EXPERIMENTAL CONSTRUCTION AND ANALYSIS OF HEAT EXCHANGER

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Declaration

It is declared hereby that this thesis paper or any part of it has not been submitted to anywhere else for the award of any degree.

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ABSTRACT

Heat exchanger is equipment used to transfer heat from one fluid to another. It has extensive domestic and industrial applications. Extensive technical literature is available on heat exchanger design, operation and maintenance, but it is widely scattered throughout the industrial bulletins, industrial design codes and standard, technical journals, etc. The purpose of this book chapter is to consolidate into basic background and concepts design of heat exchangers, operation, cleaning and green technology maintenance on heat exchanger closely related to the industrial practices. A shell and tube heat exchanger model is presented in this paper. By this experiment, it is possible to know the features of heat exchanger as well as different kind of materials which are most commonly used as tube materials. In this thesis, a comparison between overall heat transfer coefficient for copper and aluminum tube heat exchanger has been presented. The model structure, its range of validity and accuracy are described in detail.

CHAPTER 1

INTRODUCTION

1.1 Background:

Heat exchangers play an important role in the performance of thermal machines, namely, electric power generators, engines and refrigerators. Regarding thermoelectric, this influence is even higher, owing to the difficulty of transferring heat from the small surface area of a typical thermoelectric module to a bigger one. Particularly, in the hot face of an average 40 mm x 40 mm Peltier module, the heat flux readily yields 40600 W/m2. The thermoelectric effects, namely, Joule, *Seebeck*, Peltier and Thomson, describe the interaction between thermal and electric fields, and are well known since the XIX century (Rowe, 2006).

German physicist Thomas J. *Seebeck* discovered in 1821 that an electric circuit composed of two dissimilar conductors A and B connected electrically in series and exposed to a thermal gradient induces an electric current -or an electromotive force (EAB) if the circuit is opened- which depends on the materials and the temperature difference between junctions (ΔT). This phenomenon is called *Seebeck* effect, characterized by the *Seebeck* coefficient α

.

$$\alpha_{AB} = \frac{\Delta E_{AB}}{\Delta T} = \alpha_A - \alpha_B$$

Likewise, in 1834, French physicist Jean Peltier discovered that if an electrical current (I) is applied across the electric circuit composed of two dissimilar conductors, the inverse effect takes place, that is, heating occurs at one junction whereas cooling occurs at the other. This phenomenon is called Peltier effect, described by the Peltier coefficient π.

$$\dot{Q}_P = \pm I\pi_{AB} = \pm I T(\alpha_B - \alpha_A)$$

In 1851, William Thomson stated the Thomson effect, which indicates that a homogeneous material exposed to thermal and electrical gradients absorbs or generates heat. Moreover, he described the relation between *See beck* and Pelletier effects, given by Thomson coefficient τ.

$$\tau_A - \tau_B = -T\frac{\partial \alpha_A}{\partial T} + T\frac{\partial \alpha_B}{\partial T} = T\frac{\partial}{\partial T}(\alpha_B - \alpha_A)$$

The possibility of using thermoelectric devices to produce electric power was raised by John W. Strutt in 1885. Subsequently, between 1909 and 1911, Edmund Altenkirch proved that thermoelectric materials must feature high *Seebeck* coefficient (α), high electrical conductivity (σ) and low thermal conductivity (λ), in order for the material to retain heat in the junctions and minimize losses due to Joule effect. These three parameters were combined to form the Figure of merit ($Z = \alpha 2\sigma/\lambda$), key parameter in the characterization of thermoelectric materials. By then, further developments had been rejected because of the low efficiencies attained, and it was not until the application of semiconductor materials to thermoelectric devices by Abram F. Ioffe in 1957, that thermoelectric technology contemplated its major breakthrough. Since that moment, scientific efforts focused on increasing the Figure of merit via new thermoelectric materials.

Although the thermoelectric effects were discovered almost two centuries ago, the application of thermoelectric technology to either heating or cooling, and electric power generation was not relevant until the fifties of the last century, when this technology was successfully used for military and aerospace purposes. The application to other fields was then rejected because of the high price of thermoelectric materials, but now has become a reality. In this regard, some in-depth reviews on the state of the art of thermoelectric technology can be found in the literature (Goldsmid, 1964, 1986, 1995; Riffat & Xiaoli, 2003). Nowadays, the successful development of thermoelectrics for civil purposes depends mainly on two aspects: thermoelectric materials development and heat exchangers thermal design. Whereas the first one intends to increase the Figure of merit and efficiency of the devices via new thermoelectric materials, the second one focuses on enhancing the heat transfer via improving the heat exchangers. Thermoelectric technology presents significant advantages with respect to common devices used for refrigeration or electric power generation, since thermoelectric devices have no moving parts (no compressor, turbine, etc. must be installed), which makes them virtually noiseless and increases their lifespan to a great extent. Furthermore, thermoelectric devices are easily and accurately controlled. All these advantages, along with the fact that the prices of Peltier modules are constantly decreasing, boosted the development of highly interesting thermoelectric applications, competing nowadays in the civil market with good prospects for the future (Bell, 2008; Chang et al., 2009; Chein & Huang, 2004; Gordon et al., 2002; Hongxia & Lingai, 2007; Khattab & El Shenawy, 2006; Martínez et al., 2010; Min & Rowe, 1999, 2006; Omer et al., 2001; Riffat et al., 2006; Vian et al., 2002; Vian & Astrain, 2009a, 2009b; Yang & Stabler, 2009; Yodovard et al., 2001). Regarding the last comment, it is common knowledge that efficiency of thermoelectric devices represents the key point to bear in mind, in order for these prospects to become reality. A proper analysis of thermoelectric applications requires detailed studies on heat transfer between the thermoelectric modules, the heat source and the heat sink. In this sense, wrong selection of either the dissipation method (natural or forced convection, thermosiphons, etc.) or the refrigerant (air, water, eutectic fluids, etc.) leads to poor heat transfer and finally to low efficiencies. Although published improvements on heat transfer processes for other fields of knowledge are very common in scientific literature, thermoelectric developers have not been able to use all this information and apply it to the thermoelectric field, though this fact is being corrected nowadays. Thus, several studies have come out recently which address the application of different dissipation techniques to thermoelectric modules (Astrain et al., 2003, 2005, 2010; Knight et al., 1991; Omer et al., 2001; Ritzer & Lau, 1994, 2000; Rowe et al., 1995, Stockholm & Stockholm, 1992; Vian & Astrain, 2008, 2009a). This chapter shows in the first place the influence of heat exchangers on the performance of both thermoelectric generation and thermoelectric refrigeration devices. Then, there are presented different types of heat exchangers specifically designed for dissipating high heat fluxes from the cold and the hot side of thermoelectric devices. After that, the chapter studies the improvement in the efficiency of thermoelectric devices achieved with these heat exchangers. Finally, the concept of thermoelectric self-refrigeration is introduced; this application uses thermoelectric technology for the refrigeration and temperature control of a device, without electricity consumption. Heat transfer continues to be a field of major interest to engineering and scientific researchers, as well as designers, developers, and manufacturers. Considerable effort has been devoted to research in traditional applications such as chemical processing, general manufacturing, energy devices, including general power systems, heat exchangers, and high performance gas turbines.

1.2 Objective:

The proposed system of this project is based on some common and easy step but it gives more progress and usable for any area of water heat exchange process

- The main objective of this project is to design & construct heat exchanger.
- To determine the overall heat transfer coefficient under different flow condition.
- To know about the different characteristics of heat exchanger tube material such as aluminum and copper.
- To compare the overall heat transfer coefficient for aluminum and copper tube heat exchanger.

1.3 Methodology

- Creating an idea for Design and construction of water heat exchange. And designing a block diagram & circuit diagram to know which components need to construct it.
- Collecting the all components and hardware device to controlled the system.
- Assembling the all block in a board and finally run the system & checking.

CHAPTER 2

THERMAL HEAT EXCHANGER

2.1 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.

2.2 Classification of heat exchangers

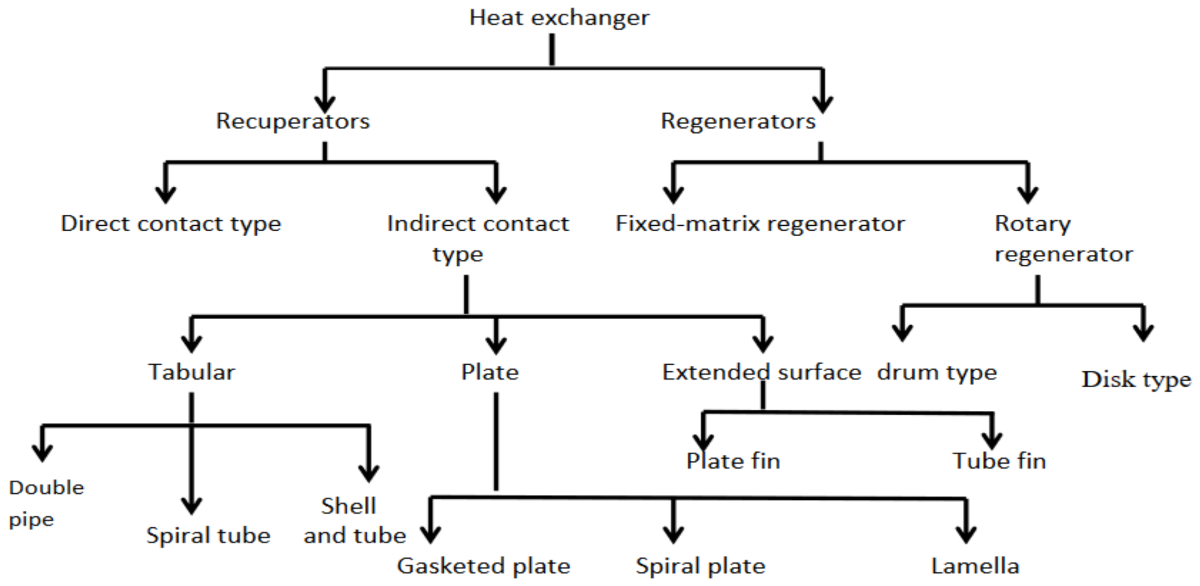

Figure 2.1: Classification of heat exchanger

2.3 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.

2.4 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.

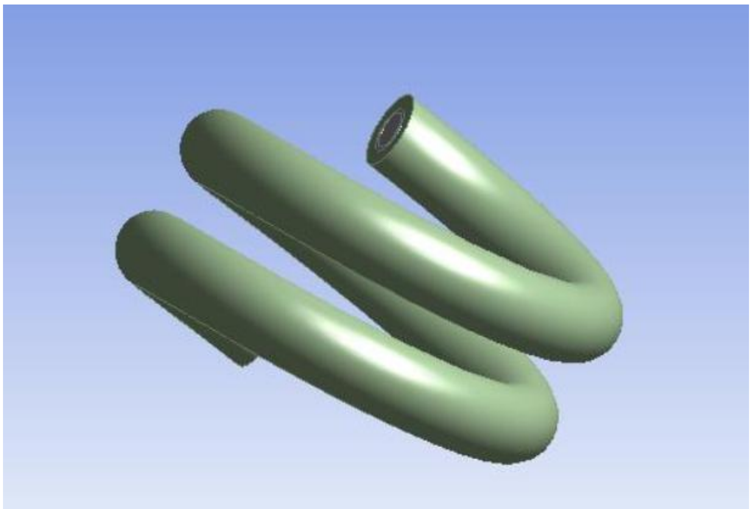

Figure 2.2: Double Pipe Heat Exchanger

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.

2.5 Literature Survey

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.

CHAPTER 3

SYSTEM ARCHITECTURE

3.1 Block Diagram of Parallel Flow:

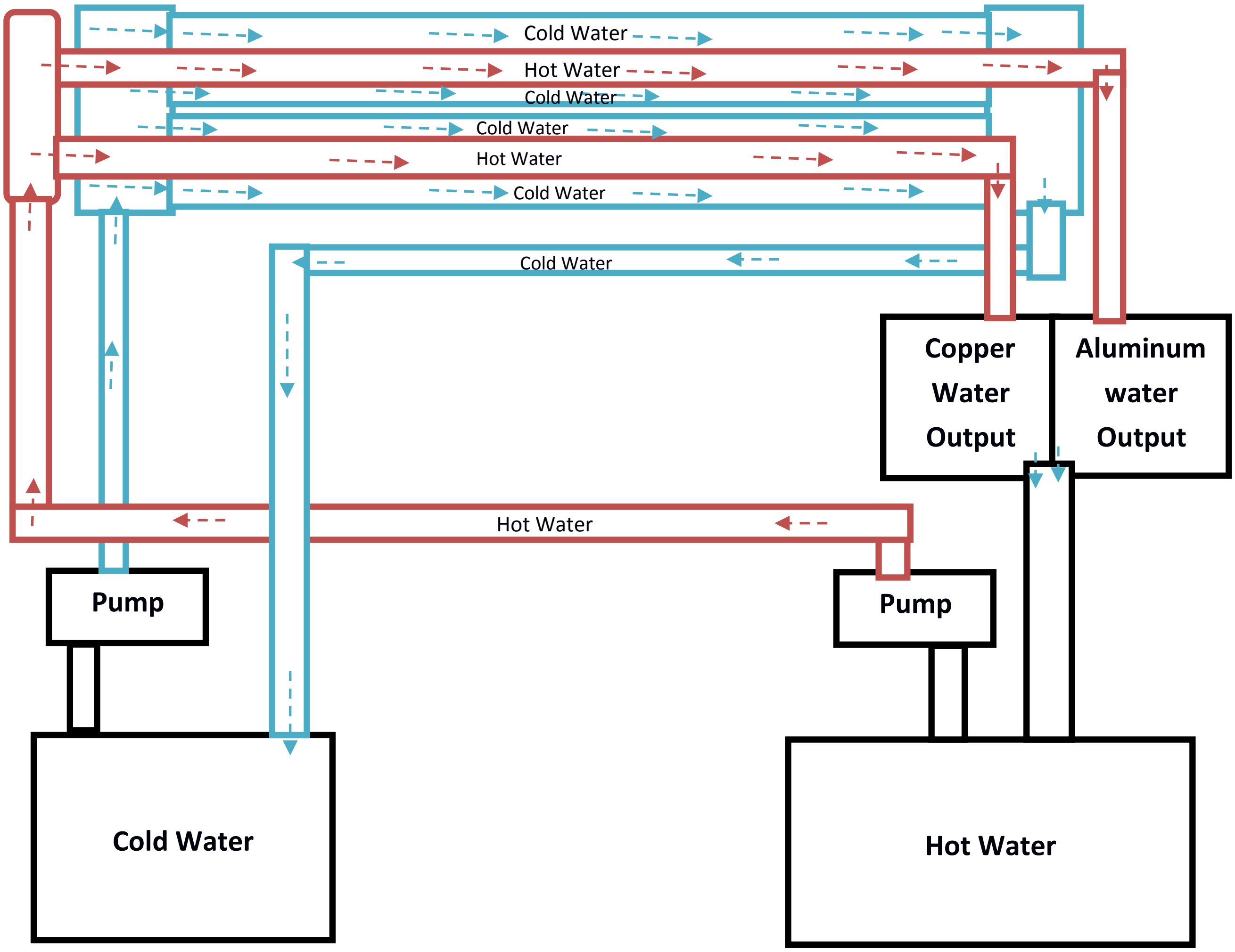

Figure 3.1: Block Diagram of Parallel Flow Heat Exchanger System.

3.2 Block Diagram of Counter Flow:

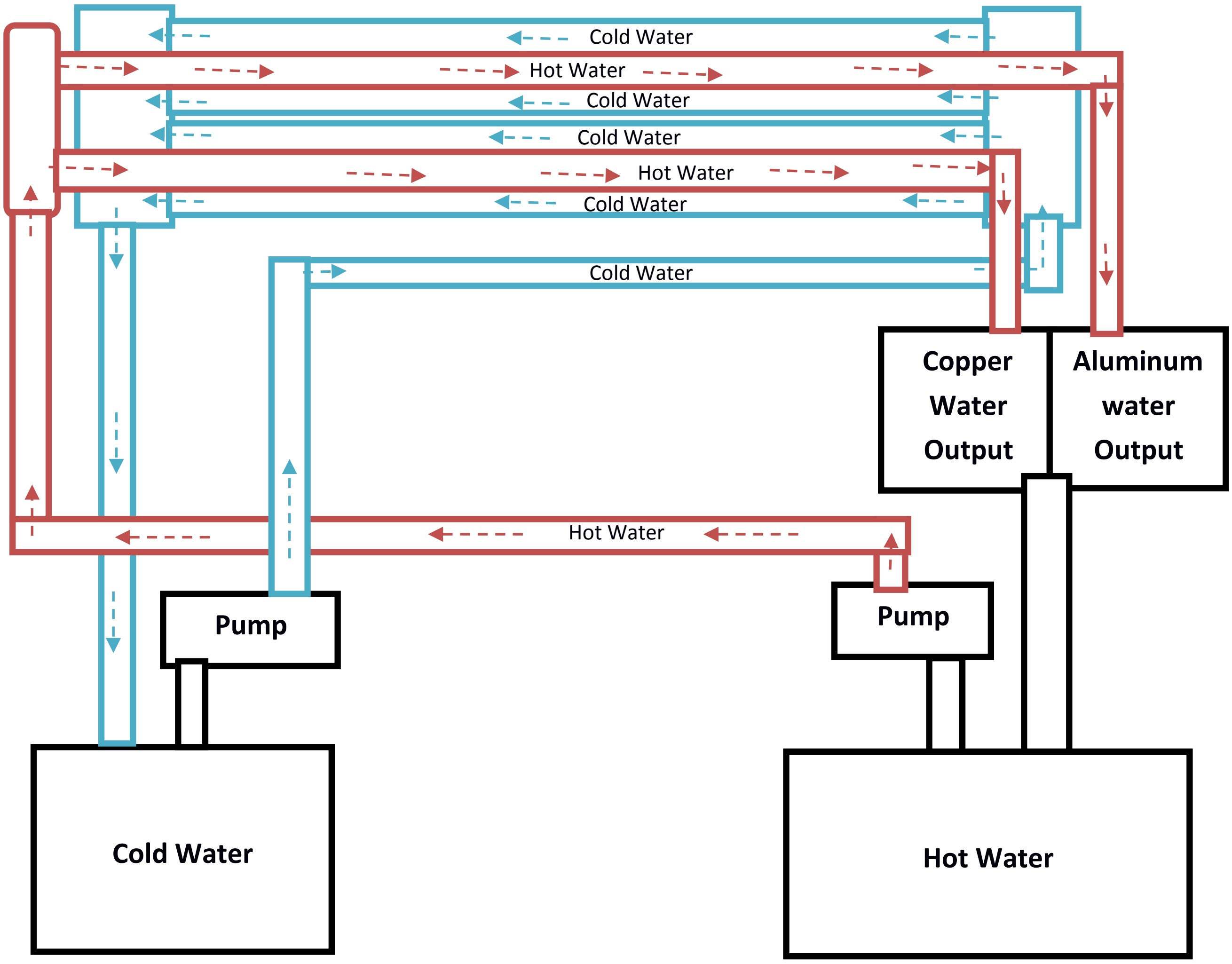

Figure 3.2: Block Diagram of Counter Flow Heat Exchanger System

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This setup consists of concentric tubes as shown in figure. Steam from the boiler at a specified temperature flows through the inner tube. cold water flows through the annulus. The exchanger can be setup quickly for counter and parallel flow adjusting the valves shown in the figure.

3.3 Working Principle:

So the plan of this project is there will be two water tank and both have temperature meter, then from the Hot Water Reserve Tank, hot water will be pass through the pump motor to coper pipe through the water cooling heat sink and to power up the Pump Motor we setup SMPS Power Supply, now water will go through the Aluminum & Copper Metal pipe, so the cool water will store in Recycle Water tank. We also setup a Temperature Meter on Recycle Water Tank, so we can measure the difference between the Hot water and Cold water.

3.4 Advantage:

- 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.

3.5 Application

The project has a major application in the

- 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.

3.6 Future Scope:

The model can be improved by making some changes in the program and components. Some suggestions are given below.

1. By using the same set of tabulators, heat transfer augmentation for various fluids can be studied.
2. Instead of using steam as isothermal source to maintain constant wall temperature hot water can be used as isothermal source.
3. These variant tabulators can be used for heat transfer augmentation studies also in refrigeration system.
4. For the same set of tabulators, heat transfer and friction characteristics can be studied for laminar flow condition.

3.7 List of Components :

SL.NO	Particulars	Specification	Qty.
1	SMPS Power Supply	12V	1
2	Pump Motor	12 Volt	1
3	Temperature Meter	0 to 100 Degree Celsius	2
4	Water Cooling Heat Sink Block		1
6	Copper Pipe		1
7	Aluminum		1
8	Others		
	Total		

Table 3.1: List of Components

CHAPTER 4
HARDWARE ANALYSIS

4.1 SMPS Power Supply:

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.

Figure 4.1: SMPS

Specification:

110-220 V AC Input +-15%12v 5A (Maximum) DC Output , 60W Power Output

Terminal Board Design for Easy connections (5 Pin Terminal Board L,N, E, +V, -V)Short Circuit Protection Passive Cooling Design with Heat Sink Sturdy Steel Bod

Adjustable output Voltage from (10V to 12.5V DC)

Dimensions=16cm, B=10 cm, H=4.5 cm

Mounting Fitting: Screw mount via Bottom or Side Panel

Application: SMD Led Strip, Battery Charger, Toys, Lights, CCTV, Wall Clocks, Night Lamps, Door Bell, Water Overflow Tank, School and College Projects etc.

100% Quality control via in-house test facility with automating machine and experience technicians

Sales Package Content:1 x 12v 5A DC power Supply

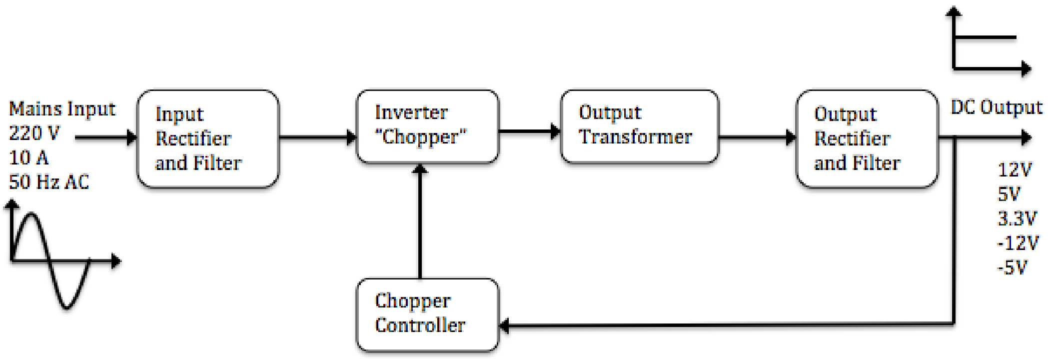


Fig: Schematics of SMPS

4.2 Pump Motor:

Figure 4.2: Pump Motor

DC 12V Water Pump Motor 700L/H

- Power:16.8W
- Max Flow Rate: 700 L/H
- Max Water Head: 5M Max
- Circulating Water Temperature: 60°C

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
- Max Water Head: 5M
- Max Circulating Water Temperature: 60°C

4.3 Temperature Meter:

A temperature meter *is an instrument used to measure the* temperature *of beings or things. The most widely recognized* temperature meter *is a mercury thermometer used to measure the* temperature *of people.*

Figure 4.3: Temperature Meter

Digital Temp Meter

- Digital Display -50C to +110C.
- Modeling simple, elegant, LCD panels inline connections, moisture-resistant.
- Strong anti-interference, applies to refrigerated cabinets, display counters and other needs of temperature measurement and display of various equipment.
- Remote wired probe can read temperature up to 3 feet away.
- No need to wire to any permanent power source. Size:48 x 28 x 15 mm.

4.4 Copper Pipe:

Copper pipes are commonly used 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 4.4: Copper Pipe

CHAPTER 5
DATA ACQUISITION

5.1 Data table:

Parallel Flow:

For Copper:

Cold water IN($T_{c\ in}$)	Cold water Out(T_{out})	Hot water In($T_h\ in$)	Hot water Out($T_{h\ out}$)	Heat transfer Rate Q (watt)	Overall heat transfer Co-efficient u($w/m^2\ k$)
27℃	30℃	60℃	56℃	840	1513.78

For Aluminum:

Cold water IN($T_{c\ in}$)	Cold water Out(T_{out})	Hot water In($T_h\ in$)	Hot water Out($T_{h\ out}$)	Heat transfer Rate Q (watt)	Overall heat transfer Co-efficient u($w/m^2\ k$)
27℃	29℃	60℃	58℃	504	651.78

Counter Flow:

For copper:

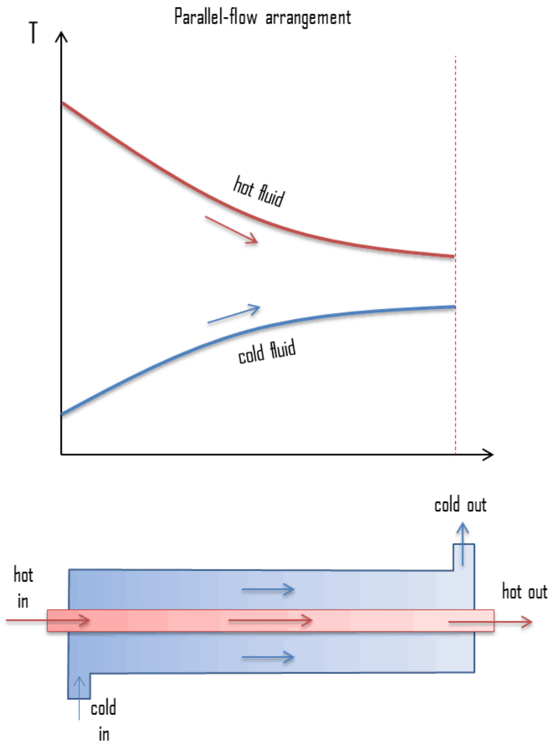
Cold water IN($T_{c\,in}$)	**Cold water Out(T_{out})**	**Hot water In($T_h\,in$)**	**Hot water Out($T_{h\,out}$)**	**Heat transfer Rate Q (watt)**	**Overall heat transfer Co-efficient u(w/$m^2\,k$)**
27℃	30℃	60℃	56℃	504	1506.5

For Aluminium:

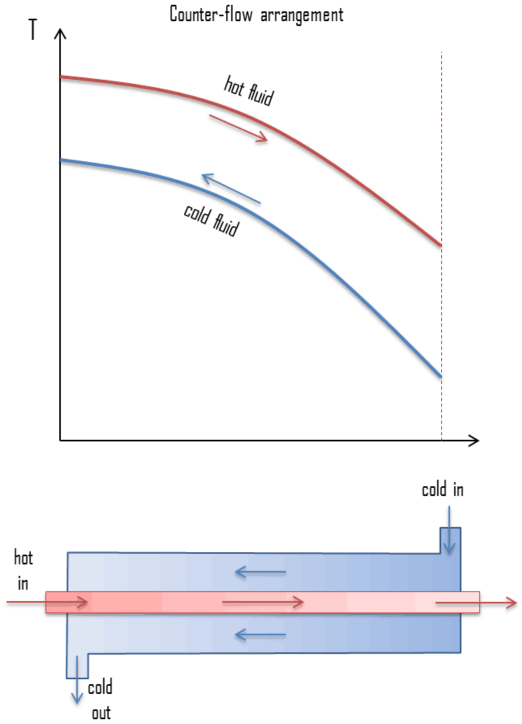
Cold water IN($T_{c\,in}$)	**Cold water Out(T_{out})**	**Hot water In($T_h\,in$)**	**Hot water Out($T_{h\,out}$)**	**Heat transfer Rate Q (watt)**	**Overall heat transfer Co-efficient u(w/$m^2\,k$)**
27℃	28℃	60℃	58℃	504	640

5.2 Flow chart:

Parallel Flow:



Counter Flow:

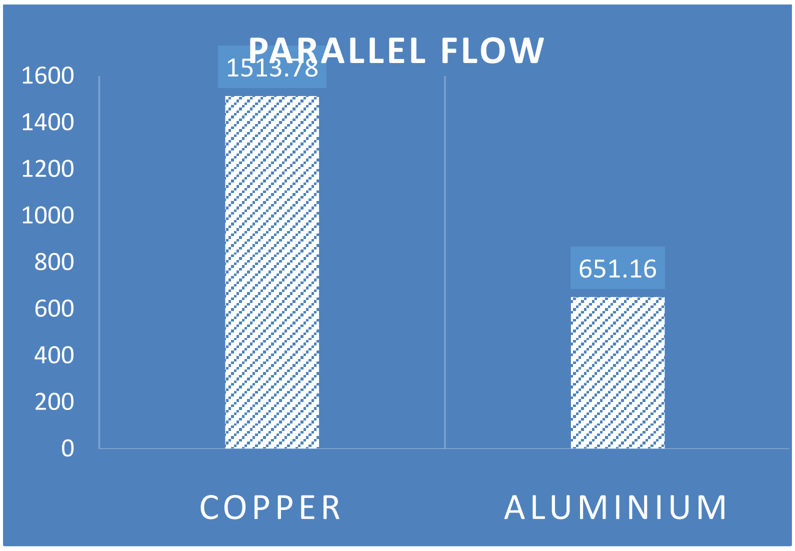


CHAPTER 6

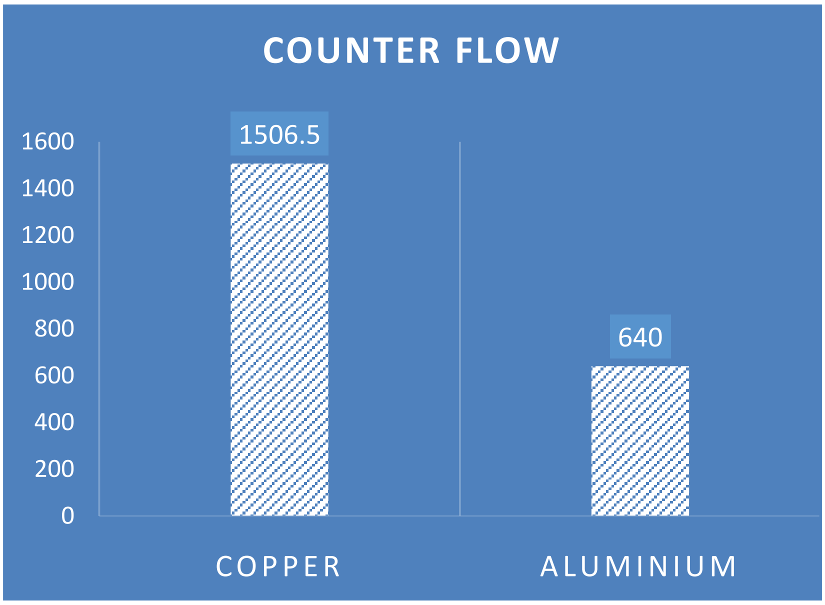
RESULTS AND DISCUSSION

6.1 Result:

Graph of Parallel Flow



Graph of Counter Flow:



6.2 Discussion:

In this experimental investigation two tube materials like copper and aluminum are used to determine the overall heat transfer coefficient at various flow condition. Various Enhancement methods are applied to increase thermal performance of heat transfer devices such as treated surfaces, rough surfaces, swirling flow devices, coiled tubes, and surface tension devices. These are used to augment the heat transfer by creating turbulence in the fluid flow. The overall heat transfer coefficient decreases with increasing inlet temperature of the water. The overall coefficient depends on temperature area heat transfer flow rate and LMTD.The overall heat transfer coefficient varied due to LMTD variations using this project resulted in parallel and counter flow. The LMTD increases then the overall heat transfer coefficient decreases for aluminum and copper tube heat exchanger. The variation in the value of heat transfer coefficient may be due to formation of scale on the surface of conduit and it may also due to variation in fluid flow profile along the length.

CHAPTER 7

CONCLUSION & RECOMMENDATION

7.1 Conclusion:

This project is an efficient operation completive cost. In the design of heat exchanger overall heat transfer coefficient is an important parameter because it includes both conduction and convection parameter of heat exchanger. The rate of heat transfer can be increased by increasing the surface area with increasing the length of the tube, the lesser the diameter of tube, higher the heat transfer coefficient can be obtained. Use of water in a copper tube heat exchanger shows enhancement of overall heat transfer coefficient. Considering its uses is efficient becomes relatively cheap when compared to other units. This project is an efficient operation and competitive. It becomes relative cheap when compared to others unit.

7.2 Recommendation:

Fouling and corrosion are the major unresolved crisis in heat exchanger operation. Though the fouling deposition problems and the impact to the economy are a serious concern, still there is lack of awareness in concerned authorities. By using this heat exchanger, heat transfer augmentation for various fluids can be studied. For this heat exchanger, heat transfer and friction characteristics can be studied for laminar flow condition. In future Development in this project can be added motor speed controller & totally automation system.

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Parallel Flow:

For Copper:

$m_h = 0.05 kg/s$

$m_c = 0.08 kg/s$

$T_c, in = 27℃$

$T_c, out = 30℃$

$T_h, in = 60℃$

$T_h, out = 56℃$

$l \qquad = 0.4m$

$D \qquad = 0.015m$

$A = \pi \text{DL} = \pi \times 0.015 \times 0.4$

$= 0.189 m^2$

$Q = mhcp(T_h, in - T_h, out)$

$= 0.05 \times 4.2 \times 10^3 \times (60 - 56)$

$= 840\, watt$

$$\Delta Tcm = \frac{(T_h, in - T_c, in) - (T_c, out - T_c, out)}{ln \frac{T_h, in - T_c, in}{T_h, out - T_c, out}}$$

$$= \frac{(60° - 27°) - (56° - 30°)}{ln \frac{60° - 27°}{56° - 30°}}$$

$$= \frac{7}{ln \frac{33°}{26°}}$$

$$= 29.36℃$$

$$Q = UA \text{ LMTD}$$

$$\Rightarrow \; U = \frac{Q}{A \, LMTD}$$

$$= \frac{840}{0.0189 \times 29.36℃}$$

$$= 1513.78 w/m^2 k$$

***For* Aluminium:**

$M_h = 0.06kg/s$

$M_c = 0.07kg/s$

$T_c, in = 27°C$

$T_c, out = 29°C$

$T_h, in = 60°C$

$T_h, out = 58°C$

$L = 0.4m$

$D = 0.02m$

$A = \pi DL = \pi \times 0.02 \times 0.4$

$= 0.025m^2$

$Q = mhcp(T_h, in - T_h, out)$

$= 0.06 \times 4.2 \times 10^3 \times (60° - 58°)$

$= 504watt.$

$$\Delta Tcm = \frac{(T_h, in - T_c, in) - (T_h, out - T_c, out)}{ln\frac{T_h, in - T_c, in}{T_h, out - T_c, out}}$$

$$= \frac{(60° - 27°) - (58° - 29°)}{ln\frac{60° - 27°}{58° - 29°}}$$

$$= \frac{4}{ln\frac{33°}{29°}}$$

$$= 30.96℃$$

$$Q = UA\ LMTD$$

$$\Rightarrow U = \frac{Q}{A \quad LMTD}$$

$$= \frac{504}{0.025 \times 30.96}$$

$$= 651.16w/m^2k$$

Counter Flow:

For Copper:

$m_h = 0.05kg/s$

$m_c = 0.08kg/s$

$T_c, in = 27℃$

$T_c, out = 30℃$

$T_h, in = 60℃$

$T_h, out = 56℃$

$l \quad = 0.4m$

$D \quad = 0.015m$

$A = \pi \mathrm{DL} = \pi \times 0.015 \times 0.4$

$= 0.189m^2$

$Q = mhcp(T_h, in - T_h, out)$

$= 0.05 \times 4.2 \times 10^3 \times (60 - 56)$

= 840 Watt

$$\Delta Tcm = \frac{(T_h, in - T_c, out) - (T_h, out - T_c, in)}{ln\frac{T_h, in - T_c, out}{T_h, out - T_c, in}}$$

$$= \frac{(60° - 30°) - (56° - 27°)}{ln\frac{60° - 30°}{56° - 27°}}$$

$$= \frac{1}{ln\frac{30°}{29°}}$$

$$= 29.50℃$$

$$Q = UA\ LMTD$$

$$\Rightarrow U = \frac{Q}{A \times LMTD}$$

$$= \frac{840}{0.0189 \times 29.50}$$

$$= 1506.5\ w/m^2k$$

For **Aluminium:**

$M_h = 0.06kg/s$

$M_c = 0.07kg/s$

$T_c, in = 27℃$

$T_c, out = 28℃$

$T_h, in = 60℃$

$T_h, out = 58℃$

$L = 0.4m$

$D = 0.02m$

$A = \pi\text{DL} = \pi \times 0.02 \times 0.4$

$= 0.025m^2$

$Q = mhcp(T_h, in - T_h, out)$

$= 0.06 \times 4.2 \times 10^3 \times (60° - 58°)$

$= 504watt.$

$$\Delta Tlm = \frac{(T_h, in - T_c, out) - (T_h, out - T_c, in)}{ln \frac{T_h, in - T_c, out}{T_h, out - T_c, in}}$$

$$= \frac{(60° - 28°) - (58° - 27°)}{ln \frac{60° - 28°}{58° - 27°}}$$

$$= \frac{1}{ln \frac{32°}{31°}}$$

$$= 31.50℃$$

$$Q = UA\ LMTD$$

$$\Rightarrow U = \frac{Q}{A \times LMTD}$$

$$= \frac{504}{0.025 \times 31.50}$$

$$= 640\ w/m^2k$$