EXPERIMENTAL INVESTIGATION OF THERMO-HYDRAULIC PERFORMANCE ON DOUBLE PIPE HEAT EXCHANGER WITH NOVAL BAFFLE DESIGN

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

The project is aimed at studying the thermo-hydraulic performance of double pipe heat exchanger having a continuous helical baffle with counter flow and with the effect of varying baffle pitches over the heat exchanger. A double pipe heat exchanger is fabricated and by using hot as well as cold fluid in heat exchanger, the heat transfer rate for each varied pitch baffles are calculated. It is also then analysed by Computational Fluid Dynamics (CFD) using ANSYS (Fluent 18.0) software to investigate the heat transfer rate and fluid flow for different baffle configurations. The outer shell of the double pipe heat exchanger is made up of stainless steel and the inner pipes with baffles are made up of copper, since, copper is a better thermal conductor than steel Input parameters, such as flow-rate and temperature of hot fluid are adjusted to obtain different set of readings. From this experiment, the effect of different baffles, the performance of the double pipe heat exchanger is studied. For all the three baffle tested during the process. The lower the baffle spacing the higher the heat transfer rate as well as fluid velocity.

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SYMBOL	DESCRIPTION
ΔT_{lm}	Logarithmic Mean Temperature Difference
ρ	Density (Kg/m^3)
v	Kinematic viscosity (m^2/s)
π	3.14159 (constant)

CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

A heat exchanger is a system designed to transfer heat between two fluids to control the temperature of one of the fluids. A heat exchanger could remove thermal energy from a fluid used in an air-conditioning system or add thermal energy to a system where processes require a certain temperature to work properly. The controlled fluid flows through tubes while the controlling fluid is used to transfer heat. They are widely used refrigeration, air-conditioning, power stations, chemical plant and food processing industries. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant. Heat exchanger is a device that exchanges the heat between two fluids of different temperatures that are separated by a solid wall. The temperature gradient or the differences in temperature facilitate this transfer of heat. Heat exchangers are a vital part of chemical engineering process designs. To illustrate, in prototyping testing, an inventor discovers that his new device is prone to overheating, even though heat sinks are already installed to provide cooling to the system. To solve this problem, the engineer decides to install a heat exchanger into the system. A heat exchanger is a device that is commonly used when heat sinks alone cannot prevent a device from overheating. The most well-known application of heat exchangers is radiators. Radiators use antifreeze to transfer heat energy from the engine to the air surrounding the car.

There are many different types of heat exchangers, each having various applications. Three examples include regenerative, plate and shell and tube type heat exchangers.

Regenerative heat exchangers are a unique type of heat exchanger that are used to maintain a temperature, rather than vary it, In order to achieve this, initial thermal energy from a fluid is used to reheat the same fluid as it loses its thermal energy throughout the process. Due to the nature of heat exchanger, very little external energy is required to maintain the overall temperature of the heat exchanger. Conversely, plate heat exchangers have many join plates inside with small gaps between each plate. Alternating fluid then flows through each gap, causing the two fluids to exchange thermal energy. This type of heat exchanger can be used to either cool, or heat a fluid. Plate heat exchangers are commonly used in household refrigerators. Similar to a plate heat exchanger, a shell and tube type heat exchanger utilizes two separate fluids to transfer thermal energy from one to the other. To achieve this, one fluid is routed through a tube inside a hollow shell. The shell has the second fluid flowing through it, allowing to transfer heat, between the two.

1.2 MODES OF HEAT TRANSFER

Transfer of heat happens by three principle means:

- Radiation
- Conduction
- convection

In the use of heat exchangers radiation does take place. However, in comparison to conduction and convection, radiation does not play a major role. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall. To maximize the heat transfer, the wall should be thin and made of a very conductive material.

The biggest contribution to heat transfer in a heat exchanger is made through convection. In a heat exchanger forced convection allows for the transfer of heat of one moving stream to another moving stream.

With convection as heat is transferred through the pipe wall it is mixed into the stream and the flow of the stream removes the transferred heat. This maintains a temperature gradient between the two fluids. The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. This is a concentric tube construction. Flow in a double-pipe heat exchanger can be co-current or counter-current.

1.3 TYPES OF FLOW CONFIGURATIONS

There are two flow configurations:

- Co-current is when the flow of the two streams is in the same direction
- Counter current is when the flow of the streams is in opposite directions.

1.4 PARAMETERS

As conditions in the pipes change: inlet temperatures, flow rates, fluid properties, fluid composition, etc., the amount of heat transferred also changes. This transient behaviour leads to change in process temperatures, which will lead to a point where the temperature distribution becomes steady. When heat is beginning to be transferred, this changes the temperature of the fluids. Until these temperatures reach a steady state their behaviour is dependent on time. In this double-pipe heat exchanger a hot process fluid flowing through the inner pipe transfers its heat to cooling water flowing in the outer pipe.

The system is in steady state until conditions change, such as flow rate or inlet temperature. These changes in conditions cause the temperature distribution to change with time until a new steady state is reached. The new steady state will be observed once the inlet and outlet temperatures for the process and coolant fluid become stable.

In reality, the temperatures will never be completely stable, but with large enough changes in inlet temperatures or flow rates a relative steady state can be experimentally observed.

1.5 IDEOLOGY

The equation used to determine this energy is,

$$Q=mC_p\Delta T$$

-Where 'm' is the mass flow rate of the water, and is a measure of the flow of water into the system is at steady state.

-C_p is the specific heat capacity of the material, which is the amount of energy per unit mass required to raise the temperature of a substance by one degree.

-ΔT is the change of temperature of the fluid throughout the system.

This calculation is done for the cold and hot side of the heat exchanger to obtain Q_{cold} and $Q_{hot.}$ To determine the efficiency of the unit, the equation,

$$Q_{hot} = Q_{cold} + Q_{loss}$$

can be used to determine $Q_{loss.}$ This quantity will determine how much heat has been lost during the experiment. Since the shell-side is hot side, some of the energy escapes through conduction to the outside environment, contributing to this value.

For an efficient system, Q_{loss} should be minimized. Another calculation used when analysing heat exchange is calculating heat transfer between two elements. The equation used is

$$Q = UA\Delta T_{lm}$$

Where 'U' is the overall heat transfer co-efficient. This heat transfer co-efficient is the function of the fluid properties and material composition of the heat exchanger.

- 'Q' in this equation is calculated from 1st equation and is the energy gained or lost by the system.
- 'F' is a correction factor that must be used for this heat exchanger to accommodate for concurrent or parallel flow in the heatexchanger. In opposition, counter current flow occurs when the steams are flowing in opposite directions. This leads to a constant flow of heat at each point of contact and a higher rate of heat transfer.

$$\text{LMTD} = \Delta T_{lm} = \frac{\Delta T_A - \Delta T_B}{\ln(\frac{\Delta T_A}{\Delta T_B})}$$

$$\Delta T_A = T_1 - T_4$$

$$\Delta T_B = T_2 - T_3$$

The log mean temperature difference (LMTD) is unlike the other ΔT's calculation in previous equations. It is the temperature difference between two streams. In the previous calculations, ΔT was simply the temperature change over each single stream analysed.

Since in the system, temperatures are constantly along a path, the log mean temperature difference is used to give an average temperature gradient. The two technical objectives of the experiment are to evaluate the effect of the tube-side flow rate and shell-side flow rate on the steady state heat duty and the overall heat transfer co-efficient of the heat exchanger.

1.6 HEAT EXCHANGER

1.6.1 TYPES OF FLOW IN HEAT EXCHANGER:

In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is higher. See counter current exchange. In a cross-flow heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

The three types of flow in heat exchanger are

1. Parallel flow
2. Counter flow
3. Cross flow

1.6.1.1 PARALLEL FLOW:

It exists when both the tube side fluid and the shell side fluid flow in the same direction. In this case, the two fluids enter the heat exchanger from the same end with a large temperature difference. As the fluids transfer heat, hotter to cooler, the temperature of the two fluids approach each other. Note the hottest cold fluid temperature is always less than the coldest hot fluid temperature.

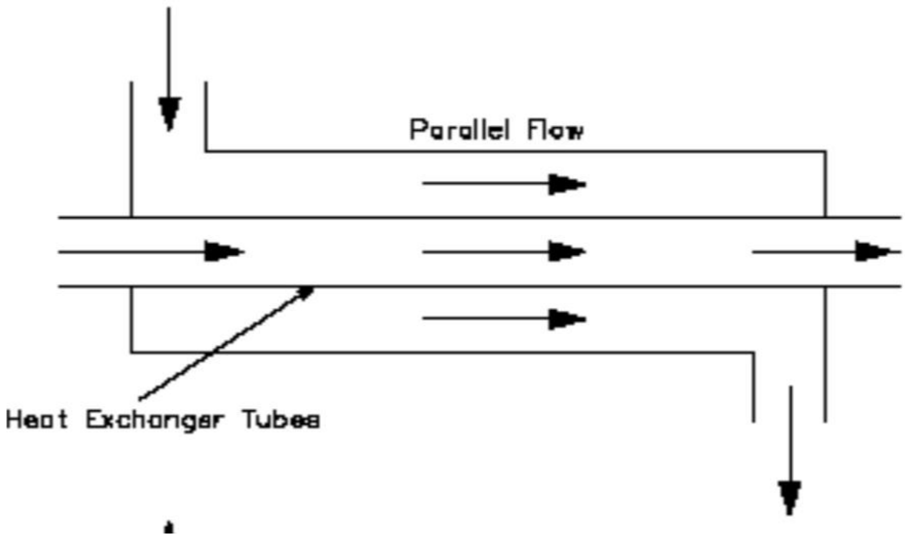


Figure 1.1 Parallel Flow Heat Exchanger

1.6.1.2 COUNTER FLOW:

It exists when the fluids enter the heat exchanger at opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. Counter flow heat exchangers are the most efficient of the three types. In contrast to the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold fluid temperature greater than the coldest hot fluid temperature.

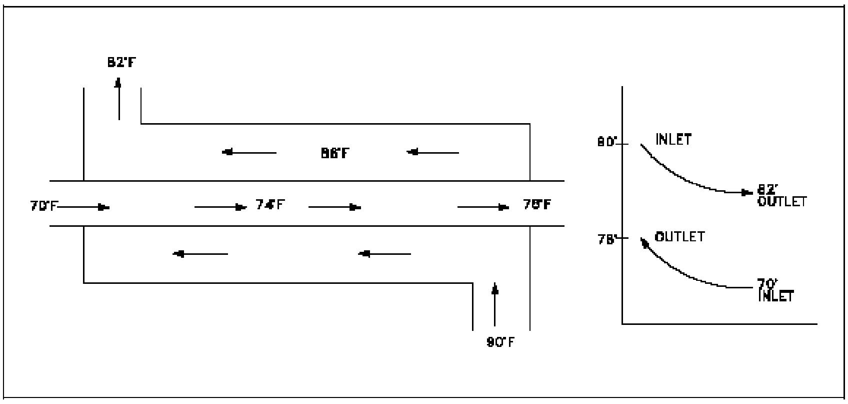


Figure 1.2 Counter Flow Heat Exchanger

1.6.1.3 CROSS FLOW:

It exists when one fluid flows perpendicular to the second fluid, that is, one fluid flows through the tube and the second fluid passes around the tubes at 90 degree angle. Cross flow heat exchangers are usually found in applications where one of the fluids change state (2-phase flow). An example is a steam existing the turbine enters the condenser, in which the steam exiting the turbine enters the condenser shell side, and the cold water flowing in the tubes absorbs the heat from the stream, condensing it into the water. Large volumes of vapour may be condensed using this type of heat exchanger flow.

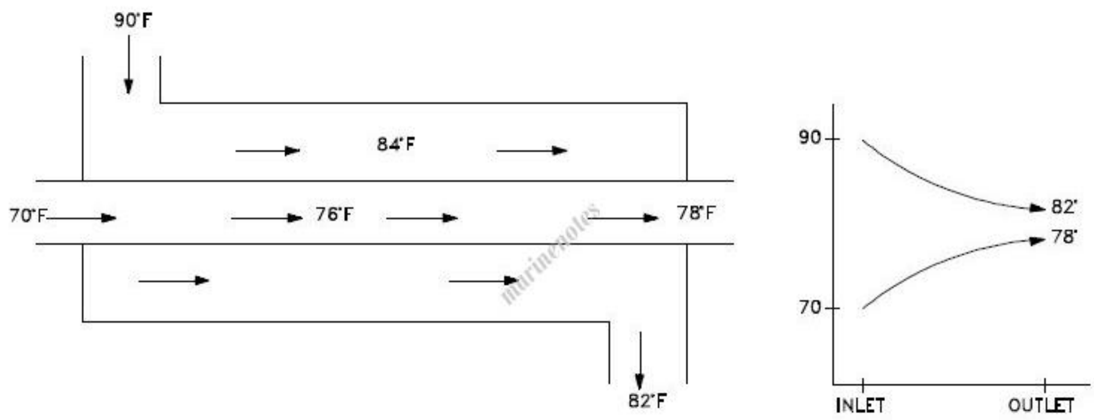


Figure 1.3 Cross Flow Heat Exchanger

1.6.2 TYPES OF HEAT EXCHANGER:

There are different types of heat exchangers are available widely, they are:

- Shell and Tube Heat Exchanger
- Plate Heat Exchanger
- Regenerative Heat Exchanger
- Adiabatic Wheel Heat Exchanger
- Double pipe heat exchanger
- Plate and shell heat exchanger

- Plate fin heat exchanger
- Pillow plate heat exchanger
- Fluid heat exchanger
- Waste heat recovery unit
- Dynamic scraped surface heat exchanger
- Phase change heat exchanger
- Direct contact heat exchanger
- Micro heat exchanger
- HVAC air coils
- Helical coil heat exchanger
- Spiral plate heat exchanger

1.6.2.1 SHELL AND TUBE HEAT EXCHANGER:

Shell and tube heat exchangers are comprised of multiple tubes through which liquid flows. The tubes are divided into two sets: the first set contains the liquid to be heated or cooled. The second set contains the liquid responsible for triggering the heat exchange, and either removes heat from the first set of tubes by absorbing and transmitting heat away in essence, cooling the liquid or warms the set by transmitting its own heat to the liquid inside. When designing this type of exchanger, care must be taken in determining the correct tube wall thickness as well as tube diameter, to allow optimum heat exchange. In terms of flow, shell and tube heat exchangers can assume any of three flow path patterns.

1.6.2.2 PLATE HEAT EXCHANGER:

Plate heat exchangers consist of thin plates joined together, with a small amount of space between each plate, typically maintained by a small rubber gasket.

The corners of each rectangular plate feature an opening through which fluid can flow between plates, extracting heat from the plates as it flows.

The fluid channels themselves alternate hot and cold fluids, meaning that heat exchangers can effectively cool as well as heat fluid they are often used in refrigeration applications. Because plate heat exchangers have such a large surface area, they are often more effective than shell and tube heat exchanger.

1.6.2.3 REGENERATIVE HEAT EXCHANGER:

In a regenerative heat exchanger, the same fluid is passed along both sides of the exchanger, which can be either a plate heat exchanger or a shell and tube heat exchanger. Because the fluid can get very hot, the exiting fluid is used to warm the incoming fluid, maintaining a near constant temperature. A large amount of energy is saved in a regenerative heat exchanger because the process is cyclical, with almost all relative heat being transferred from the exiting fluid to the incoming fluid. To maintain a constant temperature, only a little extra energy is need to raise and lower the overall fluid temperature.

1.6.2.4 PLATE AND SHELL HEAT EXCHANGER:

The plate-Shell Heat Exchanger (PSHX) is a completely welded heat exchanger that combines the best features of a shell and tube heat exchanger with that of a plate heat exchanger. With this, a fully welded plate pack is inserted into the shell which distributes the stress and eliminates the need for gaskets. Designed and manufactured to meet the customer specific needs, this heat exchanger can withstand extreme operating temperatures; pressures; and works with liquids, gases, and transitioning phases of the two.

1.6.2.5 PLATE FIN HEAT EXCHANGER

A plate-fin heat exchanger is a type of heat exchanger design that uses plates and finned chambers to transfer heat between fluids. It is often categorized as a compact heat exchanger to emphasise its relatively high heat transfer surface area to volume ratio.

The plate-fin heat exchanger is widely used in many industries, including the aerospace industry for its compact size and lightweight properties, as well as in cryogenics where its ability to facilitate heat transfer with small temperature differences is utilized

1.6.2.6 PILLOW PLATE HEAT EXCHANGERS

Pillow-plate heat exchangers (PPHE) are a novel heat exchanger type based on wavy pillow-like plate geometry. Typically, they are composed of parallel plates arranged as a stack. In this way, inner channels within the pillow-plates alternate with outer channels between the adjacent plates, and thus, a structure with alternating inner and outer channels is arranged for the heat transfer media

1.6.2.7 FLUID HEAT EXCHANGERS

Fluid heat exchangers are used to pass heat from one fluid to another without the fluids coming into physical contact. They can also be used to reclaim waste heat for preheating other processes, heating the work environment, or cleaning.

1.6.2.8 WASTE HEAT RECOVERY UNIT

A waste heat recovery unit (WHRU) is an energy recovery heat exchanger that transfers heat from process outputs at high temperature to another part of the process for some purpose, usually increased efficiency. The WHRU is a tool involved in cogeneration. It is often categorized as a compact heat exchanger to emphasise its relatively high heat transfer surface area to volume ratio.

Waste heat may be extracted from sources such as hot flue gases from a diesel generator, steam from cooling towers, or even waste water from cooling processes such as in steel cooling.

1.6.2.9 DYNAMIC SCRAPED SURFACE HEAT EXCHANGER

The dynamic scraped surface heat exchanger (DSSHE) was designed to face some problems found in other types of heat exchangers. They increase heat transfer by: removing the fouling layers, increasing turbulence in case of high viscosity flow, and avoiding the generation of ice and other process by-products.

1.6.2.10 PHASE CHANGE HEAT EXCHANGERS

Phase Change heat exchangers store thermal energy during the phase change from solid to liquid, since the latent heat from melting or freezing is at least 1-2 orders of magnitude higher than the energy stored by the specific heat.

1.6.2.11 DIRECT CONTACT HEAT EXCHANGER

The exchange of heat between two fluid streams can, in general, be accomplished using either direct contact or surface-type heat exchangers. The advantages in utilizing a direct contactor include the lack of surfaces to corrode or foul or otherwise degrade the heat transfer performance.

1.6.2.12 MICRO HEAT EXCHANGERS

Micro heat exchangers, Micro-scale heat exchangers, or micro-structured heat exchangers are heat exchangers in which (at least one) fluid flows in lateral confinements with typical dimensions below 1 mm. The most typical such confinement are micro channels, which are channels with a hydraulic diameter below 1 mm. Micro channel heat exchangers can be made from metal, ceramic.

1.6.2.13 HVAC AIR COILS

The three major functions of heating, ventilation, and air conditioning are interrelated, especially with the need to provide thermal comfort and acceptable indoor air quality within reasonable installation, operation, and maintenance costs. HVAC systems can be used in both domestic and commercial environments.

1.6.2.14 HELICAL COIL HEAT EXCHANGER

The main advantage of the HCHE, like that for the Spiral heat exchanger (SHE), is its highly efficient use of space, especially when it’s limited and not enough straight pipe can be laid.

1.6.2.15 SPIRAL PLATE HEAT EXCHANGER

The Spiral Plate Heat Exchanger is actually a family of heat exchangers based on the basic Type A spiral core. A variety of spiral heat exchangers can be created by adding or taking away weld-seams and head arrangements.

1.6.2.16 ADIABATIC WHEEL HEAT EXCHANGER

In this type of heat exchanger, an intermediate fluid is used to store heat, which is then transferred to the opposite side of the exchanger unit. An adiabatic wheel consists of a large wheel with threads that rotate through the fluids both hot and cold to extract or transfer heat.

1.6.2.17 DOUBLE PIPE HEAT EXCHANGER

A double pipe heat exchanger (also sometimes referred to as a 'pipe-in-pipe' exchanger) is a type of heat exchanger comprising a 'tube in tube' structure. It is a concentric tube construction. As the name suggests, it consists of two pipes, one flowing within the other.

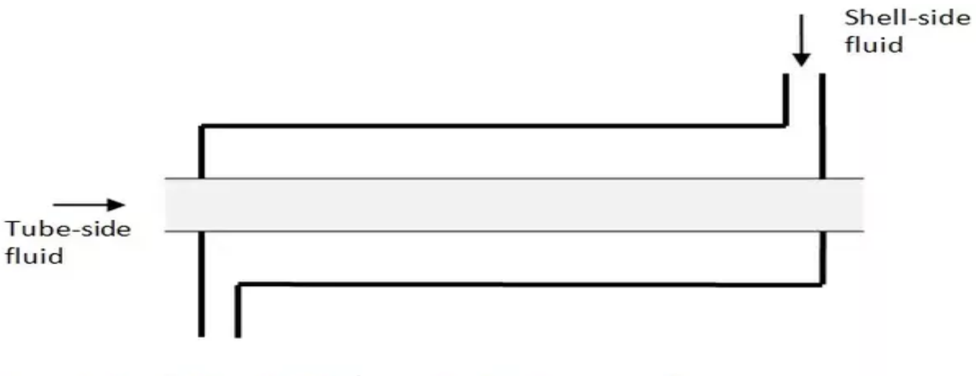


Figure 1.4 Cross section of double pipe heat exchanger

One fluid flows through the inner pipe (analogous to the tube-side in a shell and tube type exchanger) whilst the other flows through the outer pipe, which surrounds the inner pipe (analogous to the shell-side in a shell and tube exchanger). A double-pipe heat exchanger has two concentric pipes, usually in the form of a U-bend design. Double pipe heat exchangers with U-bend design are known as hairpin heat exchangers. A number of double-pipe heat exchangers can be connected in series or parallel as necessary.

Their usual application is for small duties and they are suitable for high pressures and temperatures and thermally long duties. This has the advantage of flexibility since units can be added or removed as required, and the design is easy to service and requires low inventory of spares because of its standardization.

Either longitudinal or circumferential, within the annulus on the inner pipe wall are required to enhance the heat transfer from the inner pipe fluid to the annulus fluid. Design pressures and temperatures are broadly similar to shell and tube heat exchangers (STHEs). When the process calls for a temperature cross (when the hot fluid outlet temperature is below the cold fluid outlet temperature), a hairpin heat exchanger is the most efficient design and will result in fewer sections and less surface area. Also, they are commonly used for high-fouling services such as slurries and for smaller heat duties.

CHAPTER 2

LITERATURE REVIEW

Anas El Maakoul et.al [1] In this paper, the design and thermo-hydraulic performance of a double pipe heat exchanger with continuous helical baffles in the annulus side, are investigated numerically. Three-dimensional computational fluid dynamics(CFD) model, using the software FLUENT, have been performed to investigate the annulus side fluid flow, heat transfer coefficient and pressure drop for different configurations. A numerical analysis is conducted for different values of Reynolds number and baffle spacing. The numerical model was first validated for a simple double pipe heat exchanger by comparison with empirical correlations. The model was then used to investigate the continuous helical baffles effects. The results obtained for a helically baffled annulus side provide enhanced heat transfer performance and high-pressure drop compared to the simple double-pipe exchangers. Thermal performance and high-pressure drop is an increasing function of baffle spacing and Reynolds's number. In addition, empirical correlations expressing the results were developed based on curve fitting.

The inference from the paper is that the baffles are to be used to enhance the heat transfer, the design calculation of the baffle especially its spacing is known from this paper.

Mohamad Omidi et.al [2] this paper gives information about the growing need to develop and improve the effectiveness of heat exchangers has led to a broad range of investigations for increasing heat transfer rate along with decreasing the size and cost of the industrial apparatus accordingly. One of these many apparatus which are used in different industries is double pipe heat exchanger. This type of heat exchanger has drawn many attentions due to simplicity and wide range of usages.

In recent years, several precise and invaluable studies have been performed in double pipe heat exchangers. In this review, the development procedure that this type of heat exchanger went through has been analysed in details and the heat transfer enhancement methods in aforementioned heat exchangers have also been widely discussed.

The paper gave us immense knowledge about the double pipe heat exchanger and was instrumental in designing the layout of the double pipe heat exchanger.

M. Sheikholeslami et.al [3] In this paper, heat transfer and pressure loss in an air to water double pipe heat exchanger are experimentally investigated. Typical circular-ring (TCR) and perforated circular-ring (PCR) turbulators are placed in annular pipe. The working fluids are air, flowing in the annular pipe, and water through the inner circular tube. The experiments are conducted for different governing parameters namely; air flow Reynolds number, pitch ratio and number of perforated hole. Correlations for friction factor, Nusselt number and thermal performance are presented according to experimental data.

From this paper we observed that the results indicated using PCRs leads to obtain lower heat transfer enhancement than the CRs because of reduction of intersection angle between the velocity and the temperature field. Thermal performance increases with increase of N but it decreases with increase of Reynolds number and pitch ratio.

Muhammad MahmoodAslam Bhutta et.al [4] this review focuses on the applications of Computational Fluid Dynamics (CFD) in the field of heat exchangers. It has been found that CFD has been employed for the following areas of study in various types of heat exchangers: fluid flow maldistribution, fouling, pressure drop and thermal analysis in the design and optimization phase.

Different turbulence models available in general purpose commercial CFD tools i.e. standard, realizable and RNG $k - \varepsilon$ RSM, and SST $k - \varepsilon$ in conjunction with velocity-pressure coupling schemes such as SIMPLE, SIMPLEC, PISO and etc. have been adopted to carry out the simulations.

This paper qualifies the solutions obtained from these simulations are largely within the acceptable range proving that CFD is an effective tool for predicting the behavior and performance of a wide variety of heat exchangers.

Usman Salahuddin et.al [5] this paper provides a review about the major work done on helical baffles to improve the performance of shell and tube heat exchangers. Some of the major factors affecting the performance of shell and tube heat exchanger are discussed. A comparison between segmental baffles and helical baffles is also presented to show that helical baffles are more advantageous than segmental baffles. In most cases, discontinuous, folded as well as low baffle spacing will give the best results when integrated in some combination, whereas continuous helical baffles eliminate dead regions. Moreover, sealing strips are more likely to improve the performance of shell and tube heat exchangers with continuous helical baffles.

The inference from this paper is that helical baffles are the most predominant and effective use in the heat transfer conditions.

Qiuwang Wang et.al [6] Helical baffles are employed increasingly in shell-and-tube heat exchangers for their significant advantages in reducing pressure drop, vibration, and fouling while maintaining a higher heat transfer performance. Improvements on helixchangers, which includes the discontinuous helical baffles, continuous or combined helical baffles, and the combined multiple shell-pass helixchangers.

This paper explodes extensive results from experiments and numerical simulations indicate that these helixchangers have better flow and heat transfer performance than the conventional segmental baffled heat exchangers.

CHAPTER 3

METHODOLOGY

3.1 IDENTIFICATION OF PROBLEMS

In the modern industry 'time' is the most considered factor for production as well as timely delivery for efficient run. Many factories needs efficient heat exchangers of great heat transfer rate for faster production. By considering normal heat exchanger, different baffles design has been modified in a double pipe heat exchanger to ensure greater heat transfer rate.

3.2 METHODOLOGY

The solutions have been achieved by the following methodology:

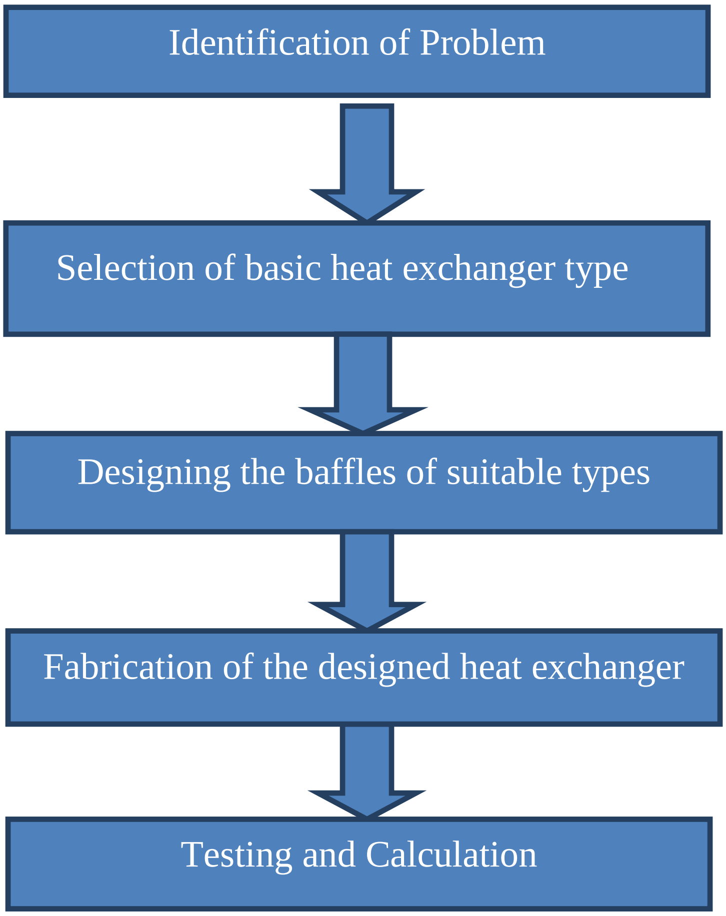


Figure 3.1 Methodology

CHAPTER 4

DESIGN OF EXPERIMENTAL SETUP

4.1. DESIGN PROCEDURE

Design factors to be considered are as follows:

1. Type of heat exchanger
2. Type of flow
3. Material
4. Type of baffles
5. Number of passes
6. Heat transfer rate
7. Pressure drop
8. Pumping power
9. Fouling factor
10. Initial Cost and operating cost

4.1.1 CHOOSING THE TYPE OF HEAT EXCHANGER:

From the various types of heat exchangers available Double pipe heat exchanger is chosen.

The Double pipe heat exchanger comes under the following classification.

Heat exchanger →Recuperative →Indirect contact type→ Tubular→ Double pipe

4.1.2 CHOOSING THE TYPE OF FLOW:

From studying various literatures it has been found that counter flow is found to be more efficient than parallel and cross flow. So counter flow is chose for effective heat transfer.

4.1.3 MATERIAL:

The inner pipe of heat exchanger is to be made with a material which has good thermal conductivity so that maximum heat exchange takes place so copper is chosen for inner tube and the baffles.

The outer pipe is made up of hardened stainless steel.

4.1.4 TYPE OF BAFFLES:

Continuous helical baffles are chosen due to their simple yet efficient design.

4.1.5 NUMBER OF PASSES:

As the goal of the experiment is to investigate the properties of Nano fluids only single pass is given to reduce the complexity of thermal calculation.

4.1.6 HEAT TRANSFER RATE:

Heat transfer rate is calculated by the formula

$$Q=mC_p\Delta T$$

Where m = mass flow rate

C_p = specific heat in constant pressure

ΔT = temperature difference

The ideal design of a heat exchanger should have maximum heat transfer as possible.

4.1.7 PRESSURE DROP:

The pressure drop should be as high as possible so that heat transfer is also increased.

4.1.8 PUMPING POWER:

Pumping power should be in such a way that the flow of water overcomes the friction force of the pipes.

4.1.9 FOULING FACTOR:

The deposition of any undesired material on heat transfer surfaces is called fouling.Fouling causes a reduction in heat transfer which is calculated by a mathematical expression.

4.1.10 INITIAL COST AND OPERATING COST:

Initial cost of a double pipe heat exchanger is comparatively less when compared to other heat exchangers like shell and tube heat exchanger. Operating costs include costs like cost of electricity, maintenance and durability and the operating costs is also less for the double pipe heat exchanger.

4.2 SPECIFICATIONS OF HEAT EXCHANGER SETUP

Inner diameter of outer pipe (D_i)

For the process industry, 113 mm tends to be the most common.

Outer diameter of outer pipe(D_o)

The outer diameter is around 124 mm.

Outer pipe thickness

The outer shell is made with a thickness of 11 mm.

Tolerance value of ± 4 mm.

Inner diameter of the inner pipe(d_i)

The diameter of the inner copper pipe is 29 mm.

Outer diameter of the inner pipe(d_0)

The Outer diameter of the pipe is made to be 31 mm.

Outer diameter of the inner pipe with baffles

The Outer diameter of the inner pipe with baffles is 98 mm.

The design calculation of baffle is as follows:

Required outside diameter D = 102 mm

A tolerance of 4 mm is provided

Required outside diameter D = 102 – 4 = 98 mm

Required inner diameter d = 31 mm

Pitch p = 70 mm

Let D = (1/pi) ($\sqrt{(\pi D^2 + p^2)}$) = $\sqrt{(\pi(98)^2 + 70^2)}$ = 315.75/3.14 mm

d = (1/pi) $\sqrt{(\pi D^2 + p^2)}$ = $\sqrt{(\pi(31)^2 + 70^2)}$ = 119.93/3.14 mm

Considering Flat screw flight :

Outer diameter = D = 108.03 mm

Inner diameter = d = 41.03 mm

Baffle type

Continuous helical baffle are used here to make the heat transfer more efficient. Baffles are used to increase the surface area so that more heat transfer takes place. Baffles are also made up of copper material as same as that of the pipe.

4.3 THERMAL CALCULATION:

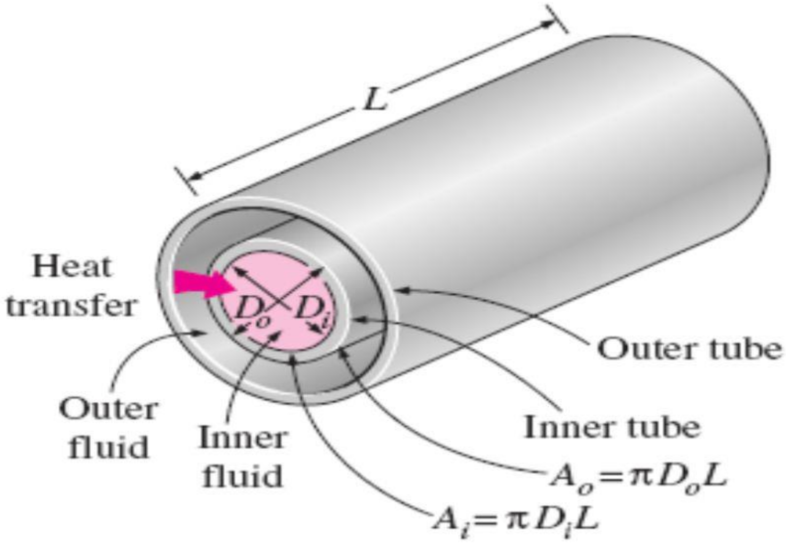


Figure 4.1 Flow parameters

Heat transfer in a heat exchanger

Convection of heat transfer from hot fluid to inner tube → conduction of heat through inner pipe → convection from inner pipe to cold fluid.

Conduction of heat transfer within the pipe can be neglected as inner pipe is made up of copper which is a good thermal conductor.

$$\frac{1}{UA_s} = \frac{1}{A_i h_i} + \frac{1}{A_o h_o}$$

U= overall heat transfer coefficient

A_s= total surface area = area of inner pipe + area of baffles

A_s= $\pi d_0 L$ + (no. of baffles $\times \frac{1}{2} \times \frac{\pi}{4} \times (D^2 - d_o^2)$)

Average temperature of hot fluid and cold fluid:

Average temperature of hot fluid (T_h) = $\frac{T_1 + T_2}{2}$

Average temperature of cold fluid (T_c) = $\frac{T_3 + T_4}{2}$

Calculation of heat transfer coefficient for cold fluid (h_o)

Find the density (ρ), thermal conductivity (k), kinematic viscosity (v), prandtl number (Pr) and specific heat (c) from HMT data book pg. 22 using T_c

Velocity of cold fluid = V = $\frac{m_c}{\rho A_c} = \frac{m_c}{\rho \times \frac{\pi}{4} \times (D_i^2 - d_o^2)}$

Reynold's number (Re):

Re = $\frac{VD}{v} = \frac{V(D_i - d_0)}{v}$

If Reynold's number Re<2300 then the flow is laminar, Re>2300 then the flow is turbulent.

Nusselt number (Nu):

Nu = $0.0296 Re^{0.8} Pr^{0.33}$

Heat transfer coefficient for cold fluid (h_o):

Nu =$\frac{h_o D}{k} \rightarrow h_o = \frac{Nu \times k}{D} = \frac{Nu \times k}{D_i - d_o}$

Calculation of heat transfer coefficient for hot fluid (h_i)

Find the density (ρ), thermal conductivity (k), kinematic viscosity (v), prandtl number (Pr) and specific heat (c) from HMT data book pg. 22 using T_h

Velocity of cold fluid = V = $\frac{m_h}{\rho A_c} = \frac{m_h}{\rho \times \frac{\pi}{4} \times d_i^2}$

Reynold’s number (Re):

$$Re = \frac{VD}{v} = \frac{Vd_i}{v}$$

If Reynold’s number Re<2300 then the flow is laminar, Re>2300 then the flow is turbulent.

Nusselt number (Nu):

$$Nu = 0.0296Re^{0.8}Pr^{0.33}$$

heat transfer coefficient for hot fluid (h_i):

$$Nu = \frac{h_i D}{k} \rightarrow h_i = \frac{Nu \times k}{D} = \frac{Nu \times k}{d_i}$$

Calculation of Overall heat transfer coefficient (U):

$$\frac{1}{UA_s} = \frac{1}{A_i h_i} + \frac{1}{A_o h_o}$$

$$A_i = \pi d_i L$$

$$A_o = \pi D_i L + \text{surface area of baffles}$$

$$A_o = \pi D_i L + (\text{No. of baffles} \times \frac{1}{2} \times \frac{\pi}{4} \times (D^2 - d_o^2))$$

After finding U we must find heat transfer coefficient Q

Calculation of Heat transfer rate (Q):

$$\text{Heat transfer rate (Q)} = U \times A_s \times \Delta T_{lm}$$

$$LMTD = \Delta T_{lm} = \frac{\Delta T_A - \Delta T_B}{\ln(\frac{\Delta T_A}{\Delta T_B})}$$

$$\Delta T_A = T_1 - T_4$$

$$\Delta T_B = T_2 - T_3$$

4.4 PERFORMANCE PARAMETERS OF DOUBLE PIPE HEAT EXCHANGERS

4.4.1 PRESSURE DROP

Pressure drop is a major constraint in thermal design of double pipe heat exchanger. A thermal design of a double pipe heat exchanger is meaningful only when it is optimum and the extent of the optimality is constrained by the pressure drop. Optimization of thermal design requires maximization of overall heat transfer coefficient and/or effective mean temperature difference (EMTD) so as to minimize the heat transfer area subject to the constraints, pressure drop being the major one. Other constraints may be flow induced vibration, space limitation etc. overall heat transfer coefficient can be maximised by maximising the flow velocities which in turn is governed by the allowable pressure drop as higher velocity means higher pressure drop. The pressure drop should be managed in such a way that the calculated pressure drop is closest possible to achievable pressure drop. On the other hand if pressure drop is surplus during thermal design, the calculated pressure drop should be increased as close to the allowable pressure drop.

4.4.2 FOULING FACTOR

The deposition of any undesired material on heat transfer surfaces is called fouling. Fouling may significantly impact the thermal and mechanical performance of heat exchangers. Fouling is a dynamic phenomenon which changes with time. Fouling increases the overall thermal resistance and lowers the overall heat transfer coefficient of heat exchangers. Fouling also impedes fluid flow, accelerates corrosion and increases pressure drop across heat exchangers. Different types of fouling mechanisms have been identified. They can occur individually but often occur simultaneously.

Common types of fouling are:

- Chemical fouling
- Biological fouling
- Deposition fouling
- Corrosion fouling

Other terms used in the literature to describe fouling include: deposit formation, encrustation, deposition, scaling, scale formation, slagging, and sludge formation.in heat exchangers fouling reduces thermal efficiency, decreases heat flux, increases temperature on the hot side, decreases temperature on the cold side, induces under-deposit corrosion, increases use of cooling water.

$$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}}$$

4.4.3 LOGARITHMIC MEAN TEMPERATURE DIFFERENCE

The logarithmic mean temperature difference (also known as log mean temperature difference, LMTD) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers.. For a given heat exchanger with constant area and heat transfer coefficient, the larger the LMTD, the more heat is transferred. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties.

We assume that a generic heat exchanger has two ends (which we call "A" and "B") at which the hot and cold streams enter or exit on either side; then, the LMTD is defined by the logarithmic mean as follows:

$$\text{LMTD} = \Delta T_{lm} = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)}$$

Where ΔT_A is the temperature difference between the two streams at end A, and ΔT_B is the temperature difference between the two streams at end B. With this definition, the LMTD can be used to find the exchanged heat in a heat exchanger:

$$Q = U \times A_s \times \Delta T_{lm}$$

Where Q is the exchanged heat duty (in watts), U is the heat transfer coefficient (in watts per kelvin per square meter) and As is the exchange area. Note that estimating the heat transfer coefficient may be quite complicated.

This holds both for cocurrent flow, where the streams enter from the same end, and for counter-current flow, where they enter from different ends.

In a cross-flow, in which one system, usually the heat sink, has the same nominal temperature at all points on the heat transfer surface, a similar relation between exchanged heat and LMTD holds, but with a correction factor. A correction factor is also required for other more complex geometries, such as a shell and tube exchanger with baffles.

4.4.4 NUMBER OF TRANSFER UNITS (NTU)

The Number of Transfer Units (NTU) Method is used to calculate the rate of heat transfer in heat exchangers (especially counter current exchangers) when there is insufficient information to calculate the Log-Mean Temperature Difference (LMTD). In heat exchanger analysis, if the fluid inlet and outlet temperatures are specified or can be determined by simple energy balance, the LMTD method can be used; but when these temperatures are not available The NTU or The Effectiveness method is used.

$$q_{max} = C_{min}(T_{hi} - T_{ci})$$

To define the effectiveness of a heat exchanger we need to find the maximum possible heat transfer that can be hypothetically achieved in a counter-flow heat exchanger of infinite length. Therefore one fluid will experience the maximum possible temperature difference, which is the difference of (The temperature difference between the inlet temperature of the hot stream and the inlet temperature of the cold stream). The method proceeds by calculating the heat capacity rates (i.e. mass flow rate multiplied by specific heat) and for the hot and cold fluids respectively, and denoting the smaller one must be used as it is the fluid with the lowest heat capacity rate that would, in this hypothetical infinite length exchanger, actually undergo the maximum possible temperature change. The other fluid would change temperature more quickly along the heat exchanger length. The method, at this point, is concerned only with the fluid undergoing the maximum temperature change.

4.4.5 FLOW RATE

Velocity also has an effect on the thermal transfer characteristics of the heat exchanger. The higher the velocity through the heat exchanger, the higher the turbulence, the more efficient the thermal transfer. This turbulence forces the fluid against the metal wall and the greater the volumes of fluid in contact with the walls of the exchanger, the greater the thermal transfer. The opposite of turbulent flow is laminar flow which is defined as a smooth, linear flow through the system. As turbulence falls, the film on the walls of the heat exchanger increases which is called film coefficient as it increases the thermal transfer efficiency is reduced.

4.4.5 REYNOLDS NUMBER

The Reynolds number (Re) is an important dimensionless quantity in fluid mechanics used to help predict flow patterns in different fluid flow situations.

At low Reynolds numbers, flows tend to be dominated by laminar (sheet-like) flow, while at high Reynolds numbers turbulence results from differences in the fluid's speed and direction. Increasing the Reynolds number positively influence the thermal transfer, the increase in friction also increase the pressure drop through the heat exchanger, whereas the smooth flow through the heat exchanger associated with laminar flow produces a low pressure drop, but also a lower thermal efficiency. It is noted that as the viscosity of the fluid being dispensed increases, the greater the velocity required to drive the Reynolds number up and prevent laminar flow, which has a greater impact on pressure drop through the heat exchanger.

4.5 APPLICATIONS

The simple design of a double pipe heat exchanger makes it an ideal cooling solution for a wide variety of applications. Double pipe heat exchangers can be used in fuel cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, food processing industries, heat exchanger and boiler flue gas temperature reduction.

CHAPTER 5

DESIGN IN 2D&3D

5.1 DESIGN OF OUTER AND INNER PIPE:

Inner pipe is designed specifically to fit with the Outer pipe as a model in SOLIDWOKS software. AutoCAD software is used to design and overview the desired model. These are one of the top modelling software widely used in the industries. SolidWorks is a solid modeller, and utilizes a parametric feature-based approach which was initially developed by PTC to create models and assemblies.

Figure 5.1 Isometric view of Inner pipe with Baffles

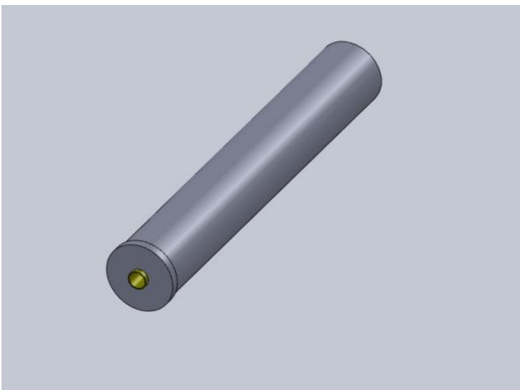


Figure 5.2 Enclosed isometric Sectional view

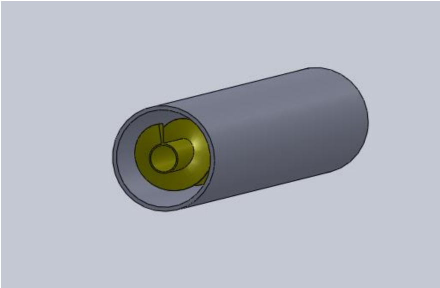


Figure 5.3 Enclosed isometric x-Sectional Sectional view

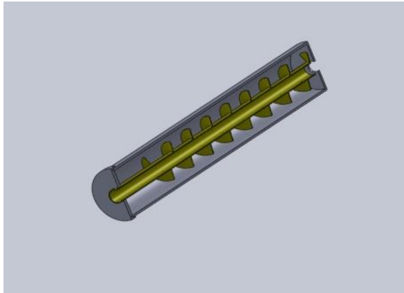


Figure 5.4 Enclosed isometric y-

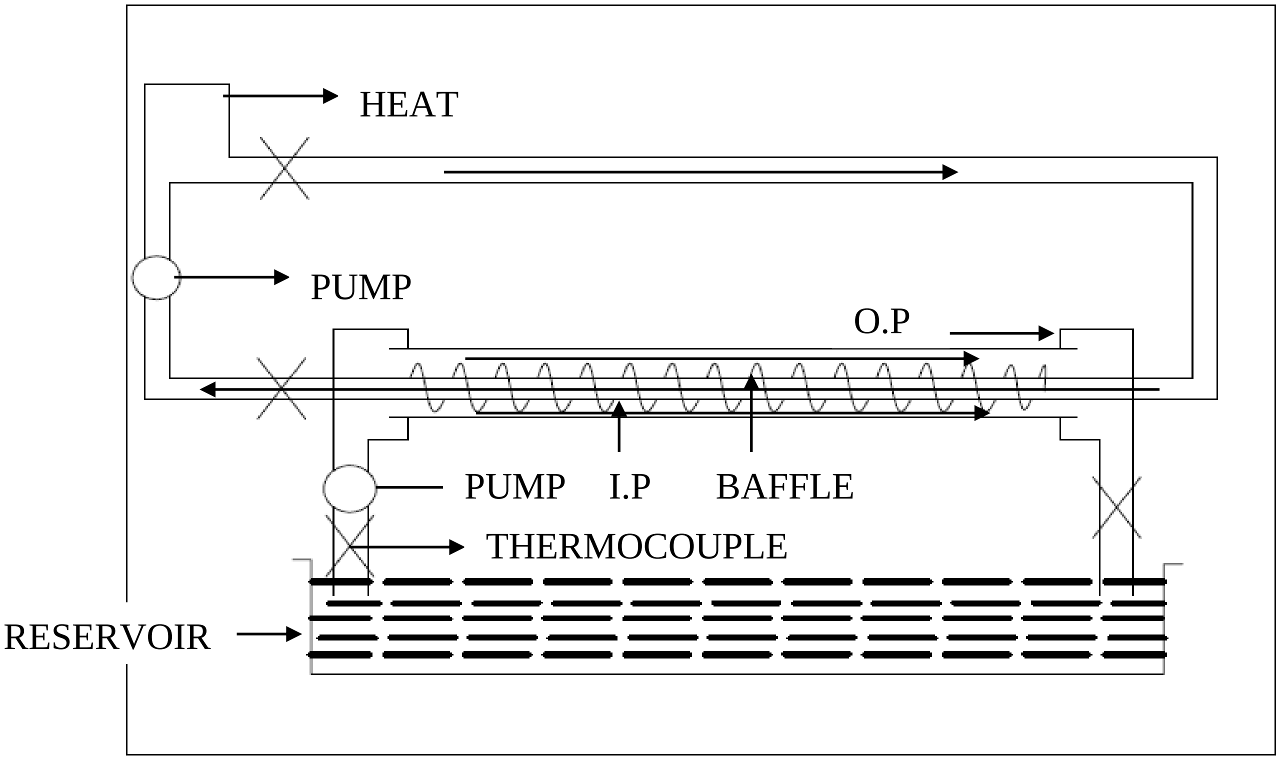


Figure 5.5 2D-Overall Outline of setup

CHAPTER 6

FABRICATION OF EXPERIMENTAL SETUP

6.1 FABRICATION OF OUTER PIPE

The outer pipe is made up of hardened stainless steel. The outer pipe is used here to host the inner pipe which is made up of copper. The fluids pass through the outer tube. Dimensions of the outer pipe are as follows, for the process industry, 113 mm tends to be the most common. The outer shell is made with a thickness of 11 mm. A tolerance value of ±4 mm is provided for the outer pipe. The outer pipe has one inlet and one outlet at a perpendicular angle to its cross section. The outer pipe also has one hole on one side of the pipe to insert the inner pipe with baffle while other hole is made on the other side from which the pipe that is connected to the inner tube protrudes out. The one side which is large enough to house the inner tube is closed after inserting the inner tube inside the outer tube by means of a cap like structure which is threaded internally.

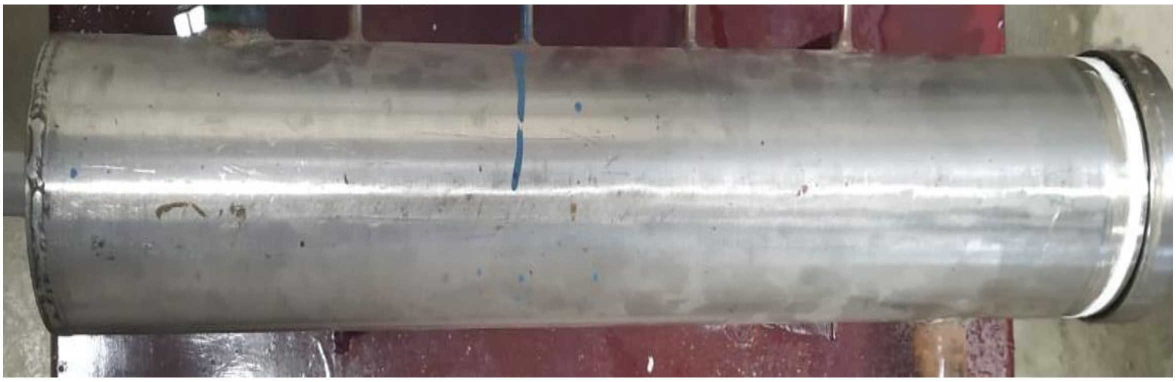


Figure 6.1 Outer pipe

6.2 FABRICATION OF INNER PIPE:

The inner pipe is made up of copper as it has high thermal conductivity so that heat transfer will be maximum as possible. Heat transfer also depends on the surface area that is heat transfer is directly proportional to the surface area, so in order to increase the surface area where heat transfer occurs baffles are used. .

Baffles are similar to fins which are used to increase the surface area thereby increasing the heat transfer. Continuous helical baffles are chosen in our experiment. The baffles are done with a pitch of 70 mm. The diameter of the inner copper pipe is 28.75 mm. The Outer diameter of the pipe is made to be 31 mm. The Outer diameter of the inner pipe with baffles is 98 mm.

The design calculation of baffle is as follows:

Required outside diameter D = 102 mm

A tolerance of 4 mm is provided

Required outside diameter D = 102 – 4 = 98 mm

Required inner diameter d = 31 mm

Pitch p = 70 mm

Let D = (1/pi) $\sqrt{(\pi D^2 + p^2)} = \sqrt{(\pi(98)^2 + 70^2)}$ = 315.75/3.14 mm

d = (1/pi) $\sqrt{(\pi D^2 + p^2)} = \sqrt{(\pi(31)^2 + 70^2)}$ = 119.93/3.14 mm

Using Flat screw flight:

Outer diameter = D = 108.03 mm

Inner diameter = d = 41.03 mm

Figure 6.2 Inner pipe with baffle arrangement

6.3 PUMPS:

Two pumps are used in this experiment; one pump is used to pressurize the cold fluid, while the other pump is used for the hot fluid. Centrifugal pumps having 0.25 horse power and 0.5 horse power are used for hot fluid and cold fluid respectively. 0.25 horse power pump is used for hot fluid as it fulfils the minimum requirements. 0.5 horse power pumps are chosen for cold fluid as the water has to overcome the friction of both the inner and outer pipes. The pumps have a suction head which is attached into the reservoir and the delivery head. Both the pumps are clamped separately at two ends of the reservoir.

Hot fluid pump specifications:
Horse power: 0.25
Make: Almonard
Head: 18 metres
R.P.M: 2800
Type of priming: self priming
Voltage: 230 V

Cold fluid pump specifications:
Horse power: 0.5
Make: SBE
Head: 18 metres
R.P.M: 3000
Type of priming: Self priming
Voltage: 230 V

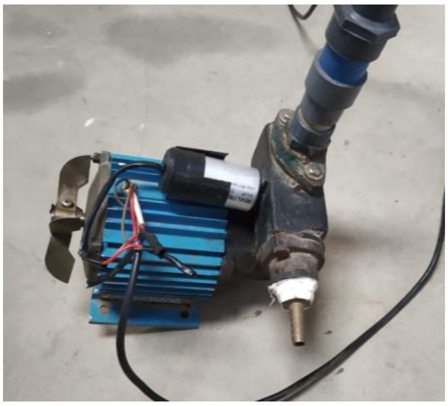


Figure 6.3 0.25 Hp Pump

Figure 6.4 0.5 Hp Pump

6.4 WATER RESERVOIR

Reservoir is used in the heat exchanger to store and circulate water. Reservoirs are made up of mild steel. Usually reservoir is made as a single compartment where both the hot and cold fluids are dumped together but since we use Nano fluids here it is not feasible to use a single reservoir, therefore after fabricating the reservoir with dimensions of 1000 mm(1 m) length, 400 mm(0.4 m) breadth and 500mm(0.5 m) depth. The reservoir is divided into two halves so that Nano fluids and water which is heated and used as hot fluid are kept separately from the water which is used as cold fluid.

The reservoir also has two welded bars near both ends of the reservoir. These bars are used to mount the pumps at a certain height and also to provide necessary suction head.

Volume of the reservoir having a cuboid shape = length× breadth× height

Volume of the reservoir = 1×0.4×0.5 = 0.2 m^3

6.5 ROTAMETERS:

Rotameters are used to measure the flow rate in the heat exchanger. Rotameters can also be used for adjusting the flow of fluid through it. Two rotameters have been used in this experiment both of them consists of a glass like structure with a metal ball inside it to measure the flow. The rotameters also have a lead screw with which the flow through the rota meter can be increased or decreased.

Figure 6.5 Rotameters

6.6 GEYSER:

A geyser is used to heat the water to a certain temperature so that it can be used as hot fluid in the experiment.

Geyser specifications:

Manufacturer: Bajaj

Voltage: 230 V

Capacity: 3litres

Heating element: copper tube

Figure 6.6 Geyser

6.7 TEMPERATURE INDICATOR AND THERMOCOUPLES:

In order to measure the temperature of the inlet and outlet of the hot fluid and the cold fluid thermocouples are used. Thermocouples are used to measure the temperature accurately. Multiple temperature sensors are attached to a thermocouple in such a way that all the temperatures can be known by simply changing the button in the thermocouple. Four temperature sensors are used to measure the inlet and outlet temperatures of the hot fluid and cold fluid respectively. The temperature readings are shown in degree Celsius.

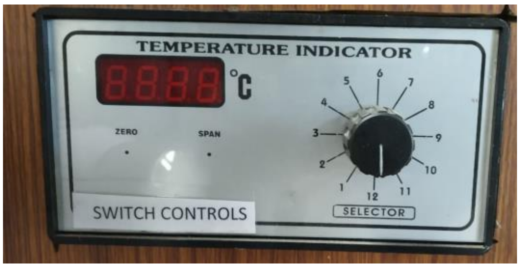


Figure 6.7 Temperature Indicator **Figure 6.8 Thermocouple**

6.8 STAND AND FRAME:

In order to mount the heat exchanger a stand is made up by using mild steel material. The stand has two supports on which the double pipe is setup. Another support is attached to the stand by means of screws in order to clamp a wooden stand to which both the geyser and the temperature indicator is attached.

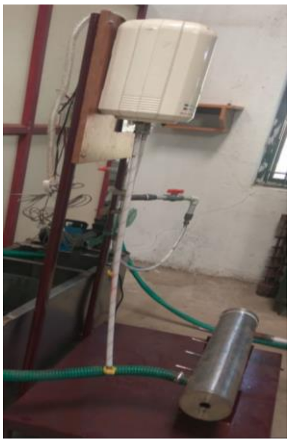


Figure 6.9 Stand & Frame

6.9 OTHER FITTINGS:

In order to make flow of water possible, various fittings are used for plumbing such as poly-vinyl chloride (PVC) pipes, hose, couplers and reducers are used. It is necessary to make the experiment with a simple yet efficient design and also choosing the fittings in such a way so that they can fulfil the requirements of the experiment. The hose and pipes used in the experiment have heat withstanding capabilities.

CHAPTER 7

EXPERIMENTAL ANALYSIS AND RESULTS

7.1 EXPERIMENTAL READINGS:

Pitches	**Q_h(lpm)**	**Q_c(lpm)**	**T_1(H.I)°C**	**T_2(H.O)°C**	**T_3(C.I)°C**	**T_4(C.O)°C**
80	**0.5**	**0.9**	**66**	**63**	**26**	**28**
75	**0.5**	**0.9**	**72**	**68**	**26**	**27**
70	**0.5**	**0.9**	**73**	**68**	**25**	**27**

Table 7.1 Experimental Readings

Given:

D_i = 113mm D_o = 124mm   T = 11mm

d_i = 29mm d_o = 31mm   t = 2mm   L = 600mm

A_{s70} = (7299.07 x 2 sides x 9 revolutions) + Pi*d_o*L

= 0.189786 m^2

A_{s75} = (7369.45 x 2 x 8) + Pi*d_o*L

= 0.1763152 m^2

A_{s80} = (7450.15 x 2 x 7) + Pi*d_o*L

= 0.1627061 m^2

A_i = Pi*d_i*L

= 0.054636 m^2

A_{o70} = (7299.07 x 2 sides x 9 revolutions) + Pi*D_i*L

= 0.34438198 m^2

A_{o75} = (7369.45 x 2 x 8) + Pi*D_i*L

= 0.3309111 m^2

A_{o80} = (7450.15 x 2 x 7) + Pi*D_i*L

= 0.317302 m^2

For 80mm pitch:

$T_h = (T_1+T_2)/2 = 64.5\ ^oC$

$T_c = (T_3+T_4)/2 = 27\ ^oC$

To find h_o:

$V = m_c / (\rho*(pi/4)*(D_i^2 - d_o^2))$ From HMT data book pg.no:22

= 0.001621 m/s with T_c as reference

$Re = (V*(D_i - d_o)) / v$

= 159.85

$Nu = 0.0296*Re^{0.8}*Pr^{0.8}$

= 3.0422

$h_o = (Nu*k) / (D_i - d_o)$

= 22.73 $W/m^{2o}C$

To find h_i :

$V = mh / (\rho*(pi/4)*(d_i^2))$ From HMT data book pg.no:22

= 0.0128 m/s with T_h as reference

$Re = (V*d_i) / v$

= 776.56

$Nu = 0.0296*Re^{0.8}*Pr^{0.8}$

= 8.7464

$h_i = (Nu*k) / d_i$

$= 196.43\ W/m^{2o}C$

To find overall heat transfer coefficient, U:

$1/(UA_s) = (1/(A_ih_i)) + (1/(A_oh_o))$

$U = 26.5259\ W/m^{2o}C$

To find Net Heat transfer, Q:

$\Delta T_A = T_1 – T_4$

$\Delta T_B = T_2 – T_3$

$LMTD = (\Delta T_A - \Delta T_B) / \ln(\Delta T_A/\Delta T_B)$

$= 37.4977^oC$

$Q = U*A_s*LMTD$

$Q = 161.83\ W$

Similarly for 75 mm pitch,

$Q = 195.8\ W$

Similarly for 70 mm pitch,

$Q = 200.83\ W$

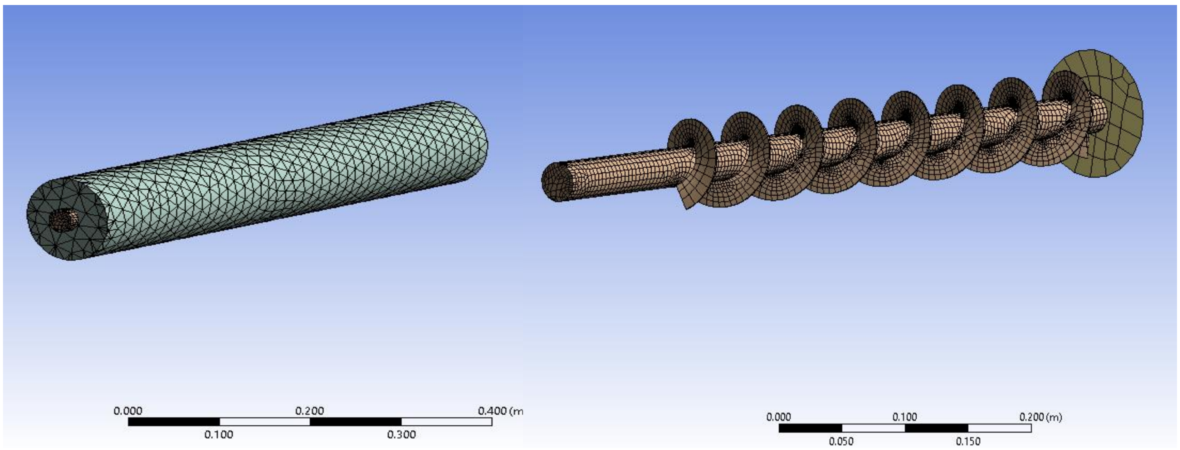


Figure 7.1 Meshed model

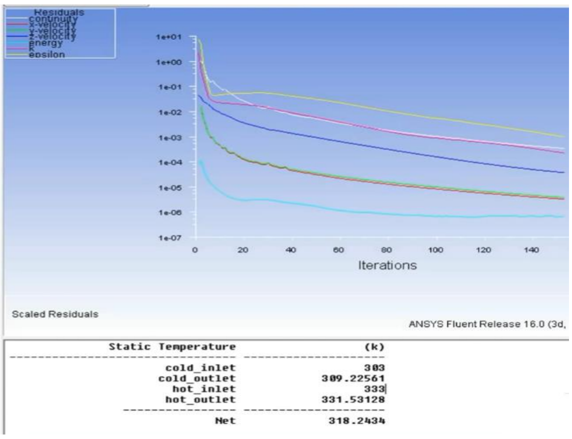


Figure 7.2 Scaled residuals

Residuals are the measure of convergence of the iterative approach. In CFD, after discretization, the partial differential equations are converted in to a set of algebraic equations and each algebraic equation has to be solved for individual control volume (Meshing the whole domain into a number sub domains or control volumes).

Hence, residual signifies the local imbalances of any conserved field variable in individual control volumes. In an iterative numerical solution, the residual will never be exactly zero.

In FLUENT: the scaled residuals for continuity, momentum, energy etc has to be defined in the monitor window, which is generally known as Convergence criteria.

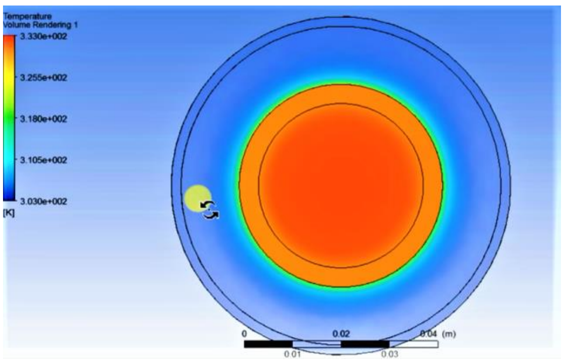


Figure 7.3 Temperature readings without baffles

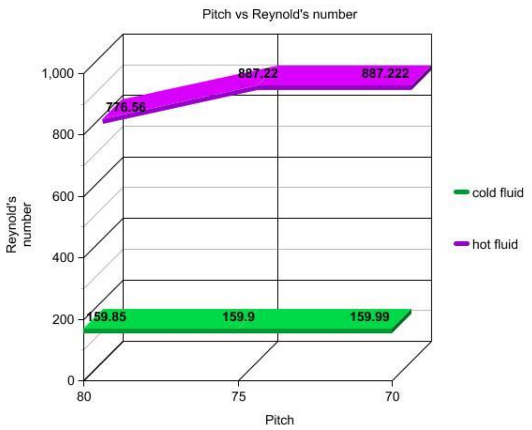


Figure 7.4 Pitch vs. Re

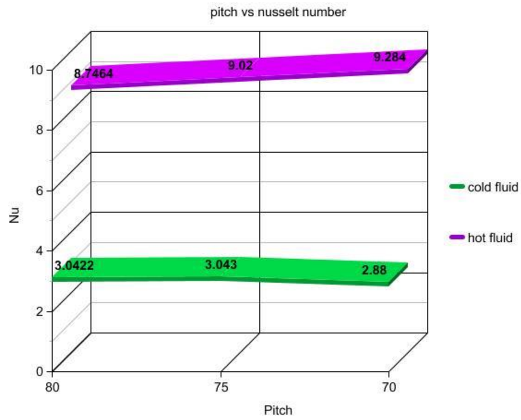
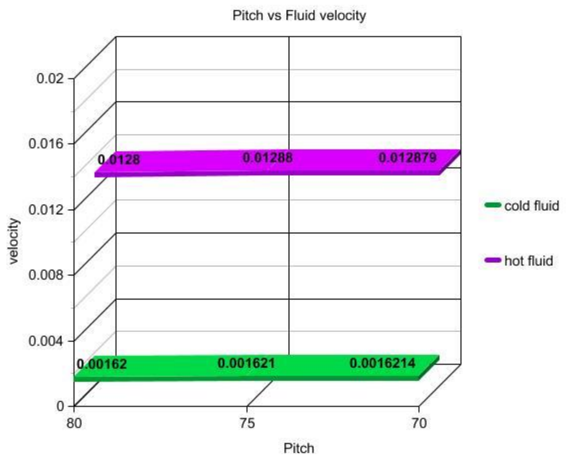


Figure 7.5 Pitch vs. Nu



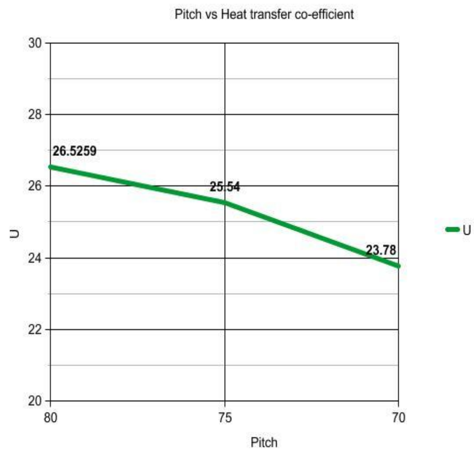


Figure 7.6 Pitch vs. Fluid velocity & Pitch vs. Heat transfer Coefficient

CHAPTER 8

CONCLUSION

8.1 SCOPE OF THE PROJECT

The double pipe heat exchangers are simple but effective in applications of heat transfer. Due to their simplicity they are preferred in many applications. There are a several operational factors that affects is performance. Various researches are considering nano material coating in order to improve the efficiency of heat exchanger. Various researches are going on to use Nano fluids in heat exchanger in order to improve the efficiency of the heat exchanger so as to conserve energy.

8.2 CONCLUSION

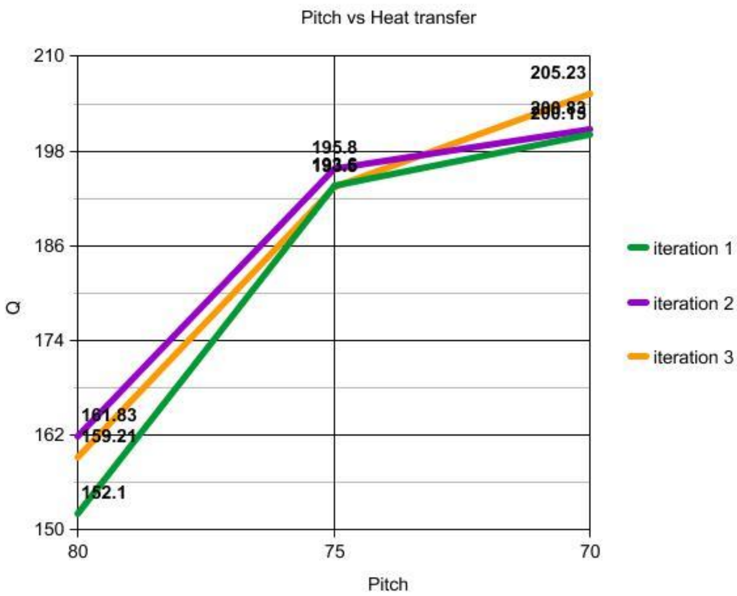


Figure 8.1 Pitch vs. Heat transfer

The above graph/result indicates that, compared to different baffle spacing of 80mm, 75mm, 70mm, ‘70mm’ has higher heat transfer rate ,when compared with the remaining two baffles tested during the process. It clearly shows that the lower the baffle spacing the higher the heat transfer rate as well as fluid velocity.

ANNEXURE

BILL OF MATERIALS

S.NO	DESCRIPTION	UNIT	COST
1	geyser	1	3000
2	Inner tube with baffles	3	12000
3	pump	2	4000
4	Outer pipe, stand, frame	1	3500
5	Pipe, valves, hose	-	2000
6	Thermocouple	4	2500
7	Temperature indicator	1	1500
8	Rotameter	2	3500
9	miscellaneous	-	1000
	TOTAL		33000

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