DESIGN AND FARICATION OF A CONCENTRIC TUBE HEAT EXCHANGER FOR EXPERIMENTAL PURPOSES

BY

IBRAHIM HUSSEINI CHADO

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NIGERIA.

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DECLARATION

I IBRAHIM HUSSEINI CHADO declare that this project work is my own except for quotations and reviews which have been duly acknowledged.

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IBRAHIM HUSSEINI CHADO SIGNATURE AND DATE

CERTIFICATION

This is to certify that this project titled “Design and Fabrication of Concentric Tube Heat Exchanger for Experimental Purposes,” was carried out by IBRAHIM HUSSEINI CHADO, with Registration Number 2015/1/56246EM, under the supervision of Engr. Prof. A. Nasir and submitted to the department of Mechanical Engineering, School of Infrastructure, Process and Engineering Technology, Federal University of Technology, Minna, in partial fulfillment for the award of a Bachelor of Engineering (B.ENG) Degree in Mechanical Engineering.

Engr. Prof. A. NASIR	________________________
PROJECT SUPERVISOR	SIGNATURE AND DATE
Engr. Dr. A. S. LAWAL	_________________________
HEAD OF DEPARTMENT	SIGNATURE AND DATE
__________________	_________________________
EXTERNAL EXAMINER	SIGNATURE AND DATE

DEDICATION

This work is dedicated to God and my family who has been my strength and sufficiency in times difficulties and challenges throughout the degree program.

ABSRACT

This dissertation presents the design of fabrication of a concentric of heat exchanger for experimental purposes having a flow path configuration of parallel flow and counter flow using water as the working fluid with a single pass arrangement. Hot water flows via the inner tube and cold water flows via the annular region. Temperature readings were taking at the inlet, intermediate and outlet of both tubes. LMTD was used determined to evaluate the performance of the heat exchanger.

NOMENCLATURE

SYMBOLS

A	=	Area of Heat Transfer, M^2
M	=	Rate of Mass Flow
μ	=	Dynamic Viscosity (N·s/m_2)
h_i	=	Heat Transfer Coefficient for The Inside Flow
h_o	=	Heat Transfer Coefficient for The Outside Flow
Q	=	Heat Transfer Rate, W
U	=	Overall Heat Transfer Coefficient, W/m^2 K
ΔT_m	=	Local Temperature Difference, K
Pr	=	Prandtl Number (dimensionless)
Re	=	Reynolds number (dimensionless)
ρ	=	Density (kg/m^3)
T_{h1}	=	Temperature of Hot Fluid Inlet, K
T_{h2}	=	Temperature of Hot Fluid Outlet, K
T_{c1}	=	Temperature of Cold Fluid Inlet, K
T_{c2}	=	Temperature of Cold Fluid Outlet, K

L = Total Length of Pipe, m

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CHAPTER ONE

1.0 Introduction

1.1 Background of Study

Heat exchangers are devices meant to transfer heat energy between fluids moving in a device with different chambers from a high temperature fluid to a low temperature fluid. Therefore, the fluid that enters hot will come out colder and the fluid that enters cold will come out hotter. There are many ways of cooling a hot object while heating the other like pouring cold water on a hot car engine, it will be noticed that the temperature of the car engine will be decreased, while the temperature of the water will be increased but the problem is that it is quite dangerous, the water won't be of any use again as some will be lost as vapor and the environment will be messy. Avoiding such is one of the essence of heat exchangers. Heat exchangers have an extensive use from industrial to domestic. Different types of heat exchangers have been manufactured for use in heat and air conditioning systems, petroleum refineries, waste heat recovery, steam power plants, chemical processing plants, and petrochemical plants. Furthermore, heat exchangers are used for drying, pasteurization, cooling, evaporation and for freezing purposes. It is very important that a heat exchanger must be patterned in such a way that it delivers the desired heat transfer while taking little space and of light weight while being priced competitively. Heat transfer is a discipline of thermal engineering that concerns the conversion, generation, use and exchange of heat (thermal energy) between two or more physical systems. Heat travels via different mechanisms such as thermal conduction, thermal convection and thermal radiation. Engineers also put into consideration the transfer of mass of different chemical species (e.g. AL_2O_3) either hot or cold, in order to achieve maximum heat transfer. These mechanisms have completely different characteristics, but often occur at the same moment in a system (Farzaneh et al, 2019). There are also two key factors for the effectiveness of heat transfer which are the materials used for heat conduction and the amount of surface area in contact with heat source.

Concentric tube heat exchanger shows the fundamental principle of heat transfer, also with well proven facts backed with several experiments from experts in the field of engineering, it can be said that the process of transferring heat via fluid to fluid heat exchangers is based on the fundamental properties of heat conduction. When there are two or more independent circuit carrying fluids of different temperatures in contact, the heat certainly moves to cold attempting to locate equilibrium.

Concentric tube heat exchanger can be set up in various parallel and series arrangements to acquire the desired pressure drop and mean temperature difference requirements, this configuration is more effective if one or both fluids are at high pressure (turbulent flow) because of the smaller diameter of the pipe, but the major drawback is that concentric tube heat exchanger are expensive per unit transfer surface and bulky (Quadri et al, 2016).

1.2 Aim of Study

The aim of this study the design and fabrication of a concentric tube heat exchanger for experimental purposes.

1.3 Objectives of the Study

The objectives of the study are to

- Design and fabricate a concentric tube heat exchanger,
- Conduct an experiment on a concentric tube heat exchanger,
- Evaluate the performance of a concentric tube heat exchanger.

1.4 Statement of the Problem

Heat exchanger is very useful in in our daily lives and has helped the human race immensely in various ways and are designed in various ways to meet different needs purposes. The reason for this project is to study heat transfer between two fluids of different temperature and take into account the details of the experiment. This study will give further insight to the theoretical background of heat transfer knowledge acquired within the five years deemed for the honor of B.Eng. and can also be of help for lecturers when lecturing on the course heat transfer for practical example.

1.5 Justification of the Study

There is a daily need for heating and cooling in our everyday life, for example, there is a need to heat or cool our houses or workplaces depending on weather and there is also a need to heat things in an industry like the in use of boiler and there is also a need to cool things in food industries, etc. The need for heating and cooling or better put as the need for heat transfer ranges from domestic need to industrial need, therefore the necessities for heat exchanger cannot be overstressed.

1.6 Scope and Limitation

This dissertation is the design and fabrication of concentric tube heat exchanger for experimental purpose to aid theoretical learning

The limitation is in some materials used as the required materials were unavailable and time was short.

CHAPTER TWO

2.0 Literature Review

2.1 Definition of Heat Exchanger

Heat is the form of energy that is transmitted between objects or systems with different temperatures (flowing from a high temperature body or system to a lower temperature body or system) (Engineering ToolBox, 2003). Heat energy basically surrounds us, as all matter embodies heat energy. The result of the movement of small particles (i.e. ions, molecule or atoms) in matter (i.e. solids liquid or gas) is nothing more than thermal energy. Thermal energy can be transferred from one substance to another, and the flow due to the temperature difference between two objects is called heat. There are different sources of heat energy for example, the sun, Bunsen burner, electric heater, geothermal energy, electric iron, boilers etc.

Heat transfer according to thermodynamic system can be defined as the movement of heat across the border of the system due to a difference in temperature between the system and its surrounding (Herbert, 1985) or can be said as a discipline of thermal engineering that governs the conversion, generation, use and exchange of heat (thermal energy) between two or more physical systems. Heat transfer can be classified into three distinct mechanisms such as,

i. Thermal conduction: The process by which thermal energy is transmitted from one point to another, while the average position of the particles of the material remains the same.

ii. Thermal convection: The process by which thermal energy is transmitted in a fluid (liquid and gas) by the actual movement of the heated fluid from the hotter region to a cooler region.

iii. Thermal radiation: The process by which heat is transmitted from a hotter region to a cooler region without heating of the intervening medium (i.e. no material medium).

Engineers also put into consideration into consideration the transfer of mass different chemical species, either hot or cold, in other to achieve maximum heat transfer. These mechanisms have completely different characteristics, however the rarely occur at the same time in the same system. (Abbot et al, 2005 & Anyakoha ,2015).

The four basic modes of heat transfer are,

Advection

Advection is the lateral or horizontal transport mechanism of heat transfer in a fluid from one region to another.

Conduction (diffusion)

The transfer of heat energy across the length and width of an object or between two or more objects that are in contact. Thermal conductivity is a property of a material to conduct heat.

Convection

Convection is the vertical transport mechanism of heat transfer in a fluid from one region to another.

Radiation

Radiation is the transfer of heat energy by the emission of electromagnetic radiation.

Heat exchanger is a device used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid at different temperatures and most importantly in thermal contact (Ramesh et al, 2003). A heat exchanger is made up of heat exchanging components for instance a matrix or core embodying the heat transfer surface, and elements of fluid distribution (i.e. tanks, manifolds, headers, outlet and inlet pipes, or seals, or nozzles). Heat exchanger usually has no moving parts. However, there are few exceptions for instance a scraped surface heat exchanger whereupon a rotary element with a scraper blade rotates continuously inside the heat transfer tube and a rotary regenerator whereupon the matrix is driven mechanically to rotate at some design speed.

There is direct contact with the fluids and the heat transfer surface in which heat is transmitted by conduction. Primary or direct contact surface that is the surface that separate the fluids, however heat transfer area can be increased by the introduction of secondary surface which are referred to as fins which may be fasten to the primary surface. Heat is conveyed and attracted from the fin (via the area of the surface) to the surrounding fluid or vice versa, depending on whether the fin is getting cooled or heated. The inclusion of fins to the primary surface lowers the thermal resistance on that side and thereby rises the total heat transfer from the surface for the identical temperature. Fins may form flow passages for the individual fluids but doesn’t separate two or more fluids in the heat exchanger. Fins may be added primarily to provide thorough mixing of a highly viscous liquid or for structural purposes. (Ramesh et al, 2003).

Heat exchangers has an extensive use from industrial to domestic use. Different types of heat exchangers have been manufactured for use in building heat and air conditioning systems, petroleum refineries, waste heat recovery, steam power plants, chemical processing plants, petrochemical plant.

In engineering practice, drying, heating, pasteurization, cooling and evaporation of fluids and materials is of high importance in production and fabrication jobs. Heat exchangers are utilized to achieve the above by applying the basic principles of heat transfer alongside appropriate physical principle and engineering tenet. Heat transfer augmentation a process causing an incremental rate of heat transfer and thermos-hydraulic effectuation of a system of a system applying differing methods. The methods of heat transfer augmentation are engaged for creating the heat transfer without modifying the overall cognizance of the system significantly (Orhan et el, 2017). Heat transfer rate can be increased by applying different augmentation techniques. Heat transfer augmentation are classified into three separate categories:

Passive techniques

Passive techniques don’t require any external power, the thermo-hydraulic effectuation of the system is increased by modifying the surface or geometry of the flow passage or by the use of fluid additives. The rough surface or inserts and ribs are employed to promote turbulence and fluid mixing in the flow, therefore causing an increment causing an increment of the total rate of heat transfer. The following are methods of passive techniques used:

i. Coiled tubes – the secondary flow generated in the coiled tube yields higher single phase coefficient and improvement in nearly all boiling regimes.
ii. Rough surfaces – they can be integrated to the surface of the base or produced by placing the “roughness” adjoined to the surface.
iii. Coated surfaces – they include non – metallic or non-metallic coating of the surface e.g. non-wetting coating (i.e. Teflon).
iv. Swirl flow – they devices consist of a number of tube inserts or geometrical alignments for forced flow that generate secondary or rotating flow.

Active techniques

Active techniques are complicated than passive techniques in its application and manifestation of design and considering the absolute requisite of extrinsic energy to adjust to the passage of fluid so as to acquire an improvement in heat efficiency. The use of active techniques is limited because it is difficult to provide external energy in nearly all application. The following are methods of active techniques used;

i. Surface vibration – either high or low frequency has been applied primarily to enhance single phase heat transfer (e.g. a piezoelectric device can be utilized to cause vibration on a surface and impinge unto a heated surface small droplet to stimulate ‘spray cooling’.

ii. Electrostatic fields – they are utilized in dissimilar ways to dielectric fluids. Speaking generally, electrostatic fields may be engineered to produce greater bulk mixing of the fluid in the surrounding of the heat transfer surface.

iii. Mechanical aids – they include mixing of the fluids by rotating the surface or by mechanical means e.g. mechanical surface scraper.

iv. Fluid vibration – it is a more practical category of vibration augmentation owing to the fact of various mass of heat exchangers. The vibration varies from pulsation of about 1Hz to ultrasound.

Compound techniques

A compound technique is a combination of two or more heat transfer augmentation method (i.e. passive and/or active) to give increment in the thermo-hydraulic effectuation of heat exchangers. It can be engaged concurrently to procreate an enhancement that elevate the performance of the system of either of the techniques functioning independently. Introductory research on compound passive enhancement technique of this kind are reasonably reassuring. (Orhan et al, 2017 & Vignesh, et al, 2017)

2.2 Types and Classification of Heat Exchangers

The veritable design of heat exchanger is a cumbersome hurdle. It necessitates beyond heat transfer analysis alone. Quotation of production and installation, size and weight play paramount part in the determination of the conclusive design and comprehensive cost of proprietorship frame of reference. Oftentimes, notwithstanding the fact that cost is a paramount deliberation, footprint and size usually tend to be the paramount elements in selecting a design. There are different types of heat exchanger are different types and classification of heat exchanger based on, transfer process, flow path configuration, construction types etc.

2.2.1 Heat Exchanger Based on Transfer Process

a. Recuperative heat exchanger

The recuperative heat exchanger (also known as recuperators) is one in which there is a simultaneous flow of two or more fluid via a separating wall causing a continuous transfer of heat. The two major types of recuperators are direct and in-direct. Establishment of a recuperator for retrieving the thermal energy of the exhaust gas by foreheating the combustion air may rise the thermal efficiency of a compact gas turbine greatly. Notwithstanding, recuperators has been in evolution for some years, the thermal design is still developing, which is a cumbersome and exacting task. The primordial recuperators was manufactured centered on boiler standards. It proved to be large, heavy and bulky, with a low-level effectiveness. The design shift today is to heighten the compactness and to ameliorate the heat transfer coefficient in the tubes of the units. (Sunden 2013)

b. Regenerative heat exchanger

The regenerative heat exchanger (also known as capacitive heat exchanger or regenerators) is one in which both fluids flow alternatively via the same passage containing a matrix of material or packed bed that provides alternately a sink and a source for heat flow therefore heat transfer is intermittent. Regenerators are majorly utilized in gas/gas heat recuperation applications in some intensive industries and power plants. The two major types of regenerators are dynamic and static, they are momentary in operation and except extreme caution is taken in the design there is usually cross contamination of the cold and hot streams. However, experiments are made to enhance energy efficiency and retrieve low-grade heat in regenerators. Recuperators are more common because regenerators tend to be employed for specialist operations. (Hartnett, 1973)

c. The Evaporative heat exchanger

It is one in which a liquid is cooled evaporative and continuously in the same space as the coolant.

2.2.2 Heat Exchanger Based on Pass Arrangement

a. Single pass heat exchanger

It is one in which the fluid flow via the entire length of the pipe of the heat exchanger only once.

b. Multipass heat exchanger

It is one in which the fluid is reserved and made to flow the length of the pipes of the heat exchanger twice or thrice. When the design of a heat exchanger outcomes is either extremely lengthy, low effectiveness, or significantly low velocities, or due to other specifications, a multipass heat exchanger is engaged. Multipassing is employed to raise the heat exchanger thermal performance over the single pass performance. (Kuppan, 2013).

2.2.3 Heat Exchanger Based on Phase of Fluid

a. Gas – Liquid

The liquid is usually pumped via the pipes which has a tremendous convective heat transfer coefficient. The gas circulates the tubes in crossflow. The gas has a low heat transfer coefficient. To augment the heat transfer rate, fins are usually utilized on the outer surface of the pipes.

b. Liquid – Liquid

The fluids are pumped via the exchanger. The principal method of heat transfer is forced thermal convection. Liquid has a tremendous coefficient of convective heat transfer owing to it comparatively high density.

c. Gas – Gas

Oftentimes, one of the gas is compressed as to obtain a high density and the other gas is at a lower density and pressure. In comparison to the liquid – liquid exchanger, the magnitude of gas – gas exchanger is much bigger due to the low convective heat transfer coefficient of gas in comparison to liquid. (Kuppan, 2013).

2.2.4 Heat Exchanger Based On Flow Path Configuration

a. Parallel flow or concourrent flow

Both fluids enter simultaneously at one end, parallel to each other in the same direction and leave at the other end. Heat transfer between the fluids is from hotter to cooler as the temperature draw near each other and also the coldest temperature of the hot fluid is greater than the hottest temperature of the cold fluid. (Department of Energy, 1993)

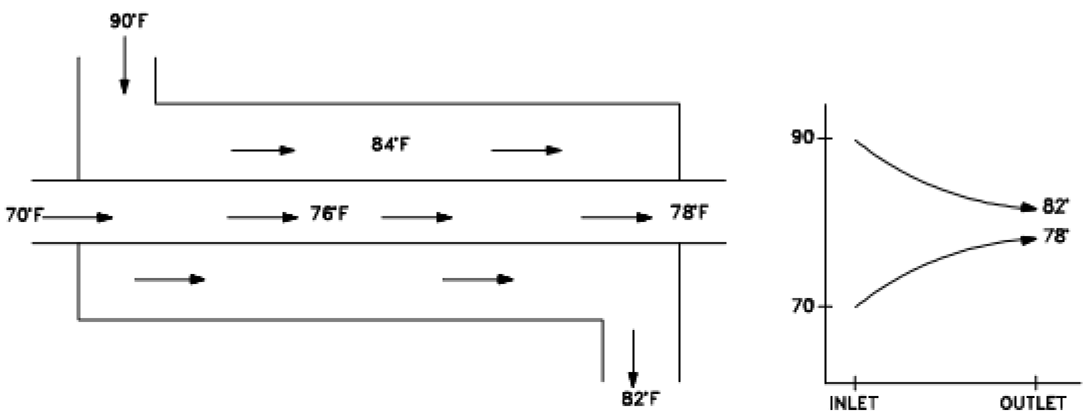

Figure 2.2.4 a: Parallel flow path configuration. Suorce: (Department of Energy, 1993)

b. Counter flow or countercurrent flow. Both fluids enter and leaves in opposition directions but parallel to each other. It is also the most efficient among the three types and also we can have the hottest temperature of the cold fluid greater than the coldest temperature of the of the hot fluid. (Department of Energy, 1993)

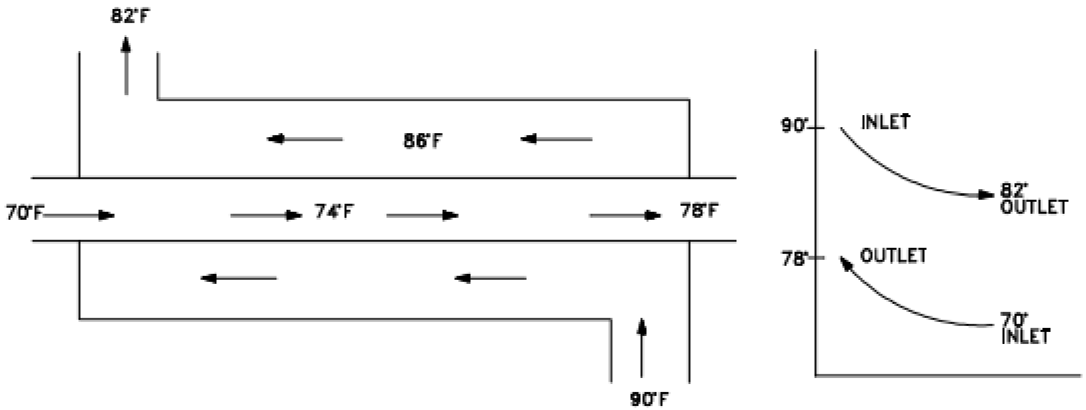

Figure 2.2.4 b: Counter flow path configuration. Suorce: (Department of Energy, 1993)

c. Single-pass cross flow. The flow of both fluids are mutually perpendicular to each other. Its application is usually found where either one of the fluids changes phase (2-phase flow) and an example will be a steam system's condenser. (Department of Energy, 1993)

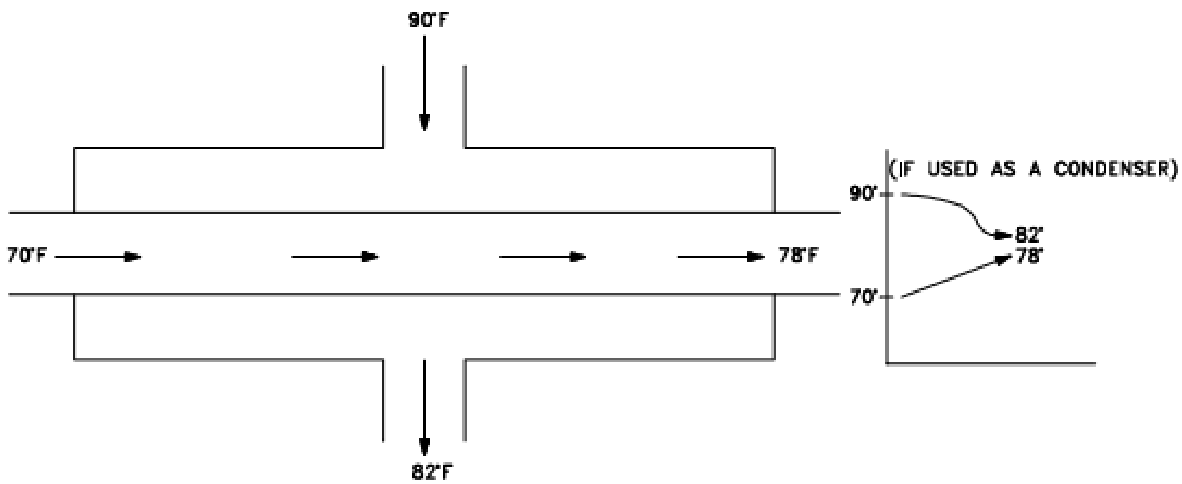

Figure 2.2.4 c. Single-pass cross flow path configuration. Suorce: (Department of Energy, 1993)

d. In multi-pass cross flow units one fluid stream moves (to-and-fro) across the flow path of the other fluid stream, giving a cross flow approximation to counter flow. (Department of Energy, 1993)

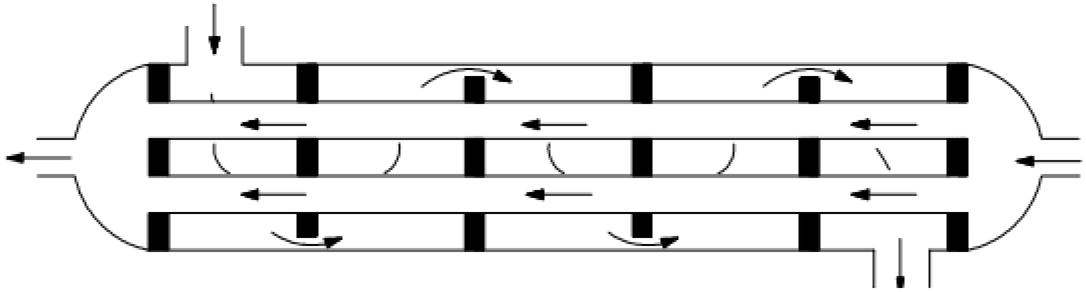

Figure 2.2.4 d. Multi-pass cross flow path configuration. Suorce: (Department of Energy, 1993)

2.2.5 Heat Exchanger Classified by Construction Types

Heat exchanger can be characterized also based on their construction type, however heat exchangers that have a lager surface area are more desirable because the allow more thermal contact which increase the rate of heat transfer hence a key performance factor for all heat exchangers is the amount of heat transfer surface area within the volume of the heat exchanger. This is called its compactness factor and is measured in square meters per cubic meter.

1. Plate Fin Exchanger: It is one that uses plate and finned chambers for the transfer between fluids, it’s classified as a compact heat exchanger to betone its relatively high heat transfer surface area to volume ratio. It is used widely in industries like aerospace industry for it light weight and compact characteristics, it is also used in cryogenics because of its ability to help bring about heat transfer with little temperature difference being utilized.

   Plate fin heat exchanger are usually used in industries where the fluids have small chances of fouling and also the cost is usually higher than a typical heat exchanger owing to the fact that a higher level of detail is desired during manufacture. (Sadik et al, 2002)

Advantages

a. it has a true counter-flow operation

b. it has a close temperature approach and also has a high thermal effectiveness

c. it has a multi stream operation

Disadvantage

a. Clogging may occur because its pathways are very narrow

b. It is not easy to clean pathways

Applications

i. cryogenic air separation

ii. ii. Nuclear engineering

iii. iii. Syngas production

Figure 2.2.5 a: plate fin heat exchanger. Source: (shutterstock.com)

1. Plate Heat Exchanger: It is one that uses metal plate for the transfer of heat between two fluids. It has an extensive advantage over a typical heat exchanger in that the fluids are

exposed to a much wider surface area given the fact that the fluids are spread out over the plates. This accelerate heat transfer and tremendously escalate the sped of the temperature change.

Small plate heat exchanger has made a huge significance in domestic heating and hot water. The conceptualization behind a heat exchanger is the use of pipes or any containing vessel to heat or cool on fluid by transmitting heat amidst it and the other fluid. In nearly all scenario, plate heat exchanger comprises of a screw-like pipe encompassing one fluid the passes via a case encompassing the other fluid. Dr. Richard Seligman invented plate heat exchanger in 1923 (Wang, 2011)

Advantages

a. easy to maintain.

b. they have an uncomplicated design and are compact in size.

c. it has more heat exchange effectiveness.

d. no fouling because of high turbulence hence cleaning is made easy.

Disadvantages

a. its pressure drop is high.

b. it is not good for vacuum service.

c. it is not good for hazardous material.

d. it has poor ability to handle solids.

Applications

i. Juice and fruit processing

ii. Hydrocarbon processing

iii. Chemical processing

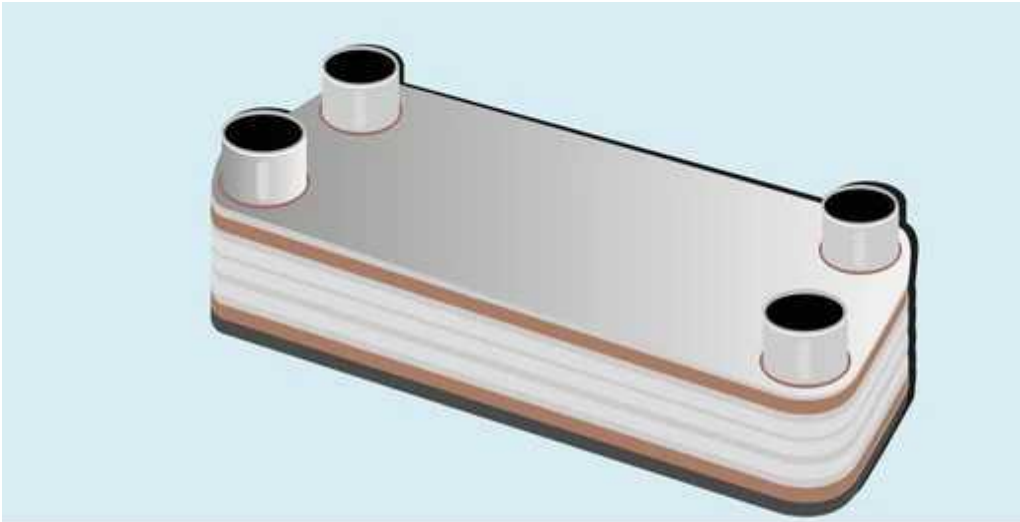

Figure 2.2.5 b: Plate heat exchanger. Source: (shutterstock.com)

2. Shell and Tube Heat Exchanger: it is a typical type of heat exchanger found in oil refineries and it is suitable for higher pressure application. Shell and tube heat exchanger consist of a shell and a pile of tubes in it. One of the fluid flow via the tubes and the other fluid run over the tubes (via the shell) for heat transfer between the fluids (Perry, 1984).

   Advantages

   a. it cost less in comparison to plate heat exchanger type.

   b. it has a less pressure drop over tube cooler.

   c. its pressure test is easy hence leaks on tube are found easily and stopped.

   Disadvantages

   a. it calls for a larger space in comparison to plate heat exchanger.

   b. in comparison to plate heat exchanger it has less heat exchange effectiveness.

   c. it maintenance and cleaning is not easy.

Figure 2.2.5 c: Shell and tube heat exchanger. Source: (shutterstock.com)

3. Double Pipe Heat Exchanger: Among the type of heat exchanger, the double pipe heat exchanger is the easiest of all. Double pipe heat exchanger are manufactured using two pipe, one encompassing the other. One of the fluid flow via the inner pipe and the other flow via the space between the two pipes. It can be used for single phase cooling and heating for heat transfer of a small area. (Saunders, 1988)

Advantages

a. it isn’t expensive

b. it is easily designed for high pressure service

Disadvantages

a. It is hard to clean a shell side when fouling occurs

b. Thermal expansion may be a problem

c. It is best suited for small size

Application

i. Anaerobic Digestion(AD)

ii. Sewage treatment

iii. Pasteurization of sludge waste water

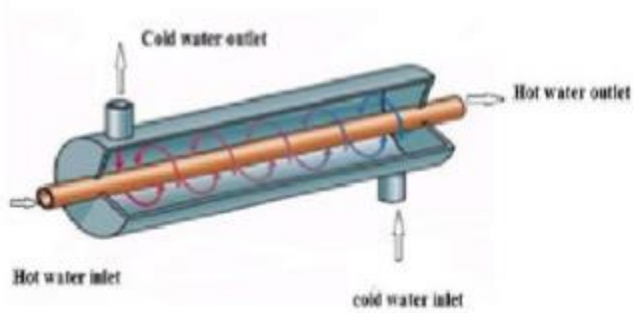

Figure 2.2.5 d: Double pipe heat exchanger. Suorce: (Vignesh et el 2017)

Boda M. A, Deshetti S. S, & Gavade M. A (2017) conducted a research on design and development of parallel – counter flow heat exchanger, for different heat exchangers to understand heat exchangers and development in heat exchangers modified for improved performance and they found out that, in the heat exchanger design, the estimation of the minimum heat transfer area is very important for a given heat transfer duty, as it governs the overall cost, size, and weight of the heat exchanger, and by increasing mass flow rate of cold fluid, heat transfer coefficient increases which results in increase in the Reynolds number.

Timothy J.R & Vijaya G. S (2005) conducted a study in numerical studies of a double-pipe helical heat exchanger, modeled for laminal flow and also heat transfer characteristics by varying the size of the inner tube and the mass flow of the annulus and the inner tube for both counter-flow and parallel heat exchanger. it was discovered that the total resistance for the most part was majorly dominated by the annulus (annular region). It was then recommended that the annular region should *receive more attention to effectively increase the overall heat transfer effectiveness. In addition, increment in the size of the inner tube leads to lower thermal resistance in the annulus region.

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2.2.3 Selection Requirement for a Heat Exchanger

Selection requirement for a heat exchanger is quite numerous, but basic requirement is cost, temperature, type of fluids to be utilized and heat duty. The fluids employed in heat exchanger can be categorized by pressure, temperature, phase, toxicity, fouling tendency, corrosivity and physical properties. Operating determinants for heat exchangers extend over an extensive range, and a wide range of demands is exploited for their performance and design. (Kuppan, 2013). The following factors must be evaluated when choosing a heat exchanger for a given task:

- Materials of construction
- Operating pressure and temperature
- Flow rate
- Flow arrangements
- Performance parameters
- Fouling tendencies
- Types and phases of fluid
- Overall economy
- Fabrication technique

2.3.1 Materials of Construction

For a dependable and constant usage, the manufacturing materials for pressure vessels and heat exchangers should have an explicit corrosion rate in the service environments. Moreover, the material should manifest strength to hold out against the operating pressure and temperature. Shell and tube heat exchanger can be constructed with almost any material that may be essential for corrosion resistivity e.g. from non-metals like Teflon, graphite, and glass to exotic metals like zirconium, titanium, and tantalum etc. Plate heat exchanger need a material that can be welded or pressed. compact heat exchanger with augmented surfaces are majorly fabricated from any metal that has, malleablity, drawability, and formability. (Kuppan, 2013)

2.3.2 Operating Pressure and Temperature

2.3.2.1 Pressure

In design pressure, it is crucial to decide the thickness of the pressure retaining elements. The greater the pressure, the greater the desired thickness of the pressure retaining membranes and the additional benefits there is to positioning the high pressure fluids on the tube-side. The pressure level of the fluids has an exceptional outcome on the type of unit choose.

- the vapour phase volumetric flow rates at high pressures, are lower and permissible pressure drop are higher, which gives rise to additional compact units.
- The vapour phase volumetric flow rate at low pressures, is high and the low permissible drop may have a need of a design that will maximize the area accessible for flow i.e. split flow or crossflow with several nozzles.

  Generically, greater heat transfer rates are acquired by positioning the low pressure in the exterior of the tubular surfaces. (Kuppan, 2013)

2.3.2.2 Temperature

Design temperature – This parameter is fundamental as it stipulate whether a material at the design temperature can hold out against the operating pressure and numerous loads saddled on the components. For cryogenic and low temperature applications, toughness is a key requirement and for high temperature applications, the material has to manifest creep resistance.

Temperature driving force – The effectual temperature driving force is an estimate of the authentic potential for heat transfer that exist at the design constrains. With a counterflow arrangement the effectual temperature difference is explained by the log mean temperature difference (LMTD). (Kuppan, 2013)

2.3.4 Flow Rate

Flow rate governs the flow area, the greater the flow rate, the greater will be the crossflow area. Greater flow area is essential to restrict the flow velocity via the channels and flow passages and the higher velocity is restricted by erosion, impingement, pressure drop and by shell side flow – induced vibrations in the case of shell and tube heat exchanger. Oftentimes, a minimal flow velocity is required to enhance heat transfer to annihilate stagnant areas and to reduce fouling.

2.3.4 Flow Arrangements

The selection of a specific flow arrangement is influenced by the desired downstream and upstream ducting, exchanger construction type, packing envelope, exchanger effectiveness, and other design specifications. (Kuppan, 2013)

2.3.5 Performance Parameter

Pressure drop – Pressure drop is a crucial parameter in the design of a heat exchanger. Restrictions may be imposed either by process limitations or by pumping cost, or both. The heat exchanger should be design along the lines that unproductive pressure drop is circumvented to the maximum expanse in some areas (i.e. outlet and inlet bends, manifolds, and nozzles). Concurrently, any pressure drop restrictions that is imposed ought to be employed as nearly as realizable for an economic design. (Kuppan, 2013)

2.3.6 Fouling Tendencies

Fouling is defined as the developments on heat exchanger internal surfaces of infelicitous sediments that hinders the heat transfer and increase the resistance of fluid flow, resulting in greater pressure drop. The growths of theses sediments cause a reduction of the thermohydraulic effectuation of the heat exchanger with time. Fouling alters the energy dissipation of industrial processes and it also determine the quantity of more materials needed to provide auxiliary heat transfer surface to counterbalance the effects of fouling. (Kuppan, 2013)

2.3.7 Types and Phases of Fluids

The phase of fluids inside a unit is a cardinal deliberation in the determination of the heat exchanger of the heat exchanger type. Several combinations of fluid phase used in heat exchangers are gas – gas, liquid – gas, and liquid – liquid. Liquid – liquid phase fluids are usually the easiest to deal with. The high density of liquid and the reassuring values of several transport properties permit high heat transfer coefficient to be procured at relatively low – pressure drop. (Kuppan, 2013)

2.3.8 Overall Economy

The vital costs to deliberate over in designing a heat exchanger are the operating cost, maintenance cost, and the manufacturing cost. Usually, the lower the design complication and the lower the area of the heat transfer surface, the lower the manufacturing cost. The operating cost is the pumping quotation due to the pumping devices i.e. blowers, pumps, and fans.

2.3.9 Fabrication Technique

Fabrication technique are distinctly possible to be the critical factors in the selection of a surface matrix or core of a heat exchanger. They are the predominant components in the preliminary cost and substantially affect the service life, integrity, and ease of maintenance of the completed heat exchanger i.e. automobile aluminum radiators and plate fin exchanger are fabricated by mechanical assembly, copper – brass radiators by soldering and shell and tube units are majorly fabricated by welding etc. (Kuppan, 2013)

CHAPTER THREE

3.0 Materials and Methodology

3.1 Proposed Materials

3.1.1 Electric Heater

Electric heater is an electric device that convert an electric current into thermal energy using metals as the heating elements. The metal must have high resistance that allows a specified amount of electric current to flow via them to provide the desired thermal energy. Majority of the contemporary electric heater uses nichrome wire as the active element. (https://www.greenspec.co.uk/building-design/insulation-material-and-thier-properties/)

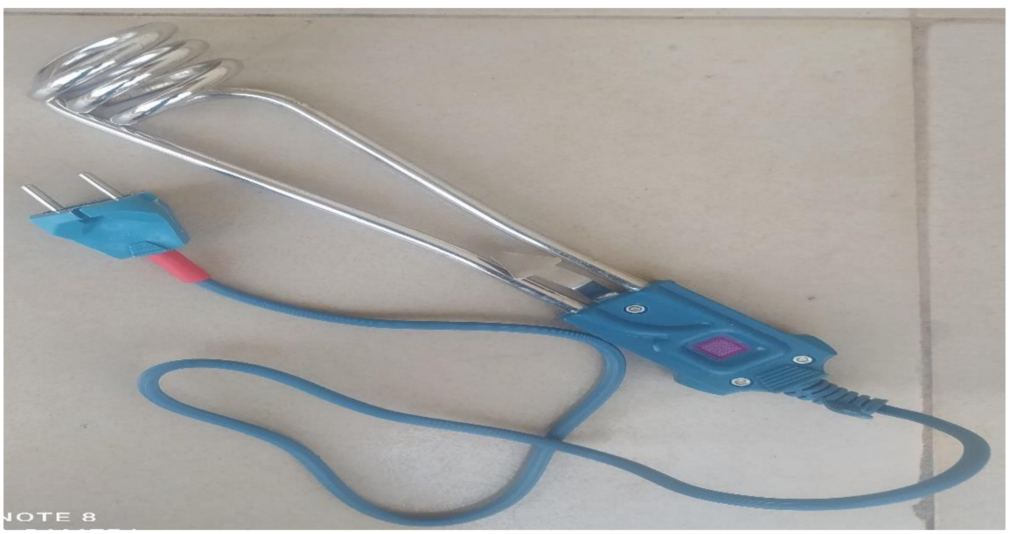


Plate 3.1 Electronic heater

3.1.2 Valve

A valve in mechanical engineering is a device that is used to regulate the flow and pressure of fluids, fluidized solids, liquids or slurries (a slurry is a sloppy mixture, which is generated in different varieties), within a system or process by opening, closing, or partially obstructing various passageways. In electronic engineering the valve refers to an electronic device that regulates the flow of current integrated with other devices. Valves are technically fittings but are usually discussed as a separate category. Valves have many uses, from controlling water for irrigation to industrial uses for controlling processes, residential uses such as on/off and pressure control to dish and clothes washers and even taps in the house. Valves are also used in the military and transport and many other fields of operation.

Plate 3.2 Valves

3.1.3 Storage Tank

Storage tanks are containers that hold liquids, compressed gases they could also be said to be mediums used for the short or long term storage of heat or cold. Storage tanks are available in many shapes such as vertical and horizontal cylindrical, open top and closed top; flat bottom, cone bottom etc. Most storage tanks for handling liquids during transportation are designed to handle varying degrees of pressure. Some types of tanks include; Atmospheric, High pressure, Thermal storage, Milk, Septic tanks. They all carrying out various storage functions.

Plate 3.3 Storage tank

3.1.4. Centrifugal Water Pump

A pump is a device that uses mechanical means to move fluid from one point to another usually, by converting electrical energy into hydraulic energy. There are three basic type of pump namely; positive-displacement pumps, axial pump and centrifugal pump. (https://en.m.wikipedia.org/wiki/Pump/)

The centrifugal water pump works by using a close impeller in the pump to move water. Water enters through a central pipe and is pushed out to the peripheral by centrifugal force. When water reaches the edge of the outtake, the pressure from the water behind it forces it through. (https://chucta.com/how-does-a-water-pump-work/)

The water pump used in this experiment are characterized by the following parameters: flowrate (0.2-2.2 m^3/h), H=32-12m, horsepower (0.5), maximum head (35m), minimum head (10m), Voltage (220-240V), frequency (50Hz), current (2.3A)

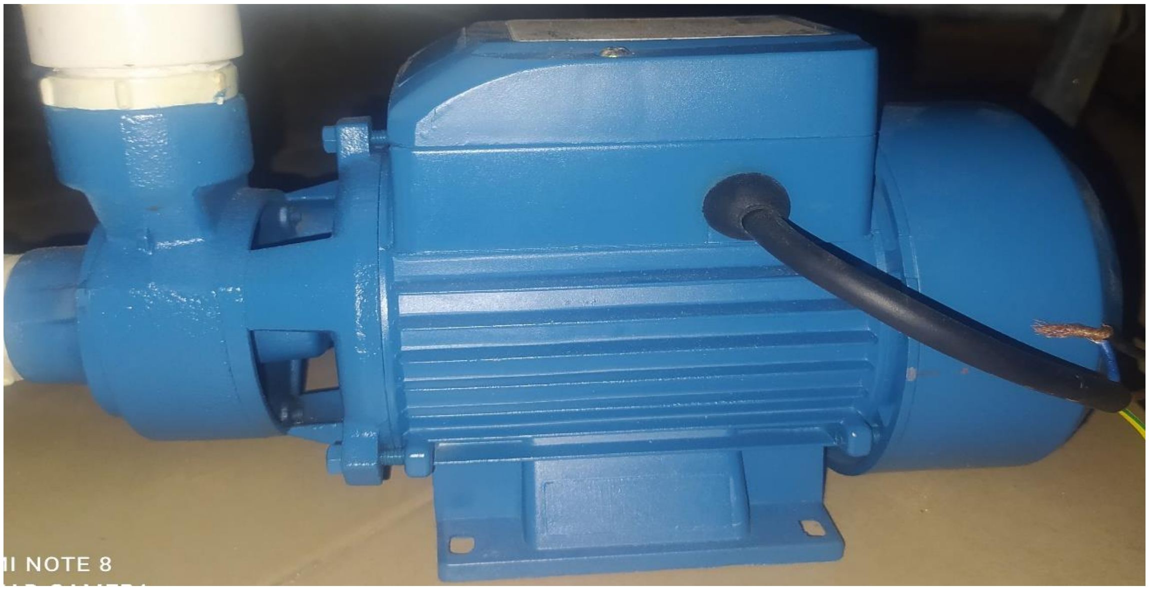


Plate 3.4 Electric water pump

3.1.5 PVC Adhesive

Adhesive is any nonmetallic substance applied to one or both sides of two separate items that binds them together and prevents their separation. (Kinloch, A.J. (1987). p1.) A PVC glue is a solvent based glue that dissolves the surface of PVC sheets, with both surfaces fusing and melting together to form a strong bond. It is made up of vinyl chloride polymers with additional solvent and fillers. (https://plasticsheetsshop.co.uk/gluing-pvc/)

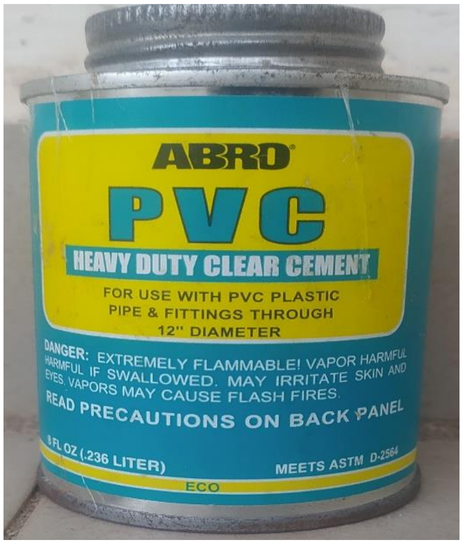


Plate 3.5 PVC adhesive

3.1.6 Polyvinyl Chloride Joints and Fittings

PVC, or polyvinyl chloride, is a type of plastic used in numerous industries. It is durable, inexpensive and resistant to heat, water and chemicals. Its durability makes it suitable for a variety of construction applications (https://sciencing.com/uses-pvc-plastic/). PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. Its thermodynamic properties /characteristics are usually categorized based on rigid and flexible PVCs they are as follows: Density (1.3-1.45g/cm^3), Thermal Conductivity (0.14-0.28W/mk), Yield strength (31-60 MPa), Young's Modulus (3.4 GPa), Coefficient of thermal expansion (5×10^{-5}), Resistivity (10^{16}**Ωm).**

Plate 3.6 Polyvinyl chloride joints and fittings

3.1.7 Polypropylene Plastics (PPR)

Polypropylene (PPR), also known as polypropene, is a thermoplastic polymer used in a wide variety of applications. It is made from Polypropylene Random Copolymer Plastic, manufactured through a continuous extrusion process. They have good heat resistance, corrosion resistance and non-fouling performance. The working water temperature is 95℃, 120℃ working water temperature for short term and 60℃ for long term continues use. The density of (PPR) is between 0.895 and 0.92 g/cm^3), thermal conductivity at 20℃ is 0.23-0.24W/mK. (https://tianyanpipes.com/info/the-charateristics-of-ppr-pipe/)

Plate 3.7 polypropylene plastics

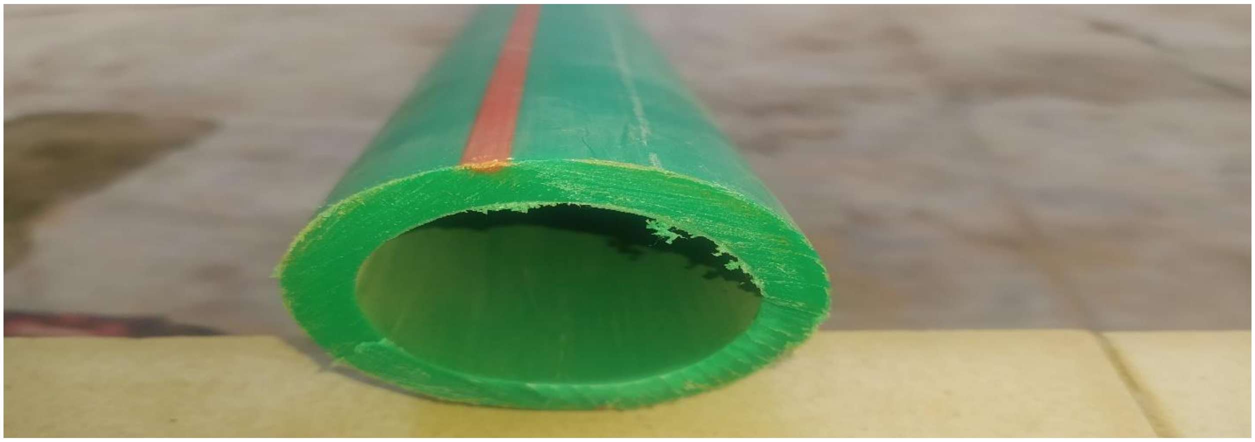


Plate 3.8 polypropylene plastics

3.1.8 Galvanized Steel

Galvanized steel is a type of steel that has been galvanized by the application of a zinc coating throughout its body so that it can be protected from corroding or rusting.(https://corrosionpedia.com/definition/2153/galvanized-steel/). Thermodynamic properties of galvanized steel includes; Thermal Conductivity at 20ºC is (60.0000 W/mºK), Specific Heat Capacity at 20ºC is (0.0900 cal/g), Coefficient of Thermal Expansion is (0.0108 mm/mºC), Linear Thermal Expansion Coefficient Electrical Conductivity (0.0934 Ω/mm/m) (20 to 300ºC)

3.1.9 Threading Tape

Threading tape or Thread seal tape (also known as PTFE tape, Teflon tape or plumber's tape) is a polytetrafluoroethylene PTFE) film tape commonly used in plumbing for sealing pipe threads.

Temperature Range of PTFE: -268°C to +260°C (-450°F to +500°F). PTFE is completely stable up to +260˚C (500˚F). Decomposition is slow up to 400°C (750°F). Decomposition will occur on contact with open flames. (https://uk.rs-online.com/web/ptfe-tapes-guide/)

Plate 3.9 Threading tape

3.1.10 Arduino Uno

Arduino is an open source programmable circuit board that can be integrated into a wide variety of projects both simple and complex. This board contains a micro controller which is able to be programmed to sense and control objects in the physical world. By responding to sensors and inputs, the Arduino is able to interact with a large array of outputs such as LEDs, motors and displays (markerspaces.com).

Arduino code is written in **C++** with an addition of special methods and functions.

3.1.11 Temperature Sensors

A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor, or signal temperature changes. There are many different types of temperature sensors. Some temperature sensors require direct contact with the physical object that is being monitored (contact temperature sensors), while others indirectly measure the temperature of an object (non-contact temperature sensors).

Non-contact temperature sensors are usually infrared (IR) sensors. They remotely detect the IR energy emitted by an object and send a signal to a calibrated electronic circuit that determines the object's temperature. (https://www.fierceelectronics.com/sensors/)

3.1.12 Silicone Sealant

Silicone sealant is a liquid form of adhesive. Typically, it looks, feels, and acts like a gel. It has a different chemical make-up from other organic polymer-based adhesives. Unlike other adhesives, silicone keeps its elasticity and stability in both high and low temperatures. Furthermore, silicone sealant is resistant to other chemicals, moisture, and weathering. This makes it less likely to fail when building and repairing objects. (https://hotmelt.com/blogs/blog/silicone-sealant-handook/)

Plate 3.10 Silicon sealant

3.1 Methodology

3.2.1 Thermal and Hydraulic Design

Thermal and hydraulic design of heat exchanger is mainly concerned with heat exchanger rating and sizing. Thermal and hydraulic design is mainly divided into two;

1. Enthalpy rate equations

$$q = q_j = \dot{m}_j \Delta h_j \tag{1}$$

2. Heat transfer rate equation

$$q = UA\Delta T_m \tag{2}$$

3.2.1.1 Basic Thermal and Hydraulic Design Method

Different thermal and hydraulic design methods includes e-NTU, P-NTU, LMTD correction factor. The type to be adopted is dependent on the dimensionless groups and relationships between them. Dimensionless groups can be classified into dependent and independent and they are established when deciding the basic thermal and hydraulic design method to be used.

3.2.2 Basic Design Equation

The basic design equation stated in this chapter can be used to design all types of recuperator heat exchanger including the concentric tube heat exchanger. In the concentric tube heat exchanger, the fluids are separated by a solid surface used for heat transfer.

When designing heat exchangers, the thermal analysis also known as the sizing problem is done to ascertain the heat transfer area of the heat exchanger. The rating problem also known as the performance calculation is carried out after the heat exchanger is designed and constructed. In addition to the rating and sizing problems, other factor such as the economic, structural and safety factors are considered.

Using the first law of thermodynamic for an open system under steady state we can derive the following equation.

$$\delta Q = \dot{m} dh \tag{3}$$

Where $\dot{m}$ = rate of mass flow

h = fluid specific enthalpy

δQ = heat transfer rate

Integrating equation (1) we have the following

$$Q = \dot{m}\,(h_2 - h_1) \tag{4}$$

Where h_1 = fluid inlet enthalpies

h_2 = fluid outlet enthalpies

When the fluid is hot the equation turns to

$$Q = \dot{m}\ (h_1 - h_2) \tag{5}$$

When the fluid is cold the equation turns to

$$Q = \dot{m}\ (h_1 - h_2) \tag{6}$$

If the fluid is a single phase fluid and does not undergo phase change with constant specific heat we derive the following equation

For hot fluid the equation is

$$Q = \left(\dot{m}c_p\right)_h = (T_{h1} - T_{h2}) \tag{7}$$

For cold fluid the equation is

$$Q = \left(\dot{m}c_p\right)_c = (T_{c2} - T_{c1}) \tag{8}$$

The total heat transfer rate on a differentia area can be deduced from the following equation

$$Q = UA\Delta T_m \tag{9}$$

Where U = is the heat transfer coefficient on the area under consideration

A = the total heat transfer area on the hot or cold side

ΔT_m = is the local temperature difference.

3.2.3 Overall Heat Exchanger Transfer Coefficient

Heat exchangers are usually constructed with a single material. Although bimetallic materials are often used in constructing them. The thermal resistance of a heat exchanger can changed due to factors such as fouling, corrosion and depositions which can increases the thermal resistance of a heat exchanger. The overall heat transfer equation of a heat exchanger with an even can be gotten from the equation

$$UA = \frac{1}{R_t} = \frac{1}{\frac{1}{h_i A} + \frac{t}{KA} + \frac{1}{h_o A}} \tag{10}$$

Where R_t = Overall thermal resistance

t = wall thickness

h_i = Heat transfer coefficient for the inside flow

h_o = Heat transfer coefficient for the outside flow

For tubular heat exchanger the overall thermal resistance is derived as

$$U_o A_o = U_t A_t = \frac{1}{R_t} = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln\left(\frac{r_o}{ri}\right)}{2\pi KL} + \frac{1}{h_o A_o}} \tag{11}$$

The thermal resistance R_s can be defined the equation (10) due to further thermal resistance caused by fouling

$$\frac{\Delta T_s}{Q} = R_s = \frac{1}{Ah_s} \tag{12}$$

Where R_s = thermal resistance due to fouling

h_s = coefficient of thermal resistance

ΔT_s = Temperature drop across the scale

Due to fouling on both the inside and outside surface of the heat exchanger the thermal resistance can be expresses as

$$R_t = \frac{1}{U_A} = \frac{1}{U_o A_o} = \frac{1}{U_t A_t} = \frac{1}{h_i A_i} + R_w + \frac{R_{fi}}{A_i} + \frac{R_{fo}}{A_o} + \frac{1}{A_o h_o} \tag{13}$$

$R_w = \frac{t}{KA}$ (for plain plane wall)

$R_w = \frac{\ln\left(\frac{r_o}{ri}\right)}{2\pi LK}$ (for plain tube wall)

3.2.4 Using the LMTD Method for Heat Exchanger Design

Designing parallel flow and counter flow heat exchanger

$$\delta Q = -\left(\dot{m}c_p\right)_h dT_h = \pm\left(\dot{m}c_p\right)_c dT_c \tag{14}$$

Or

$$\delta Q = -c_h dT_h = \pm\, c_c\, dT_c \tag{15}$$

Where δQ = degree of heat transfer between both fluids

dT_h= change in the temperature of the hot fluid

dT_c = change in the temperature of the cold fluid

c_h = heat capacity of the hot fluid

c_c = heat capacity of the cold fluid

$$\delta Q = U(T_h - T_c)dA \tag{16}$$

Where dA = heat transfer area

$$d(T_h - T_c) = dT_h - dT_c = \delta Q\left(\frac{1}{c_c} - \frac{1}{c_h}\right) \tag{17}$$

Replacing equation (14) to equation (15)

$$\frac{d(T_h - T_c)}{(T_h - T_c)} = U\left(\frac{1}{c_c} - \frac{1}{c_h}\right)dA \tag{18}$$

$$\ln\frac{T_{h2} - T_{c1}}{T_{h1} - T_{c2}} = UA\left(\frac{1}{c_c} - \frac{1}{c_h}\right) \tag{19}$$

For counter flow

$$T_{h2} - T_{c1} = (T_{h1} - T_{c1})\, exp\left[UA\left(\frac{1}{c_c} - \frac{1}{c_h}\right)\right] \tag{20}$$

For parallel flow

$$T_{h2} - T_{c2} = (T_{h1} - T_{c1})\, exp\left[-UA\left(\frac{1}{c_c} + \frac{1}{c_h}\right)\right] \tag{21}$$

Substituting c_c and c_h into equation (17) finding Q

$$Q = UA\,\frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln\left(\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}\right)} \tag{22}$$

Or

$$Q = UA\,\frac{\Delta T_1 - \Delta T_2}{\ln\left({}^{\Delta T_1}/_{\Delta T_2}\right)} \tag{23}$$

Where $\Delta T_1 =$ temperature change at entry

ΔT_1 = temperature change at exit

Juxtaposing the equation to find the average temperature change results to equation (24)

$$\Delta T_{int} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \tag{24}$$

This equation is known as the log mean temperature difference (LMTD). In counter flow the heat transfer rate between the hot and cold fluid can be expressed as

$$Q = AU\Delta T_{int} \tag{25}$$

For counter flow

$$\left(\dot{m}c_p\right)_h = \left(\dot{m}c_p\right)_c$$

$$(T_{h1} - T_{h2}) = (T_{c2} - T_{c1}) = \Delta T_1 - \Delta T_2 \tag{26}$$

Applying L'Hospitals rule

$$Q = UA(T_h - T_c) \quad \text{With} \quad (T_h - T_c) = \Delta T_1 = \Delta T_2 \tag{27}$$

3.2.5 Using the E-NTU Method

The number of transfer (E-NTU) unit may be used in the thermal analysis of heat exchanger over the log mean temperature difference (LMTD) to prevent a guessing procedure.

The following dimensionless group are derived from equation (7), (9), and (19)

1. Capacity rate ratio

$$C^* = {}^{C_0}/_{C_1} \tag{27}$$

Where C_0 = the smaller magnitude of C_h

C_1 = the bigger magnitude of C_c

$C^* \leq 1. C^* = 0$ Corresponds to a finite C_0 and C_1 as it approaches ∞

2. Heat transfer effectiveness of the heat exchanger

$$\varepsilon = Q/Q_1 \tag{28}$$

From equation (7) and (8)

$$Q = (\dot{m}c_p)_h (T_{h1} - T_{h2}) = (\dot{m}c_p)(T_{c2} - T_{c1}) \tag{29}$$

$$\text{If } c_h > c_c \ then \ (T_{h1} - T_{h2}) < (T_{c2} - T_{c1}) \tag{30}$$

$$\text{If } c_h < c_c \ then \ (T_{h1} - T_{h2}) > (T_{c2} - T_{c1}) \tag{32}$$

Highest heat transfer attainable is

$$Q_{max} = (\dot{m}c_p)_c (T_{h1} - T_{c1}) \qquad \text{If} \qquad c_h < c_c \tag{33}$$

$$Or$$

$$Q_{max} = \left(\dot{m}c_p\right)_h (T_{h1} - T_{c1}) \qquad \text{If} \qquad c_h < c_c \tag{33}$$

For counter flow heat exchanger effectiveness is

$$\varepsilon = \frac{c_h(T_{h1} - T_{h2})}{c_0\,(T_{h1} - T_{c1})} \tag{34}$$

$$\varepsilon = \frac{c_c\,(T_{c1} - T_{c2})}{c_0(T_{h1} - T_{c1})} \tag{35}$$

$c_h = c_0$ for equation (34) and $c_c = c_0$ for equation (36)

The exact heat transfer rate can be obtained from equation (28) when temperature effectiveness P is equal to effectiveness of the heat exchanger ε.

$$Q = \varepsilon\left(\dot{m}c_p\right)_{min} (T_{h1} - T_{c1}) \tag{36}$$

Equation (34) is employed when the heat exchanger effectiveness is known.

3. $NTU = \frac{AU}{c_0} = \frac{1}{c_0}\int_A UdA$ (37)

Assuming $c_c > c_h$ for a single pass heat exchanger similarly $c_h = c_0$and $c_c = c_1$ from equation (20) and equation (37)

$$T_{h2} - T_{c1} = (T_{h1} - T_{c2})\,exp\left[-NTU\,\left(\pm 1 - \frac{c_0}{c_1}\right)\right] \tag{38}$$

$(+)$ is used for counter flow similarly, $(-)$ is used for parallel flow.

For counter flow

$$\varepsilon = \frac{1 - exp\left[-NTU\left(1 + \frac{c_0}{c_1}\right)\right]}{1 + \left({}^{c_0}/_{c_1}\right)} \tag{39}$$

Due to cases of ${}^{c_0}/_{c_1} = 1\ and\ 0$ thus making equation (38) to be indeterminate. Applying L'Hopitals rule on equation (38) result to;

$$\text{For counter flow } \varepsilon = \frac{NTU}{1+NTU} \tag{40}$$

$$\text{For parallel flow } \varepsilon = 0.5(1 - e^{2NTU}) \tag{41}$$

When ${}^{c_{min}}/_{c_{max}}$ = 0For parallel or counter flow equation (38) and equation (39) turns to

$$\varepsilon = 1 - e^{-NTU} \tag{42}$$

$$\varepsilon = \emptyset\ (NTU, c^*, arrangement\ of\ flow\ ) \tag{43}$$

Equation (43) was deduced from observation of Equation (38) and Equation (39)

3.2.6 Variable Overall Heat Transfer Coefficient

The heat transfer variables coefficient varies in real application to factors such as Reynolds number, density, surface tension, viscosity and surface geometry.

For a concentric tube heat exchanger, the overall heat transfer co-efficient can be expressed as;

$$U_i = U_i\ (T_{hi}, T_{ci}) \tag{44}$$

Where T_{hi} = hot fluid temperature

T_{ci} = cold fluid temperature

Change in heat transfer in the increment in surface area ΔA_i can be expressed as;

$$\Delta Q_i = \left(\dot{m}c_p\right)_{hi}\left(T_{h(i+!)} - T_{hi}\right) = \left(\dot{m}c_p\right)_{ci}\left(T_{c(i+1)} - T_{ci}\right) \tag{45}$$

From equation (14) we can express δQ as;

$$\delta Q = U_i \Delta A (T_h - T_c)_i \tag{46}$$

For parallel flow arrangement were δQ is mandatory to be little to preserve the preciseness of the solution. Equation (18) can be expressed as;

$$\frac{d(T_h - T_c)}{(T_h - T_c)} = -U\left(\frac{1}{c_h} + \frac{1}{c_c}\right) dA \tag{47}$$

Consequently

$$\frac{(T_h - T_c)_{i+1} - (T_h - T_c)_i}{(T_h - T_c)_i} = U_i\left(\frac{1}{c_{ci}} + \frac{1}{c_{hi}}\right) \Delta A_i \tag{48}$$

Solving for $(T_h - T_c)_{i+1}$

$$(T_h - T_c)_{i+1} = (T_h - T_c)_i\,(1 - M_i \Delta A_i) \tag{49}$$

$$\text{Where } M_i = U_i\left(\frac{1}{c_{ci}} + \frac{1}{c_{hi}}\right) \tag{50}$$

CHAPTER FOUR

4.0 Result and Discussion

4.1 Experimental Setup

The experiment was conducted with an experimental setup consisting of a concentric tube heat exchanger in which hot water was through the inner tube and cold water flows through the annulus from their individual storage tanks. Galvanized tube is used for the inner tube having a length of 2.0m and a diameter of 0.01905m, while polypropylene plastics (PPR) is used for the outer pipe with a length of 2.0m and a diameter of 0.0508m. Polypropylene plastics is used as the outer tube because of it low thermal conductivity thereby acting also as an insulator. Pumping machines are used to pump water into the inner and outer tubes from their storages tanks. Thermocouple sensors are fixed at the outlet and mid-points of both tubes connected to Arduino kits to get digital readings.

Plate 4.1. Experimental Setup

4.2 Experimental Procedure

1. The experiment was set up for counter flow heat exchanger operation. The hot water inlet temperature to was raised to T= 60 ºC. Then, the cold water mass flow rate ($\dot{m}_c$) was set to run at a constant 1200 cm³/min.
2. The hot fluid mass flow rate (m_c) was set to 1200 cm³/min. After the six temperature readings (hot fluid inlet, hot fluid midpoint, hot fluid outlet, cold fluid inlet, cold fluid midpoint, cold fluid outlet) were recorded. The experiment was repeated.
3. The values for density (ρ_c and ρ_h) and constant pressure specific heat (c_{pc} and c_{ph}) for the cold fluids at a temperature of $T_{c.1}$ and for hot fluid $T_{h.1}$.

4. Using the data, the following heat exchanger performance factors: Heat transfer rate for hot fluid (Q_h), heat transfer rate for cold fluid (Q_c), heat transfer efficiency (η), logarithmic mean temperature difference (ΔT_m) and overall heat transfer coefficient (U) were calculated and recorded
5. The experiment was repeated and set up for parallel flow with the same steps for the counter flow.

4.3 Results

Theoretical analysis

For Parallel Flow

TABLE 1 Parallel Flow Readings

S/No	$v_h(cm/min)$	$T_{h,in}$(°C)	$T_{h,mid}$(°C)	$T_{h,out}$(°C)	$T_{c,in}$(°C)	$T_{c,mid}$(°C)	$T_{c,out}$(°C)
1	1200	60.00	52.00	47.90	29.00	33.00	34.50

2	1200	60.00	55.50	51.00	29.00	34.50	35.60

The properties of water at 60℃ are

Density (ρ) = 983kg/m^3

c_p= 4.185kJ/kg.k

K= 0.654W/m.k

Dynamic viscosity (μ) = 0.454 x 10^{-3}Pa.s

Diameter of inner pipe= 0.01905m

The hot water mass flow is;

Q = $(mc_p)_c\ \Delta T_c = (mCp)_h\ \Delta T_h$

To find m_h;

m_h = $(mc_p)_c \Delta T_c$/ $c_p \Delta T_h$

m_h= (0.32277x 4.178) x (34.5- 29)/ 4.185 x (60- 47.9)

=0.153kg/s

At 29℃ c_p= 4.178kJ/kg.k

The velocity and Reynold's number are calculated as:

μ_m= $m_h/p_n.A_c$

$= 0.153/ (983.3 x \pi/4 x 0.01905^2)$

= 0.5m/s

To Find the Reynold's number

$R_e = p\mu_m d_1/\pi$

$= 4m_h/\pi x \mu d_1$

$=4 \times 0.153/\pi \times 0.454 \times 0.01905 = 22{,}524$

Prandtl's correlation is used here with constant properties:

$N_{ub} = (f/2) (R_{eb}) P_{rb} / 1+ 8.7(f/2)$

$f = (1.58 InRe - 3.28)^{-2}$

$=6.34 \times 10^{-3}$

$N_{ub} = (6.34 \times 10^{-3}/2) (22{,}524) (2.82)/ 1+ 8.7(6.34 \; x \; 10^{-3}/2) \quad ^{-1/2}(2.82-1)$

= 106.45

$h_i = N_{ub} K/d_i$

= 106.45 x 0.654/0.01905

$h_i = 3{,}654.5 w/m^2.K$

At 29°c

Density (p) = 996.2 kg/m^3

$^{Cp}{}_c$ = 4.178 kj/kg.k

K = 0.618 w/m.k

$\mu = 0.798 \times 10^{-3}$

Pr = 5.23

m = 0.32277

Diameter of outer pipe = 0.0508m

Velocity of cold water μ_m through annulus

μ_m= m/A_{cp}= 0.32277/π/4 x (0.0508^2-0.019^2) x 996.2

=0.1889m

D_h = 4 x A_c/p = $D_i - d_0$

= 0.0508 – 0.01905

= 0.0317m

R_e = p$\mu_m D_n$/ μ

= 996.2 x 0.1889 x 0.0317/0.798 x 10^{-3}

= 7439.7

f = (3.64$Log_{10}R_e$- 3.28) $^{-2}$

= 8.5577 x 10^{-3}/ 2

f = 4.27 x 10^{-3}

N_{ub} = (4.2789 x10^{-3}) (7439.7) (5.23)/ 1+ 8.7(4.27 $x10^{-3}$) $^{1/2}$x (5.23 – 1)

=48.79

Equivalent diameter for heat transfer

D_0 = ${D_i}^2$- di^2/ d_0

= $0.0508^2 - 0.01095^2$/0.01905 = 0.1164m

h_0 = Nμ_bK/ D_0

= 48.79 x 0.617/ 0.1164

= 259.07 w/m^2.K

Heat Transfer Rate

Q_h = m $c_p(T_{1-}T_2)$

Q_h = 0.333 x 4.185 (60-47.90)

Q_h = 16.8778W

Q_c = m $c_p(T_{2-}T_1)$

Q_c = 0.333 x 4.178(34.5 – 29)

Q_c = 7.65890W

The overall heat efficiency (η)

η = (Q_c /Q_h) x 100

η = 7.6589/ 16.8770 x 100

η = 45%

Log-Mean Temperature Difference (ΔT_m)

ΔT_m = ($\Delta T_1 - \Delta T_2$) / In ($\Delta T_1/\Delta T_2$)

ΔT_1 = 25.5°C

ΔT_2 = 18℃

ΔT_m = (25.5−18) / In $(25.5/18)$

ΔT_m = 22.04℃

Overall Heat Transfer Coefficient (U)

Q = UAΔT_m

U = Q/AΔT_m

U = 7.65890/ 2.024 x 10^{-3} x 22.04℃

U = 171.45 W/m^2℃

For Counter Flow

TABLE 2 Counter Flow Readings

S/No	$v_h(cm/min)$	$T_{h,in}$(℃)	$T_{h,mid}$(℃)	$T_{h,out}$(℃)	$T_{c,in}$(℃)	$T_{c,mid}$(℃)	$T_{c,out}$(℃)
1	1200	60.00	53.00	47.20	28.50	31.00	35.50
2	1200	60.00	55.50	50.50	28.50	33.00	38.00

The properties of water at 60°C are

Density (p) = 983kg/m^3

c_p= 4.07kj/kg.k

K= 0.654W/m.k

Dynamic viscosity (µ) = 0.454 x 10^{-3}Pa.s

Diameter of inner tube = 0.01905m

The hot water mass flow is;

Q = $(mc_p)_c\ \Delta T_c = (mCp)_h\ \Delta T_h$

To find m_h;

m_h = $(mc_p)_c \Delta T_c$/ $c_p \Delta T_h$

m_h= (0.32277x 4.178) x (35.5- 28.5)/ 4.185 x (60- 47.20)

=0.17kg/s

At 28.5°C c_p= 4.178kJ/kg.k

The velocity and Reynold's number are calculated as:

μ_m= $m_h/p_n.A_c$

= 0.1762/ (983.3xπ/4x0.01905^2)

= 0.6287m/s

To Find the Reynold's number

R_e= pμ$_m d_1$/π

= $4m_h$/πxμd_1

=4 x 0.1762/π x 0.454 x 0.0190 = 25,939.71

Prandtl’s correlation is used here with constant properties:

N_{ub} = (f/2) (R_{eb})P_{rb}/ 1+ 8.7(f/2)

f = $(1.58 InRe - 328)^{-2}$

=6.124 x 10^{-3}

N_{ub} = (6.124 x 10^{-3}/2) (25,939.71) (2.82)/ 1+ 8.7$(6.124\ x\ 10^{-3}/2)^{-1/2}$(2.82-1)

= 119.383

h_i= N_{ub}K/d_i

= 119.383 x 0.654/0.01905

h_i= 4098.5w/m^2.K

At 28.5℃

Density (p) = 996kg/m^3

c_p = 4.07 kJ/kg.K

K = 0.617w/m.k

μ = 0.803 x 10^{-3}

Pr = 5.30

m = 0.32277

Diameter of outer pipe = 0.0508m

Velocity of cold water μ_m through annulus

μ_m= m/A_{cp}= 0.32277/π/4 x (0.0508^2-0.019^2) x 996

=0.1889m/s

D_n = 4 x A_c/p = $D_i - d_0$

= 0.0508 – 0.01905

= 0.0317m

R_e = pμ$_m$ D_n/ μ

= 996 x 0.1889 x 0.0317/0.803 x 10^{-3}

= 7427.38

f = (3.64Log_{10} R_e- 3.28) $^{-2}$

= 8.5577 x 10^{-3}/ 2

f = 4.2789 x 10^{-3}

N_{ub} = (4.2789 x10^{-3}) (7427.38) (5.3)/ 1+ 8.7(4.789 $x10^{-3}$) $^{1/2}$ x (5.3 – 1)

=46.92

Equivalent diameter for heat transfer

D_0 = ${D_i}^2$- di^2/ d_0

= $0.0508^2 - 0.01095^2$/0.01905 = 0.1164m

h_0 = Nμ$_b$K/ D_0

= 46.92 x 0.617/ 0.1164

= 248.70 w/m^2.K

Heat Transfer Rate

Q_h = m c_p($T_{1-}T_2$)

Q_h = 0.333 x 4.105(60-47.2)

Q_h = 17.8381kw

Q_c = m c_p($T_{2-}T_1$)

Q_c = 0.333 x 4.07(35.5 – 28.5)

Q_c = 9.48717kw

The overall heat efficiency (η)

η = (Q_c /Q_h) x 100

η = 17.8381/9.48717 x 100

η = 53.18%

Log-Mean Temperature Difference (ΔT_m)

ΔT_m = ($\Delta T_1 - \Delta T_2$) / In ($\Delta T_1/\Delta T_2$)

ΔT_1 = 24.5℃

ΔT_2 = 18.7℃

ΔT_m = (24.5 – 18.7)/ In (24.5/18.7)

ΔT_m = 21.47℃

Overall Heat Transfer Coefficient (U)

Q = UAΔT_m

U = Q/AΔT_m

U = 9.48717/ 2.0268 x 10^{-3}x 21.47

U = 218W/m^2℃

4.4 Discussion of Result

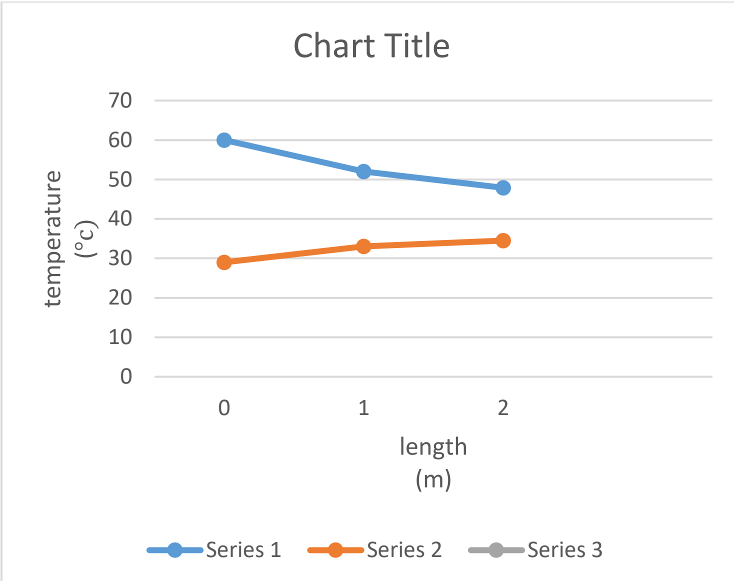


Figure 4.4a: Parallel Flow Graph of Temperature against Length

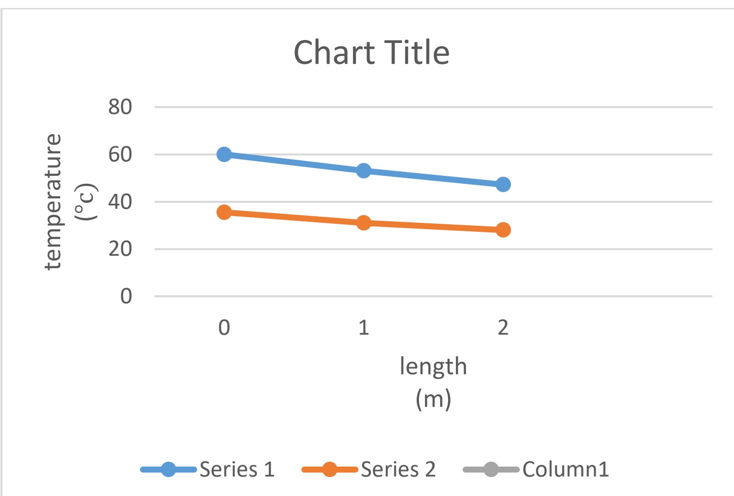


Figure 4.4b: Counter Flow Graph of Temperature against Length

It was observed from the results that the when it was arranged in counter flow direction, the heat exchanger factor was higher than parallel flow arrangement. The power absorbed by counter flow arrangement was more than parallel arrangement. The highest heat capacity rate for parallel is 16.8778W, which was lower than that of counter flow which is 17.8381W. In terms of heat capacity rate of cold and heat capacity rate of hot, counter flow utilizes more of the power emitted by the hot fluid for each flow, resulting in a lower power loss from each volumetric flow rate than parallel flow. The overall efficiency in counter flow was 53.18% which was higher compared to parallel which had an efficiency of 45% . When the volumetric flow rate increases in parallel flow, the efficiency of the system also increases linearly but in counter flow when the volumetric flow rate is increased the efficiency of the system reduces linearly. Counter flow has a lower value of logarithmic mean temperature than parallel flow. The heat transfer coefficient increased linearly for both of the flows when the volumetric flow rate is increased. The reasons as to why there might be errors in this experiment is going to be either systematic or human error. For human error during the adjusting of the volumetric flow rate obtaining the exact value may be quite difficult as the eyes may not be accurately perpendicular to the scale while taking readings.

4.5 Material Costing

Table 3 Material Costing

ITEMS	UNIT	COST ₦
Pump	2	35,000
Boiling ring	1	2,000
Nipples 1 ¼	7	5,500
Nipple 1”	6	4,000
Nipple ¾	2	1,500
Elbow 1 ¼	3	1,700
Elbow 1’	6	3,500
Tee 1 ¼	2	1,500
Elbow 1 ¾	2	1,500
Ball gauge 1 ¼	6	10,000
Union 1 ¼	4	3,000
Tin of gum	1	3,000
Pipe 1 ¼	1	5,500
Tread tape	3	2,000
Con rubber	2	2,000
Plug 2’	2	1,000

PPR 1	1	10,000
Bucket 20kg	2	1,200
Bucket 30kg	1	3,000
Galvanized pipe	1	3,000
Arduino components	1	25,000
Battery	1	300
Jumper wire	20	1,000
LCD	1	2,000
Battery Head	1	300
Silicon sealant	1	2,000
Thermocouple Sensors	4	15,000
Thermometer	2	1,800
Labor		10,000
Overhead cost		15,000
Total		150,300

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

1. The design and the fabrication of a concentric tube heat exchanger was successfully carried out. The heat exchanger was designed and fabricated in a way that is was able to achieve a parallel flow configuration and a counter flow configuration.
2. The experiment was successfully carried out for both counter flow and parallel arrangement and readings were taking
3. The heat exchanger was evaluated using the Logarithm Mean Temperature Difference (LMTD) method and Reynold number, Nusselt Number, rate of heat transfer and overall heat transfer coefficient was determined. It was concluded that the rate of heat transfer (Q), the overall heat transfer coefficient (U) and the efficiency of the counter flow was greater than that of parallel flow, however it was discovered that the LMTD value for parallel flow was higher than the LMTD value of the counter flow.

5.2 Recommendation

Heat exchanger practical should be included in the course synopsis of MEE527 in order to bridge the gap between the theoretical and practical knowledge of heat exchanger with student

More research work should be done on this experiment in order to increase its performance and efficiency, also a different working fluid can be use, this will in turn widen the practical knowledge to know different fluids properties while using the heat exchanger.

REFERENCE

Abbott J.M.; Smith H.C.; Van N.M. (2005). *Introduction to Chemical Engineering Thermodynamics (7th edition)*. Boston, Montreal: McGraw-Hill. ISBN 0-07-310445-0

Anyakoha M. W. (2015). *New School Physics: For Senior Secondary School*. Onitcha: Africana First Publishers

Boda M. A, Deshetti S. S, & Gavade M. A (2017). Design and Development of Parallel – Counter Flow Heat Exchanger. *International Journal of Innovative Research in Advanced Engineering, 4*(02) 29-33. https://www.researchgate.net/publication/314231192

Department of Energy (1993). *Heat Exchanger Fundamental*. 301Mission Dr Units, New Smyrana Beach: Ezekiel Enterprise,LLC

Engineering ToolBox, (2003). *Heat, Work and Energy*. [online] Available at: https://www.engineeringtoolbox.com/heat-work-energy-d_292.html, 24 February, 2021

Farzaeh M.; Forouzandeh A.; Al-Sammarraie A. T.; Salimpour M. R. (2019). "Constructual Design of Circular Multilayer Microchannel Heat Sink". *Journal of Thermal Science and Engineering Applicattions*.11. doi.10.1115/1.4041196.

Herbert B.C. (1985). Thermodynamics and an introduction to Thermostatic, 2nd Edition. http//cvika.grimoar.cz/callen

https://sciencing.com/properties-thermal-insulators

https://www.greenspec.co.uk/building-design/insulation-material-and-their-properties

Orhan K. & Veysel O. (2017). A Review of heat exchanger Enhancement Methods Using Twisted Tape Inserts. *International Journal of thermal Science 28*(6), 52-54. DOI:10.5772/intechopen.74516

Perry R. H. and Green D.W. (1984). *Perry's Chemical Engineers' Handbook* (6th ed). McGraw-Hill. ISBN 0-07-049479-7

Quadri S. A and Shakib J. S. S (2016). Evaluating the Performance of Concentric Tube Heat Exchanger With and Without Dimples by Using CFD Analysis. *ISOR Journal of Mechanical and Civil Engineering 13*(5), 46-52. www.isorjournals.org

Ramesh K. S. and Dusan P. S. (2003). *Fundamentals of Heat Exchanger Design*. Hoboken, New Jersey: John Wiley & Sons Inc

Rohsenow W.M and Hartnett J.P. (1973). *Handbook of Heat Transfer*. New York. McGraw-Hill Book Company. DOI: 10.1016/0017-9310(75)90148-9

Sadik K. Hongtan L. (2002). Heat Exchangers: Selection, Rating and Thermal Design (2nd ed). CRC Press. ISBN 978-0-8493-0902-1

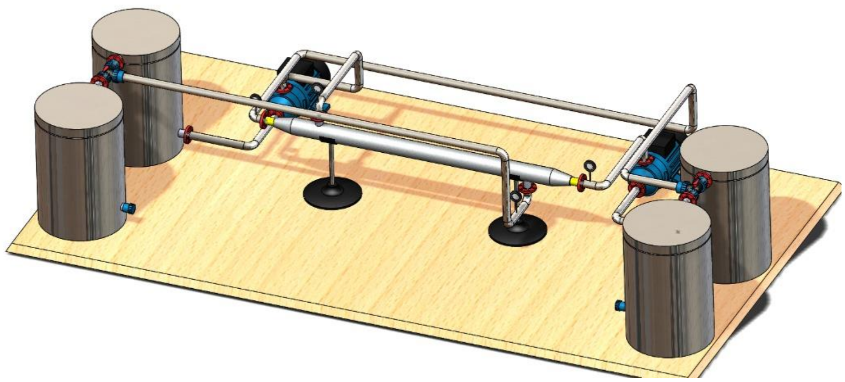
Saunders E.A (1988). Heat Exchanges: Selection, Design and Construction. New York: Longman Scientific and Technical

Sunden B. (2013). Modern Gas Turbine System.

Timothy J. R, & Vijaya G.S (2005). Experimental Studies of a Double-Pipe Helical Heat Exchanger. Experimental Thermal and Fluid Science 26(3). www.elevier.com/locate/apthermeng

APPENDICES

MODEL OF A CONCENTRIC TUBE HEAT EXCHANGER



3D model of the concentric tube heat exchanger with all its component assembled

A cut through 3D model of just the concentric tube heat exchanger