Republic Of Iraq
Ministry of Higher Education and Scientific Research
University of Misan
College of Engineering
Department of Mechanical Engineering

Comparison between the performance of shell and tube heat exchanger by using Nano-fluid and water as working Fluid

A project submitted in partial fulfillment of the requirements for the degree of Bachelor in Mechanical Engineering

By

Ahmed Abbas Jodeh

Karar Taleb Saleh

Mohammed Saad Shiyal

Supervisor

Dr. Sabah Falih Habeeb Ahmed Alhamdi

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بسم الله الرحمن الرحيم

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ

صدق الله العظيم

[المجادلة: 11]

Abstract

Shell and tube heat exchangers are offering versatility in industrial applications. In this project, Nano-fluid mixture of Aluminum Oxide and water is used to facilitate efficient heat transfer between fluids. It can be concluded that the difference in temperature for the hot water for counter flow arrangement is from 6.9 ^oC to 11.9 ^oC. However, the difference in temperature for the hot fluid for counter flow arrangement is from 10.9 ^oC to 17.4 ^oC when using Nano-fluid in tubes. Therefore, using the Nano-fluid increases the temperature difference for the hot fluid from 3 ^oC to 5 ^oC.

For parallel flow arrangement, the difference in temperature for the hot water is from 10.5 ^oC to 15.9 ^oC. However, the difference in temperature for the hot fluid is from 14.8 ^oC to 17.1 ^oC when using Nano-fluid in tubes. Therefore, using the Nano-fluid increases the temperature difference for the hot fluid from 2 ^oC to 4 ^oC.

The effectiveness of heat transfer for counter flow arrangement before using the Nano-fluid is from 0.38 to 0.57. After using the Nano-fluid in tubes, the effectivencess is from 0.41 to 0.58. This means using Nano-fluid is improved the effectivencess by 17 to 19 percent. For parallel flow arrangement, The effectiveness before using the Nano-fluid is from 0.37 to 0.52. After using the Nano-fluid in tubes, the effectivencess is from 0.4 to 0.56. This means using Nano-fluid is improved the effectivencess by 15 to 16 percent. In conclusion, Using Nano-fluid maxture of pure water and Aluminum Oxide in shell and tubes heat exchangers improves the heat transfer rate, temperature difference, and eefectivencess.

Dedication

الحمد لله الذي وفقنا لتثمين هذه الخطوة في مسيرتنا الدراسية بمذكرتنا هذه ثمرة الجهد والنجاح بفضله تعالى مهداة إلى أهالي غزة الأحرار ومقاومتها الباسلة والى الوالدين الكريمين حفظهما اللهوالى شهدائنا الأبرارولكل من كان لهم أثر على حياتي، وإلى كل من أحبهم قلبي ونسيهم قلمي.

طلبة المشروع

Acknowledgment

شكر وتقدير

قال تعالى (وَلَقَدْ آتَيْنَا لُقْمَانَ الْحِكْمَةَ أَنِ اشْكُرْ لِلَّهِ ۚ وَمَنْ يَشْكُرْ فَإِنَّمَا يَشْكُرُ لِنَفْسِهِ ۖ وَمَنْ كَفَرَ فَإِنَّ اللَّهَ غَنِيٌّ حَمِيدٌ) (لقمان:12)

وقال رسوله الكريم:"من لم يشكر المخلوق، لم يشكر الخالق"

أحمد الله تعالى حمداً دائما لا ينقطع ابدا على ما أكرمني به من إتمام هذا المشروع

ثم أتوجه بجزيل الشكر وعظيم الامتنان إلى الدكتور الفاضل

صباح فالح حبيب احمد الحمدي البطاط حفظه الله وأمد في عمره

ولا أنسي من الشكر والتقدير أبي و أمي تلك الشموع التي تحترق لتنير لنا الطريق

طلبة المشروع

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Chapter One: Introduction

1.1. Introduction

Heat Exchangers Overview Heat exchangers are fundamental components widely used in various engineering and industrial applications. Their main function is to facilitate the transfer of heat between two fluids without allowing them to mix directly. They operate based on the principles of thermodynamics, enabling effective energy exchange between hot and cold mediums. This makes them essential in systems such as heating and cooling units, power generation plants, petrochemical industries, water treatment systems, and domestic appliances like air conditioners and water heaters. The heat transfer process in these devices relies on the temperature gradient between two fluids, where thermal energy moves from the hot fluid to the cold one until thermal equilibrium is reached. The efficiency of a heat exchanger is influenced by several factors, including the heat transfer surface area, the thermal conductivity of the materials used, and the temperature difference between the fluids. There are various types of heat exchangers, each designed to meet specific operating conditions and requirements. Common types include shell-and-tube, plate, parallel-flow, cross-flow, and more advanced configurations. Each type varies in terms of performance, cost, thermal efficiency, and ability to withstand pressure and temperature levels. For instance, shell-and-tube heat exchangers are known for their robustness and suitability for high-pressure, high-temperature applications, making them ideal for industrial use. On the other hand, plate heat exchangers are compact and provide higher thermal efficiency due to their larger surface area, making them suitable for applications with space constraints and moderate conditions. The selection of a suitable heat exchanger type depends on multiple factors such as required heat transfer rate, fluid properties, maintenance requirements, and the overall system design. In recent years, advancements in heat exchanger technology have focused on improving thermal performance and energy efficiency through the use of enhanced materials and innovative working fluids. One of the most promising developments in this area is the use of Nano-fluids—fluids containing suspended nanoparticles, typically metals or metal oxides such as aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), or copper (Cu). These nanoparticles significantly increase the thermal conductivity of the base fluid, resulting in improved heat transfer performance within the exchanger. Nano-fluids enhance convective heat transfer rates due to their superior thermal properties and higher surface area-to-volume ratio of the suspended particles. This allows for a more efficient thermal exchange process, particularly in compact heat exchanger designs. Additionally, Nano-fluids can help reduce the size and weight of heat exchangers while maintaining or even improving performance, which is especially beneficial in applications where space and weight are critical factors, such as automotive and aerospace systems. Moreover, studies have shown that the use of Nano-fluids can reduce the required pumping power due to improved thermal performance, leading to lower operational costs and enhanced system efficiency. However, the application of Nano-fluids also presents challenges, including stability issues, increased viscosity, and potential erosion of internal surfaces, which must be considered during the design and operation of the system. Overall, integrating Nano-fluids into heat exchanger systems represents a promising direction in thermal engineering, offering significant improvements in heat transfer efficiency and energy savings. Ongoing research aims to further optimize Nano-fluid formulations and understand their behavior in different heat exchanger configurations, paving the way for more efficient and sustainable thermal systems in the future [1].

1.2. Types of Heat Exchangers:

Based on the design characteristics indicated in the previous section, there are several different variants of heat exchangers available. Some of the more common variants employed throughout industry include [2]:

- Shell and Tube Heat Exchangers
- Double Pipe Heat Exchangers
- Tube in Tube Heat Exchangers
- Plate Heat Exchangers

1.2.1. Shell and Tube Heat Exchangers:

Shell and tube heat exchangers, comprising a tube bundle enclosed in a shell, facilitate efficient heat transfer between fluids, with design options like finned tubes and various flow arrangements. Applications range from preheating and oil cooling to steam generation, offering versatility in industrial processes.

1.2.2. Double Pipe Heat Exchangers:

Double pipe heat exchangers, with a straightforward design of concentric tubes, enable versatile heat transfer configurations, including concurrent or countercurrent flows. Their modular adaptability in series, parallel, or series-parallel setups enhances efficiency within diverse industrial systems.

1.2.3. Tube in Tube Heat Exchangers:

Tube-in-tube heat exchangers, with coiled tubes forming an inside-outside pattern, offer compact designs suitable for high-temperature and high-pressure applications. Their efficiency is notably higher due to the coiled configuration, making them versatile in various industrial settings.

1.2.4. Plate Heat Exchangers:

Plate heat exchangers, featuring thin, corrugated plates, efficiently transfer heat with fluid channels formed between stacked pairs. Variations like plate fin and pillow plate designs offer versatility, enabling multiple flow configurations and enhanced heat transfer efficiency in diverse industrial applications

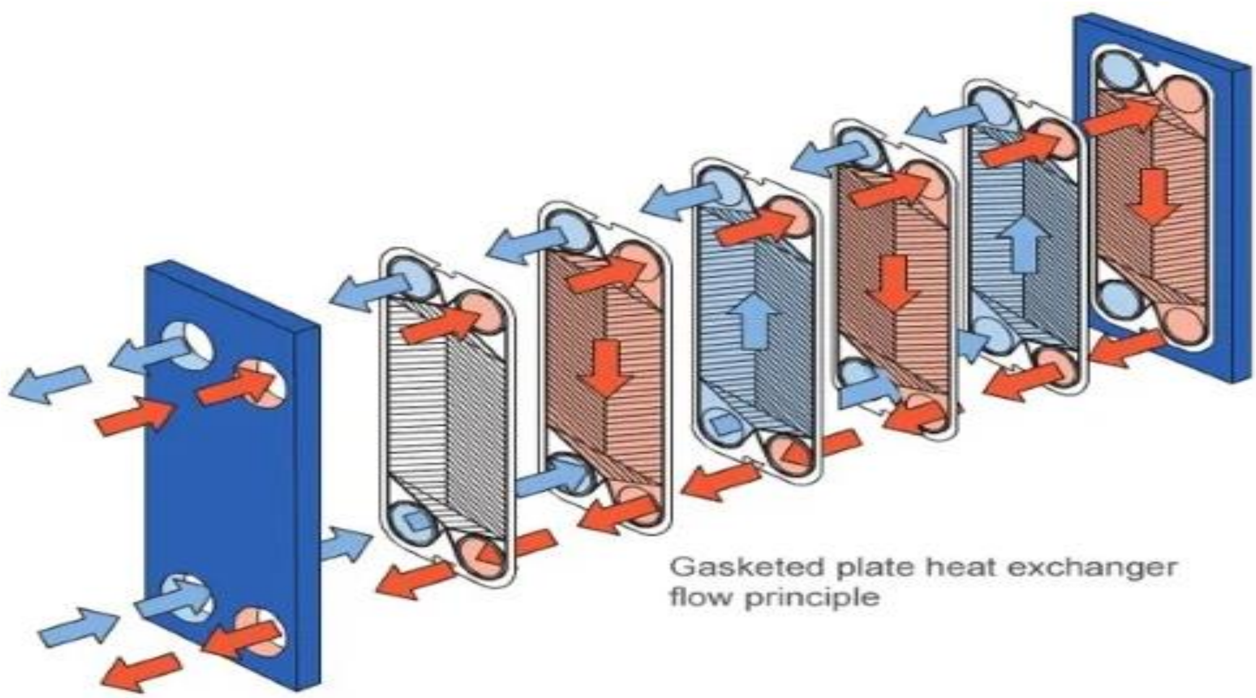


Figure (1.1): Plate heat exchanger [3].

1.3 The main objectives of project:

The objectives of this experimental project are to study and analyze the effect of using Nano-fluids compared to conventional water on the performance of heat exchangers. Furthermore, these objectives are to

1. Study the heat transfer efficiency in order to investigate whether Nano-fluids improve heat transfer compared to conventional water.
2. Analyze performance coefficient (COP) through evaluating the difference in COP between different fluids.
3. Study energy consumption for examining whether Nano-fluids help reduce energy consumption in heat transfer processes.
4. Examine thermal properties through analyzing properties such as thermal conductivity, viscosity, and density, and their effect on overall performance.
5. Evaluate economic feasibility by comparing the performance and cost to assess whether Nano-fluids offer a viable solution for industrial applications.

In summary, the goal is to study whether Nano-fluids can enhance heat exchanger performance compared to water, while considering both technical and economic aspects.

1.4. Literature review:

R. Subramanian etal in 2019 studied the effect of a Nano-fluid composed of TiO_2 nanoparticles suspended in water was evaluated in a counter-flow double-pipe heat exchanger. The results showed a 25% increase in heat transfer rate compared to pure water at a volume concentration of 0.5% [4]. Moreover, “this work presents the effect of heat transfer and pressure drop of the TiO_2–water Nano-fluids flowing in a double-tube counter-flow heat exchanger with various flow patterns. In this experimental study, performance of TiO_2–water Nano-fluid on heat transfer in three different cases such as laminar, transition, and turbulent flow region were analyzed. TiO_2 nanoparticles with average diameters of 20 nm dispersed in water with three volume concentrations of 0.1, 0.3 and 0.5 vol% were used as the test fluid. The results show that the heat transfer of Nano-fluids is higher than that of the base liquid (water) and increased with the increase in Reynolds number and particle concentrations. The heat transfer rate of Nano-fluid with 0.5 vol% was 25% greater than that of base liquid, and the results also show that the heat transfer coefficient of the Nano-fluids at a volume concentration of 0.5 vol% was 15% higher than that of base fluid at given conditions. Pressure drop of Nano-fluid was increased with increase in volume concentration, and it is slightly higher than that of the base fluid" [4].

Navid Bozorgan and Maryam Shafahi in 2017 performed a numerical study on a plate heat exchanger using a Nano-fluid composed of γ-Al_2O_3 and water. The optimal volume concentration of the Nano-fluid for maximum performance was found to be 0.016, leading to a 12.3% increase in heat transfer rate compared to pure water, with only a 1.15% increase in the required pumping power [5].

Adnan Sözen etal in 2019 studied the effect of using TiO_2-water Nano-fluid with a 1.5% weight concentration in a plate heat exchanger. Results showed an improvement in heat transfer rate of up to 11% compared to pure water [6].

Amr M. Hassaan in 2022 investigated the effect of using a Nano-fluid composed of multi-walled carbon nanotubes (MWCNTs) in a double-pipe heat exchanger. Results showed an increase in overall heat transfer coefficient with increasing nanoparticle concentration and flow rate, leading to a 68% rise in Nusselt number compared to distilled water [7].

These studies highlight the significant improvement in heat exchanger performance when using Nano-fluids instead of pure water, emphasizing the impact of nanoparticle type and concentration on heat transfer and pressure drop.

Chapter Two: Theoretical part

2.1. Definitions

To define the effectiveness of a heat exchanger, we must first determine the maximum possible heat transfer rate, q_{max} , for the exchanger. This heat transfer rate could, in principle, be achieved in a counterflow heat exchanger of infinite length. In such an exchanger, one of the fluids would experience the maximum possible temperature difference, $T_{h,i} - T_{c,i}$. To illustrate this point, consider a situation for which $C_c < C_h$, in which case $|dT_c| > |dT_h|$. The cold fluid would then experience the larger temperature change, and since $L \rightarrow \infty$, it would be heated to the inlet temperature of the hot fluid ($T_{c,i} = T_{h,i}$). Accordingly, from energy balances to the hot and cold fluids [8]:

$$C_c < C_h: \qquad q_{max} = C_c\,(T_{h,i} - T_{c,i}) \tag{2.1}$$

Similarly, if $C_h < C_c$, the hot fluid would experience the larger temperature change and would be cooled to the inlet temperature of the cold fluid ($T_{h,o} = T_{c,i}$). We then obtain [8]:

$$C_h < C_c: \qquad q_{max} = C_h\,(T_{h,i} - T_{c,i}) \tag{2.2}$$

From the foregoing results we are then prompted to write the general expression [8]:

$$q_{max} = C_{min}\,(T_{h,i} - T_{c,i}) \tag{2.3}$$

where C_{min} is equal to C_c or C_h, whichever is smaller. For prescribed hot and cold fluid inlet temperatures, Equation (2.3) provides the maximum heat transfer rate that could possibly be delivered by an exchanger. A quick mental exercise should convince the reader that the maximum possible heat transfer rate is not equal to C_{max} $(T_{h,i} - T_{c,i})$. If the fluid having the larger heat capacity rate were to experience the maximum possible temperature change, conservation of energy in the form C_c $(T_{c,o} - T_{c,i}) = C_h$ $(T_{h,i} - T_{h,o})$ would require that the other fluid experience yet a larger temperature change. For example, if $C_{max} = C_c$ and one argues that it is possible for $T_{c,o}$ to be equal to $T_{h,i}$, it follows that $(T_{h,i} - T_{h,o}) =$

$(C_c\ /C_h)(\ \mathbf{T_{h,i}} - \mathbf{T_{c,i}})$, in which case $(\ \mathbf{T_{h,i}} - \boldsymbol{T_{h,o}})>(\ \mathbf{T_{h,i}} - \mathbf{T_{c,i}})$. Such a condition is clearly impossible. It is now logical to define the effectiveness, ε, as the ratio of the actual heat transfer rate for a heat exchanger to the maximum possible heat transfer rate **[8]**:

$$\varepsilon = \frac{q}{q_{max}} \tag{2.4}$$

From equations (2.1), (2.2), and (2.3) it follows that

$$\varepsilon = \frac{C_h\ (T_{h,i} - T_{c,i})}{C_{min}\ (\ T_{h,i} - T_{c,i})} \tag{2.5}$$

or

$$\varepsilon = \frac{C_c\ (T_{c,o} - T_{c,i})}{C_{min}\ (\ T_{h,i} - T_{c,i})} \tag{2.6}$$

By definition the effectiveness, which is dimensionless, must be in the range $0 \leq \varepsilon \leq 1$. It is useful because, if ε, $\mathbf{T_{h,i}}$, and $\mathbf{T_{c,i}}$are known, the actual heat transfer rate may readily be determined from the expression **[8]**

$$q_{max} = \varepsilon C_{min}\ (T_{h,i} - T_{c,i}) \tag{2.7}$$

For any heat exchanger it can be shown that [T1]

$$\varepsilon = f\left(\mathrm{NTU}, \frac{C_{min}}{C_{max}}\right) \tag{2.8}$$

where $C_{min}\ /C_{max}$is equal to $C_c\ /C_h$or $C_h\ /C_c$, depending on the relative magnitudes of the hot and cold fluid heat capacity rates. The number of transfer units (NTU) is a dimensionless parameter that is widely used for heat exchanger analysis and is defined as **[8]**

$$\mathrm{NTU} = \frac{UA}{C_{min}} \tag{2.9}$$

2.2 Effectiveness–NTU Relations

To determine a specific form of the effectiveness–NTU relation, Equation (2.8), consider a parallel-flow heat exchanger for which $C_{min} = C_h$. From Equation (2.5) we then obtain **[8]**

$$\varepsilon = \frac{T_{h,i} - T_{c,i}}{T_{h,i} - T_{c,i}} \tag{2.10}$$

and

$$\frac{C_{min}}{C_{max}} = \frac{m_h c_{p,h}}{m_c c_{p,c}} = \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{h,o}} \tag{2.11}$$

From Equation (2.9)

$$\frac{T_{h,o} - T_{c,o}}{T_{h,i} - T_{c,i}} = \exp\left[-NTU\left(1 + C_{min}/C_{max}\right)\right] \tag{2.12}$$

Rearranging the left-hand side of this expression as

$$\frac{T_{h,o} - T_{c,o}}{T_{h,i} - T_{c,i}} = \frac{T_{h,o} - T_{h,i} + T_{h,i} - T_{c,o}}{T_{h,i} - T_{c,i}}$$

and substituting for $T_{c,o}$ from Equation (2.11), it follows that

$$\frac{T_{h,o} - T_{c,o}}{T_{h,i} - T_{c,i}} = \frac{(T_{h,o} - T_{h,i}) + (T_{h,i} - T_{c,o}) - \left(\frac{C_{min}}{C_{max}}\right)(T_{h,i} - T_{h,o})}{T_{h,i} - T_{c,i}}$$

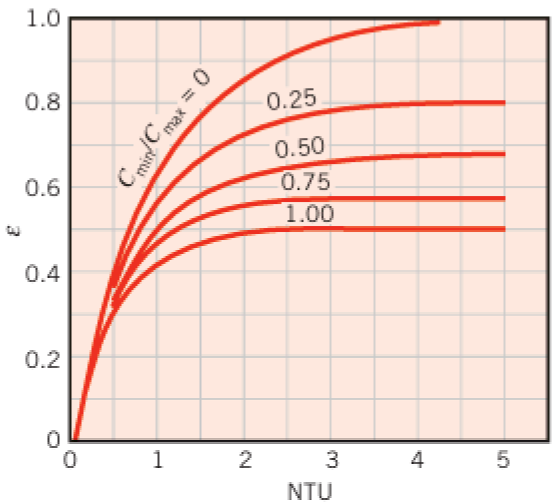
Substituting the above expression into Equation (2.12) and solving for , we obtain for the parallel-flow heat exchanger **[8]**

$$\varepsilon = \frac{1 - \exp\{-NTU[(1 + C_{min}/C_{max})]\}}{1 + (C_{min}/C_{max})} \tag{2.13}$$

Since precisely the same result may be obtained for $C_{min} = C_c$, Equation (2.13) applies for any parallel-flow heat exchanger, irrespective of whether the minimum heat capacity rate is associated with the hot or cold fluid. Similar expressions have been developed for a variety of heat exchangers [A1], and representative results are summarized in Table 2.1, where C_r is the heat capacity ratio $C_r = C_{min} / C_{max}$. In deriving Equation (2.16) for a shell-and-tube heat exchanger with multi pleshell passes, it is assumed that the total NTU is equally distributed between shell passes of the same arrangement, NTU= n(NTU)1. In order to determine ε , $(NTU)_1$ would first be calculated using the heat transfer area for one shell, ε would then be calculated from Equa tion (2.15), and ε would finally be calculated from Equation (2.16) **[8]**.

TABLE11.3 Heat Exchanger Effectiveness Relations [T1] [8]

Flow Arrangement	**Relation**	
Parallel flow	$\varepsilon = \frac{1-\exp[-NTU(1+C_r)}{1+C_r}$	(2.13)
Counter flow	$\varepsilon = \frac{1-\exp[-NTU(1-C_r)]}{1-C_r\exp[-NTU(1-C_r)]}$ $(C_r < 1)$	
$\varepsilon = \frac{NTU}{1+NTU}$	$(C_r = 0)$	(2.14)
shell-and-tube		
one shell pass (2, 4, …. Tube passes)	$\varepsilon = 2\{1+C_r+(1+C_r^2)^{1/2} \times \frac{1+\exp[-NTU(1-C_r^2)^{1/2}]}{1-\exp[-NTU(1-C_r^2)^{1/2}]}\}^{-1}$	(2.15)
n shell passes (2n, 4n, …. tube passes)	$\varepsilon = \left[\left(\frac{1-\varepsilon C_r}{1-\varepsilon}\right)^n - 1\right]\left[\left(\frac{1-\varepsilon C_r}{1-\varepsilon}\right)^n - C_r\right]^{-1}$	(2.16)



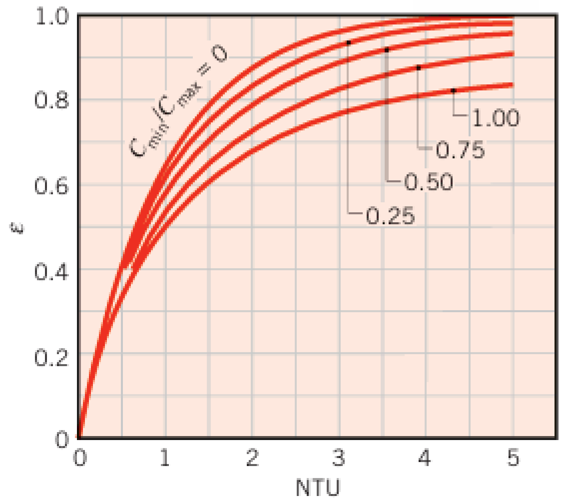
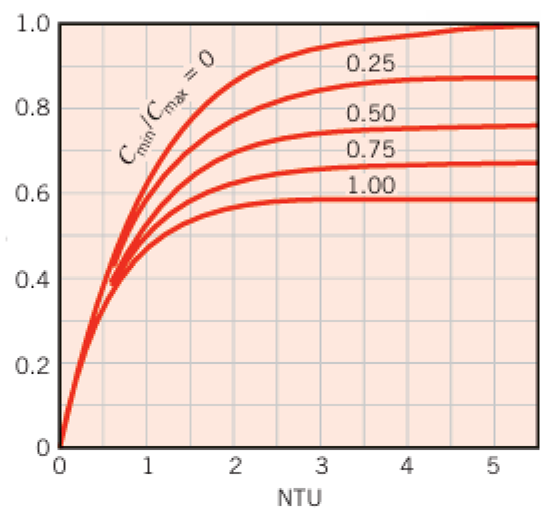


Figure (2.1): Effectiveness of a parallel flow heat exchanger (Equation 2.13) [8].

Figure (2.2) Effectiveness of a counterflow heat exchanger (Equation 2.14) [8].



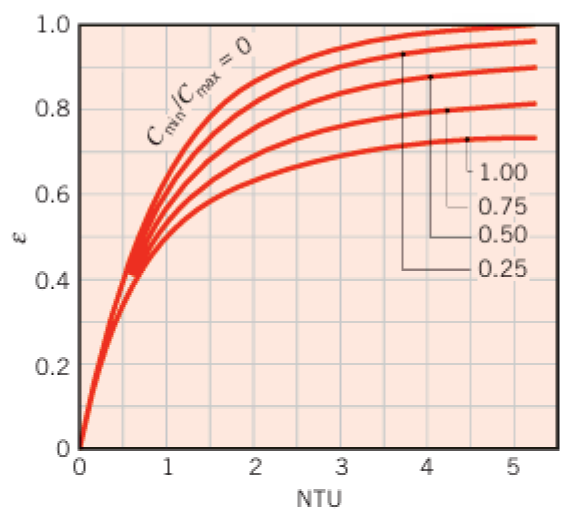


Figure (2.3) Effectiveness of a shell-and tube heat exchanger with one shell and any multiple of two tube passes (two, four, etc. tube passes) (Equation 2.15) [8].

Figure (2.4) Effectiveness of a shell-and-tube heat exchanger with two shell passes and any multiple of four tube passes (four, eight, etc. tube passes) (Equation 2.16 with n=2) [8].

Chapter Three : Devices and tools:

3.1. Devices and tools:

3.1.1. Shell and tube heat exchanger:

Shell and tube heat exchanger is one of the most used types in industrial applications because of its high efficiency and ability to work under high pressures and temperatures. It consists of an outer shell containing a group of tubes. One fluid passes inside the tubes, while the other passes inside the shell, allowing heat to transfer from one fluid to another without mixing between them. This type is used in power plants, oil refineries, refrigeration and air conditioning systems [9].

Shell and tube heat exchanger was used is shown in Figure (3.1) below:

Figure (3.1): Shell and tube heat exchanger.

3.1.1.1. Pump:

The pump is used to ensure the movement of the fluid through the system, as it secures a continuous flow of fluid within the pipes and the exchanger. Without a pump, there would not be enough flow to transfer heat between the fluids. The efficiency of the heat exchanger depends on the ability of the pump to provide stable and regular flow. Centrifugal pumps or gear pumps can be used depending on the nature of the fluid [9]:

Figure (3.2): Pump used in shell and tube heat exchanger.

3.1.1.2. Flow meter:

In heat exchanger systems, determining the rate of fluid flow is necessary to calculate the amount of heat exchanged between fluids. This is done using flow meters, which are an important part of the design and operation of the system. The mass flow rate (Mass Flow Rate) or volume (Volumetric Flow Rate) of the fluid in and out, and this is linked to the temperature to determine the efficiency of the exchanger's thermal performance Therefore, an accurate Flow Meter is essential for correct thermal measurements [1].

3.1.1.3. Temperature sensors:

Temperature sensors are used to measure the temperatures of the fluid entering and out of the heat exchanger. These readings are essential for determining the performance and efficiency of the system, Therefore, accurate temperature measurements at entry and exit points are very necessary [9].

Type o the sensors:

- **Thermocouples** are common and cheap sensors that generate a small voltage due to the temperature difference.
- **RTDs (Resistance Temperature Detectors)** are more accurate and stable sensors in the long run.
- **Thermistors** are used in small applications, but less accurate than RTDs.

Figure (3.3): Temperature sensors.

3.1.1.4. Water tank:

The water tank will be used in heat exchanger systems as a storage and regulation element for the flow of thermal fluid (usually water) in small educational, experimental or industrial applications as shown in Figure (3.4).

Figure (3.4): Water tank.

3.1.1.4. Data logging device:

A data logger is an electronic unit used to record the readings of various sensors continuously and regularly during the operation of the heat exchanger system. It is as shown in Figure (3.5) stores time data such as:

- Temperatures (from temperature sensors).
- Flow rate (from flow meter).

Figure (3.5): Data logging device.

3.1.1.6. Connecting pipes and control plugs:

Connecting pipes are used to connect the equipment as shown in the Figures in this chapter. Different types of control plugs are used to control the flow rate and the electric power.

3.2. Specification:

When designing or choosing a heat exchanger, a set of technical specifications must be specified that ensure the effective and safe performance of the device within the desired application. These specifications include thermal, physical, hydraulic and mechanical properties **[1].**

4.2.1. Shell

In shell and tube heat exchangers, the shell is the outer cylindrical part that contains the tube bundle inside. One fluid circulates inside this shell (usually a fluid with a higher flow rate or pressure), while the second fluid flows inside the pipes. The two fluids are separated by a thin metal wall (tube), allowing heat transfer without direct mixing between the fluid [9]. The shell is made of Pyrex with length of 500 mm. The inner and outer diameters of the shell are 120 mm and 110 mm, respectively.

3.2.2. Tube:

Tubes are the main element in heat transfer within the shell and tube exchangers, where one fluid flows inside these tubes, while the other fluid flows externally around them inside the shell, pipes play a key role in the heat transfer process, because the thin wall of the pipe separates the two fluids and allows heat to transfer from one fluid to another with high efficiency [10]. The tubes are made of copper with 6.2 mm outer diameter and 6 mm inner diameter. The number of tubes is 18 and each one is 600mm length. The number of spaces is 3 and the distance between any two spaces is 125mm.

3.2.3. Temperature indicator:

Temperature indicator is used its digital reading from 0 to 200 °C with multi-channel switch.

3.3. Operational procedure:

It is very important to follow the operational procedure carefully in order to get an accurate measurement, the stability of the devices also is important to fulfill accurate procedure in each measured data, to do so we should wait for a suitable period of time to take the measurement. The procedure was followed to take the data is [10]:

1. Clean the apparatus and make water bath free from dust.
2. Close all the drain valves provided.
3. Fill water bath ¾ with clean water and ensure that no foreign particles are there.

4. Connect cold water supply to the inlet of cold water flow meter line and run the exchanger as counter flow.
5. Connect outlet of cold water from shell to drain.
6. Ensure that all ON/Off switches given on the panel are at off position.
7. Now switch on the main power supply.
8. Switch on heater by operating rotary switch given on the panel.
9. Set temperature of the water bath with the help of digital temperature controller.
10. Open flow control valve and By-pass valve for hot water supply.
11. Switch on the pump for hot water supply.
12. Adjust hot water flow rate with the help of flow control valve and rota meter.
13. Record the temperatures of hot and cold water inlet and outlet when steady state is achieved.
14. Repeat the experiment for different flow rates and for different temperatures. The same method is followed for parallel flow also.

CHAPTER FOUR: Calculation, Results, and Discussion

4.1. Equations used for calculation:

Heat transfer for hot water:

$$\boldsymbol{Q_h} = \dot{m}_h c_{p,h}\left(\mathrm{T_{h,i}} - \mathrm{T_{h,o}}\right) \tag{4.1}$$

Heat transfer for cold water:

$$\boldsymbol{Q_c} = \dot{m}_c c_{p,c}\left(\mathrm{T_{c,o}} - \mathrm{T_{c,i}}\right) \tag{4.2}$$

Average heat transfer:

$$\mathbf{Q} = \frac{\boldsymbol{Q_h} - \boldsymbol{Q_c}}{\mathbf{2}} \tag{4.3}$$

LTMD:

$$\boldsymbol{\Delta T_M} = \frac{\boldsymbol{\Delta T_1} - \boldsymbol{\Delta T_2}}{\mathbf{Ln}\left(\frac{\boldsymbol{\Delta T_1}}{\boldsymbol{\Delta T_2}}\right)} \tag{4.4}$$

- $\boldsymbol{\Delta T_1} = \mathbf{T_{h,i}} - \boldsymbol{T_{c,i}}$
- $\boldsymbol{\Delta T_2} = \mathbf{T_{h,o}} - \boldsymbol{T_{c,o}}$

Overall. H.T:

$$\mathbf{U_i} = \frac{\boldsymbol{Q A_i}}{\boldsymbol{\Delta T_M}} \tag{4.5}$$

$$\mathbf{U_o} = \frac{\boldsymbol{Q A_o}}{\boldsymbol{\Delta T_M}} \tag{4.6}$$

- $\boldsymbol{A_i} = \boldsymbol{\pi}\, \boldsymbol{D_i L}\, N$
- $\boldsymbol{A_o} = \boldsymbol{\pi}\, \boldsymbol{D_o L}\, N$

Effectiveness–NTU Relations:

$$\boldsymbol{\varepsilon} = \frac{\mathbf{q}}{\mathbf{q_{max}}} \tag{4.7}$$

- $\boldsymbol{C_c} < \boldsymbol{C_h}$: $\quad \boldsymbol{q_{max}} = \boldsymbol{C_c}\, (\mathbf{T_{h,i}} - \boldsymbol{T_{c,i}})$ (4.8)
- $\boldsymbol{C_h} < \boldsymbol{C_c}$: $\quad \boldsymbol{q_{max}} = \boldsymbol{C_h}\, (\mathbf{T_{h,i}} - \boldsymbol{T_{c,i}})$ (4.9)

$$\varepsilon=2\{1+C_r+(1+C_r^2)^{1/2}\times\frac{1+\exp[-NTU(1-C_r^2)^{1/2}]}{1-\exp[-NTU(1-C_r^2)^{1/2}]}\}^{-1} \tag{4.10}$$

4.2. Counter flow using water as a working fluid for shell and tube heat exchanger:

4.2.1.: Thermal power for different flow rates:

Table (4.1): Thermal power for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	Q_c (kw)	Q_h (kw)	$Q_{average}$ (kw)	ΔT_M (C^0)	U_i (w/m.k)	U_o (w/m.k)
1	0.45	1.46	24.5	43.7	54.7	46.8	36.6	48.2	42.44	11.90	10.79	8.97
2	0.75	1.50	24.6	41.8	54.5	46.0	53.9	53.3	53.68	13.09	10.84	9.02
3	1.0	1.42	24.7	38.1	54.0	43.8	56.0	60.6	58.36	14.40	11.19	9.30
4	1.25	1.35	25.5	37.5	54.5	43.3	62.7	63.2	60.68	14.41	11.68	9.71
5	1.52	1.43	26.5	36.7	54.3	42.9	64.8	68.2	66.56	14.39	12.61	10.49
6	1.75	1.68	26.9	36.9	54.0	43.4	73.2	69.6	71.43	14.42	12.84	10.68
7	2.0	1.54	26.5	35.5	54.0	41.1	75.3	70.1	72.74	14.51	12.85	10.69
8	2.25	1.42	27.3	35.2	54.3	41.7	75.3	74.3	74.82	14.64	13.94	11.22
9	2.50	1.44	27.3	34.8	54.3	41.4	78.4	77.7	78.11	14.73	14.03	11.67

Table (4.2): Effectiveness and NTU for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU

1	**0.45**	**1.46**	**24.5**	**43.7**	**54.7**	**46.8**	**0.30**	**0.635**	**1.22**
2	**0.75**	**1.50**	**24.6**	**41.8**	**54.5**	**46.0**	**0.499**	**0.575**	**1.14**
3	**1.0**	**1.42**	**24.7**	**38.1**	**54.0**	**43.8**	**0.70**	**0.457**	**0.806**
4	**1.25**	**1.35**	**25.5**	**37.5**	**54.5**	**43.3**	**0.92**	**0.413**	**0.741**
5	**1.52**	**1.43**	**26.5**	**36.7**	**54.3**	**42.9**	**0.94**	**0.39**	**0.671**
6	**1.75**	**1.68**	**26.9**	**36.9**	**54.0**	**43.4**	**0.96**	**0.384**	**0.657**
7	**2.0**	**1.54**	**26.5**	**35.5**	**54.0**	**41.1**	**0.77**	**0.426**	**0.731**
8	**2.25**	**1.42**	**27.3**	**35.2**	**54.3**	**41.7**	**0.561**	**0.469**	**0.789**
9	**2.50**	**1.44**	**27.3**	**34.8**	**54.3**	**41.4**	**0.569**	**0.487**	**0.849**

The effectiveness – NTU method is used to calculate the effectiveness of shell and tube heat exchanger. To ensure that the exchanger readings are correct, we will choose the same values of C_r that used by [9] in order to validate the results.

4.2.2. C_r=1 for all:

Table (4.3): Effectiveness and NTU for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid at C_r=1.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	**0.5**	**0.5**	**24.5**	**43.7**	**54.7**	**46.8**	**1**	**0.58**	**3.5**
2	**0.7**	**0.7**	**24.6**	**41.8**	**54.5**	**46.0**	**1**	**0.57**	**2.44**
3	**0.9**	**0.9**	**24.7**	**38.1**	**54.0**	**43.8**	**1**	**0.46**	**0.985**
4	**1.1**	**1.1**	**25.5**	**37.5**	**54.5**	**43.3**	**1**	**0.42**	**0.8**
5	**1.3**	**1.3**	**26.5**	**36.7**	**54.3**	**42.9**	**1**	**0.40**	**0.724**
6	**1.5**	**1.5**	**26.9**	**36.9**	**54.0**	**43.4**	**1**	**0.39**	**0.689**

7	2	2	26.5	35.5	54.0	41.1	1	0.328	0.508

4.2.3. C_r=0.75 for all:

Table (4.4): Effectiveness and NTU for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid at C_r=0.75

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.65	0.85	24.5	43.7	54.7	46.8	0.75	0.61	1.84
2	0.75	1	24.6	41.8	54.5	46.0	0.75	0.58	1.51
3	0.87	1.15	24.7	38.1	54.0	43.8	0.75	0.48	1.12
4	0.9	1.2	25.5	37.5	54.5	43.3	0.75	0.43	0.737
5	1	1.35	26.5	36.7	54.3	42.9	0.75	0.39	0.621
6	1.05	1.4	26.9	36.9	54.0	43.4	0.75	0.37	0.580
7	1.14	1.5	26.5	35.5	54.0	41.1	0.75	0.33	0.477

4.2.4. C_r=0.5 for all:

Table (4.5): Effectiveness and NTU for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid at C_r=0.5.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.5	1	24.5	43.7	54.7	46.8	0.5	0.63	1.44
2	0.6	1.2	24.6	41.8	54.5	46.0	0.5	0.59	1.26
3	0.75	1.5	24.7	38.1	54.0	43.8	0.5	0.5	0.860
4	0.8	1.6	25.5	37.5	54.5	43.3	0.5	0.44	0.699

5	**0.85**	**1.7**	**26.5**	**36.7**	**54.3**	**42.9**	**0.5**	**0.4**	**0.592**
6	**0.9**	**1.8**	**26.9**	**36.9**	**54.0**	**43.4**	**0.5**	**0.37**	**0.531**
7	**1**	**2**	**26.5**	**35.5**	**54.0**	**41.1**	**0.5**	**0.32**	**0.455**

4.2.5. C_r=0.25 for all:

Table (4.6): Effectiveness and NTU for different flow rates of shell and tube heat exchanger counter flow using water as a working fluid at C_r=0.25

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	**0.375**	**1.5**	**24.5**	**43.7**	**54.7**	**46.8**	**0.25**	**0.644**	**1.21**
2	**0.5**	**2**	**24.6**	**41.8**	**54.5**	**46.0**	**0.25**	**0.594**	**1.03**
3	**0.625**	**2.5**	**24.7**	**38.1**	**54.0**	**43.8**	**0.25**	**0.507**	**0.781**
4	**0.75**	**3**	**25.5**	**37.5**	**54.5**	**43.3**	**0.25**	**0.448**	**0.644**
5	**1**	**4**	**26.5**	**36.7**	**54.3**	**42.9**	**0.25**	**0.408**	**0.562**
6	**1.25**	**5**	**26.9**	**36.9**	**54.0**	**43.4**	**0.25**	**0.371**	**0.493**
7	**1.5**	**6**	**26.5**	**35.5**	**54.0**	**41.1**	**0.25**	**0.329**	**0.421**

4.2.6. Discussion and validation for counter flow using water as a working fluid shell and tube heat exchanger:

Figure (4.1a) shows the distribution of the effectiveness with the total number of transfer units (NTU) for four different specific heat ratios (C_r), the abscissa corresponds to the total number of transfer units (NTU). The specific heat ratios used are 0.25, 0.5, 075, and 1. These C_r values were chosen in order to validate our results by comparing them with the results in the literature.

To validate our results, we compared them with the results in [1]. The comparison shows good agreement between our result and the results in the literature that shown in Figure (4.1b). The curves for the effectives at the chosen C_r are similar in the direction, shape, and the values of effectiveness and NTU. However, there are small differences raised from the human errors that it is really difficult to be controlled.

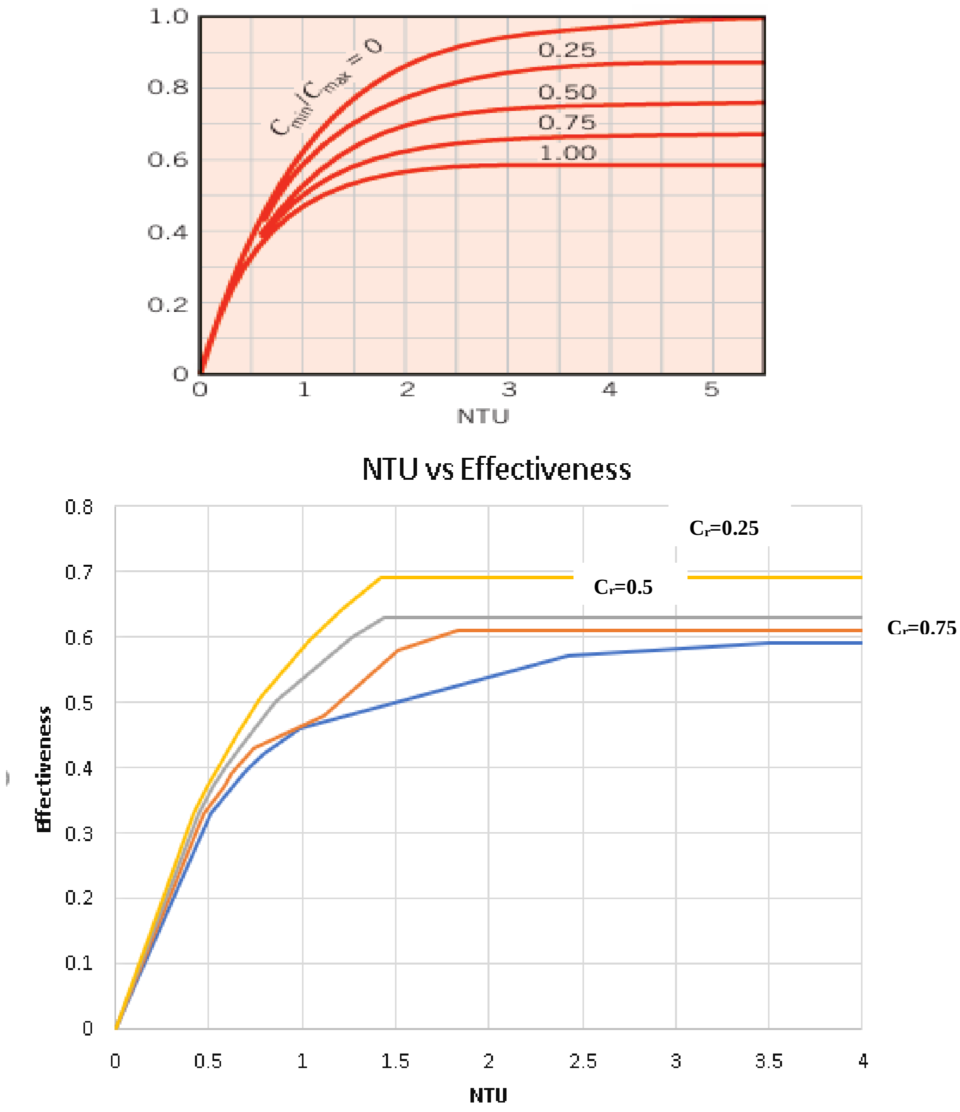


Figure (4.1): Comparison between the effectiveness of a shell-and tube heat exchanger counter flow and the results of [9].

4.2.7 . Summary counter flow arrangment shell and tube heat exchanger using water as a working fluid:

In a counter-flow heat exchanger, the outlet temperature of the cold fluid is higher than its inlet temperature, as observed consistently across all measured points. For example, at the first point:

• Cold fluid outlet temperature = 43.7°C

• Cold fluid inlet temperature = 24.5°C

Similarly, for the hot fluid, the inlet temperature is higher than the outlet temperature throughout all the points. For instance:

• Hot fluid inlet temperature = 54.7°C

• Hot fluid outlet temperature = 46.8°C

The amount of heat transferred to the hot or cold fluid increases with an increase in the mass flow rate and decreases with a decrease in flow rate, assuming the specific heat capacity remains constant. The temperature difference behaves in an increasing (ascending) trend because the outlet temperatures of the fluid are progressively higher than the inlet temperatures across all measurement points. Moreover, the overall heat transfer coefficient at both the inlet and outlet also follows an ascending trend due to the increased flow velocity, which leads to a transition of the flow regime from laminar to turbulent, thereby enhancing the convective heat transfer performance.

4.3. Parallel flow using water as a working fluid for shell and tube heat exchanger:

4.3.1.: Thermal power for different flow rates:

Table (4.7): Thermal power for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	Q_c (kw)	Q_h (kw)	Q_{averag} (kw)	ΔT_M (C^0)	U_i (w/m.k)	U_o (w/m.k)
1	0.5	1.20	34.5	25.8	44.9	37.2	18.2	38.6	28.43	10.89	9.44	7.85
2	0.75	1.10	41.9	26.2	54.3	42.8	49.2	52.9	51.12	14.39	9.10	7.57

3	**1**	**1.10**	**39.5**	**26.2**	**54.3**	**42.0**	**55.6**	**56.6**	**56.15**	**15.29**	**9.36**	**8.05**
4	**1.25**	**1.07**	**38.0**	**26.5**	**54.7**	**41.2**	**60.0**	**60.3**	**60.23**	**15.67**	**10.19**	**8.48**
5	**1.5**	**1.07**	**36.7**	**26.7**	**55.4**	**40.5**	**62.7**	**66.6**	**64.67**	**16.12**	**10.99**	**9.14**
6	**1.75**	**1.04**	**36.0**	**26.8**	**54.1**	**39.6**	**67.3**	**63.0**	**65.17**	**15.06**	**10.74**	**8.93**
7	**2.0**	**1.01**	**35.0**	**27.0**	**54.3**	**38.5**	**66.8**	**64.5**	**65.74**	**15.06**	**11.10**	**9.16**
8	**2.25**	**1.01**	**34.5**	**27.1**	**54.5**	**37.8**	**69.6**	**67.5**	**68.57**	**14.86**	**12.08**	**10.05**
9	**2.5**	**0.95**	**33.9**	**27.0**	**54.7**	**37.8**	**72.1**	**66.8**	**69.47**	**15.25**	**11.65**	**9.69**

Table (4.8): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	**NTU**
1	**0.5**	**1.20**	**34.5**	**25.8**	**44.9**	**37.2**	**0.41**	**0.189**	**0.219**
2	**0.75**	**1.10**	**41.9**	**26.2**	**54.3**	**42.8**	**0.681**	**0.558**	**2.08**
3	**1**	**1.10**	**39.5**	**26.2**	**54.3**	**42.0**	**0.90**	**0.473**	**0.979**
4	**1.25**	**1.07**	**38.0**	**26.5**	**54.7**	**41.2**	**0.85**	**0.476**	**0.964**
5	**1.5**	**1.07**	**36.7**	**26.7**	**55.4**	**40.5**	**0.68**	**0.487**	**0.909**
6	**1.75**	**1.04**	**36.0**	**26.8**	**54.1**	**39.6**	**0.59**	**0.516**	**0.967**
7	**2.0**	**1.54**	**26.5**	**35.5**	**54.0**	**41.1**	**0.505**	**0.579**	**1.168**
8	**2.25**	**1.42**	**27.3**	**35.2**	**54.3**	**41.7**	**0.40**	**0.601**	**1.171**
9	**2.50**	**1.44**	**27.3**	**34.8**	**54.3**	**41.4**	**0.38**	**0.654**	**1.409**

4.3.2. C_r=1 for all:

Table (4.9): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid at C_r=1.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.5	0.5	34.5	25.8	44.9	37.2	1	0.455	0.959
2	0.7	0.7	41.9	26.2	54.3	42.8	1	0.558	2.029
3	0.9	0.9	39.5	26.2	54.3	42.0	1	0.473	1.06
4	1.1	1.1	38.0	26.5	54.7	41.2	1	0.407	0.724
5	1.3	1.3	36.7	26.7	55.4	40.5	1	0.348	0.561
6	1.5	1.5	36.0	26.8	54.1	39.6	1	0.335	0.526
7	2	2	26.5	35.5	54.0	41.1	1	0.293	0.427

4.3.3. C_r=0.75 for all:

Table (4.10): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid at C_r=0.75.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.65	0.85	35.5	25.8	44.9	37.2	0.75	0.542	1.224
2	0.75	1	41.9	26.2	54.3	42.8	0.75	0.60	1.712
3	0.87	1.15	40.5	26.2	54.3	42.0	0.75	0.518	1.089
4	0.9	1.2	39.0	26.5	54.7	41.2	0.75	0.45	0.803
5	1	1.35	37.7	26.7	55.4	40.5	0.75	0.422	0.712

6	1.05	1.4	37.0	26.8	54.1	39.6	0.75	0.39	0.621
7	1.14	1.5	27.5	35.5	54.0	41.1	0.75	0.353	0.529

4.3.4. C_r=0.5 for all:

Table (4.11): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid at C_r=0.5.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.5	1	34.5	25.8	43.9	37.2	0.5	0.59	1.21
2	0.6	1.2	41.9	26.2	53.3	42.8	0.5	0.73	2.762
3	0.75	1.5	39.5	26.2	53.3	42.0	0.5	0.622	1.392
4	0.8	1.6	38.0	26.5	53.7	41.2	0.5	0.536	0.985
5	0.85	1.7	36.7	26.7	54.4	40.5	0.5	0.458	0.736
6	0.9	1.8	36.0	26.8	53.1	39.6	0.5	0.442	0.694
7	1	2	26.5	35.5	53.0	41.1	0.5	0.38	0.547

4.3.5. C_r=0.25 for all:

Table (4.12): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using water as a working fluid at C_r=0.25.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.375	1.5	35.5	25.8	43.9	37.2	0.25	0.62	1.122
2	0.5	2	41.9	26.2	53.3	42.8	0.25	0.75	1.792

3	**0.625**	**2.5**	**40.5**	**26.2**	**53.3**	**42.0**	**0.25**	**0.65**	**1.239**
4	**0.75**	**3**	**39.0**	**26.5**	**53.7**	**41.2**	**0.25**	**0.56**	**0.925**
5	**1**	**4**	**37.7**	**26.7**	**54.4**	**40.5**	**0.25**	**0.48**	**0.716**
6	**1.25**	**5**	**37.0**	**26.8**	**53.1**	**39.6**	**0.25**	**0.45**	**0.649**
7	**1.5**	**6**	**27.5**	**35.5**	**53.0**	**41.1**	**0.25**	**0.43**	**0.607**

4.3.6. Discussion and validation for parallel flow using water as a working fluid shell and tube heat exchanger:

Figure (4.2a) shows the distribution of the effectiveness with the total number of transfer units (NTU) for four different specific heat ratios (C_r), the abscissa corresponds to the total number of transfer units (NTU). The specific heat ratios used are 0.25, 0.5, 075, and 1. These C_r values were chosen in order to validate our results by comparing them with the results in the literature.

To validate our results, we compared them with the results in [9]. The comparison shows good agreement between our result and the results in the literature that shown in Figure (4.2b). The curves for the effectives at the chosen C_r are similar in the direction, shape, and the values of effectiveness and NTU. However, there are small differences raised from the human errors that it is really difficult to be controlled.

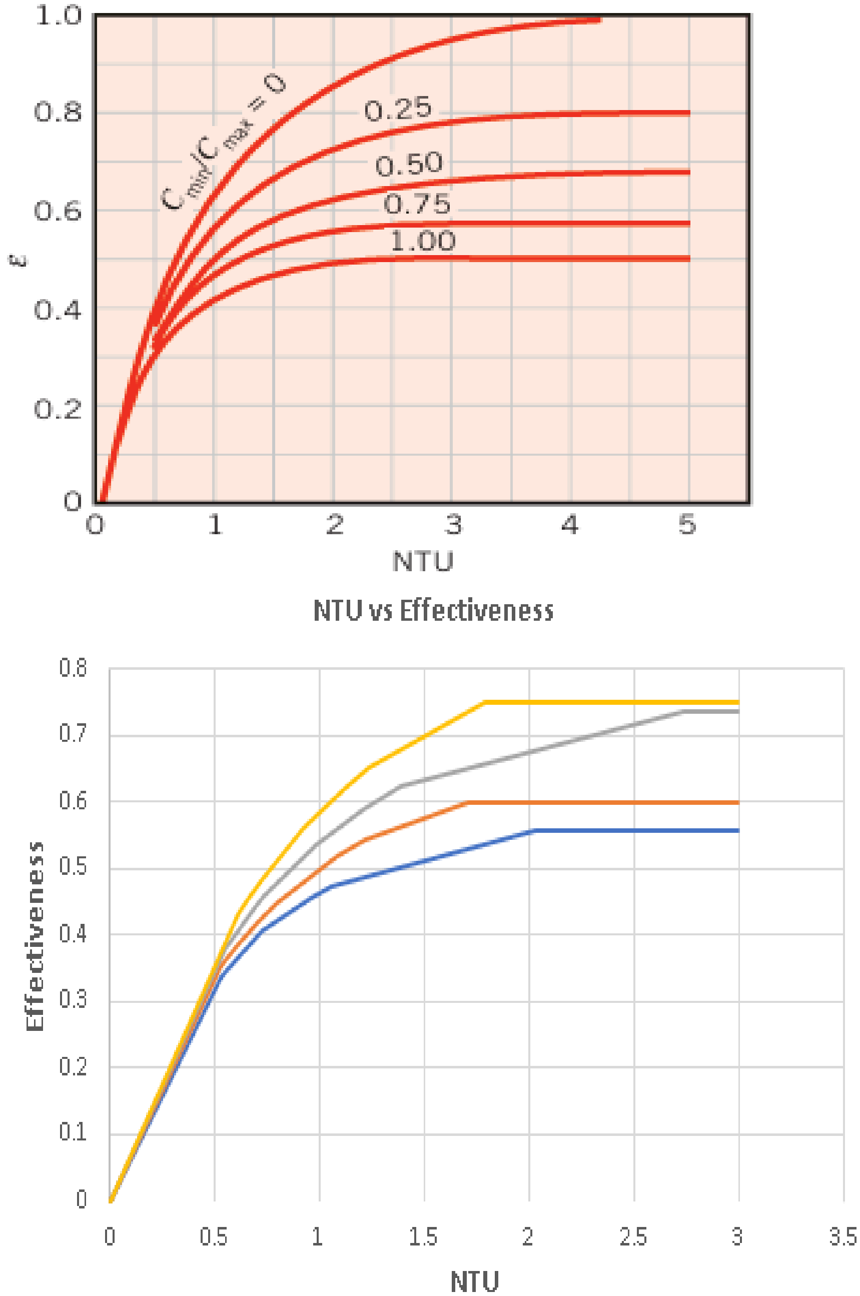


Figure (4.2): Comparison between the effectiveness of a shell and tube heat exchanger parallel flow and the results of [9].

4.3.7. Summary of parallel flow arrangement of shell and tube heat exchanger using water as a working fluid:

In a parallel flow water system, the temperature of the cold fluid at the inlet is higher than its temperature at the outlet, and this behavior is observed at all measured points. For example, at the first point, the cold fluid's inlet temperature is 34.5°C, while the outlet temperature decreases to 25.8°C. Similarly, for the hot fluid, the inlet temperature is also higher than the outlet temperature. For instance, at the first point, the hot fluid's inlet temperature is 44.9°C, and the outlet temperature drops to 37.2°C. The amount of heat transferred increases with the increase in the cold fluid's flow rate. It is observed at point 9 that when the flow rate reaches its highest level, the amount of heat transferred becomes greater. It should be noted that the total heat transfer at the inlet and outlet is not constant, as it fluctuates during operation. This variation is due to several factors, such as changes in specific heat, viscosity, and the presence of deposits within the system.

4.4. Praiparing the Nano-fluid:

The Nano-fluid is praipred in Chemsitry Laboratory at Department of Chemical Engineering at University of Misan. The Aluminium oxide paticles were mixed with pure water. The specifications of the particles and the procedure to prepaire the Nano-fluid are:

- **Aluminum Oxide with the chemical formula Al_2O_3 was used at a rate of 3%, meaning that the concentration is 3%, by mixing 30 g per 10 liters.**
- **When you mix water with Aluminum Oxide (Al_2O_3) at 3% (30 g per 10 l), you are practically making a Nano-fluid, a liquid containing very fine particles (Nanoparticles) from a solid particles of Aluminum Oxide (Al_2O_3).**
- **A concentration of 30 g per 10 liters (0.3%) is considered a relatively low concentration, which is safe and suitable for initial experiments or limited thermal improvement.**

- **What happens when using this mixture in a shell and tube heat exchanger?**
  - **Possible positive effects:**
    1. Improve heat transfer:
    • Aluminum oxide has a higher thermal conductivity than water.
    • The presence of solid particles in water increases the total thermal conductivity of the mixture.
    • This leads to better heat exchanger performance and increased

heat exchange rate between the two sides (shell & tube).

2. Improve the overall thermal performance of the exchanger

- **For negative or attention to be aware of:**

  1. Increased viscosity:

  By adding Al_2O_3 particles, the viscosity of the fluid increases slightly, which means that it may require more pumping energy to move the liquid inside the tubes or casing.

  2. Corrosion or abrasive corrosion (Erosion):

  Although aluminum oxide is a stable chemical, the presence of solid particles may cause corrosion in the internal surfaces of the exchanger over time, especially if the design is not suitable.

  3. Sedimentation or particle aggregation:

  If the particles are not well distributed or dispersants are not used, particle deposition may occur inside the tubes resulting in clogging or reduced efficiency.

Figure (4.3): Weighting the Aluminum Oxide.

Figure (4.4): mixing water with aluminum oxide

4.5.Counter flow using Nano-fluid in tubes and water in shell as a for shell and tube heat exchanger:

4.5.1. Thermal power for different flow rates:

Table (4.13): Thermal power for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid in tubes.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	Q_c (kw)	Q_h (kw)	Q_{averag} (kw)	ΔT_M (C^0)	U_i (w/m.k)	U_o (w/m.k)
1	0.45	1.46	25.5	42.9	55.1	44.2	27.6	56.6	42.1	9.05	16.63	13.83
2	0.75	1.50	25.9	41.9	55.7	42.6	38.1	62.5	50.3	7.75	21.44	17.84
3	1.0	1.42	26	40.1	54.9	40.6	44.8	64.6	54.7	7	24.54	20.41
4	1.25	1.35	26.5	39.6	54.9	39.8	52	64.8	58.4	5.69	30.28	25.19
5	1.52	1.43	26.6	38.7	54.9	38.9	57.5	72.7	65.1	5.67	34.52	28.72
6	1.75	1.68	26.8	38	55.6	48.1	62.3	93.5	77.9	17.84	13.93	11.59
7	2.0	1.54	26.7	37	55.6	37.2	65.5	90.1	77.8	5.77	41.52	34.54
8	2.25	1.42	27	37.1	55.7	37.4	72.2	82.6	77.4	6.22	35.31	29.37
9	2.50	1.44	27.1	37.3	55.3	37.3	81.1	82.4	81.75	0	--------	---------

The effectiveness – NTU method is used to calculate the effectiveness of shell and tube heat exchanger. The same values of C_rs that picked when using water as a working fluid were chosen in order to compare the two cases to determine the enhancement due to using the Nano-fluid.

4.5.2. C_r=1 for all:

Table (4.14): Thermal power for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid using Nano-fluid in tubes at C_r=1.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.45	1.46	25.5	42.9	55.1	44.2	0.30	0.587	1.047
2	0.75	1.50	25.9	41.9	55.7	42.6	0.499	0.537	0.988
3	1.0	1.42	26	40.1	54.9	40.6	0.70	0.471	0.855

4	1.25	1.35	26.5	39.6	54.9	39.8	0.92	0.445	0.864
5	1.52	1.43	26.6	38.7	54.9	38.9	0.94	0.439	0.849
6	1.75	1.68	26.8	38	55.6	48.1	0.96	0.412	0.752
7	2.0	1.54	26.7	37	55.6	37.2	0.77	0.475	0.907
8	2.25	1.42	27	37.1	55.7	37.4	0.561	0.565	1.154
9	2.50	1.44	27.1	37.3	55.3	37.3	0.569	0.645	1.695

4.5.3. C_r=0.75 for all:

Table (4.15): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid in tubes at C_r=0.75.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.5	0.5	25.5	42.9	55.1	44.2	1	0.587	2.082
2	0.7	0.7	25.9	41.9	55.7	42.6	1	0.537	1.636
3	0.9	0.9	26	40.1	54.9	40.6	1	0.471	1.047
4	1.1	1.1	26.5	39.6	54.9	39.8	1	0.445	0.909
5	1.3	1.3	26.6	38.7	54.9	38.9	1	0.427	0.828
6	1.5	1.5	26.8	38	55.6	48.1	1	0.402	0.731
7	2	2	26.7	37	55.6	37.2	1	0.369	0.622
8	2.1	2.1	27	37.1	55.7	37.4	1	0.352	0.572
9	2.15	2.15	27.1	37.3	55.3	37.3	1	0.362	0.601

4.5.4. C_r=0.5 for all:

Table (4.16): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid in tubes at C_r=0.5.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.65	0.85	25.5	42.9	55.1	44.2	0.75	0.587	1.572
2	0.75	1	25.9	41.9	55.7	42.6	0.75	0.537	1.194
3	0.87	1.15	26	40.1	54.9	40.6	0.75	0.471	0.88
4	0.9	1.2	26.5	39.6	54.9	39.8	0.75	0.445	0.786
5	1.35	1	26.6	38.7	54.9	38.9	0.75	0.547	1.034
6	1.4	1.05	26.8	38	55.6	48.1	0.75	0.507	1.188
7	1.5	1.14	26.7	37	55.6	37.2	0.75	0.537	1.194
8	1.6	1.2	27	37.1	55.7	37.4	0.75	0.5378	1.200
9	1.65	1.23	27.1	37.3	55.3	37.3	0.75	0.538	1.206

4.5.5. C_r=0.5 for all:

Table (4.17): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid in tubes at C_r=0.5.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.5	1	25.5	42.9	55.1	44.2	0.5	0.587	1.201
2	0.6	1.2	25.9	41.9	55.7	42.6	0.5	0.537	0.988
3	0.75	1.5	26	40.1	54.9	40.6	0.5	0.471	0.773

4	**0.8**	**1.6**	**26.5**	**39.6**	**54.9**	**39.8**	**0.5**	**0.445**	**0.701**
5	**1.7**	**0.85**	**26.6**	**38.7**	**54.9**	**38.9**	**0.5**	**0.565**	**1.101**
6	**1.8**	**0.9**	**26.8**	**38**	**55.6**	**48.1**	**0.5**	**0.607**	**1.305**
7	**2**	**1**	**26.7**	**37**	**55.6**	**37.2**	**0.5**	**0.637**	**1.482**
8	**2.2**	**1.1**	**27**	**37.1**	**55.7**	**37.4**	**0.5**	**0.638**	**1.496**
9	**2.5**	**1.25**	**27.1**	**37.3**	**55.3**	**37.3**	**0.5**	**0.639**	**1.503**

4.5.6. C_r=0.25 for all:

Table (4.18): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow using Nano-fluid in tubes at C_r=0.25.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	**0.375**	**1.5**	**25.5**	**42.9**	**55.1**	**44.2**	**0.25**	**0.587**	**1.009**
2	**0.5**	**2**	**25.9**	**41.9**	**55.7**	**42.6**	**0.25**	**0.537**	**0.860**
3	**0.625**	**2.5**	**26**	**40.1**	**54.9**	**40.6**	**0.25**	**0.471**	**0.695**
4	**0.75**	**3**	**26.5**	**39.6**	**54.9**	**39.8**	**0.25**	**0.445**	**0.638**
5	**4**	**1**	**26.6**	**38.7**	**54.9**	**38.9**	**0.25**	**0.85**	**3.280**
6	**5**	**1.25**	**26.8**	**38**	**55.6**	**48.1**	**0.25**	**0.77**	**1.95**
7	**6**	**1.5**	**26.7**	**37**	**55.6**	**37.2**	**0.25**	**0.712**	**1.540**
8	**6.1**	**1.525**	**27**	**37.1**	**55.7**	**37.4**	**0.25**	**0.703**	**1.491**
9	**6.2**	**1.55**	**27.1**	**37.3**	**55.3**	**37.3**	**0.25**	**0.723**	**1.608**

4.5.7. Discussion for counter flow shell and tube heat exchanger using Nano-fluid in tubes:

Figure (4.5) shows the distribution of the effectiveness with the total number of transfer units (NTU) for four different specific heat ratios (C_r), the abscissa corresponds to the total number of transfer units (NTU). The specific heat ratios used are 0.25, 0.5, 075, and 1. These C_r values were chosen in order to compare results between using Nano-fluid and water in tubes.

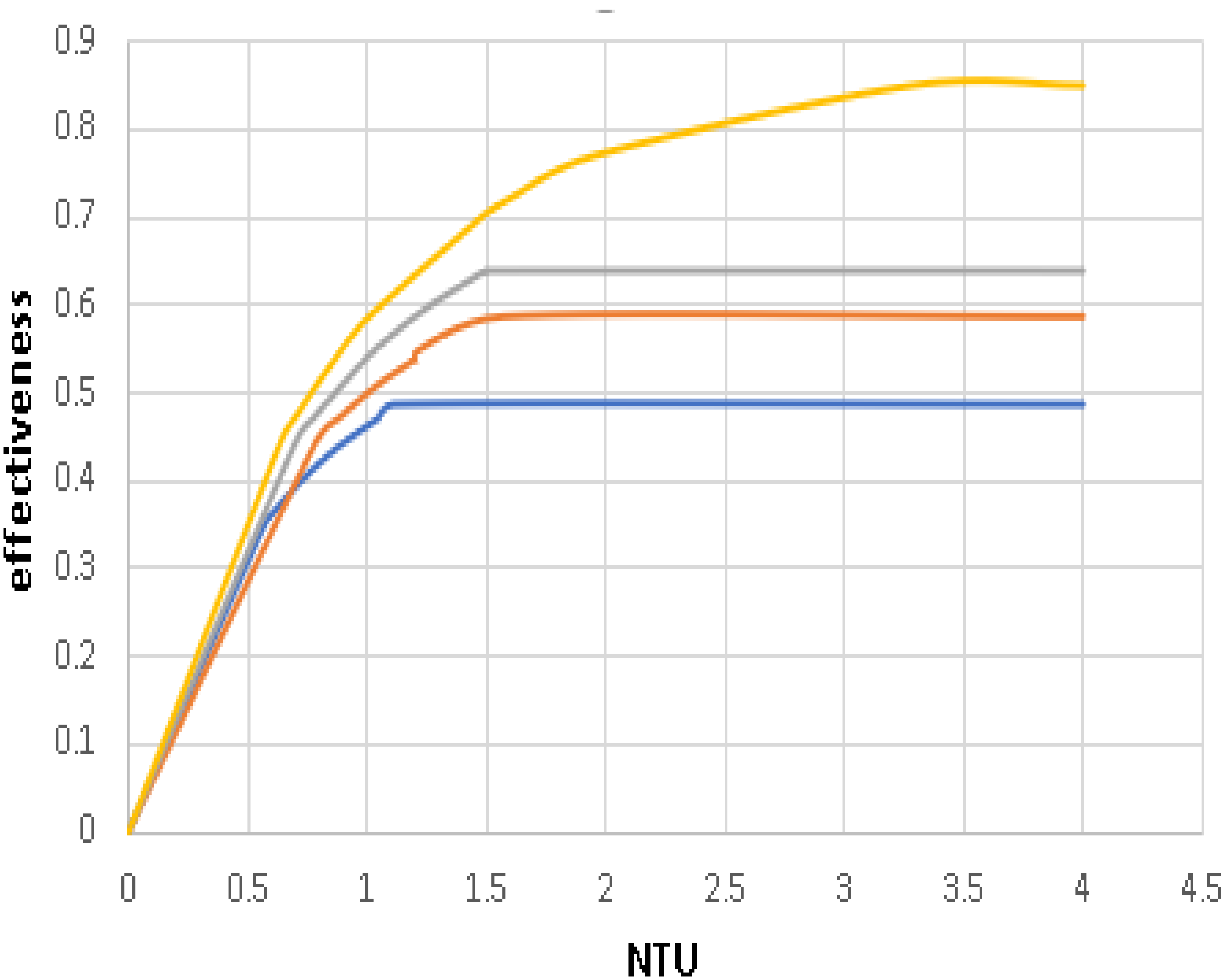


Figure (4.5): The effectiveness of a shell-and tube heat exchanger counter flow using Nano-fluid in tubes.

4.6.: Parallel flow arrangment using Nano-fluid in tubes and water in shell for shell and tube heat exchanger:

4.6.1.Thermal power for different flow rates:

Table (4.19): Thermal power for different flow rates of shell and tube heat exchanger parallel flow arrangment using Nano-fluid in tubes and water in shell.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	Q_c (kw)	Q_h (kw)	$Q_{average}$ (kw)	ΔT_M (C^0)	U_i (w/m.k)	U_o (w/m.k)
1	0.45	1.46	25	31.2	45.1	37.5	8.87	35.2	23.18	11.89	7.87	6.54
2	0.75	1.50	25.1	37.6	55.3	40.5	29.8	70.6	50.2	11.65	16.11	13.40
3	1.0	1.42	25.1	36.8	55	39.3	37.2	70.9	54.05	11.01	17.12	14.24
4	1.25	1.35	25.6	35.3	55.6	39	38.5	71.3	54.9	12.56	15.09	12.55
5	1.52	1.43	26	36	55.3	39.8	48.3	70.5	59.4	12.48	15.02	12.49
6	1.75	1.68	26.2	35.2	55	38.7	50.1	87.1	68.6	12.00	19.30	16.05
7	2.0	1.54	26.1	34	54.9	38.2	50.2	81.8	66	12.77	17.03	14.17
8	2.25	1.42	26.8	34.4	55.2	37.6	54.4	79.5	66.95	11.54	18.32	15.24
9	2.50	1.44	27	34	54.7	36.9	55.6	81.5	68.55	10.85	19.97	16.61

Table (4.20): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow arrangement using Nano-fluid in tubes and water in shell.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.45	1.46	25	31.2	45.1	37.5	0.30	0.455	0.701

2	**0.75**	**1.50**	**25.1**	**37.6**	**55.3**	**40.5**	**0.499**	**0.409**	**0.655**
3	**1.0**	**1.42**	**25.1**	**36.8**	**55**	**39.3**	**0.70**	**0.437**	**0.821**
4	**1.25**	**1.35**	**25.6**	**35.3**	**55.6**	**39**	**0.92**	**0.407**	**0.697**
5	**1.52**	**1.43**	**26**	**36**	**55.3**	**39.8**	**0.94**	**0.488**	**0.908**
6	**1.75**	**1.68**	**26.2**	**35.2**	**55**	**38.7**	**0.96**	**0.567**	**1.192**
7	**2.0**	**1.54**	**26.1**	**34**	**54.9**	**38.2**	**0.77**	**0.436**	**0.678**
8	**2.25**	**1.42**	**26.8**	**34.4**	**55.2**	**37.6**	**0.561**	**0.47**	**0.736**
9	**2.50**	**1.44**	**27**	**34**	**54.7**	**36.9**	**0.569**	**0.496**	**0.799**

4.6.2. C_r=1 for all:

Table (4.21): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow arrangement using Nano-fluid in tubes and water in shell at C_r=1.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	**ε**	**NTU**
1	**0.5**	**0.5**	**25**	**31.2**	**45.1**	**37.5**	**1**	**0.308**	**0.460**
2	**0.7**	**0.7**	**25.1**	**37.6**	**55.3**	**40.5**	**1**	**0.414**	**0.776**
3	**0.9**	**0.9**	**25.1**	**36.8**	**55**	**39.3**	**1**	**0.419**	**0.872**
4	**1.1**	**1.1**	**25.6**	**35.3**	**55.6**	**39**	**1**	**0.323**	**0.496**
5	**1.3**	**1.3**	**26**	**36**	**55.3**	**39.8**	**1**	**0.341**	**0.542**
6	**1.5**	**1.5**	**26.2**	**35.2**	**55**	**38.7**	**1**	**0.312**	**0.470**
7	**2**	**2**	**26.1**	**34**	**54.9**	**38.2**	**1**	**0.302**	**0.447**
8	**2.1**	**2.1**	**26.8**	**34.4**	**55.2**	**37.6**	**1**	**0.260**	**0.358**

9	2.15	2.15	27	34	54.7	36.9	1	0.250	0.339

4.6.3. C_r=0.75 for all:

Table (4.22): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow arrangement using Nano-fluid in tubes and water in shell at C_r=0.75.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	0.65	0.85	25	31.2	45.1	37.5	0.75	0.308	0.431
2	0.75	1	25.1	37.6	55.3	40.5	0.75	0.414	0.624
3	0.87	1.15	25.1	36.8	55	39.3	0.75	0.419	0.688
4	0.9	1.2	25.6	35.3	55.6	39	0.75	0.431	0.740
5	1.35	1	26	36	55.3	39.8	0.75	0.455	0.821
6	1.4	1.05	26.2	35.2	55	38.7	0.75	0.41	0.677
7	1.5	1.14	26.1	34	54.9	38.2	0.75	0.402	0.654
8	1.6	1.2	26.8	34.4	55.2	37.6	0.75	0.356	0.557
9	1.65	1.23	27	34	54.7	36.9	0.75	0.336	0.490

4.6.4. C_r=0.5 for all:

Table (4.22): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow arrangement using Nano-fluid in tubes and water in shell at C_r=0.5.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU

1	**0.5**	**1**	**25.5**	**42.9**	**55.1**	**44.2**	**0.5**	**0.308**	**0.407**
2	**0.6**	**1.2**	**25.9**	**41.9**	**55.7**	**42.6**	**0.5**	**0.414**	**0.624**
3	**0.75**	**1.5**	**26**	**40.1**	**54.9**	**40.6**	**0.5**	**0.419**	**0.571**
4	**0.8**	**1.6**	**26.5**	**39.6**	**54.9**	**39.8**	**0.5**	**0.64**	**1.510**
5	**1.7**	**0.85**	**26.6**	**38.7**	**54.9**	**38.9**	**0.5**	**0.682**	**1.872**
6	**1.8**	**0.9**	**26.8**	**38**	**55.6**	**48.1**	**0.5**	**0.625**	**1.410**
7	**2**	**1**	**26.7**	**37**	**55.6**	**37.2**	**0.5**	**0.604**	**1.289**
8	**2.2**	**1.1**	**27**	**37.1**	**55.7**	**37.4**	**0.5**	**0.535**	**0.981**
9	**2.5**	**1.25**	**27.1**	**37.3**	**55.3**	**37.3**	**0.5**	**0.505**	**0.876**

4.6.5. C_r=0.25 for all:

Table (4.24): Effectiveness and NTU for different flow rates of shell and tube heat exchanger parallel flow arrangement using Nano-fluid in tubes and water in shell at C_r=0.25.

No	$\dot{m}_c$ (kg/s)	$\dot{m}_h$ (kg/s)	$T_{c,i}$ (C^0)	$T_{c,o}$ (C^0)	$T_{h,i}$ (C^0)	$T_{h,o}$ (C^0)	C_r	ε	NTU
1	**0.375**	**1.5**	**25.5**	**42.9**	**55.1**	**44.2**	**0.25**	**0.308**	**0.386**
2	**0.5**	**2**	**25.9**	**41.9**	**55.7**	**42.6**	**0.25**	**0.414**	**0.574**
3	**0.625**	**2.5**	**26**	**40.1**	**54.9**	**40.6**	**0.25**	**0.419**	**0.530**
4	**0.75**	**3**	**26.5**	**39.6**	**54.9**	**39.8**	**0.25**	**0.737**	**1.69**
5	**4**	**1**	**26.6**	**38.7**	**54.9**	**38.9**	**0.25**	**0.705**	**1.502**
6	**5**	**1.25**	**26.8**	**38**	**55.6**	**48.1**	**0.25**	**0.754**	**1.822**
7	**6**	**1.5**	**26.7**	**37**	**55.6**	**37.2**	**0.25**	**0.773**	**1.983**

8	**6.1**	**1.525**	**27**	**37.1**	**55.7**	**37.4**	**0.25**	**0.82**	**2.562**
9	**6.2**	**1.55**	**27.1**	**37.3**	**55.3**	**37.3**	**0.25**	**0.856**	**3.529**

4.6.6. Discussion for Parallel flow shell and tube heat exchanger using Nano-fluid in tubes:

Figure (4.6) shows the distribution of the effectiveness with the total number of transfer units (NTU) for four different specific heat ratios (C_r), the abscissa corresponds to the total number of transfer units (NTU). The specific heat ratios used are 0.25, 0.5, 075, and 1. These C_r values were chosen in order to compare results between using Nano-fluid and water in tubes.

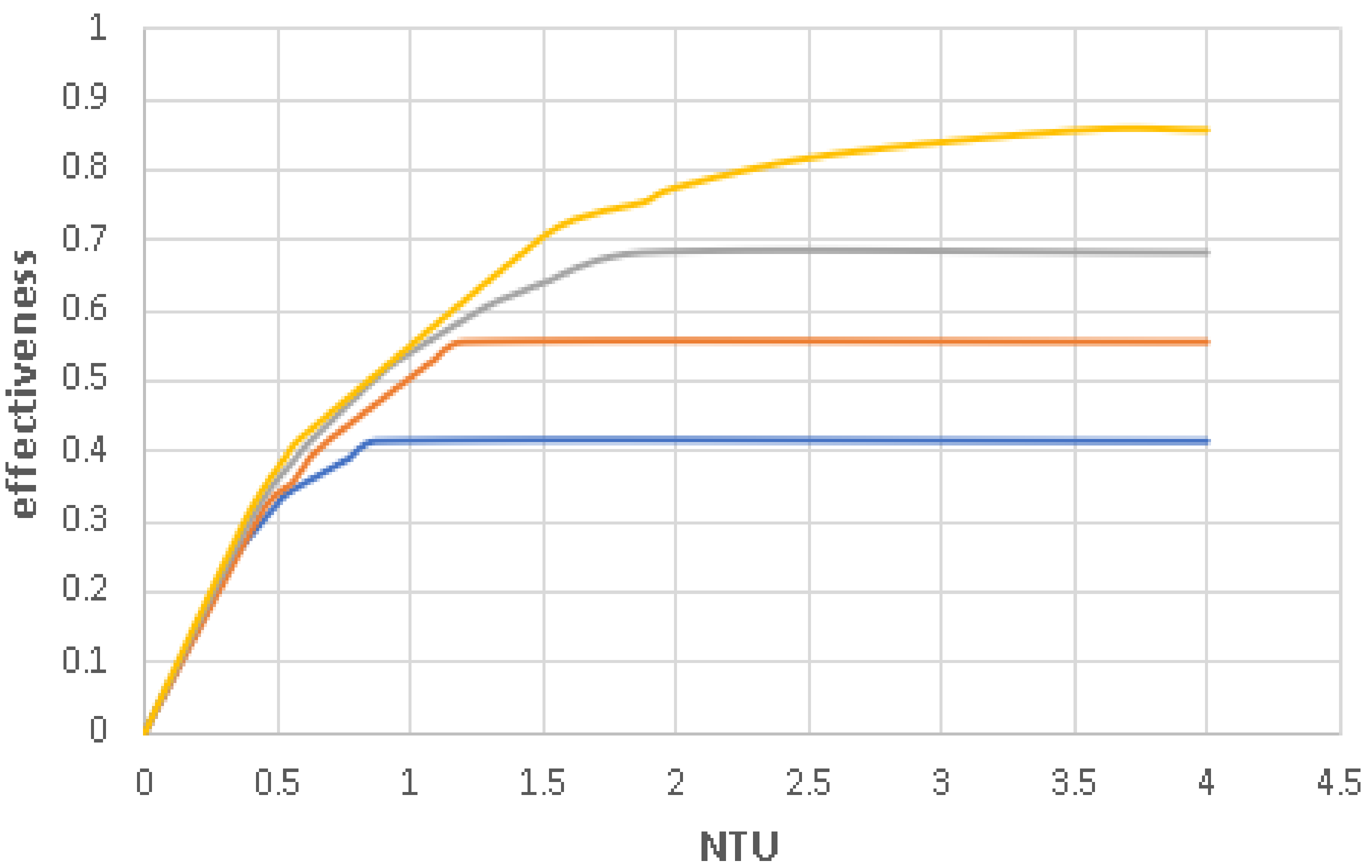


Figure (4.6): The effectiveness of a shell-and tube heat exchanger parallel flow using Nano-fluid in tubes.

4.7. Conclusions:

Shell and tube heat exchangers are offering versatility in industrial applications. In this project, Nano-fluid mixture of Aluminum Oxide and water is used to facilitate efficient heat transfer between fluids. It can be concluded that the difference in temperature for the hot water for counter flow arrangement is from 6.9 ^{o}C to 11.9 ^{o}C. However, the difference in temperature for the hot fluid for counter flow arrangement is from 10.9 ^{o}C to 17.4 ^{o}C when using Nano-fluid in tubes. Therefore, using the Nano-fluid increases the temperature difference for the hot fluid from 3 ^{o}C to 5 ^{o}C.

For parallel flow arrangement, the difference in temperature for the hot water is from 10.5 ^{o}C to 15.9 ^{o}C. However, the difference in temperature for the hot fluid is from 14.8 ^{o}C to 17.1 ^{o}C when using Nano-fluid in tubes. Therefore, using the Nano-fluid increases the temperature difference for the hot fluid from 2 ^{o}C to 4 ^{o}C.

The effectiveness of heat transfer for counter flow arrangement before using the Nano-fluid is from 0.38 to 0.57. After using the Nano-fluid in tubes, the effectivencess is from 0.41 to 0.58. This means using Nano-fluid is improved the effectivencess by 17 to 19 percent. For parallel flow arrangement, The effectiveness before using the Nano-fluid is from 0.37 to 0.52. After using the Nano-fluid in tubes, the effectivencess is from 0.4 to 0.56. This means using Nano-fluid is improved the effectivencess by 15 to 16 percent. In conclusion, Using Nano-fluid maxture of pure water and Aluminum Oxide in shell and tubes heat exchangers improves the heat transfer rate, temperature difference, and eefectivencess.

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