

Design and Performance Analysis of a Counter flow Heat Exchanger Using Industrial Waste Hot Water



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**A Graduation Exercise Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Mechanical Engineering**

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Spring,2026

DECLARATION

We do hereby solemnly declare that, the work presented here in this project report has been carried out by us and has not been previously submitted to any university and organization For award of any degree or certificate

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APPROVAL

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ABSTARCT

Industrial processes discharge a large amount of waste hot water that is commonly released without energy recovery, leading to avoidable thermal losses. This study focuses on utilizing this low-grade thermal energy through a counter flow heat exchanger system.

The primary objective is to recover heat from industrial waste hot water and transfer it to normal inlet water, thereby reducing fuel consumption, heating time, and overall energy demand in industrial applications.

A counter flow heat exchanger was designed using a GI pipe for hot waste water and a copper tube for normal water flow inside a cylindrical shell. Waste hot water entered the system at 60°C and exited at 32°C, while normal water entered at 23°C and exited at 28°C under steady-state conditions.

The system demonstrated effective heat recovery, increasing the normal water temperature by 5°C using only waste thermal energy. For counter flow operation, the temperature differences were 32°C and 9°C, resulting in a Log Mean Temperature Difference (LMTD) of approximately 18°C, indicating acceptable heat transfer performance.

The proposed heat exchanger successfully converts industrial waste hot water into a useful energy source, reducing energy loss and operating costs. This approach offers a practical and sustainable solution for improving thermal efficiency in industrial water heating systems.

LIST OF ABBREVIATIONS

TTHE=TUBE-TUBE HEAT EXCHANGER

SMPS=SWITCH MOOD POWER SUPPLY

AC=ALTERNATING CURRENT

DC=DIRECT CURRENT

PFC=POWER FACTOR CORRECTION

ABS=ACRYLONITRILE BUTADIENE STYRENE

PCB=PRINTED CIRCUIT BOARDS

LMTD=Log Mean Temperature Difference

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MATHEMATICAL SYMBOLS

| SYMBOL | PERAMETER | UNIT |
|----------------|----------------------------------------|---------------------|
| Q | Heat transfer rate | W |
| U | Overall heat transfer coefficient | W/m ² ·K |
| A | Heat transfer area | m ² |
| ΔT_m | Log Mean Temperature Difference (LMTD) | K (Kelvin) |
| T _h | Hot fluid temperature | °C or K |
| T _c | Cold fluid temperature | °C or K |
| m | Mass flow rate | kg/s |
| C _p | Specific heat capacity | J/kg·K |

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CHAPTER 1

INTRODUCTION

1.1 Project Overview

This project presents a waste heat recovery system based on a counter flow heat exchanger designed for industrial applications. In many industries, hot wastewater is discharged after use, causing significant loss of thermal energy. The proposed system captures this waste hot water and transfers its heat to normal inlet water without direct mixing. A GI pipe is used for the flow of waste hot water, while normal water passes through a copper tube placed inside a cylindrical shell in a counter flow arrangement. Experimental results show that waste water entering at 60°C is cooled to 32°C, while normal water temperature increases from 23°C to 28°C. This confirms effective heat recovery and energy reuse from low-grade waste heat. By preheating normal water using waste heat, the system reduces the need for additional fuel, lowers operating costs, and improves overall energy efficiency. The project highlights a practical and sustainable approach to minimizing energy loss and promoting efficient thermal management in industrial processes. [1]

1.2 Objective:

- To design and evaluate a counter flow heat exchanger system for recovering heat from industrial waste hot water and using it to preheat normal water for industrial applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is arranged on Literature Review. Here's a look at some of last year's literature, like our project. By reading them, we can overcome the mistakes of the previous project and make a more effective project.

2.2 Related Research/ Works

A wide range of researches are already done to study the flow characteristics and heat transfer in helical heat exchangers. The enhancement of the heat transfers in the helically coiled tubes is due to the centrifugal forces. A secondary flow field is produced due to the curvature of the tube with a circulatory motion, which causes the fluid particles to move towards the core region of the tube. The secondary flow enhances heat transfer rates by reducing the temperature gradient across the cross-section of the tube. Thus there is an additional convective heat transfer mechanism occurs, perpendicular to the main flow, which does not exist in straight tube heat exchangers. [1] A.P. Frass and M. N. Ozisik studied the characteristics of heat transfer in a double pipe helical heat exchanger and found that the overall heat transfer coefficients increase with increasing inner Dean number. However, this increase is a function of the ratio of the mass flow rates.

[2] G. Walker Nigam conducted an experiment on tube-in-tube heat exchanger and observed that with the increase in operating pressure in the inner tube, the overall heat transfer coefficient increases and the friction factor value in the inner-coiled tube was in agreement with the literature data.

[3] S. Kakac, R. K. Shah and A. E. Bergles (eds), conducted a practical experiment on a vertical helically coiled heat exchanger and found that the coil surface area was the most influential geometrical parameter on the heat transfer coefficient and effect of tube diameter is almost negligible on overall heat transfer coefficient.

[4] M. N. Ozisik, Heat Transfer experimented on the effect of various geometric parameters on a concentric helical coil heat exchanger. They plotted the graph between heat transfer coefficient versus tube diameter and coil gap and found that two most important design parameters are coil gap and tube diameter.

[5] J. P. Holman conducted an experiment on helically coiled heat exchangers using CFD and found that the use of constant values for the heat transfer and thermal properties of the fluid resulted in inaccurate heat transfer coefficients. Based on the analysis results he developed a correlation in order to evaluate the heat transfer coefficient of the coil. In this study, analysis was done for both the constant wall temperature and constant wall heat flux boundary conditions. The Nusselt numbers that were obtained were found to be highest on the outer coil and lowest in the inner side. The coil parameters like the diameters of the pipes, the Pitch Circle Diameters have significant effect on the heat transfer and the effect of the pitch is negligible.

[6] V. V. P. Dubey and R. Rajat studied the heat transfer characteristics for a double pipe helical heat exchanger for both counter and parallel flow with both the boundary conditions of constant heat flux and constant wall temperature. The results from the simulations were within the range of the pre-obtained results. The overall heat transfer coefficients were determined for dean numbers ranging from 38 to 350. He observed that the overall heat transfer coefficients varied directly with the inner dean number but the fluid flow conditions in the outer pipe had a major contribution on the overall heat transfer coefficient. So, he concluded that during the design of a double pipe helical heat exchanger, the design of the outer pipe should be given the highest priority in order to get a better overall heat transfer coefficient.

[7] Y. A. Kara and O. Guraras Bhoi studied the constant thermal and transport properties of the heat transfer medium and their effect on the prediction of heat transfer coefficients. Arbitrary boundary conditions were not applicable for the determination of heat transfer for a fluid-to-fluid heat exchanger. An experimental setup was made for studying the heat transfer and also CFD was used for the simulation of the heat transfer. The CFD simulation results were reasonably well within the range of the experimental results. Based on both the experimental and simulation results a correlation was established for the inner heat transfer coefficient.

Two fluids of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In this way, waste heat can be put to use. This is an efficient way to conserve energy.

Heat exchangers with only one phase (liquid or gas) on each side can be called one-phase or single-phase heat exchangers. Two-phase heat exchangers can be used to heat a liquid to boil it into a gas (vapor), sometimes called boilers, or cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side. Boilers in steam engine locomotives are typically large, usually cylindrically-shaped shell-and-tube heat exchangers. In large power plants with steam-driven turbines, shell-and-tube surface condensers are used to condense the exhaust steam exiting the turbine into condensate water which is recycled back to be turned into steam in the steam generator.

[8] M. V. Rane and M. S. Tandale (2005) conducted both experimental and analytical studies on water-to-water tube-to-tube heat exchangers. Their research highlighted the influence of flow arrangement, tube dimensions, and inlet temperature differences on the overall heat transfer coefficient. They found that proper design of tube diameters and mass flow rates could significantly improve thermal performance, providing practical guidance for industrial applications. The study emphasized that accurate evaluation of temperature distribution and flow characteristics is crucial for designing efficient heat exchangers and for predicting the performance under varying operating conditions.

[9] K. M. Lunsford, (1998) focused on increasing heat exchanger performance by applying design optimization techniques in industrial systems. He discussed methods to improve thermal efficiency by enhancing surface area, optimizing flow paths, and minimizing thermal resistance. His findings suggested that even minor modifications in tube placement or flow distribution could lead to substantial improvements in energy recovery without requiring major changes in existing infrastructure. Lunsford

also highlighted that the overall system efficiency is directly related to the careful management of both design parameters and operating conditions.

[10 Y. Yao, X. Zhang and Y. Guo, 2010) investigated the enhancement of heat transfer in water-to-water shell-and-tube heat exchangers using ultrasonic assistance. Their experimental study showed that applying ultrasonic vibrations to the heat exchanger increased the convective heat transfer rates significantly. The cold water outlet temperature rose higher compared to conventional setups, indicating improved energy recovery. This study introduced the potential of innovative techniques to augment conventional heat exchangers, suggesting that ultrasonic-assisted systems can achieve higher efficiency with smaller surface areas and reduced material usage, which is beneficial for both economic and energy conservation reasons.

[11] M. D. Alam, S. T. Hossain, M. H. S. Simanto, M. S. U. Mithu and M. A. Islam. (2014) performed both experimental and numerical investigations on air-to-water heat exchangers. Their study focused on temperature distribution, flow characteristics, and energy transfer efficiency. They demonstrated that numerical simulation, when validated with experimental data, can effectively predict the performance of heat exchangers under various operating conditions. Their results confirmed that preheating water using waste heat from industrial sources is feasible and can lead to significant energy and cost savings. This study also emphasized the importance of precise modeling and validation to ensure reliable performance predictions for practical applications.

Collectively, these studies indicate that heat exchanger performance depends strongly on flow arrangement, tube geometry, mass flow rates, and innovative enhancement techniques. For water-to-water systems, counter flow arrangements consistently demonstrate higher thermal effectiveness than parallel flow, as they maintain a higher temperature gradient along the entire length of the heat exchanger. Furthermore, material selection, fouling resistance, and cleaning protocols play a critical role in long-term operational efficiency. Experimental studies, supported by numerical simulations, show that even small improvements in heat recovery can result in substantial reductions in fuel consumption and operational costs over time.

The findings from these previous research works directly support the feasibility of the present project, which employs a counter flow heat exchanger to recover heat from industrial waste hot water. By transferring thermal energy from waste streams to normal water without direct mixing, the system can preheat water for industrial use, thereby reducing energy consumption and promoting sustainable operations. These studies collectively reinforce the importance of optimizing heat exchanger design and operational parameters to maximize waste heat recovery and provide a practical solution for energy-efficient industrial thermal management.

2.3 Summary

The above has been discussed in detail in the past few literature's which has given us a lot of motivation to do this project.

CHAPTER 3

HARDWARE ANALYSIS

3.1 Required Instrument

- SMPS
- Heat Exchanger
- Temperature Meter
- Pump Motor
- Water Heater
- Steel Pipe
- Switch

3.2 Switch Mode Power Supply (SMPS)

A switched-mode power supply (switching-mode power supply, switch-mode power supply, switched power supply, SMPS, or switcher) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a DC or AC source (often mains power) to DC loads, such as a personal computer, while converting voltage and current characteristics.

Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between low-dissipation, full-on and full-off states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. A hypothetical ideal switched-mode power supply dissipates no power. Voltage regulation is achieved by varying the ratio of on-to-off time (also known as duty cycles). In contrast, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. This higher power conversion efficiency is an important advantage of a switched-mode power supply. Switched-mode power supplies may also be substantially smaller and lighter than a linear supply due to the smaller transformer size and weight.



Figure 3.1: SMPS

Specification

| | |
|------------------|--------------------------------------------|
| Input Voltage | 110V-120V |
| Output voltage | 12V |
| Output power | 101-200w |
| Output Frequency | 50/60 HZ |
| Output Current | 10A |
| Efficiency | 90% |
| Case Material | Aluminium |
| Weight | 500gm |
| Working Temp | Tcase=-30~+70 |
| Size | 200*100*42 |
| Protections | Short circuit ,Overload,Overvolt, overtemp |

Table 1: Specification of SMPS

Switching regulators are used as replacements for linear regulators when higher efficiency, smaller size or lighter weight are required. They are, however, more complicated; their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor.

12V 5A Industrial SMPS Power Supply – 60W – DC Metal Power Supply – Good Quality – Non Waterproof with Aluminum casing.

- Input Voltage: AC 100 – 264V 50 / 60Hz
- Output Voltage: 5V DC, 0-7A
- Output voltage: Adjustment Range: $\pm 20\%$
- Protections: Overload / Over Voltage / Short Circuit
- Auto-Recovery After Protection
- Universal AC input / Full range
- 100% Full Load Burn-in Test
- Cooling by Free Air Convection
- High Quality and High Performance
- LED power supply with a metal body for hidden installation for LED lighting
- Design with Built-in EMI Filter, improve signal precision.
- Certifications: CE & RoHs

Switched-mode power supplies are classified according to the type of input and output voltages. The four major categories are:

- AC to DC
- DC to DC
- DC to AC
- AC to AC

A basic isolated AC to DC switched-mode power supply consists of:

- Input rectifier and filter
- Inverter consisting of switching devices such as MOSFETs

- Transformer
- Output rectifier and filter
- Feedback and control circuit

The input DC supply from a rectifier or battery is fed to the inverter where it is turned on and off at high frequencies of between 20 KHz and 200 KHz by the switching MOSFET or power transistors. The high-frequency voltage pulses from the inverter are fed to the transformer primary winding, and the secondary AC output is rectified and smoothed to produce the required DC voltages. A feedback circuit monitors the output voltage and instructs the control circuit to adjust the duty cycle to maintain the output at the desired level.

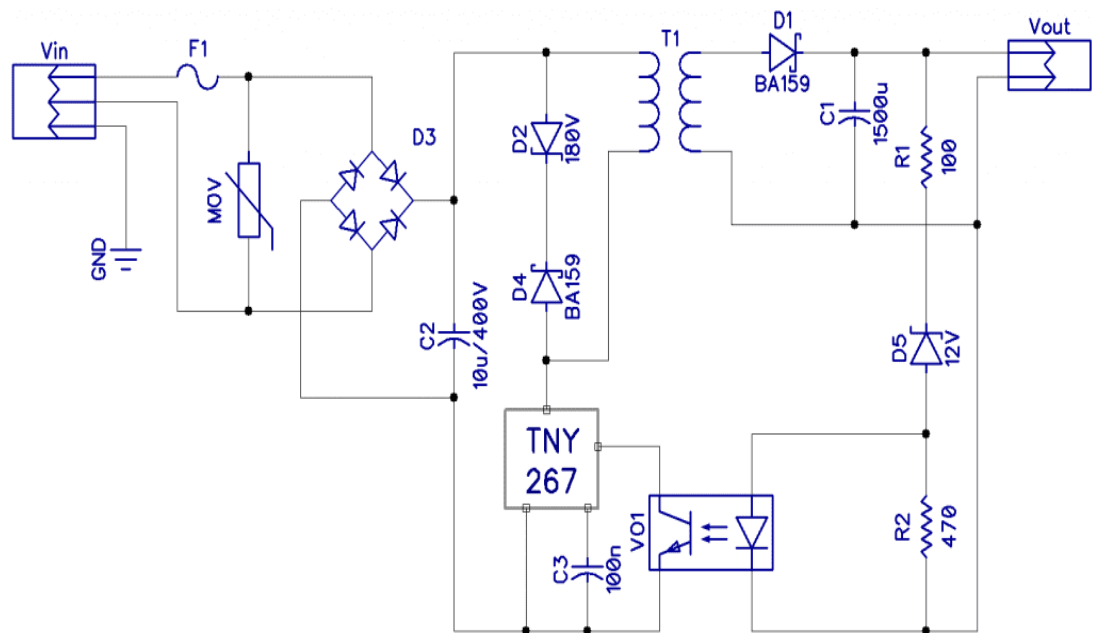


Figure 3.2: SMPS Circuit Design

Basic working concept of an SMPS

A switching regulator does the regulation in the SMPS. A series switching element turns the current supply to a smoothing capacitor on and off. The voltage on the capacitor controls the time the series element is turned. The continuous switching of the capacitor maintains the voltage at the required level.

Design basics

AC power first passes through fuses and a line filter. Then it is rectified by a full-wave bridge rectifier. The rectified voltage is next applied to the power factor correction (PFC) pre-regulator followed by the downstream DC-DC converter(s).

Most computers and small appliances use the International Electro technical Commission (IEC) style input connector. As for output connectors and pin outs, except for some industries, such as PC and compact PCI, in general, they are not standardized and are left up to the manufacturer.

There are different circuit configurations known as topologies, each having unique characteristics, advantages and modes of operation, which determines how the input power is transferred to the output. Most of the commonly used topologies such as fly back, push-pull, half bridge and full bridge, consist of a transformer to provide isolation, voltage scaling, and multiple output voltages. The non-isolated configurations do not have a transformer and the power conversion is provided by the inductive energy transfer.

Advantages of switched-mode power supplies:

- Higher efficiency of 68% to 90%
- Regulated and reliable outputs regardless of variations in input supply voltage
- Small size and lighter
- Flexible technology
- High power density

Disadvantages:

- Generates electromagnetic interference
- Complex circuit design
- Expensive compared to linear supplies

Switched-mode power supplies are used to power a wide variety of equipment such as computers, sensitive electronics, battery-operated devices and other equipment requiring high efficiency

Switch Mode Power Supply

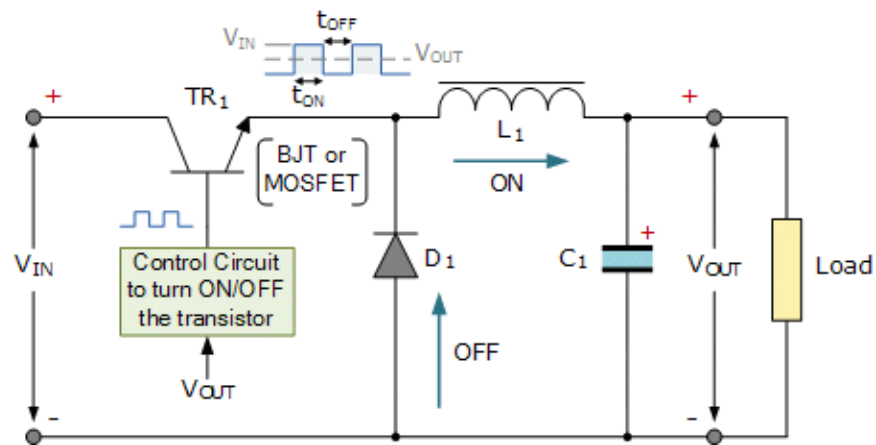


Figure 3.3: Power Supply Connection

Linear voltage IC regulators have been the basis of power supply designs for many years as they are very good at supplying a continuous fixed voltage output. Linear voltage regulators are generally much more efficient and easier to use than equivalent voltage regulator circuits made from discrete components such as a zener diode and a resistor, or transistors and even op-amps. The most popular linear and fixed output voltage regulator types are by far the positive output voltage series, and the 79 negative output voltage series. These two types of complementary voltage regulators produce a precise and stable voltage output ranging from about 5 volts up to about 24 volts for use in many electronic circuits.

There is a wide range of these three-terminal fixed voltage regulators available each with its own built-in voltage regulation and current limiting circuits. This allows us to create a whole host of different power supply rails and outputs, either single or dual supply, suitable for most electronic circuits and applications. There are even variable voltage linear regulators available as well providing an output voltage which is continually variable from just above zero to a few volts below its maximum voltage output.

Most D.C. power supplies comprise of a large and heavy step-down mains transformer, diode rectification, either full-wave or half-wave, a filter circuit to remove any ripple content from the rectified D.C. producing a suitably smooth D.C. voltage, and some form of voltage regulator or stabilizer circuit, either linear or

switching to ensure the correct regulation of the power supplies output voltage under varying load conditions. Then a typical D.C. power supply would look something like this:

Typical DC Power Supply

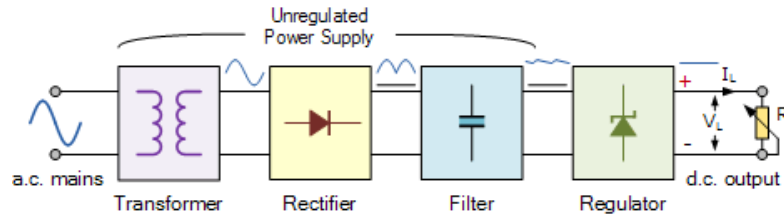


Figure 3.4: DC Power Supply Step

These typical power supply designs contain a large mains transformer (which also provides isolation between the input and output) and a dissipative series regulator circuit. The regulator circuit could consist of a single zener diode or a three-terminal linear series regulator to produce the required output voltage. The advantage of a linear regulator is that the power supply circuit only needs an input capacitor, output capacitor and some feedback resistors to set the output voltage.

3.3 Heat Exchanger

A heat exchanger is a system used to transfer heat between a source and a working fluid. Heat exchangers are used in both cooling and heating processes. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine 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.



Figure 3.5: Gear Exchanger Tube

Types

Double pipe heat exchangers are the simplest exchangers used in industries. On one hand, these heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. On the other hand, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube or plate. However, since double pipe heat exchangers are simple, they are used to teach heat exchanger design basics to students as the fundamental rules for all heat exchangers are the same.

1. Double-pipe heat exchanger

(a) When the other fluid flows into the annular gap between two tubes, one fluid flows through the smaller pipe. The flow may be a current flow or parallel flow in a double pipe heat exchanger.

(b) Parallel flow, where at the same point, the hot and cold liquids join, flow in the same direction and exit at the same end.

(c) Counter flow, where at opposite ends, hot and cold fluids join, flow in the opposite direction and exit at opposite ends.

The figure above illustrates the parallel and counter-flow flow directions of the fluid exchanger. If this is done under comparable conditions, more heat is transferred to the counter-flow device than to the parallel flow heat exchanger. Owing to the large temperature differential arising from the high thermal voltage, the temperature profiles of the two heat exchangers display two significant disadvantages in the parallel-flow design. Which indicates that the partnership is a distinct disadvantage if

it is intended a design is to increase the cold fluid temperature. Where two fluids are expected to be taken to exactly the same temperature, the parallel flow configuration is beneficial. While the counter flow heat exchanger has more significant advantages compared to parallel flow design. Where it can reduce thermal stress and produce more uniform rate of heat transfer.

2. Shell-and-tube heat exchanger

In a shell-and-tube heat exchanger, two fluids at different temperatures flow through the heat exchanger. One of the fluids flows through the tube side and the other fluid flows outside the tubes, but inside the shell (shell side).

Baffles are used to support the tubes, direct the fluid flow to the tubes in an approximately natural manner, and maximize the turbulence of the shell fluid. There are many various kinds of baffles, and the choice of baffle form, spacing, and geometry depends on the allowable flow rate of the drop in shell-side force, the need for tube support, and the flow-induced vibrations. There are several variations of shell-and-tube exchangers available; the differences lie in the arrangement of flow configurations and details of construction.

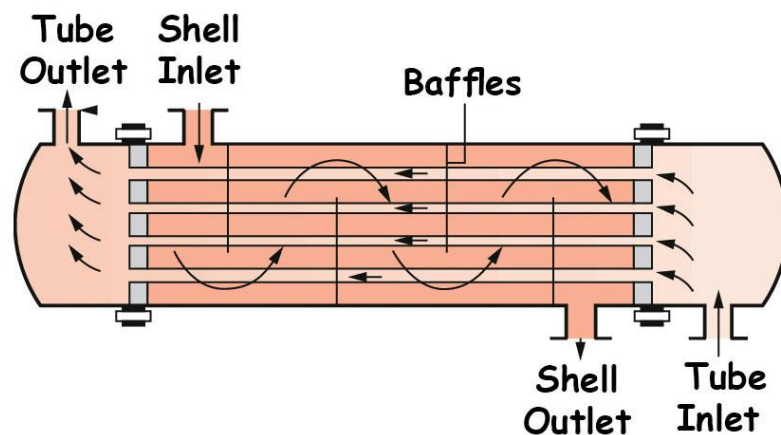


Figure 3.6: Heat Exchanger Tube inside view

3.4 Digital Thermometer

A thermometer is a device that measures temperature or a temperature gradient (the degree of hotness or coldness of an object). A thermometer has two important elements: (1) a temperature sensor (e.g. the bulb of a mercury-in-glass thermometer or the pyrometric sensor in an infrared thermometer) in which some change occurs with

a change in temperature; and (2) some means of converting this change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer or the digital readout on an infrared model). Thermometers are widely used in technology and industry to monitor processes, in meteorology, in medicine, and in scientific research. Four temperature sensors are used to measure hot inlet, hot outlet, cold inlet, and cold outlet temperatures.

Specification

| | |
|-------------------|-----------------------------------------|
| Temperature range | -50~ +110°C |
| Using environment | Temperature: -5~ +50°C Humidity: 5%~80% |
| Accuracy | ±1°C |
| Size | 47*28*14mm |
| Weight | 22g |
| Color | Black and white |

Table 2: Specification of Termometer Temperature Sensor



Figure 3.7: Digital Temperature Sensor

Some of the principles of the thermometer were known to Greek philosophers of two thousand years ago. As Henry Carrington Bolton (1900) noted, the thermometer's "development from a crude toy to an instrument of precision occupied more than a century, and its early history is encumbered with erroneous statements that have been reiterated with such dogmatism that they have received the false stamp of authority." The Italian physician Santorio Santorio (Sanctorius, 1561-1636) is commonly credited with the invention of the first thermometer, but its standardization was completed through the 17th and 18th centuries. In the first decades of the 18th century in the Dutch Republic, Daniel Gabriel Fahrenheit made two revolutionary breakthroughs in the history of thermometry. He invented the mercury-in-glass thermometer (first widely used, accurate, practical thermometer) and Fahrenheit scale (first standardized temperature scale to be widely used).

3.5 Pump Motor

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy. Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers and other components of heating, ventilation and air conditioning systems. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.



Fig. 3.8: water Pump.

Specification

| | |
|-----------------------|---------------------------------------------------------|
| Material | ABS (Acrylonitrile Butadiene Styrene) + Stainless Steel |
| Overall Size | Approx. 80 x 48 x 63mm/3.15 x 1.89 x 2.48" |
| Pump Inlet Diameter | 16mm(Outer), 12mm(Inner) |
| Pump Outlet Diameter | 12mm(Outer), 6.9mm(Inner) |
| Inlet/Outlet | 1/2" male thread |
| Voltage | 6-12V DC |
| Maximum Rated Current | 1.2A |
| Power | 16.8W |
| Max Flow Rate | 700 L/H |

Table 3 : Specification of Pump Motor

3.6 Copper Pipe

Copper pipes are commonly used for exchange heat to the another medium in the construction industry for water supply lines and refrigerant lines in HVAC(heating, cooling and air-conditioning) systems. Copper pipes can be manufactured as soft or rigid copper and offer excellent corrosion-resistance and reliable connections.



Figure 3.9: Copper Pipe

3.7 Water Heater

A water heater is a device that used to heat water or fluid. In this experiment water heater is used to heat up the water of hot cycle. Water heating is a heat transfer process that uses an energy source to heat water above its initial temperature. Typical domestic uses of hot water include cooking, cleaning, bathing, and space heating. In industry, hot water and water heated to steam have many uses.



Fig. 3.10: Water heater

Domestically, water is traditionally heated in vessels known as water heaters, kettles, cauldrons, pots, or coppers. These metal vessels that heat a batch of water do not produce a continual supply of heated water at a preset temperature. Rarely, hot water occurs naturally, usually from natural hot springs. The temperature varies with the consumption rate, becoming cooler as flow increases.

3.8 Proteus Software

The Proteus Design Suite is a proprietary software tool suite used primarily for electronic design automation. The software is used mainly by electronics design engineers and technicians to create schematics and electronics prints for manufacturing printed circuit boards.

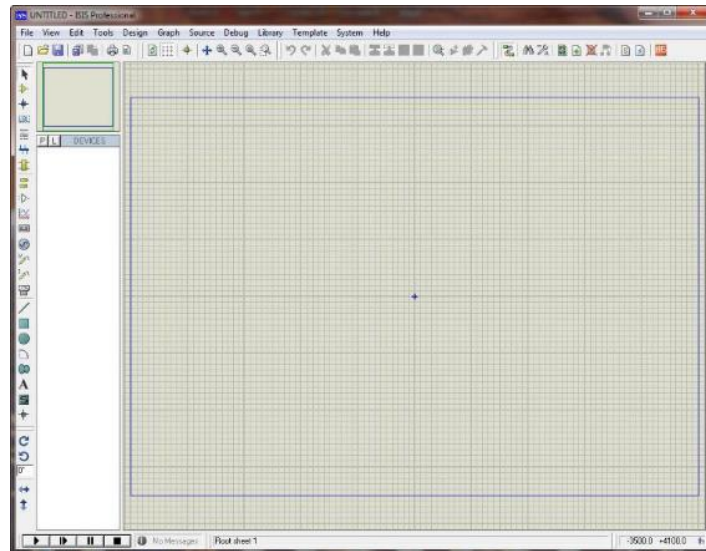


Figure 3.11: Proteus Software Interface

The first version of what is now the Proteus Design Suite was called PCB and was written by the company chairman, John Jameson, for DOS in 1988. Schematic Capture support followed in 1990 with a port to the Windows environment shortly thereafter. Mixed mode SPICE Simulation was first integrated into Proteus in 1996 and microcontroller simulation then arrived in Proteus in 1998. Shape based auto routing was added in 2002 and 2006 saw another major product update with 3D Board Visualization. More recently, a dedicated IDE for simulation was added in 2011 and MCAD import/export was included in 2015. Support for high speed design was added in 2017. Feature led product releases are typically biannual, while maintenance based service.

CHAPTER 4

EXPERIMENTAL DESIGN

4.1 Our methodologies for the project

Our methodologies for the project:

- Creating an idea for design and construction of **Design and Performance Analysis of a counter flow Heat Exchanger Using Industrial Waste Hot Water**. And designing a block diagram & circuit diagram to know which components we need to construct it.
- Collecting all the components and programming the micro-controller to control the whole system.
- Setting up all the components in a PCB board & then soldering. Lastly, assembling all the blocks in a board and to run the system & for checking purposes.

4.2 Heat exchanger

Heat exchanger may be defined as an equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running cost. The rate of transfer of heat depends on the conductivity of the dividing wall and convective heat transfer coefficient between the wall and fluids. The heat transfer rate also varies depending on the boundary conditions such as adiabatic or insulated wall conditions. Some examples of heat exchangers are:

- I. Intercoolers and pre heaters;
- ii. Condensers and boilers in refrigeration units;
- iii. Condensers and boilers in steam plant;
- iv. Regenerators;
- v. Oil coolers and heat engines;
- vi. Automobile radiators etc.

4.3 Classification of heat exchangers

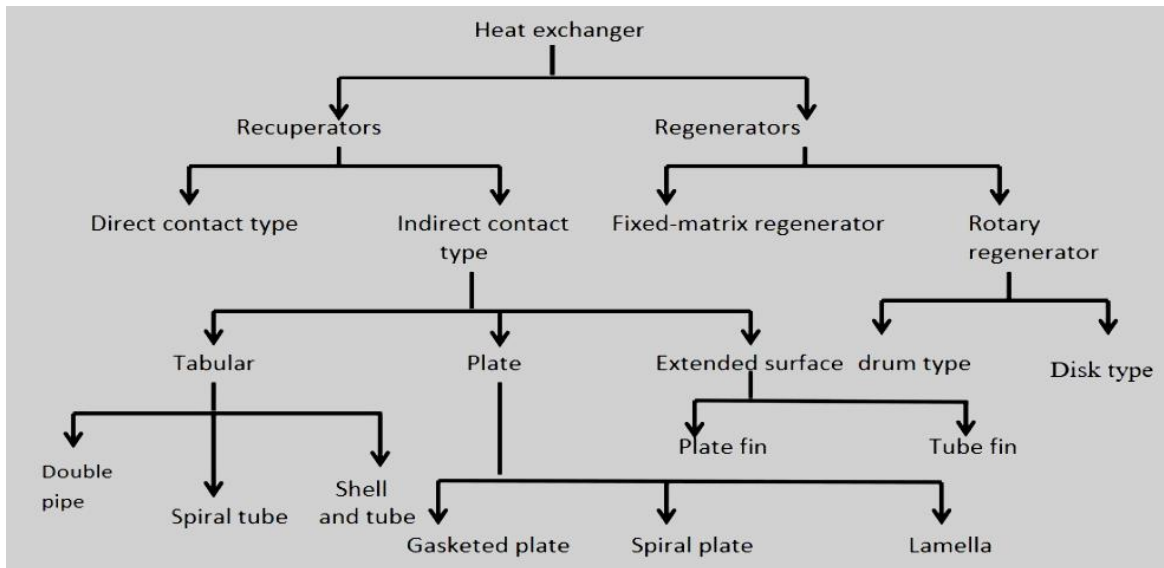


Figure 4.1: Classification of Heat Exchanger

4.4 Tabular heat exchanger

These kinds of heat exchangers are mainly made up of circular coils whereas many different shapes are also used for different applications. They provide flexibility because the geometric parameters such as length, diameter can be modified easily. These are used for phase change such as condensation, evaporation kind of operations. Again it is classified in to three different categories i.e. double pipe heat exchanger, spiral tube heat exchanger and shell and tube heat exchanger.

4.5 Double pipe heat exchanger

These are the simplest heat exchangers used in industries. These heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. In this kind of heat exchanger, two tubes or pipes having different diameters are placed concentrically, the smaller one inside the larger one. The two fluids, in between which heat transfer is required, flows in the two different tubes. The curvature of the tube gives rise to a secondary flow which makes the flow turbulent and increases the heat transfer rate.

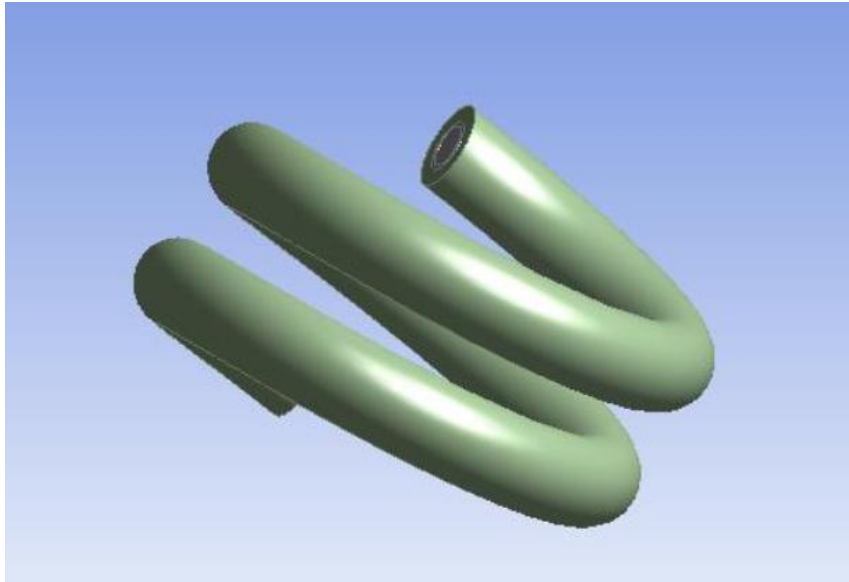


Figure: 4.2 Double Pipe

The utilization, conversion, and recovery of energy in commercial, industrial, and domestic applications usually involve a heat transfer process such as refrigerator, air conditioner etc. Improved quality of heat exchanger above the usual practice can significantly improve the thermal efficiency as well as the economics of their design and production. It has been observed that heat transfer rate in helical coils heat exchanger are higher than that of a straight tube. They are also compact in size. For this helical coil heat exchangers are being widely used in many industrial applications such as nuclear industries, power generation process plants, refrigeration, heat recovery systems, food industries, etc. The reason behind higher heat transfer rate of helical heat exchanger is that, due to the swirl flow in a coiled tube, centrifugal forces arises which gives rise to secondary flow pattern. It consists of two vertices perpendicular to the axial flow direction. As a result, the heat transfer takes place by diffusion in the radial direction and by convection. The contribution of the convective heat transfer dominates the overall process and significantly enhances the heat transfer rate per unit length of the tube, as compared to the heat transfer rate of a straight tube of equal length. Also, the coiled tube heat exchanger can provide a larger heat transfer area per unit volume having compact size.

4.6 System Design and Components

The system is designed using a double pipe heat exchanger to analyze heat transfer between hot and cold water. Hot water flows through the inner copper tube and cold water flows through the outer pipe in a counter flow arrangement. Separate hot water inlet and outlet tanks are used to ensure proper temperature measurement. Pumps circulate the fluids continuously, and temperature sensors are placed at the inlet and outlet of both fluids for performance evaluation.

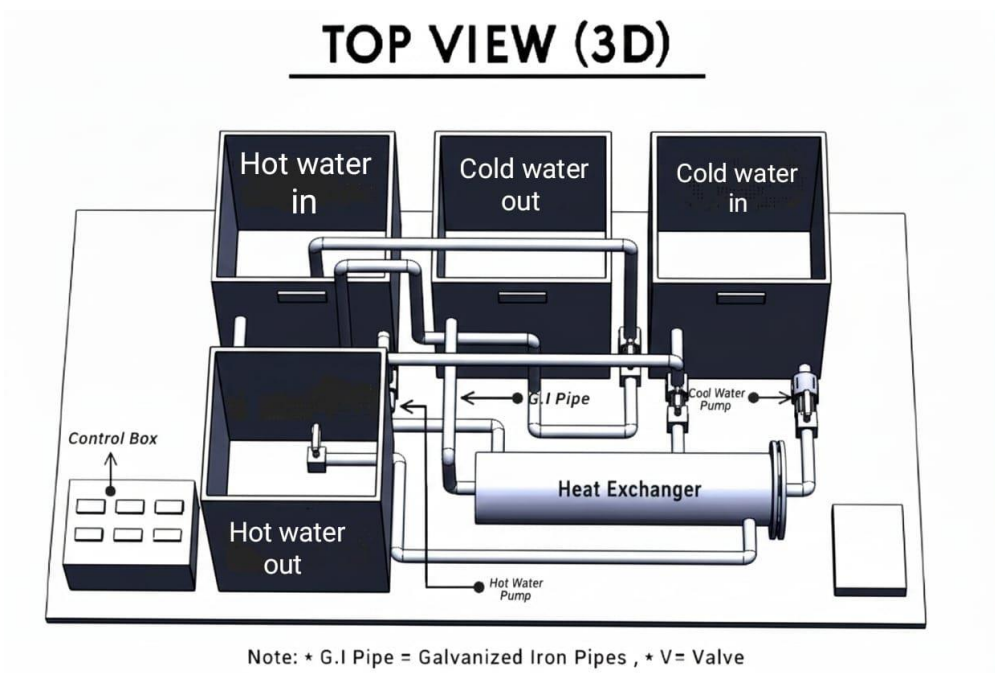


Figure 4.3: System Design Top View

4.7 Block Diagram

In this diagram we will show by block the individual parts.

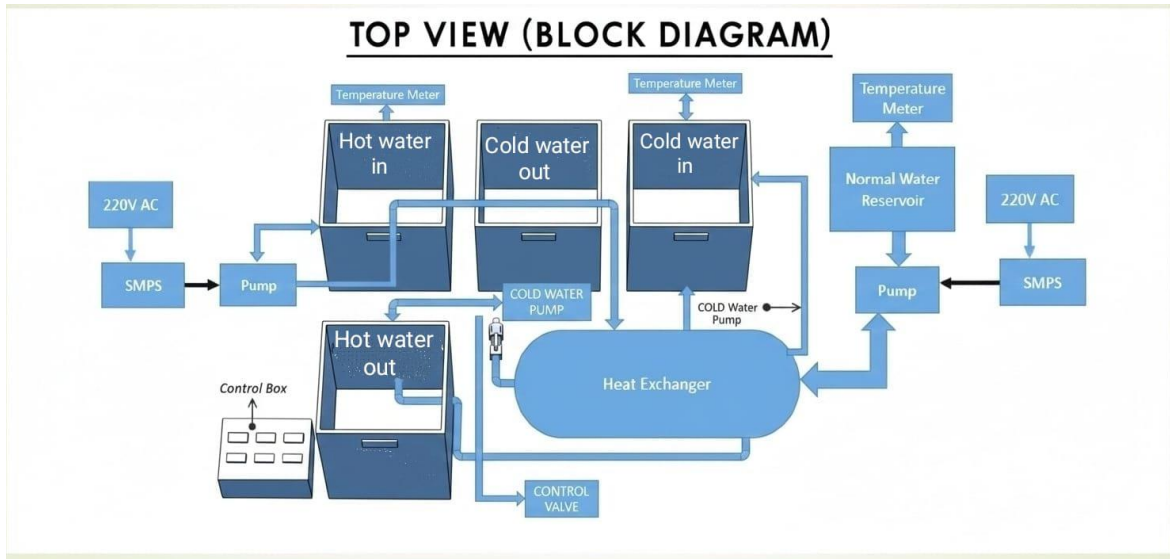


Figure 4.5: Block Diagram

4.8 Heat Exchanger Flow Configurations

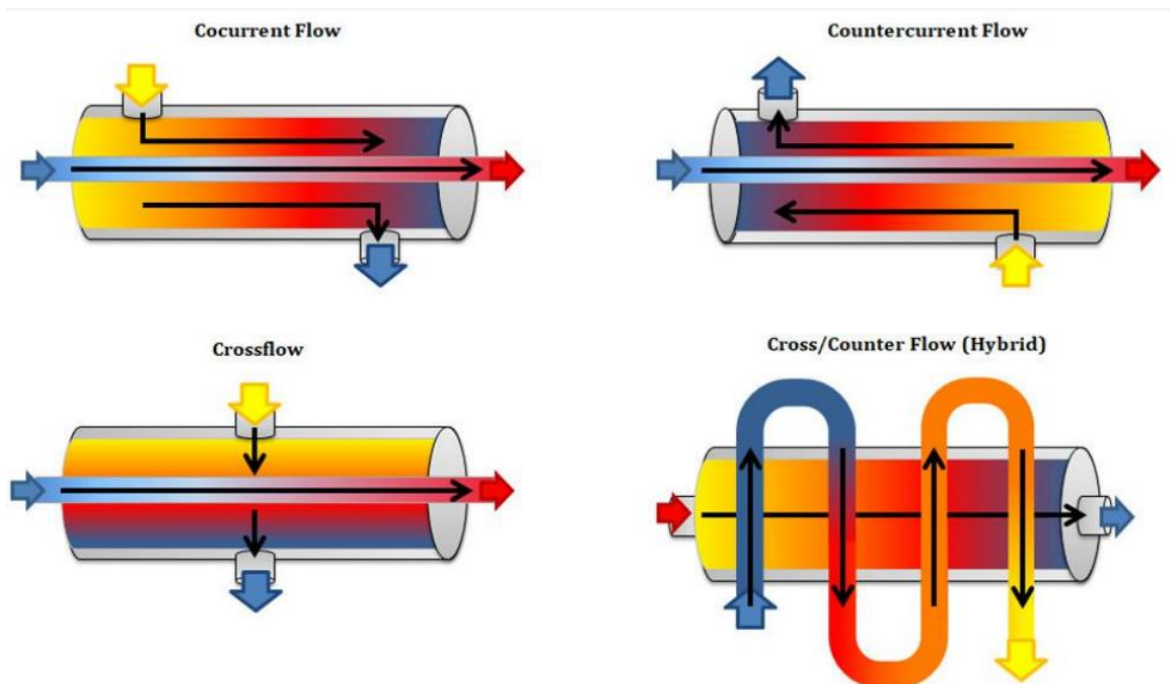


Figure 4.6: Heat Exchanger Flow Configuration

Counter Flow

Counter flow heat exchangers use flows in the opposite direction of each other. Shell and tube, and double pipes heat exchangers are examples of common exchangers using counter flow configurations. The best design for shell and tube and double-pipe exchanger is counter flow configuration, and the heat transfer between the fluid is the maximum. In counter flow, the efficiency is higher than the parallel, and temperature in the cooling fluid outlet can exceed the warmer fluid inlet temperature.

Parallel Flow

A parallel flow heat exchanger is a type of exchanger having a parallel fluid direction. In other words, the fluids having a high temperature and a cold temperature both move towards the same direction through separate tubes, which allows the heat to be transferred from a high-temperature liquid to a low-temperature liquid.

This process is less efficient compared to the counter flow method because this process cannot absorb a maximum amount of temperature from the warm liquid. This is because when the two liquids move in the same direction, the temperature difference between the two liquids becomes gradually low. However, this method is important when the flows at the outlet have a similar temperature together, and we also need these flows to have a closely similar temperature

4.9 Schematic Design Analysis

The schematic diagram here is representing the electrical circuit and the components of our System. Here we connect equipment with the smart wire connection.

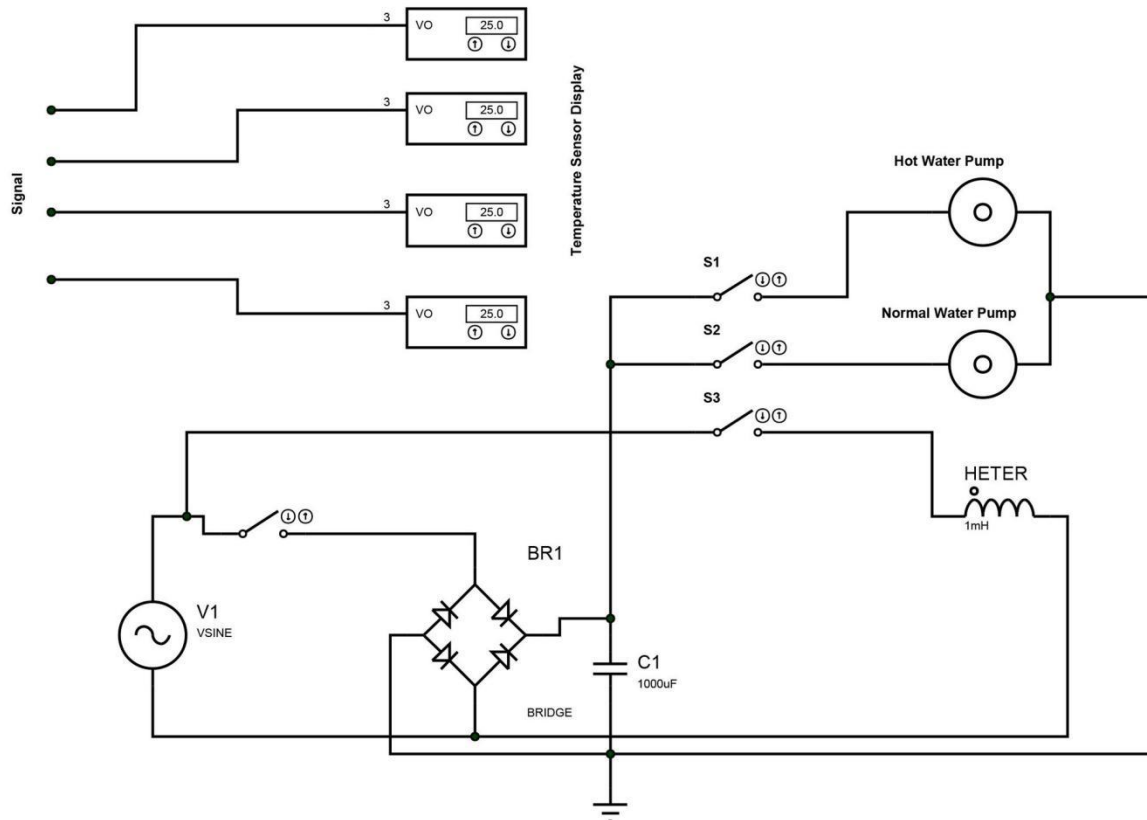


Figure 4.7: Schematic Design of our system

4.10 Working Principle

The working principle of this project is based on heat transfer through a counter flow heat exchanger. Industrial waste hot water flows through a GI pipe, while normal cold water flows simultaneously in the opposite direction through a copper tube placed inside the same cylindrical shell. As both fluids move in counter flow, a temperature gradient is maintained along the entire length of the heat exchanger. Heat is transferred from the higher-temperature waste water to the lower-temperature normal water through the pipe walls by conduction and then distributed by convection within each fluid. There is no direct mixing between the two water streams. As a result, the waste hot water leaves the system at a reduced temperature, while the normal water exits at an increased temperature. This continuous counter flow arrangement ensures efficient heat transfer and maximum utilization of waste thermal energy.

4.11 Experimental Setup of Our System

Here is our structural setup of our design is given below -

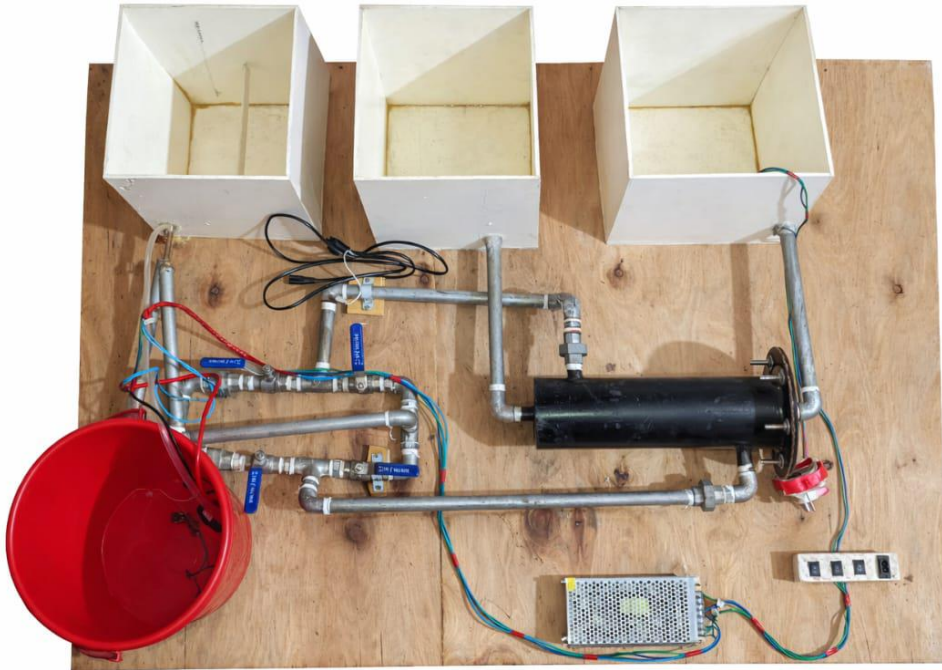


Figure 4.8: Complete Project prototype

CHAPTER 5

RESULT AND DISCUSSION

5.1 Discussion

While working on our project, we did face some difficulties as it is a very complex system but the end results, we came up with were quite satisfactory. We have put the whole system through several tasks to validate our work and also have taken necessary notes for future improvements. Some future recommendations that we have involves improvement in system design and wiring, adding features for more efficient.

5.2 Result Analysis

Energy Saving Calculation:

Cold water inlet temperature, $T_{c,in} = 23\text{ }^{\circ}\text{C}$

Cold water outlet temperature, $T_{c,out} = 28\text{ }^{\circ}\text{C}$

Cold water mass flow rate, $m_c = 0.167\text{ kg/s}$

Specific heat of water, $C_{pc} = 4.18\text{ kJ/kg}\cdot\text{K}$

Pump power consumption = $16.8\text{ W} = 0.0168\text{ kW}$

Now,

Cold water temperature rise;

$$\Delta T = T_{c,out} - T_{c,in} = 28 - 23 = 5^{\circ}\text{C}$$

$$Q = m_c \times C_{pc} \times \Delta T$$

$$Q = 0.167 \times 4.187 \times 5$$

$$Q = 3.49\text{ kW}$$

Net energy saving = Recovered thermal energy – Pump power

$$= 3.49 - 0.0168$$

$$\approx 3.47 \text{ kW}$$

Hourly Energy Saving:
 Energy saved per hour = 3.47 kWh

Conclusion:

The proposed heat exchanger system effectively recovers waste heat and significantly reduces the requirement of external heating energy. Even after considering pump power consumption, the system achieves a net energy saving of approximately 3.47 kW, demonstrating its effectiveness as a waste heat recovery solution.

Data Table:

| Parameter | 1 min (°C) | 5 min (°C) | 10 min (°C) | Average (°C) |
|-------------------|------------|------------|-------------|--------------|
| Cold Water Inlet | 23 | 23 | 23 | 23 |
| Cold Water Outlet | 27.5 | 28.0 | 28.5 | 28 |
| Hot Water Inlet | 60 | 60 | 60 | 60 |
| Hot Water Outlet | 33.5 | 32.5 | 32.0 | 32 |

The inlet temperatures of hot and cold water were maintained constant throughout the experiment. Outlet temperatures were recorded at different time intervals and the average values were used for performance analysis and energy saving calculations.

$$T_{h,in} = 60^{\circ}\text{C}$$

$$T_{h,out} = 32^{\circ}\text{C}$$

$$T_{c,in} = 23^{\circ}\text{C}$$

$$T_{c,out} = 28^{\circ}\text{C}$$

Log Mean Temperature Difference (LMTD) For Counter Flow:

$$\Delta T_1 = T_{h,in} - T_{c,out} = 60 - 28 = 32^{\circ}\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 32 - 23 = 9^{\circ}\text{C}$$

$$\text{LMTD} = (32 - 9) / \ln(32/9) = 23 / 1.268 \approx 18.14^{\circ}\text{C}$$

Ans= 18.14°C

$$T_{h,in} = 60^{\circ}\text{C}$$

$$T_{h,out} = 32^{\circ}\text{C}$$

$$T_{c,in} = 23^{\circ}\text{C}$$

$$T_{c,out} = 28^{\circ}\text{C}$$

Log Mean Temperature Difference (LMTD) For Parallel Flow:

$$\Delta T_1 = T_{h,in} - T_{c,in} = 60 - 23 = 37^{\circ}\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,out} = 32 - 28 = 4^{\circ}\text{C}$$

$$\text{LMTD} = (37 - 4) / \ln(37 / 4)$$

$$= 33 / 2.225$$

$$\approx 14.83^{\circ}\text{C}$$

Ans = 14.83°C

Comparison Table

| Parameter | Counter Flow | Parallel Flow |
|-------------------|---------------------|----------------------|
| ΔT_1 (°C) | 32 | 37 |
| ΔT_2 (°C) | 9 | 4 |
| LMTD (°C) | 18.14 | ≈14.7 |

Counter flow heat exchanger is more effective than parallel flow because the temperature difference between hot and cold fluids is maintained along the entire length of the exchanger. In parallel flow, both fluids move in the same direction, so the temperature difference is high only at the inlet and quickly decreases, reducing heat transfer in the remaining length. In counter flow, hot fluid always meets colder fluid, which keeps the average temperature difference (LMTD) higher. As a result, counter flow heat exchangers transfer more heat and give better thermal performance than parallel flow.

5.3 Diagram

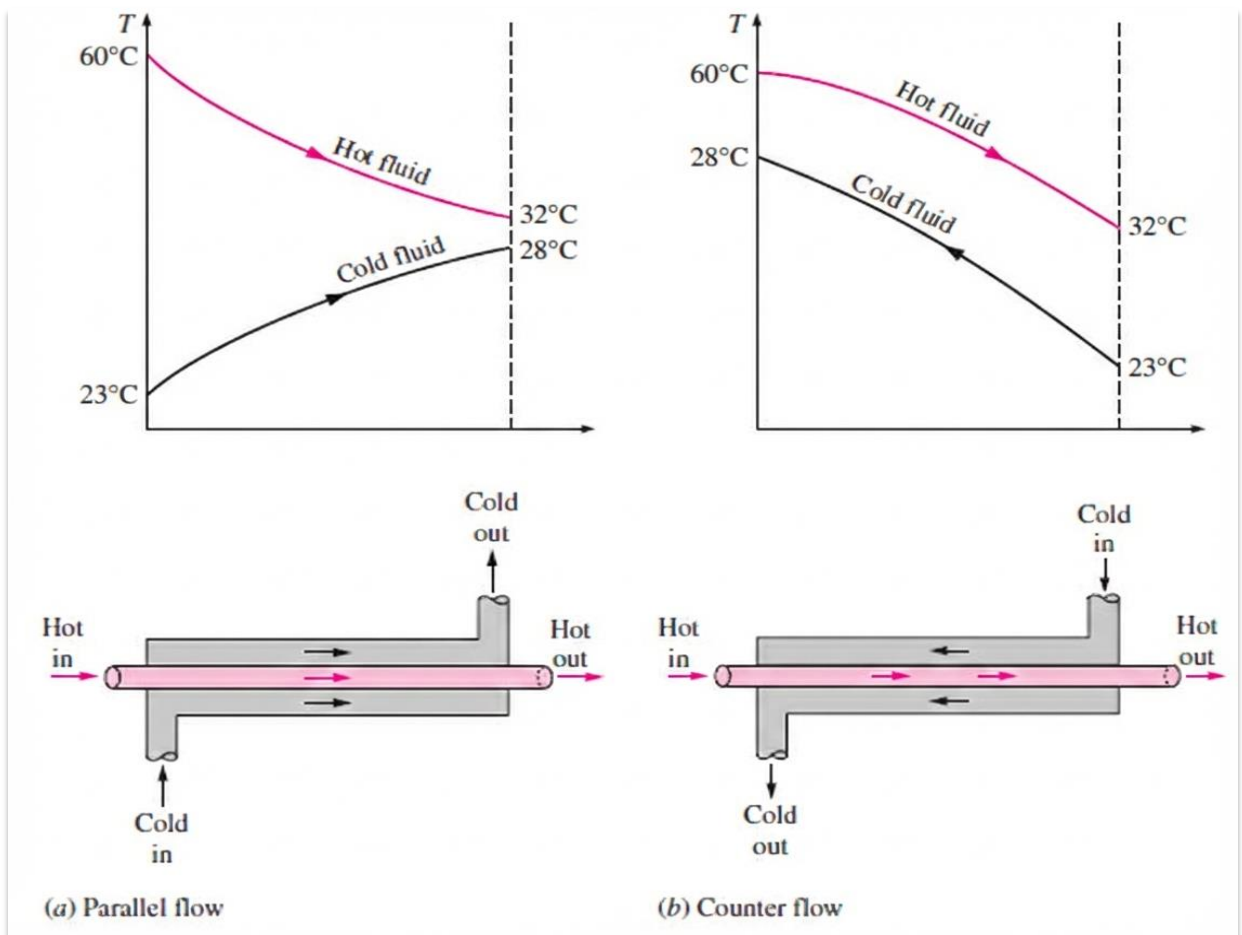


Figure 4.9: Parallel and Counter flow

Heat Transfer Rate, [Q] For Counter Flow:

$$Q = U A \Delta T_{lm}$$

- Q = Heat transfer rate ?
- U = Overall heat transfer coefficient = 1100 W/m²K
- A = Heat transfer area=0.000546m²
- ΔT_{lm} = Log Mean Temperature Difference (LMTD)= 18.14°C

Heat Transfer Area (A)

$$A = \pi \times D \times L$$

$$D = \text{pipe outer diameter} = 6 \text{ mm} = 0.006 \text{ m}$$

$$A = \pi \times 0.006 \times 0.029$$

$$L = \text{pipe length} = 29 \text{ mm} = 0.029 \text{ m}$$

$$\approx 0.000546 \text{ m}^2$$

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

$$= 1100 \times 0.000546 \times 18.14$$

$$= 1100 \times 0.000546 \times 18.14$$

$$= 1100 \times 0.000546 \times 18.14$$

$$= 10.9 \text{ W}$$

Heat Transfer Rate, [Q] For Parellel Flow:

$$Q = U A \Delta T_{lm}$$

$$= 1100 \times 0.000546 \times 14.84$$

$$= 1100 \times 0.000546 \times 14.84$$

$$= 1100 \times 0.000546 \times 14.84$$

$$= 8.91 \text{ W}$$

5.4 Advantages

There are certainly many advantages of our project and some of the major ones have been given below:

- Do not waste time.
- Very Cost Effective.
- Very fast heat exchange can be done.
- Recycle the water in a manner.
- More accuracy.
- Can usable in any area of Water Recycling

5.5 Application

Our project has many application areas and actually we need to use it in many places to verified the exact person which have the proper access. Some of the application areas of the project has been pointed out below:

- Ensuring quality control in mass production.
- By some modification it can be used to control the water cooling.
- By some modification it can be used to measure the weight of the water.
- By increasing its pipe capacity, it can be used in industry's.
- It is also very useful in laboratories and workshops.
- It's can be widely used any productive industry.

5.6 Precautions and Safety measures:

- To be careful and to wear hand gloves due to protect possible electric shock.
- To be check every pipe joints for possible water leakage.
- Carefully open and close the valves for various flow.
- Carefully note down temperature meter readings.
- To be careful about electricity leakage into water.
- Carefully handle with hot water

CHAPTER 6

CONCLUSION

6.1 Conclusion

This project demonstrates that industrial waste hot water can be effectively reused through a counter flow heat exchanger system. Experimental results show that waste hot water entering at 60°C is cooled to 32°C, while normal water temperature increases from 23°C to 28°C without any external energy input. The calculated Log Mean Temperature Difference (LMTD) of approximately 18°C confirms satisfactory thermal performance of the system. In waste heat recovery applications, an LMTD in the range of 8–20°C is generally considered acceptable, while values between 10–15°C indicate efficient heat transfer. An LMTD higher than 20°C usually suggests an oversized system or an excessively large temperature difference, whereas values below 8°C indicate poor heat transfer performance. Therefore, the obtained LMTD lies within the acceptable and practical operating range, validating the effectiveness of the counter flow arrangement. By recovering low-grade waste heat, the system can reduce fuel consumption, heating time, and operational costs in industrial processes. Overall, the proposed system offers a simple, reliable, and energy-efficient solution that supports sustainable energy utilization in industries.

6.2 Future Scope

- The heat exchanger length and heat transfer surface area can be increased to enhance heat recovery.
- Flow rates of both hot and cold water can be optimized to improve LMTD and overall efficiency.
- Alternative materials and tube configurations can be investigated to improve durability and reduce cost.
- Long-term studies can be conducted to evaluate the effects of fouling and corrosion on performance.
- The system can be scaled up and implemented in actual industrial settings for practical waste heat recovery.

REFERENCES

- [1] A.P. Frass and M. N. Ozisik, Heat Exchanger Design, Wiley, New York, 1965.
- [2] G. Walker, Industrial Heat Exchangers, Hemisphere, Washington, 1982.
- [3] S. Kakac, R. K. Shah and A. E. Bergles (eds), Low Reynolds Number Flow Heat Exchangers, Hemisphere, Washington, 1982.
- [4] M. N. Ozisik, Heat Transfer - A Basic Approach, McGraw-Hill Book Company, International edition, 1985.
- [5] J. P. Holman, Heat Transfer, McGraw-Hill Book Company, 10th Edition, 2009.
- [6] V. V. P. Dubey and R. Rajat, "Performance Analysis of Shell and Tube Type Heat Exchanger Under The Effect of Varied Operating Condition", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 11, no. 3, Ver. VI, pp. 08-17, 2014.
- [7] Y. A. Kara and O. Guraras, "A computer program for designing of Shell and tube heat exchanger", Applied Thermal Engineering, vol. 24, no. 13, pp. 1797–1805, 2004.
- [8] M. V. Rane and M. S. Tandale, "Water-to-water heat transfer in tube–tube heat exchanger: Experimental and analytical study", Applied Thermal Engineering, vol. 25, no. 17-18, pp. 2715-2729, 2005.
- [9] K. M. Lunsford, "Increasing Heat Exchanger Performance", Bryan Research and Engineering, Inc. - Technical Papers, Hydrocarbon Engineering, 1998.
- [10] Y. Yao, X. Zhang and Y. Guo, "Experimental Study on Heat Transfer Enhancement of Water-water Shell-and- Tube Heat Exchanger Assisted by Power Ultrasonic", in Proc. of the International Refrigeration and Air Conditioning Conference, School of Mechanical Engineering, Purdue University, July 12-15, 2010, paper-1110.
- [11] M. D. Alam, S. T. Hossain, M. H. S. Simanto, M. S. U. Mithu and M. A. Islam, "Experimental and Numerical Investigation of an Air to Water Heat Exchanger", in Proc. of the 3rd International Conference on Mechanical, Industrial and Energy Engineering, Khulna, Bangladesh, Dec 26-27, 2014, paper-140305.