4.28) shows that nanoparticles of Al_2O_3 in water at concentrations of (0.1, 0.2%, and 0.3%) were compared to pure water for the Reynolds number at flow rates value of (2.5, 3, 3.5, 4 and 4.5 L\min). From the figures (4.27) and (4.28), it was concluded that Reynolds number increased by increasing the concentration of nanofluid, and it is higher in Al_2O_3 /water than TiO_2 /water and water, respectively. The maximum value of Reynolds number was observed at the highest concentration of Al_2O_3/water nanofluid of o.3%.

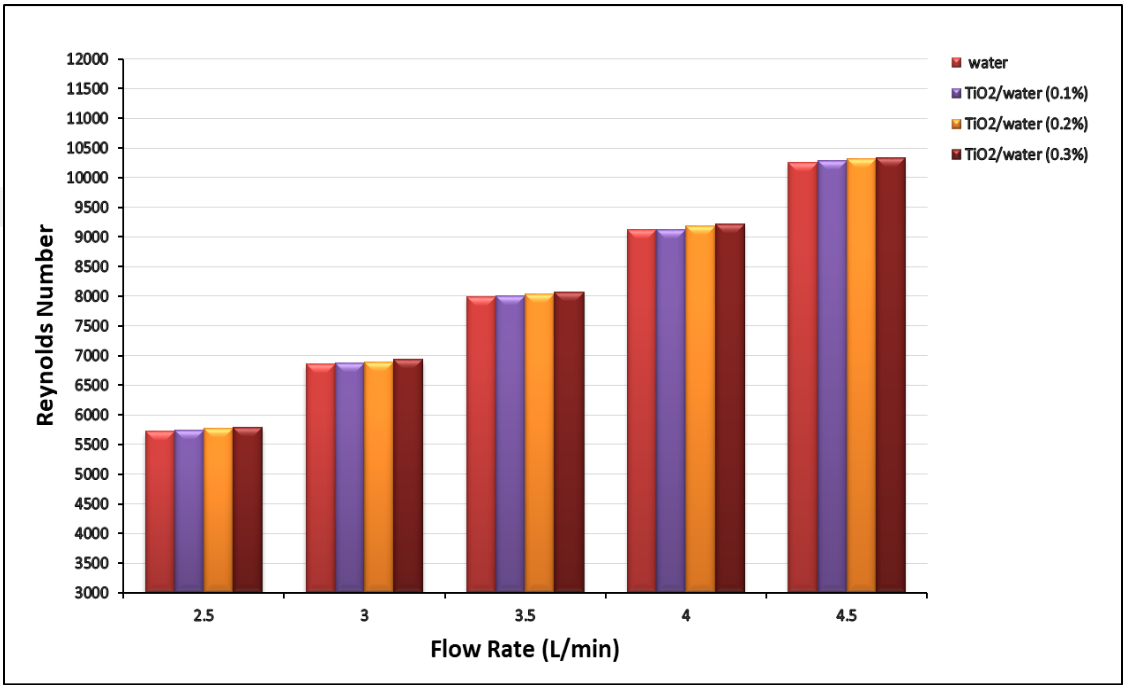


Figure 4.27: The relation between Reynolds number with mass flow rate for (Water, TiO_2 0.1, 0.2 &0.3%).

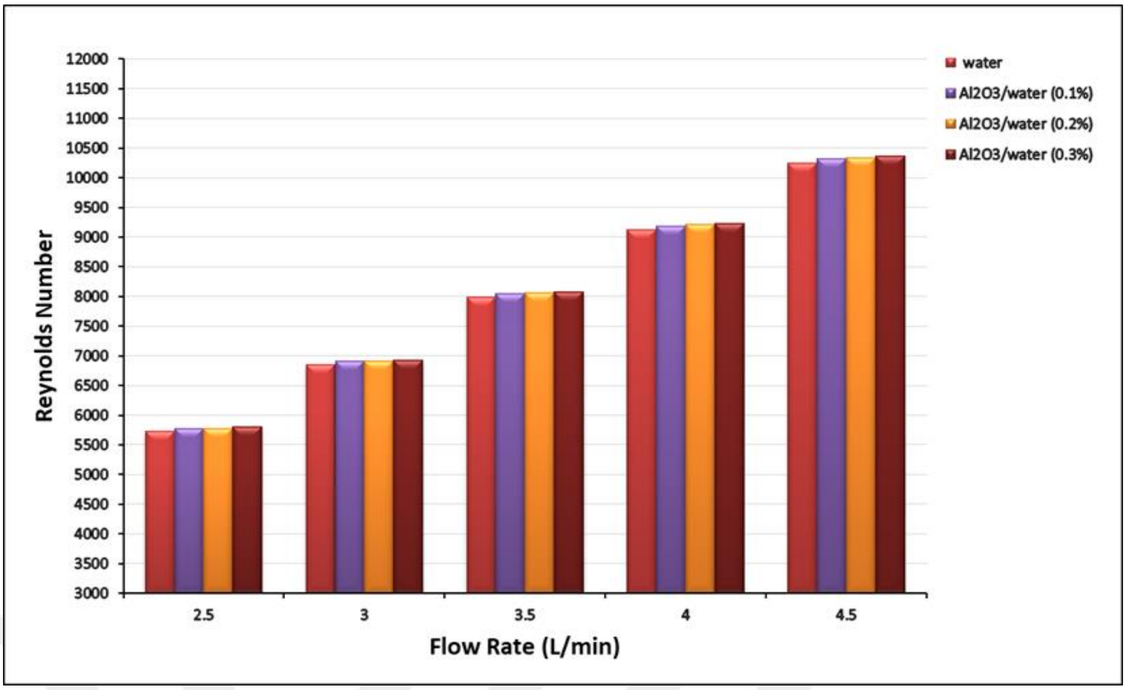


Figure 4.28: The relation between Reynolds number with mass flow rate for (Water, Al_2O_3 0.1, 0.2 &0.3%).

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The performance of heat transfer and flow characteristic of TiO_2/water and Al_2O_3/water nanofluids under several flow rates flowing in a horizontal counter flow double pipe heat exchanger was investigated experimentally. The experiments were conducted under turbulent flow conditions.

In the present study, the effect of different flow rates of (2.5, 3, 3.5, 4, and 4.5 L/min) and constant inlet temperature of (30 ˚C) with volume concentrations of (0.1, 0.2 and 0.3%) for nanofluids, and constant flow rate of (7 L/min) at a constant inlet temperature of (60 ˚C) for hot water on the properties of heat transfer was studied. The following concluding arguments have been obtained.

- The results show that each of the rates of heat transfer rate, the heat transfer coefficient, overall heat transfer coefficient and Nusselt number of nanofluid rely strongly on the type of the nanoparticles, and they were increased with the increase of the volume concentration of nanoparticles and also increased by increasing the flow rate of the nanofluid.
- The results of the experiments revealed that the heat transfer rate, the heat transfer rate, the heat transfer coefficient, overall heat transfer coefficient and Nusselt number at the minimum volume concentration (0.1%) for TiO_2/water nanofluid were better than them in the pure water, and the enhancement ratios in the heat transfer rate for the flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min) were (8.01, 5.46, 5.62, 5.8 and 6%), for the heat transfer coefficient (22.61, 16.03, 11.1, 7.16 and 4.14%), for the overall heat transfer coefficient (9.08, 6.3, 6.46,

6.63 and 6.81%) and finally for Nusselt number (22.27, 15.72, 10.8, 6.9 and 3.87%) for each value of the flow rate, respectively.

- Similarly, the heat transfer rate, the heat transfer rate, the heat transfer coefficient, the overall heat transfer coefficient and Nusselt number at the maximum volume concentration of (0.3%) for TiO_2/water nanofluid were better than them in the pure water, and the enhancement ratios in the heat transfer rate for the flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min) were (24, 21.9, 19.7, 17.34 and 14.85%), for the heat transfer coefficient (33.7, 26.52, 21.12, 16.9 and 13.43%), for the overall heat transfer coefficient (27.24, 24.85, 22.34, 20 and 17.2%) and finally for Nusselt number (32.6, 25.5, 20.15, 16 and 12.55%) for each value of the flow rate, respectively.
- For Al_2O_3/water nanofluid, The results of experiments revealed that the heat transfer rate, the heat transfer coefficient, the overall heat transfer coefficient and Nusselt number at the minimum volume concentration of (0.1%) for Al_2O_3/water nanofluid were better than them in the pure water, and the enhancement ratios in the heat transfer rate for the flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min) were (21.6, 19.41, 17.11, 17.62 and 18.15%), for the heat transfer coefficient (22.9, 16.3, 11.33, 7.47 and 4.34%), for the overall heat transfer coefficient (24.52, 22.05, 19.5, 20 and 20.55%) and finally for Nusselt number (22.43, 15.9, 11, 7.1 and 4%) for each value of the flow rate, respectively.
- Likewise, for the volume maximum concentration of (0.3%) for Al_2O_3/water nanofluid, The results of experiments revealed that the heat transfer rate the heat transfer coefficient, the overall heat transfer coefficient and Nusselt number were better than them in the pure water, and the enhancement ratios in the heat transfer rate for the flow rates of (2.5, 3, 3.5, 4 and 4.5 L\min) were (32.34, 30.5, 28.5, 29.33 and 30.22%), for the heat transfer coefficient (34, 26.75, 21.4, 17.2 and 13.8%), for the overall heat transfer coefficient (37.21, 35, 33, 33.85 and 34.8%) and finally for Nusselt number (32.7, 25.53, 20.21, 16.06 and 13%) for each value of the flow rate, respectively.

From the all above ratios, We can note that Al_2O_3/water nanofluid offers better heat transfer coefficients, overall heat transfer coefficient and Nusselt number than the ones of TiO_2/water nanofluid and the pure water fluid.

5.2 Future Work

In the present study, the nanofluids were used as a cooler, but it can be used as a heater fluid instead of the hot water, as well as another size of the same types of nanoparticles which were used in the present experiments can be used, too. Furthermore, it can use another type of nanoparticles instead of Al_2O_3 and TiO_2 nanoparticles.

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EDUCATION

Undergraduate : University of Technology / Mechanical Engineer Department، 1996.

WORK EXPERIENCE

Place	Year
Al Sama Company Its main field was importing machines, light and heavy equipment. I worked with them according to my specialty as a Mechanical Engineer in the line of Engineering consultancies.	1996 - 2000
Practical Course I attended a rehabilitation course in the field of operating and maintaining the electricity power stations (Steam Stations). The course was held in Al-Dora Power station for generating electricity which belongs to the Iraqi Ministry of Electricity.	2000 - 2001
The General company for rehabilitation of electric power systems The company belonged to the Ministry of Electricity. I carried out the following jobs:	2001 - 2004

- Install the **pipes and valves (high pressure)** for the crude oil line within the operations of establishing Al-Quds Power Station Located in the north of Baghdad. **-** Maintenance operations of the steam boilers **(pipes and valves high pressure)** for Al-Dora Power Station for electricity generation. It was located in the middle of Baghdad. **-** Maintenance operations of the steam boilers **(pipes and valves high pressure)** for Al-Musayab Power Station for electricity generation. It was located in the south of Baghdad. **-** Maintenance operations of the steam boilers **(pipes and valves high pressure)** for southern Baghdad Power Station for electricity generation. It was located in the middle of Baghdad.	
The General Company for Electric Power Transmission Projects The company belongs to the Ministry of Electricity. I am working with them as shown below: **-** Making and installing steel structures for the sealing ends for transmission lines (132 KV) measured as (1x1600 mm2) inside Al Ameen substation. **-** Making and installing the Iron bridges on the water streams for passing the transmission lines (132 KV) with the control cable used within the operation for linking the electricity power stations with one another.	2004 - 2012
Training and Energy Researches office Assistant director of the quality department.	2012 - present

FOREIGN LANGUAGE

English