HYBRID WATER HEATING SYSTEM

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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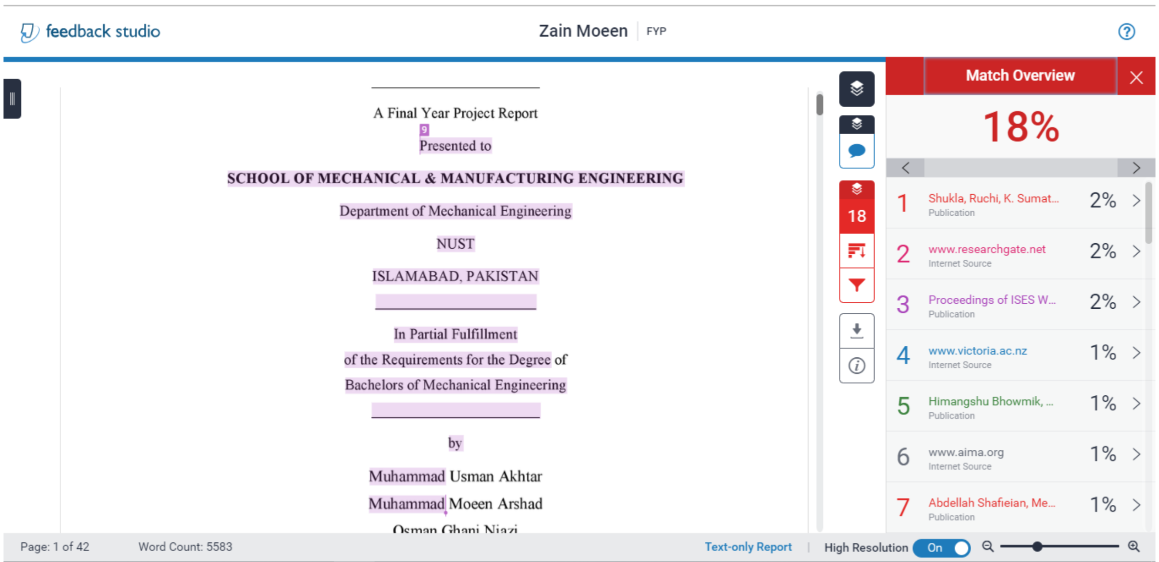
ABSTRACT

Solar hybrid water heating system is actually the axillary system coupled with existed gas or electric water heating systems. In this project we used the active solar water heating system. Flat plate collector is opted because it is easy to model and efficient. Tabulated solar data taken form standard sources and used in calculation for theoretical results. Theoretical results of losses and efficiency of solar collector are calculated. Pump of auxiliary system will be controlled by Arduino.

ACKNOWLEDGMENTS

We would like to acknowledge the efforts of Lecturer Umer. Because of his guidance and support we have been able to successfully complete this project.

ORIGINALITY REPORT



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ABBREVIATIONS

FPC	Flat plate solar collector

ETC	Evacuated Tube Collector
CPC	Compound parabolic Concentrator
SWH	Solar water heater

NOMENCLATURE

β	Collector Tilt Angle
Ta	Ambient Temperature
Tp	Absorber Plate Temperature
${}_g$	Glass emittance
${}_p$	Plate emittance
N	No of glass Covers
hw	Wind heat transfer coefficient

CHAPTER 1: INTRODUCTION

In order to have a poverty-free world, energy for all sectors must be ensured. As the fossil fuels, the conventional source of energy are limited. That means they cannot meet the increasing need of the common people causing rising cost of fossil type fuels (i.e., gas or oil) solar energy is becoming an important source of renewable energy. The added benefit is that SWHs are the cheapest and are readily available. So wide dissemination of renewable energy technologies is the only way out for problems.

With the rampant depletion of conventional energy sources like fossil fuels and their adverse effects on the environment, there is an urgent need for reliable alternative sources of energy. Pakistan, with eight to nine hours of sunlight per day, has ideal values of insolation required for solar power generation. In order to become a modern campus, NUST must focus its resources on renewable sources of energy. The water heating system already installed in the hostels, use natural gas as a source of energy. The crux of the project is to implement a hybrid water heating system with the integration of the already existing heating system with a solar powered heating system. This includes a detailed study of hot water consumption during the winter months and the measurement of natural gas consumption and its efficiency.

The project also entails the collection and interpretation of seasonal solar data including the solar fraction. An economic feasibility report including the cost analysis of integrating the installed water geyser with solar collectors will be carried out. After the analysis has been carried out, the optimized design parameters will be decided and implemented.

In solar installations related solar thermal, solar collector is the most important components of a SWH (SWH). The collectors collect Radiations coming from the sun and that radiations energy is converted into heat and that heat is due in my houses and industrial areas.

In Pakistan there is both a shortage of electricity as well as gas. In winters most of the electricity is used either to have the warm water or to have warm room in winter. Hot water is also required for swimming pools. All these needs are fulfilled by electricity and gas. On the other hand we also have the great solar potential. So why not make use of what's in abundance and eradicate the use of scarce resources. To utilize that potential solar water heaters are the best choice. Solar energy can also we used for space heating purpose.

The objective of this project is to make a hybrid SWH. Hybrid SWH is actually solar heating system integrated with axillary system.

For this weather data will be collected, then that data will be analyzed. Value of global horizontal irradiance, overall loss coefficient, usable energy and Efficiency of the solar collector will be calculated.

CHAPTER 2: LITERATURE REVIEW

Solar hybrid water heating consist of solar collector, tank, axillary system and other piping networks. Solar collector, the most important component of solar hybrid water heating system. Different types of solar collectors are available in the market. Many studies has been carried on collectors and how their efficiency can be improved.

S.A. Kalogirou in 2004 presented the survey on various kind of solar collectors and their applications. All the systems which use solar energy depend on the type of collector use such as flat plate collector, Compound parabolic collector, evacuated tubes solar collector, parabolic trough, parabolic dish and Fresnel lens,.

Motion	Collector type	Absorber type	Concentration ratio	Temperature range (°C)
Stationary	FPC	Flat	1	30-80
	ETC	Flat	1	50-200
	CPC	Tubular	(1-5)	60-240
Single-axis tracking	LFR	Tubular	(15-45)	60-250
	PTC	Tubular	(15-45)	60-300
	CTC	Tubular	(10-50)	60-300
Two-axis tracking	PDR	Point	(100-1000)	100-500
	HFC	Point	(100-1500)	150-2000

He studied flat plate collector that it consist of metal absorber in rectangular casing. There is a glass cover on the top and insulation at the bottom and sides to minimize the thermal losses of solar collector. The flat plate acts as a heat exchanger because it absorbs the thermal radiations from the sun, converts that energy into heat and that energy is used to heat the solar fluid. This heat can also use to heat water if we use water as the solar fluid.

Hussain Al-Madani in 2006 studied a SWH. Which was made of an evacuated Water was flowing through copper coils, which act as collectors, located within the glass tube. Maximum temperature difference between the inlet and outlet of the cylindrical batch system of 27.8°C was achieved by Side-by-side testing of prototypes and it gave the maximum efficiency of about 41.8%. He determined the manufacturing cost of this solar water heater to be $318 while the manufacturing cost of flat plate collector is $ 358. So proposed design was slightly cheaper than FPC.

Dharamvir Mangal, Devander Kumar Lamba, Tarun Gupta, Kiran Jhamb in 2010 presented acknowledgements to evacuate tube solar collector that when the air is evacuated from the solar collector tubes losses due to convection and conduction reduce. Due to which efficiency of collector is not much effected by air speed and cold temperature. By this collector ETC gets at high temperature early compared with the FPC. When the efficiency of flat and evacuated tube collector was calculated Flat plate collector gave more efficiency at peak hours but evacuated tube solar collected had the clear advantage for whole year.

K. S. Ong and W. L. Tong in 2011 presented the performance of SWH dependent on collector, weather conditions and size of the tank. Both long and short term performance were conducted on ETC and U-tube solar collector for natural and force convection. From the results it was seen that natural convection heat pipe system gave the best performance and using it temperature of about 100c can be achieved.

Ruchi Shukla, K.Sumathy, Phillip Erickson and Jiawei Gong in 2012 presented the advancement made in solar water heating that Evacuated tube collectors (ETC) are not as commonly used as flat plate collectors. They can produce high temperatures compared with FPCs. They are expensive in costs. ETC) consists of evacuated tubes (glass-glass seal), copper heat pipes, and aluminum casing. ETC minimizes the heat losses caused by radiation and convection. Presently, glass ETC ETC is important component of solar thermal utilization, because they have less heat loss issues and high heat extraction efficiencies compared to flat- plate solar collectors. Of all the U-tube welded inside a circular fin, U-tube welded on a copper plate, finned tube, and U-tube welded inside a rectangular duct. Of all the four collectors, best performance was given by the U-tube welded collector. Radiation from all directions can be absorb using parallel-connected evacuated tube collector design having an absorber. This design works well especially in higher latitudes. The problems of all-glass ETC designs is the extraction of heat through the long, narrow absorber tube. To get high temperature vacuum is necessary. However, providing perfect vacuum is a difficult condition because the gases released during the heating remain inside the pipe and due to this performance of it can be affected. Hence, the use of heat-pipe evacuated tube collector systems is limited. There are two basic evacuated tube collector design. One is simple fluid-in-glass and the other is fluid-in-metal designs. The fluid-in-metal design is further classified into U-tube evacuated tube collector and heat pipe evacuated tube collector. Heat pipe evacuated tube collector (ETC) and U-tube glass evacuated tube collector are the two most commonly used solar collectors in our domestic water heating. A simple oscillating, closed-loop, heat-pipe evacuated tube collector (ETC) can be used to overcome issues concerning icing during winter and corrosion. U-tube glass evacuated tube collector are most commonly used collectors. The U-tube evacuated tube collector is simple in design and is also bear high pressure as compared to the all glass evacuated tube collector and the heat-pipe evacuated tube collector. U-shaped flat-plate selectively coated absorber having fins. These fins are used to increase heat transfer area between tube walls and the working fluid. U-tube collector gives less efficiency than mini-channel tube collector. Air layer also effects the efficiency. When air layer thickness is increased, efficiency also increased. It is also noticed that with the increase in conductance, efficiency and outlet temperature increase.

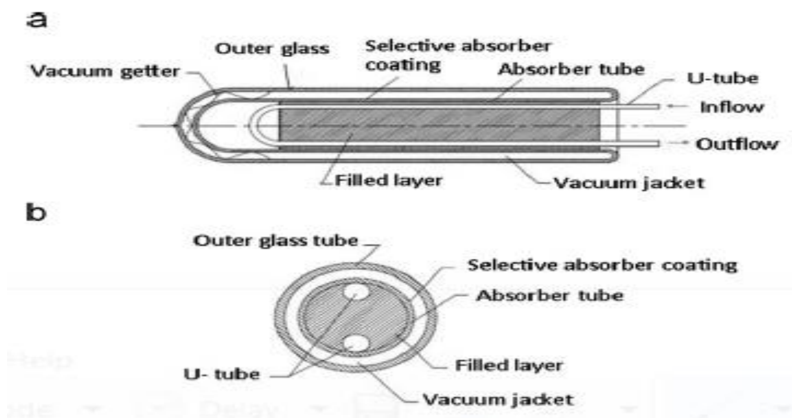


Figure 1: The filled type evacuated tube collector.

Flat-plate collectors and ETC are commonly used to provide intermediate temperatures. However, reflector should be used to get high temperature of water because it will incident maximum radiation on the collector. To avoid the heat losses, spacing between the reflector and absorber is kept but due to this amount of radiations transfer to collector will be reduced. The efficiency of the Compound parabolic concentrators was higher than the FPCs even when the operating temperatures was high. When compared to the compound parabolic concentrator collector if only one glass cover and reflector with high value of emittance is used, losses can be reduced. Introduction of the baffle into the collector can reduce heat losses by reducing internal convection thereby. Among all reflectors flat bifacial absorber gave the best results.

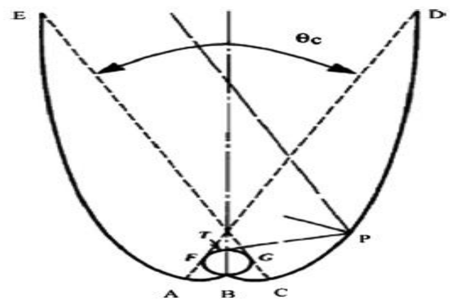


Figure 2: Schematic diagram of CPC Collector.

Passive and Active solar water heater

Active SWH is the type of system in which mechanical or electrical equipment is used for circulation of water. Just like pump installed at the inlet of collector to pump hot water into tank and take cold water from tank to collector. In active heating system, tank lies mostly below the collector. These systems are used where temperature mostly go below freezing point of water. In case of Indirect water heating system, a non-freezing heat transfer fluid circulates in the collector and then through the heat exchanger in water tank. They are used at the places where temperature gets too low and fluid might freeze in case of direct water heating system.

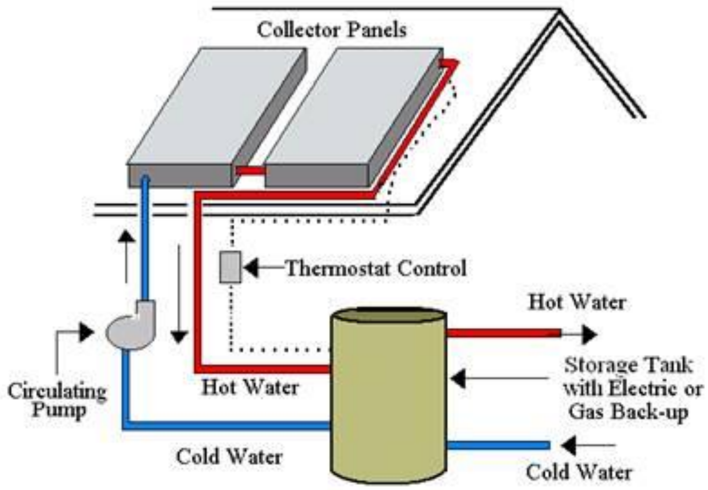


Figure 3: Active solar water heating system.

Passive water heating is the type of heating system in which no mechanical or electrical equipment is used to circulate water. Thermosiphon system uses natural convection for the circulation of water, so the tank should be located well above the collector panels - the hot water from the panels flows in the upward direction to the tank and the cooler water flows towards the collector for heating. These systems are not expensive but less efficient.

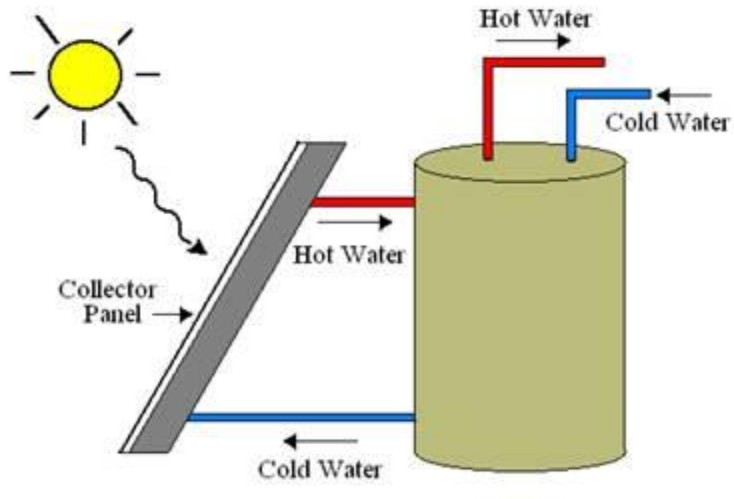
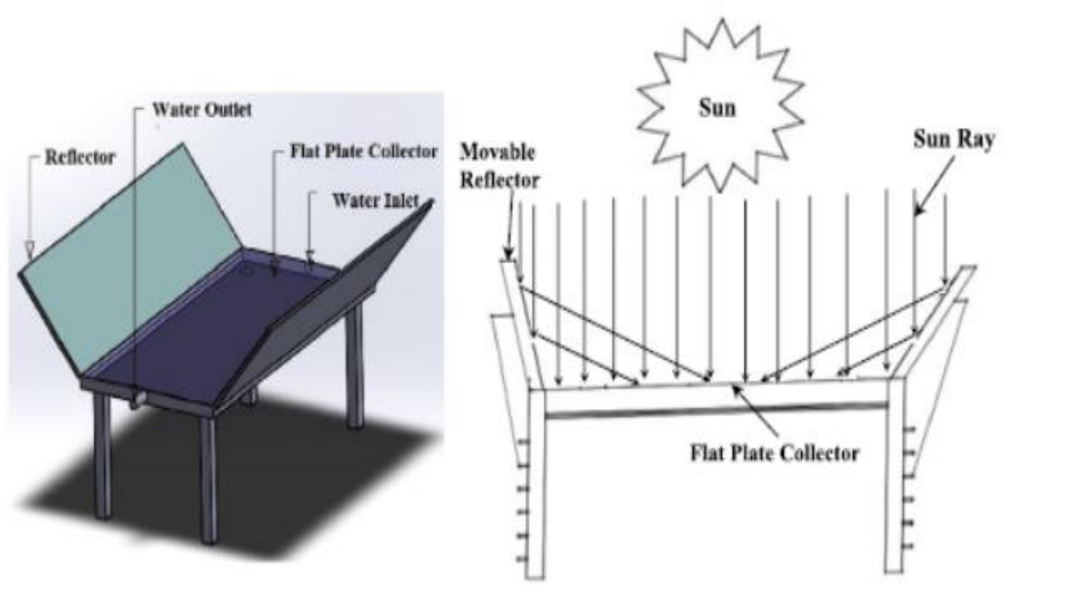


Figure 4: Passive Solar Water Heating.

Hannah Cassard, Paul Denholm, Sean Ong in 2011 presented a study that Currently used SWH in the America can save about 50–85% of the electricity used for heating purpose depending on region. For systems that is currently using electricity for this purpose, this can save in the range of under 1600kWh to over 2600kWh for an average household annually and by using these systems an annual bill of $100 to over $300 can be saved. This range in economic and technical performance means the current break-even price of SWH varies by more than a factor of four to five.

Himangshu Bhowmik and Ruhul Amin in 2016 introduce a new technology that how the performance of solar collector can be improved, especially FPCs. Basically, what indicated here is that as solar collectors work better by increasing the amount of radiations thrown on their surface so why not simply introduce an extension of solar reflectors to already existing solar setup to increase the incident solar radiation whether that is direct or diffused radiation. Thus solar concentrator is used with the solar collector to increase the radiations intensity that fall on the collector. Thus, the reflector is used to concentrate both diffuse radiations and direct radiations of the sun toward the collector.

The reflector was placed on collector in such a way that its position could be changed with daytime to maximize the radiations intensity of incident rays. This energy of radiations from the sun is converted into heat and that heat is used to heat the water. A prototype that was constructed gave the 10% more efficiency by using the reflector. So



this design has the best performance compared with the available design of collector.

Figure 5: Schematic View of flat plate collector with reflector

M.C. Rodríguez-Hidalgo in 2011 presented a study for optimize size of storage tank. Efficiency of SWH can vary with the size of storage tank. Many efforts are made for the formation of a system for the consumption of hot water by the people of a building. In that sense, much has been achieved in different domains: government policies, research agencies and manufacturers. Solar irradiance is the transient process but most of the rules related to solar plants are under steady state model. Due to this, the design of storage tank is left on designer’s decision and no performance evaluation procedure is performed to find the best optimized design of tank. This can be a problem that this system requires the large space and it cannot be implemented in a small place. In addition to that, a large storage volume cannot give more efficiency in many residential applications. Large storage tank can be costly in price, occupy large space and in some cases it can be too heavy.

E. Zambolin, D. Del Col in 2010 presented a study for both flat plate collector and ETC at steady state and quasi-dynamic conditions. In the flat plate collector the collector can give low efficiency during morning and afternoon hours due to more reflection losses. If vacuum is generated between the tubes of collector then these losses can be minimized. Most of the area of collector is exposed to quasi-normal radiations from the sun through the day. Due to these reasons ETC gives the more efficiency and best performance for the large range of condition than FPC.

Ismail H Ozsabuncuoglu presented a study that there is the great solar potential but because of problems related to economic, technical and efficiency this solar energy cannot be extracted to its fullest extent.

Initial cost of SWH is high. It is about four to five time higher than the cost of other systems those which use electricity, LPG or fuel. Repairing and maintenance cost of SWH is well below than that of other systems. This is due to the reason that they do not have any component that is much expensive but only solar collector. Solar systems has about the minimum annual cost value of US$867.19.

Abdellah Shafieian, Mehd iKhiadani and Ataollah Nosrati conducted a study. In this study they evaluate the performance of a heat pipe SWH. For that they conducted the experiment under non ideal conditions in Perth, west Australia. Both the theoretical and experimental pattern of water consumption was conducted. A mathematical model was developed and which was used to calculate the optimum number of glass tubes of the heat pipe solar collector. A design with 25 glass rigs was constructed and it was tested when the temperature of all 25 rigs reach insignificant value of 0.6%. Extraction of hot water from the collector significantly affect the efficiency, overall loss coefficient and exergy destruction of solar collector. So considering the pattern of hot water consumption is important for the analysis of the system. Auxiliary heating element is required in the morning, during the partly cloudy conditions and overcast period. The operation time of axillary system for morning was 19 minutes and for overcast periods, it was 8 minutes. The difference between the theoretical and experimental values is in agreement with standard and maximum absolute error of 1.77% and 5.6%.

CHAPTER 3: METHODOLOGY

Solar collector is the one of the most important parts of solar hybrid water heating system. There is the tradeoff between the choices of solar collector. Flat plate collector is the most efficient but can not be used in harsh climate conditions where temperature falls below freezing point of water. Also FPC is cheaper. On the other hand ETC is less efficient but it can be used in areas where temperature gets too low and ETC is expensive as well and using this we can achieve high temperature as well. There also exist another type of collector as parabolic trough collector, using this we can achieve boiling temperatures of water, but it is expensive and usually used for large scale purposes. In the country like Pakistan, where sun lasts about eight to nine hours in winters and conditions do not get that harsh so flat plate collector is viable option because as mentioned earlier it is cheaper, effective and sustainable in above freezing point conditions. So our choice was flat plate collector.

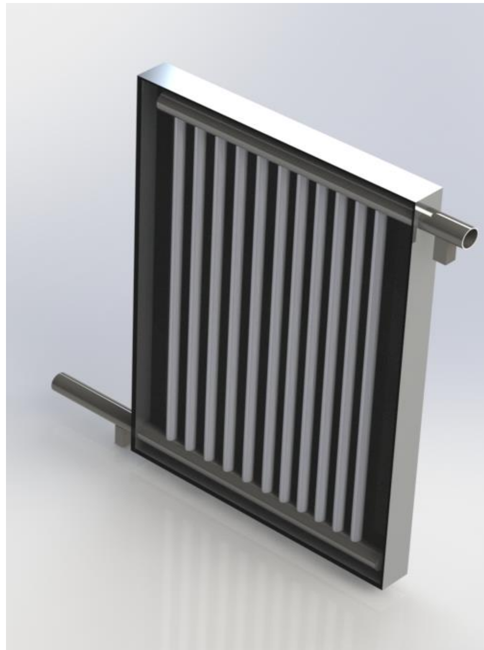


Figure 6: Flat plate collector

Figure 7: Evacuated tube collector.

Weather Data

Weather data was calculated using excel by taking the average of global irradiance at a specific time for whole month of December and January. Then the graph was plotted between time of the day and irradiance to obtain the value of energy available in radiations.

Then we performed calculations to find out the optimum material and dimensions of parts of FPC.

Calculating the loss coefficient of flat plate collector

For the analysis of flat plate collector we need to find the efficiency, which can be calculated by finding the total losses and subtracting them from the available energy. Losses are calculated by finding the thermal resistances.

Calculating the thermal resistances

To calculate the loss coefficient thermal resistances are measured. These are measured using the formula

$$R = \frac{L}{KA}$$

$$R = \frac{1}{hA}$$

Where L is the thickness

A is the cross sectional area

K is the material conductivity

h is convective heat transfer coefficient

Calculating the losses coefficient due to wind speed

To calculate the losses due to wind speed we need the nusselt number. For this the reynold’s number is needed. Which can be determined using the wind velocity.

$$Re = \frac{\rho V L}{\mu}$$

Where

μ is the viscosity of air

ρ is the density of air

L is the length

V is the wind speed

$$Nu = 0.037 Re^{0.8} Pr^{1/3}$$ For turbulent flow

The above formula is valid for

$$5 * 10^5 \leq Re \leq 10^7$$

$$0.6 \leq Pr \leq 60$$

$$Nu = 0.332 Re^{0.5} Pr^{1/3} \qquad \text{For laminar flow}$$

The above formula is valid for

$$Pr \geq 0.6$$

Nasselt number is defined as the ratio of heat transfer through convection to heat transfer through conduction.

$$Nu = \frac{Q\ convection}{Q\ conduction}$$

$$Nu = \frac{h\Delta T}{\frac{K\Delta T}{L}}$$

$$Nu = \frac{hL}{K}$$

Klein's Equation

There are 2 Klein's equations.

Old equation was valid only for the tilt angle of 45 degree and correction was required for other angles. Later an equation was proposed which uses the convection losses causes from the top of absorbing plate and it is the function of tilt angle. This equation is valid for 0 to 34 degree only.

$$U = [\frac{N}{\left(\frac{C}{Tp}\right)\left(\frac{T`p - Ta}{N + f}\right)} + \frac{1}{hw}]^{-1}$$

$$+ \frac{\sigma(Tp^2 + Ta^2)(Tp + Ta)}{(\epsilon_p + 0.00591 h_w)^{-1} + \left[\frac{2N + f - 1 + 0.133\ \epsilon_p}{\epsilon_g}\right] - N}$$

$$f = (l + 0.089 h_w - 0.1166 h_w\ \epsilon_p)\ (1 + 0.07866N)$$

$$C = 520(1 - 0.000051s^2) \text{ for } 0° \leq s \leq 70°$$

For 70° ≤ s ≤90 °, use s = 70°

$$e = 0.43(1 - \frac{100}{T_p})$$

Using the equation below, we can find the value of U with the accuracy of ± 0.25 W/m^2C

$$U = \left[\frac{N}{\left(\frac{C}{Tp}\right)\left[\frac{Tp - Ta}{N+f}\right]^e} + \frac{1}{h_w} \right]^{-1}$$

$$+ \frac{(5.67\ X\ 10^{-8})\ (Tp + Ta)\ (Tp^2 + Ta^2)}{\frac{1}{\ _p + 0.05N(1 - \epsilon_p)} + [\ \frac{2N + f - 1}{\ _g}\ ] - N}$$

Where

e=0.430(1 - $\frac{100}{Tpm}$)

N= No of glass Covers =1

C= 520 (1- 0.000051β^2)

β= Collector Tilt Angle = 30

Ta= Ambient Temperature

$\ _g$= Emittance of glass = 0.88

hw= Wind heat transfer coefficient

$\ _p$= Emittance of plate = 0.9

Tp= Absorber Plate Temperature

From the above klein's equation losses for the whole flat plate collector can be determined. When we know the losses of whole FPC, efficiency of collector can be calculated.

Sides of the solar collector are perfectly insulated and there will be very small amount of heat losses which can be minimized. Losses from the top of solar collector are need to be measured accurately.

Usable energy from the collector can be calculated by using the formula

$$Q_{use} = (\quad _g \quad _p\, I\, A) - UA(Tp - Ta)$$

$$\eta = \frac{Q_{use}}{Q_{inc}} \eta = \frac{(\quad _g \quad _p\, I\, A) - UA(Tp - Ta)}{I}$$

Factors affecting the efficiency of solar collector

Different factors affect the efficiency of solar collector.

Tilt angle

Number of class covers

Spacing

Absorber plate

Fluid inlet temperature

Transmissivity of glass

Surface area of collector

Axillary system

Electric heater will be installed at the bottom of tank. Power of the heater can be calculated by the formula

$$\dot{Q} = \dot{m} C_p \Delta T$$

$$\Delta T = T_2 - T_1$$

T_2 = tank outlet temperature

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

T_1= tank inlet temperature

C_p = heat capacity of water

Market Survey for Pump

Our collector will be placed well above the tank. So water is need to be circulated. For that pump is need to be installed at the inlet of the collector. Various types of pumps are available in the market.

- Rotary type pump
- Reciprocating type pump
- Centrifugal pump
- Vane type pump
- Screw type pump

Centrifugal pump

This type of pump is one of the most common in use today. Like other pump, centrifugal pump has an impeller. When it rotates, it sucks the fluid in and then fluid rotates between the impeller and it is drown out by the force known as centrifugal force. The pump can be driven by an engine or electric motor.

They are used for transportation purpose.

These impellers are classifies into three designs

Axial Flow:

> The axial flow impeller is designed in such a way that it discharges fluid along the axis of the shaft. So, for that reason it is not defined as centrifugal pump due to its action.

Radial Flow:

The radial flow impeller is designed in such a way that it discharges the fluid in the radial direction. Perpendicular to the direction of inlet. This type of centrifugal pump is most commonly used.

Mixed Flow:

The mixed flow impeller uses both the axial and radial directions to discharge the fluid in the conical way.

Rotary type pumps:

In this pump, there are two rotating vanes. These vanes rotate in such a way that it causes the high pressure of fluid at the discharge. They are used for small pressure ratio.

Reciprocating type pump

In this type of pump a piston is used. Fluid enters from a side. Valves are used to allow fluid flow in only one direction. Then the fluid is compressed by that piston and discharged from the exit valve.

This type of pump is used for high pressure ratio.

Submersible Pump:

This is a hermetically sealed motor which is coupled to a pump, it is used in wet or underwater regions. In this category low head pumps are also available with wide range of flow rates.

Power calculation for pump

Power of the pump can be calculated using the formula

$P = q\,\rho\,g\,h / (3.6 \times 10^6)$

Where

g = gravitational acceleration

q = flow capacity

h = differential head

ρ = density of fluid

P= hydraulic power

For our system the vertical head was 1.2 m by conservative estimate. And as we estimated that we need 3 L/min flowrate. Other parameters are constant. Power calculated is also low. So considering pipe, pump, joint and bend losses for conservative estimate. Since values of head and power are low so we used submersible pump, also it was convenient to use this type of pump. So we had selected RS-1202 submersible pump with max head of 1.8m and max flow rate of 800 L/H for our system.

Digital Control

Both Arduino and PLC can be used in our system.

Arduino has following features.

- C or C++ language
- Simple system
- Flexible
- Less robustness
- Cheap.

PLC has following features.

- Ladder language
- Simple
- Robust
- More input and output control
- Logic based Programming
- Pump control with mass flow rate control as well
- Expensive

Since as we had to develop a prototype, so robustness wasn’t that much of concern so we had used Arduino Mega for its user friendliness and comparatively feasibility. Thermocouples are mounted at the various places of design to record the temperature at various interval of time. These values of temperature are received by the Arduino and according to that values of temperatures the Arduino will either turn on the pump or turn on the axillary system or bypass both of the systems or any single system. Since pump cannot be controlled directly by Arduino but a relay will be used which will be controlled by Arduino and that rely will control the pump. As thermocouples were used for temperature values, their location of installation was important for simplifying the logic. So after optimization for logic we chose four thermocouples for the digital control of the whole series system. Two at the exit and entrance of a FPC, one in the tank and one in the electric heating tank. These values then compared as per Arduino code to achieve the desired state of the system. For obtaining real time values we connected Arduino interface with excel spread sheet to get real time values and then plotted a graph to compare actual and theoretical efficiencies for checking the effectiveness of a flat plate collector.

Manufacturing and Assembling

Components other than FPC and its stand were bought from the market while FPC and the stand were built by standard machining operations. After the procurement of required material, parts were milled, lathed, drilled etc. in workshop. After the machining processes we had to perform welding. For that we had to hire a professional welder in order to efficiently perform brazing. Brass based brazing was performed for its.

Figure 8: Incomplete flat plate collector

While in assembling we had to make sure the correct pathway for water in order to achieve simplicity in Arduino code. We had installed one way valve in front of the pump as well to avoid surge and choke effects. Piping was nylon based. At the joints steel clamps were used to avoid water leakage.

Figure 9: Assembly of the complete system

CHAPTER 4: RESULTS AND DISCUSSIONS

From the weather data, value of global irradiance was calculated. It was calculated by taking the average of global irradiance for every 10 minute interval for complete month.

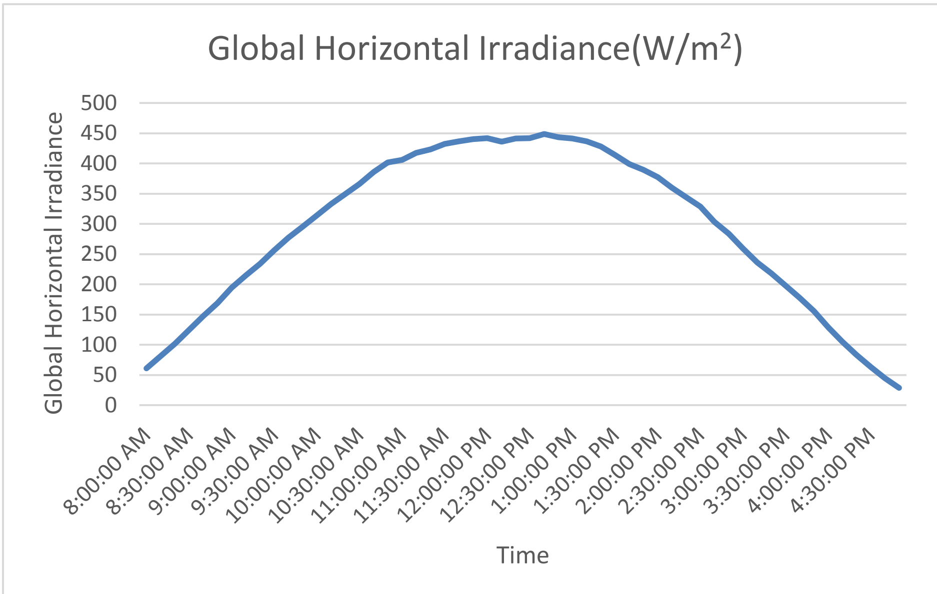


Figure 10: Global horizontal irradiance with time

From the graph, it can be seen that global irradiance increases till after noon and then it starts to decrease till sun set. So we have the maximum value of global horizontal irradiance between noon and after noon.

Using the klein's equation, loss coefficient was calculated for the flat plate collector taking the average for whole month for every 10 minutes.

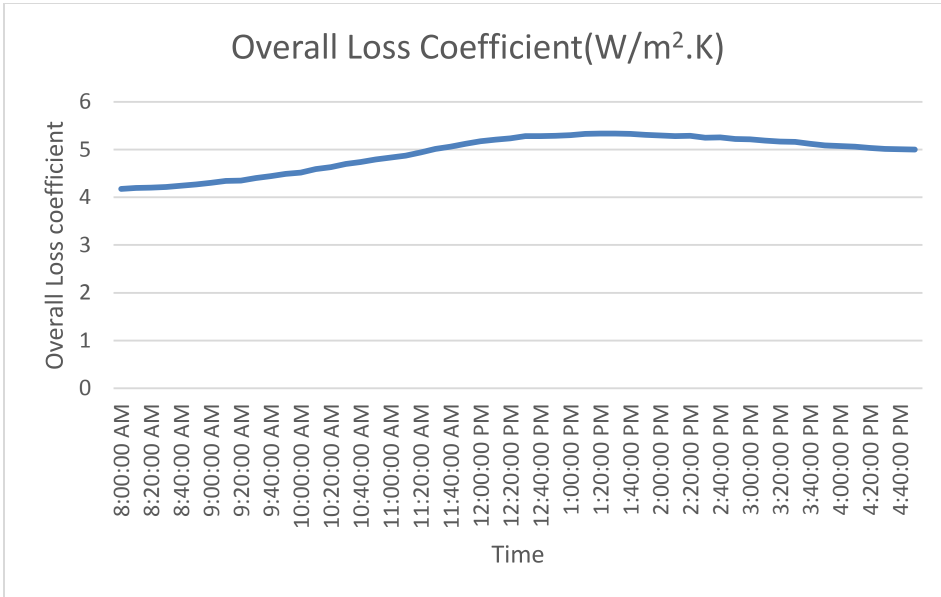


Figure 11: Overall loss coefficient with time

From the graph, it can be seen that loss coefficient increases till afternoon and then it starts decreasing the reason is that relatively more radiations are reflected back from the glazing sheet and

Efficiency of the flat plate was calculated.

$$Efficiency, \eta = \frac{Q\ usable}{Q\ available}$$

$$Qusable\ = (\quad_{g}\quad_{p} I\ A) - UA(Tp - Ta)$$

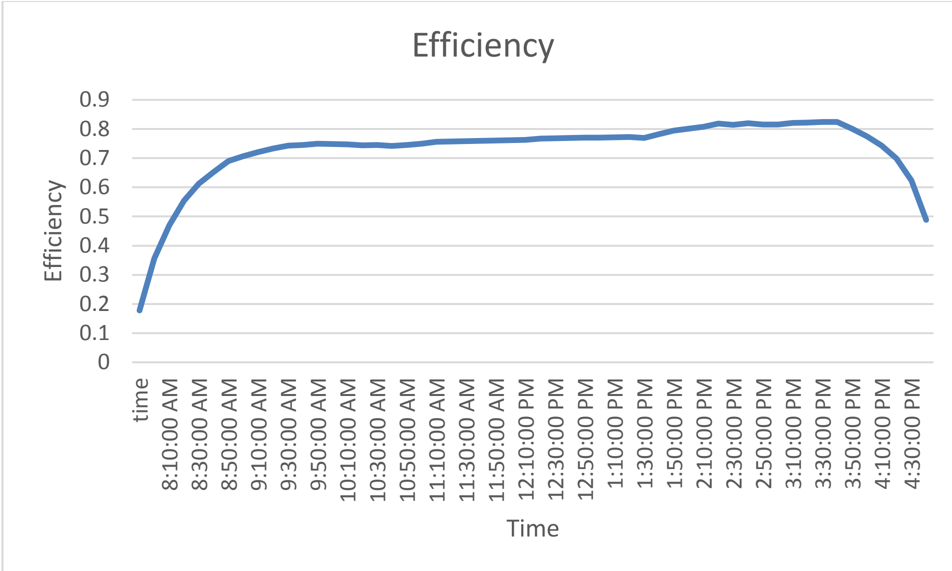


Figure 12: Efficiency with time.

From the graph, it can be seen that efficiency of solar collector increases with time. It reaches to its maximum values and then it starts to decreases. At noon when global horizontal irradiance is high, solar collector will give the maximum efficiency.

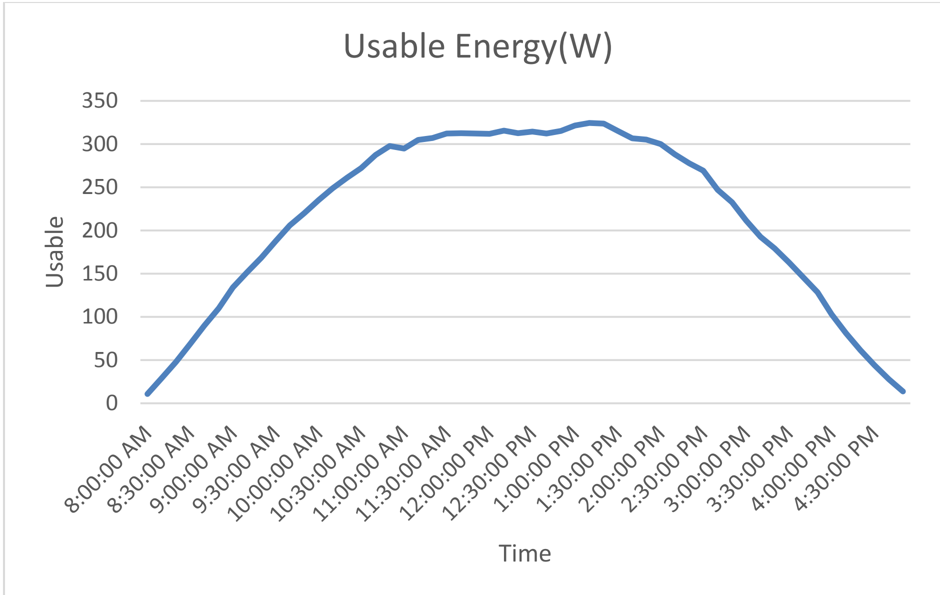


Figure 13: usable energy with time.

From the graph it can be seen that usable energy increases with time and it reaches at its mximum value at afternoon and after that it starts to decrease till sun set.

Figure 14: Collector inlet and outlet temp. at peak hours without auxiliary system.

As we can see from the above experimental readings that the outlet temperature of our collector is way above the required temperature of 40 degrees just by using solar energy for 15 minutes. That tells us that our theoretical calculations match with our experimental results. As for the auxilliary system, it will automatically be turned on when required as we are getting constant feedback from our system. The operational requirements of the auxilliary system are explained in the 'control system' section.

Design of Flat plate collector

On the top of flat plate collector there is a glazing sheet made up of glass to allow the radiations of sun enter the collector. Thickness of glass will be around 4mm. if we decrease the thickness, losses due to emissivity will increase and if we will increase the thickness, losses due to transmissivity will increases as less amount of radiations will pass through the glass. So thickness should neither be high nor be small. Transmissivity of glass is .88.

Copper is used as a metal in absorber plat because is the best conductor of heat and that metal will be painted with black color to have the maximum absorptivity. Color with about 90% absorptivity are also available in the market.

Below and at the side of solar collector, insulation is used. Polyurethane is used as the insulation material. Thickness of polyurethane will be 40mm.

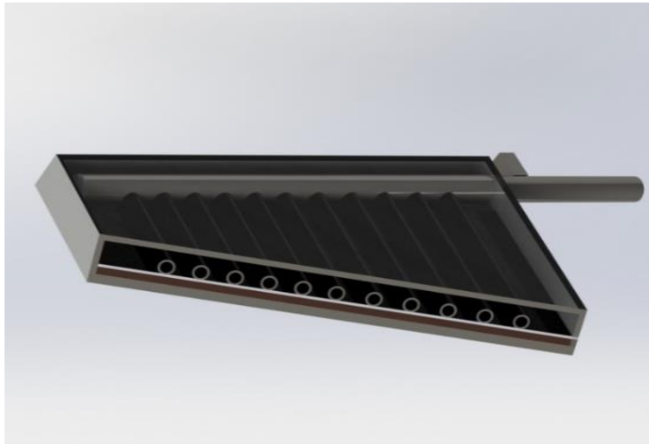


Figure 15: Section view of flat plat collector.

How factors affect the efficiency of collector

Tilt angle

Tilt angle is the angle of solar collector from horizontal axis. It should be adjusted in such a way that collector give the best performance throughout the day.

$\emptyset + 15$ For winter

$\emptyset - 15$ For summer

Number of class covers

Increasing the glass covers can decrease the losses of solar collector. This is due to the reason that solar energy from sun is trapped into the solar collector and due to this losses are reduced.

One or two glass covers give the maximum efficiency.

Gap spacing

Spacing between in glazing sheet and absorber plate should neither be too larger nor too small. 4-8 cm of spacing gives the best performance.

Absorber plate

Absorber plate must have the high value of absorptivity so that it can capture most of the energy from sun and convert it into heat.

Fluid inlet temperature

Efficiency is greatly affected by the inlet temperature of water into the collector. When inlet temperature is low efficiency is high and with the increase in inlet water temperature, the efficiency decreases.

Transmissivity of glass

Transmissivity of glass should be high so that it allow maximum of solar radiation to pass through it.

Surface Area of collector

With the increase in surface area of collector more energy is taken from the sun, so power of solar collector increases.

Active Water Heating system

Centrifugal pump will be used because it provides the constant flow rate and it gives very small pressure ratio. In our project we do not require high pressure ratio. So centrifugal is best for our project. It will be operated by a relay and that relay will be operated by Arduino. Arduino will send the signal to relay and that relay will respond according.

Control System

We used thermocouples at the inlet and outlet of collector, inside the electric geyser and inside the water tank. We gained feedback after every second from these thermocouples and used that feedback to automatically control the water pump as well as the auxiliary system using Arduino. We used MAX6675 module to convert the thermocouple readings into Arduino signals. We used 5V DC relays to control the geyser and the pump and used Arduino signal to operate them based on the following code

```
#include "max6675.h" // max6675.h file is part of the library

//introducing pins for thermocouples

int so1Pin = 2;// SO=Serial Out
int cs1Pin = 3;// CS = chip select CS pin
int sck1Pin = 4;// SCK = Serial Clock pin

int so2Pin = 5;// SO=Serial Out
int cs2Pin = 6;// CS = chip select CS pin
int sck2Pin = 7;// SCK = Serial Clock pin

int so3Pin = 8;// SO=Serial Out
int cs3Pin = 9;// CS = chip select CS pin
int sck3Pin = 10;// SCK = Serial Clock pin

int so4Pin = 11;// SO=Serial Out
int cs4Pin = 12;// CS = chip select CS pin
int sck4Pin = 13;// SCK = Serial Clock pin
```

```
//Defining which thermocouple is given which pin
MAX6675 thermocouple1(sck1Pin, cs1Pin, so1Pin);// create instance object of
MAX6675
MAX6675 thermocouple2(sck2Pin, cs2Pin, so2Pin);// create instance object of
MAX6675
MAX6675 thermocouple3(sck4Pin, cs4Pin, so4Pin);// create instance object of
MAX6675
MAX6675 thermocouple4(sck3Pin, cs3Pin, so3Pin);// create instance object of
MAX6675


void setup() {


   //Introducing pins for relays
  Serial.begin(9600);// initialize serial monitor with 9600 baud
  Serial.println("Robojax MAX6675");
pinMode(40, OUTPUT);// connected to S terminal of Relay
pinMode(42,OUTPUT);


}
```

```
void loop() {
  // basic readout test, just print the current temp
  // Temperature reading on Serial monitor
   Serial.print("Tin = ");
   Serial.println(thermocouple1.readCelsius());

   Serial.print("Tout = ");
   Serial.println(thermocouple2.readCelsius());

   Serial.print("Tgeyser = ");
   Serial.println(thermocouple3.readCelsius());

   Serial.print("Ttank = ");
   Serial.println(thermocouple4.readCelsius());
 //Conditions for the operation of pump and auxiliary system
  if (thermocouple3.readCelsius() >= 45 && thermocouple4.readCelsius() < 38){
digitalWrite(40,HIGH);
digitalWrite(42,LOW);
// if geyser temp. >= 45 and tank temp < 38, pump will turn on and geyser will turn off
}
else if( thermocouple3.readCelsius() <40 && thermocouple4.readCelsius() < 38){
```

```
digitalWrite(40,LOW);

digitalWrite(42,HIGH);

}
// if geyser temp. < 40 and tank temp < 38, pump will turn off and geyser will turn on


else if( thermocouple4.readCelsius() >40){

digitalWrite(40,LOW);

digitalWrite(42,LOW);
// if geyser temp. > 40 , pump will turn off and geyser will turn off

}

else {
//any case apart from above cases will result in continuation of existing commands

}



  delay(1000);
```

}

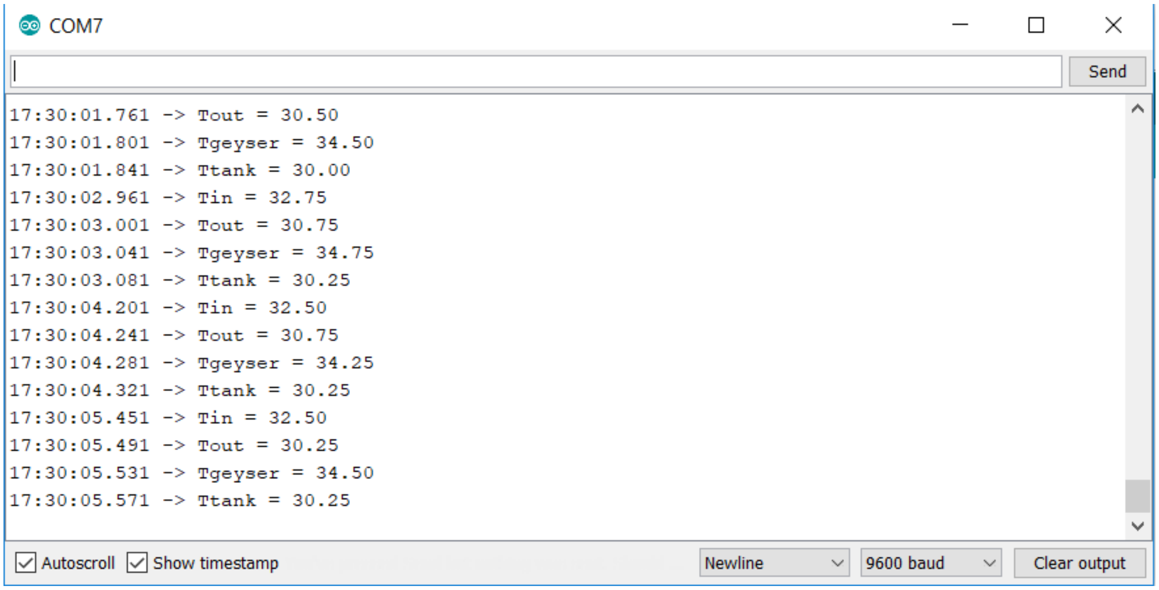


Figure 16: Thermocouple readings from Arduino.

Axillary System:

Axillary system will be placed at the bottom of the collector. The power of axillary system will be 1KW. This will be controlled by Arduino. During the time when there will be no sunlight, it will be turned on. As we are using already integrating already installed geyser with solar so we will be using the same storage tank. So no analysis is required for storage tank in our case. We are basically making a solar UPS where if the energy requirements are not met using solar energy auxiliary electrical system will be turned on.

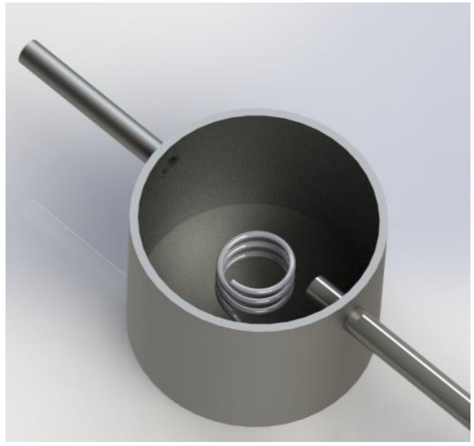


Figure 17: Axillary system.

Final 3D Design

The final design will look like this. A square box on the final models is pump.

Thermocouples are also shown by small extrude on final model design.

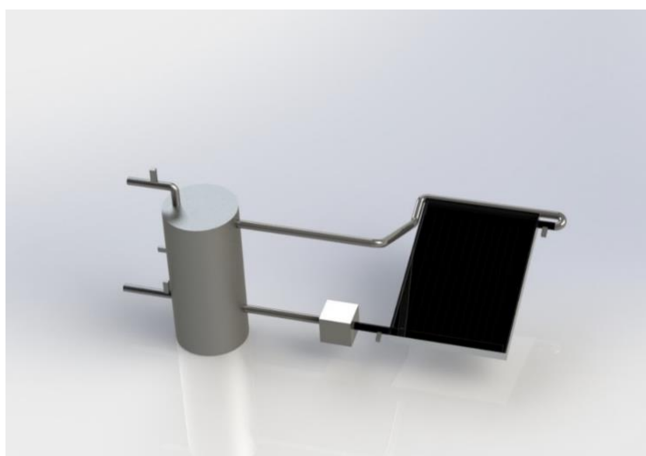


Figure 18: 3D model of hybrid water heating system.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

This projects shows that there is the great solar energy potential in Pakistan. With the adverse effects from the fossil fuels on environment and their limited availability, solar is the best alternative for this. Renewable energy research has become increasingly important. SWH is the best way to convert the energy from the sun into thermal energy which heats the water and that heat to be used in domestic and industrial areas. This is the commercialized and developed technology and there is need for more advancement in this technology. There is a great deal of opportunities to further improve the design of the system to have better performance to increase its reliability and efficiency. Many solar water heating designs are available in the market and this technology is more commonly used in developing countries.

Flat plate collector is cheap in price and it also gives the more efficiency than all other collectors. On the other hand ETC can also be used in the northern areas because they work best in harsh conditions and these areas of Pakistan have harsh winters and temperature there can fall even below melting point. Solar hybrid system is best for the country like Pakistan because we are running short of electricity and gas and solar hybrid water heating system energy is the best way to minimize the load of electricity that is caused due to typical gas and electricity geysers. We can easily see that solar water heaters are very efficient, and using this innovative system can reduce our electricity needs and costs for heating water nearly 60% annually.

Objectively, the solar water heater can’t be the only sustainable power in a house because its efficiency can vary depending on the amount of solar available on a given day. Also the global horizontal irradiances changes throughout the day. From the graphs of global horizontal irradiance we see that it increases with time, reaches to its peak value and then starts to decreases.

Overall losses coefficient also varies with the global irradiance. Losses are less at the start of the day because inlet water temperature from the tank to collector is low and it increases with the time and losses also increases because less energy from radiations is converted into heat. Efficiency of solar water heater also varies because losses vary throughout the day.

To increases the temperature of water, reflector can be used. Just 2 mirrors placed on the both side of collector and focus light from sun on to the collectors surface.

After the prototyping, experiments were be performed on it to check how close the experimental values lie with the theoretical values and they were according to our expectations.

Our system was be automatically controlled by control systems. Operation of pump and axillary system was be automatically controlled.
The system efficiently utilized the solar energy in heating the water. Our system works a UPS for water heating purpose. When the solar energy is not sufficient enough to give us the required temperature of 40 C, the auxiliary electrical system will be automatically turned on. Our project was appreciated a lot by the students, faculty members as well as the industry representatives for the quality of manufacturing, accurate results, constant feedback and the niche market it is targeting. Our system is one of its kind which is not being manufactured anywhere in Pakistan and has a lot of potential to turn into an entrepreneurial venture.

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REFRENCES

[1]S.A. Kalogirou, (2004). Solar thermal collectors and applications, Progress in Energy and Combustion Science.

[2] Al-Madani, Hussain (2006). The performance of a cylindrical solar water heater. Vol. 31, 1751-1763.

[3] Dharamvir Mangal, Devander Kumar Lamba, Tarun Gupta, Kiran Jhamb (2010). Acknowledgement of Evacuated Tube Solar Water Heater over Flat Plate Solar Water Heater, Vol. 4, 279-284.

[4] Recent advances in the solar water heating systems: Are view Ruchi Shukla, K. Sumathy, Phillip Erickson, Jiawei Gong

[5] https://www.energydepot.com/RPUres/library/Swaterheater.asp

[6] Hannah Cassard, Paul Denholm, Sean Ong. (2011). Technical and economic performance of residential solar water heating in the
United States

[7] Himangshu Bhowmik, Ruhul Amin. (2017). Efficiency improvement of flat plate solar collector using reflector

[8] M.C. Rodríguez-Hidalgo, P.A. Rodríguez-Aumente, A. Lecuona, M. Legrand, R. Ventas. (2011). Domestic hot water consumption vs. solar thermal energy storage:
The optimum size of the storage tank

[9] E. Zambolin, D. Del Col. (2010). Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions

[10] Ismail H Ozsabuncuoglu. Collectors of solar energy.

[11] Thermal performance of an evacuated tube heat pipe solar water heating system in cold season.