DESIGN, FABRICATION AND EXPERIMENTAL ANALYSIS OF A PARABOLIC TROUGH COLLECTOR USING DIFFERENT REFLECTING MATERIALS FOR HOT WATER GENERATION

A Thesis

Submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering

in

Thermal Engineering

Submitted by

Sanjay
Roll No: 801083025
Under the guidance of

(Mr. Devender Kumar)
Assistant Professor
Mechanical Engineering Department
Thapar University, Patiala

MECHANICAL ENGINEERING DEPARTMENT
THAPAR UNIVERSITY, PATIALA – 147004
JULY-2012

DECLARATION

I hereby declare that the thesis entitled **"DESIGN, FABRICATION AND EXPERIMENTAL ANALYSIS OF A PARABOLIC TROUGH COLLECTOR USING DIFFERENT REFLECTIVE MATERIALS FOR HOT WATER GENERATION"** is an authentic record of my study carried out as requirement for the award of degree of **Master of Engineering (Thermal Engineering)** at **Thapar University, Patiala** under the guidance of Mr Devender Kumar, Assistant Professor, Department of Mechanical Engineering, Thapar University, Patiala in July 2012. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any other degree.

Sanjay

(Sanjay)
Reg. No. 801083025

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge and belief.

(Devender Kumar)
(Asstt. Professor)
Department of Mechanical Engineering,
Thapar University, Patiala - 147004

Countersigned by:

Dr. Ajay Batish
Professor and Head,
Department of Mechanical
Engineering,
Thapar University, Patiala -147004

Dr. S.K. Mohapatra
Sr. Professor &
Dean of Academic Affairs,
Thapar University, Patiala -147004

ACKNOWLEDGEMENT

Words are often less to revels one's deep regards. With an understanding that work like this can never be the outcome of a single person, I take this opportunity to express my profound sense of gratitude and respect to all those who directly or indirectly helped me through the duration of this work.

I take the opportunity to express my heartfelt adulation and gratitude to my supervisor, **Devender Kumar** for their unreserved guidance, constructive suggestions, thought provoking discussions and unabashed inspiration in the nurturing work. It has been a benediction for me to spend many opportune moments under the guidance of the perfectionist at the acme of professionalism. His continuous support from the initial to the final level enabled me to develop an understanding of the project and have made the completion of this thesis work possible.

I am grateful to **Dr. Ajay Batish**, Professor. & Head, MED, **Mr. Sandeep Sharma**, P.G Coordinator, Thapar University, Patiala for providing me an opportunity to do my project work on the topic of my interest and for providing the facilities for the completion of the work.

I take pride of myself being son of ideal parents for their everlasting desire, sacrifice, affectionate blessings, and help, without which it would not have been possible for me to complete my studies.

I would like to thank Mr.Avdesh Yadav (Asstt.Professor in NIT KKR), all the members and employees of Mechanical Engineering Department, Thapar University Patiala for their everlasting support and helping advices. Above all, I express my indebtedness to the ***almighty*** for all his blessings and kindness.

Sanjay

(Sanjay)

Registration No: 801083025

TABLE OF CONTENTS

8.0 Results and Discussion

ABSTRACT

In this developing world, energy demand is growing day by day. But due to the scarcity and continuous depletion of conventional fuels, Renewable energy is an alternative source. Among all renewable energies, we have solar energy in abundance. India today has among the world's largest programs in solar energy. The India Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions.

A parabolic trough solar collector uses a mirror in the shape of a parabola to reflect and concentrate sun's radiations towards a receiver tube located at the focus line of the parabola. In the present dissertation work a Prototype Parabolic Trough Concentrator has been designed , fabricated and experimental analysis is being carried out for its feasibility in hot water generation. A Prototype parabolic Trough Concentrator is fabricated and their efficiency is compared using different reflecting materials like Stainless Steel, Aluminium foil, Glass Mirror. The absorber pipe is a copper tube with appropriate black paint and a glazing (glass cover tube) is provided to minimize the losses and comparing the test results .Water is used as heat carrying fluid in absorber tube. The concentration ratio for PTC is 11.32 with aperture area 1.40 m^2(without glazing) and 1.387 m^2(with glazing). The maximum temperature of heating water obtained is 81.2 while the average temperature of heating water was produced is 65 . A brief analysis is carried out to choose the best reflective material in terms of improved efficiency. The improvement in efficiency using glass as a reflective material in comparison to stainless steel and aluminium foil obtained 5-40%. The main objective of present study is to design, fabrication, experimental analysis of Prototype PTC with different reflecting materials for hot water generation and to check its feasibility for further practical applications . The results obtained shows that the production of heating water using the sun flux is a viable undertaking. Improvement of tracking system and the optical efficiency can improve the efficiency of fabricated PTC. Reduced mass flow rate or with different mass flow rate efficiency of prototype PTC can further be increased.

List of Figures

Stainless Steel with glazed copper tube:

Aluminium Foil with bare copper tube:

Aluminium Foil with glazed copper tube:

Glass Mirror with bare copper tube:

Glass Mirror with Glazed Copper Tube:

Stainless Steel vs Aluminium Foil vs Glass Mirror:

List of Tables

NOMENCLATURE AND ABBREVIATION

Symbol	Description
$\boldsymbol{A}$	collector aperture area, [m^2]
	collector width[m]
	diameter of absorber tube with glazing [m]
	length of collector[m]
C	concentration ratio, [–]
C_p	specific heat capacity of water, [J/kgK]
F_R	heat removal factor, [–]
I_b	beam or direct radiation, [W/m^2]
r_b	Rim angle factor
	Specular reflectivity of the concentrator
	Glass cover transmittivity for solar radiation
	Absorber tube emissivity/absorptivity
Qu	rate of useful heat received from the collector, [W]
Ta	Ambient temperature, [K]
T_{fi}	collector water inlet temperature, [K]
T_{fo}	collector water outlet temperature, [K]
T_l	storage tank water temperature, [K]
T_i	Initial storage tank water temperature, [K]
T_o	Outlet temperature of water[K]
Dt	time interval, [h]
U_L	overall heat loss co-efficient, [W/m^2 K]
V	volume, [m^3]
	Heat loss factor
	Mass flow rate[kg/s]
$_{\text{inst}}$	Instantaneous Efficiency
$_{\text{therm}}$	Thermal Efficiency
$_{\text{overall}}$	System Overall Efficiency
$_{\text{o}}$	Optical efficiency

PTC	Parabolic Trough Collector
FPC	Flate Plate Collector
CPC	Compound Parabolic Trough collector

CHAPTER -1

INTRODUCTION

1.1 Solar energy

Solar energy is a high-temperature, high-exergy radiant energy source, with tremendous advantages over other alternative energy sources. It is a reliable, domestic, robust renewable resource with large undeveloped potential, and it emits essentially none of the atmospheric emissions that are of growing concern. Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 10^{11} MW which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy sources.

Sun is a source of one of renewable energy, known as solar energy. It is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions. Its diameter is 1.39 x 10^6 km, while that of the earth is 1.27 x 10^4 km. The mean distance between the two is 1.496 x 10^8 km. Although the sun is large, it subtends an angle of only 32 minutes (0.53^0) at the earth surface. This is because it is also at a very large distance. Thus, the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its center to its edge. However, from engineering calculations, it is customary to assume that the brightness all over the solar disc is uniform.

1.2 Energy scenario:

It is nearly 35 years since the first oil shock in 1973. Since then the words ‘energy crisis’ and ‘energy security’ continue to dominate the news. Added to these worries now are the issues of climate change. In spite of efforts to promote and develop renewable sources of energy and other new sources, fossil fuels (coal, oil & natural gas) continue to dominate the energy scene. While the need for alternative sources of energy is recognized, no set of alternatives has emerged which can take over the role played by fossil fuels.

Since 1973, the word "energy" has been continuously in the news. There have been shortages of oil in many parts of the world and the price of this commodity has increased steeply. It is by now clear that the fossil fuel era of non-renewable resources is gradually coming to an end. Oil and natural gas will be depleted first, followed eventually by coal.

In India the energy problem is very serious. In spite of discoveries of oil and gas off the west coast, the import of crude oil continues to increase and the price paid for it now dominates all other expenditure. This year the country will spend more than Rs 5000 crores for the import of oil. This amount forms a major part of India's import bill. The need for developing energy alternatives is thus evident and considerable research and development work is already in progress in this direction.

One of the promising options is to make more extensive use of renewable sources of energy derived from the sun. Solar energy can be used both directly and indirectly. It can be used directly in a variety of thermal applications like heating water of air, drying, distillation, and cooking. The heated fluids can in turn be used for applications like power generation or refrigeration. A second way in which solar energy can be used indirectly is through the photovoltaic effect in which it is converted to electrical energy.

Thus today, every country draws its energy needs from a variety of sources. We can broadly categorize these sources as commercial and noncommercial. The commercial sources include the fossil fuels (coal, oil & natural gas), hydroelectric power, nuclear power and wind power, while the noncommercial sources include wood, animal wastes and agricultural wastes. In an industrialized country like the USA, most of the energy requirements are met from commercial sources, while in an industrially less developed country like India, the use of commercial and noncommercial sources is about equal.

In the past few years, it has become obvious that fossil fuel resources are fast depleting and that the fossil fuel era is gradually coming to an end. This is particularly true for oil and natural gas. It is worth nothing that while man's large scale use of commercial energy has led to a better quality of life, it has also created many problems. Perhaps the most serious of these is the harmful effect on the environment. The combustion of fossil fuels has caused serious air pollution problems in many areas because of the localized release of large amounts of harmful gases into the atmosphere. It is also the main contributor to the phenomenon of global warming which is now a matter of great concern.

1.3 India’s power scenario

India’s current electricity installed capacity is 135 401.63MW. Currently there is peak power shortage of about 10 % and overall power shortage of 7.5 % The 11th plan target is to add 100 000 MW by 2012 and MNRE has set up target to add 14500 MW by 2012 from new and renewable energy resources out of which 50 MW would be from solar energy. The Integrated Energy Policy of India envisages electricity generation installed capacity of 800 000 MW by 2030 and a substantial contribution would be from renewable energy. This indicates that India’s future energy requirements are going to be very high and solar energy can be one of the efficient and eco-friendly ways to meet the same.(Making solar thermal power generation in India a reality – Overview of technologies, opportunities and challenges **Shirish Garud, Fellow and Ishan Purohit**, Research Associate, The Energy and Resources Institute (TERI), India).

1.4 Solar energy potential

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. The India Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where development and deployment of solar technologies is maximum.

Depending on the technology, the temperature of the output thermal energy can vary from as low as ambient temperature to as high as 3000 °C. This opens up a vast area of applications including power generation and refrigeration. Solar water heating is an important application of solar energy. From many types of solar collectors developed, three types merit further consideration for hot water generation: the flat plate collector (FPC) , the compound parabolic collector (CPC) , and the parabolic trough collector (PTC) . The first two are stationary collectors, whereas the last one is a tacking collector. PTCs are generally of medium concentration ratio (15-40) and hence they require some level of solar tracking. The advantage of concentrating collectors is that the heat losses are inversely proportional to the concentration ratio. The most important advantage of PTC as compared with the other two types of collectors is its ability to function at high temperatures with high efficiency. For example, at a temperature of 100 °C, PTCs works at an efficiency of about 62%, CPCs at about 32% and the FPC at about 10% . In recent days, PTC has been used in many applications such as steam generation for industrial applications and power generation , hot water generation, sea water desalination, solar photocatalysis , solar detoxification of organic pollutants etc.

1.5 Solar radiation on the earth surface

Solar radiation is received at the earth's surface in an attenuated form because it is subjected to the mechanism of absorption and scattering as it passes through the earth's atmosphere.

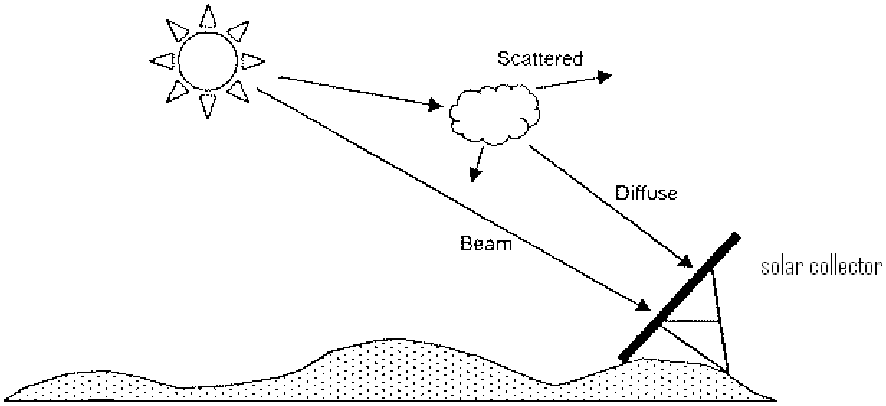


Figure1.1 [1]

Beam radiation:

Solar radiation received at the earth's surface without change of direction, i.e. in line with the sun, is called beam or direct radiation.

Diffuse radiation:

The radiation received at the earth surface from all part of the sky's hemisphere (after being subjected to scattering in the atmosphere) is called diffuse radiation.

Total radiation:

The sum of the beam and diffuse radiation is referred to as total or global radiation.

1.6 Solar Energy collectors:

A solar collector is a device used for collecting solar radiation and transfers the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. These are general of two types:

- Non-concentrating type
- Concentrating type

Solar collectors are the devices used to convert solar energy into heat energy. Solar collector with associate absorber (absorb the solar radiation) collects and converts the solar energy into heat energy that can be used in many applications. Fig. shows the working principal of solar collector.

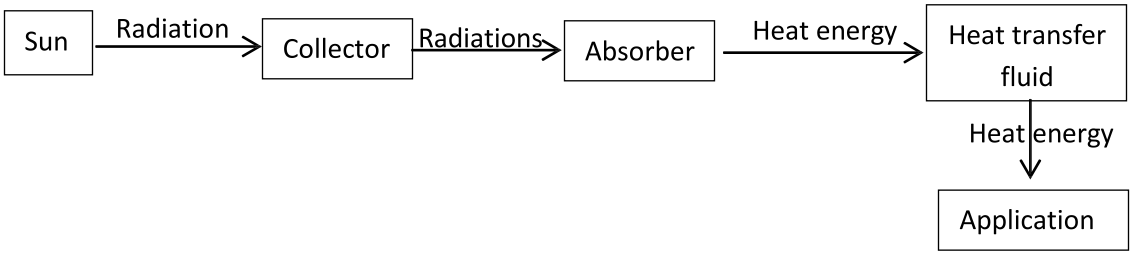


Fig 1.2 Working Principle of solar collector

In the table some collectors are given which are used for to convert solar energy into heat energy with their approximate working temperature range.

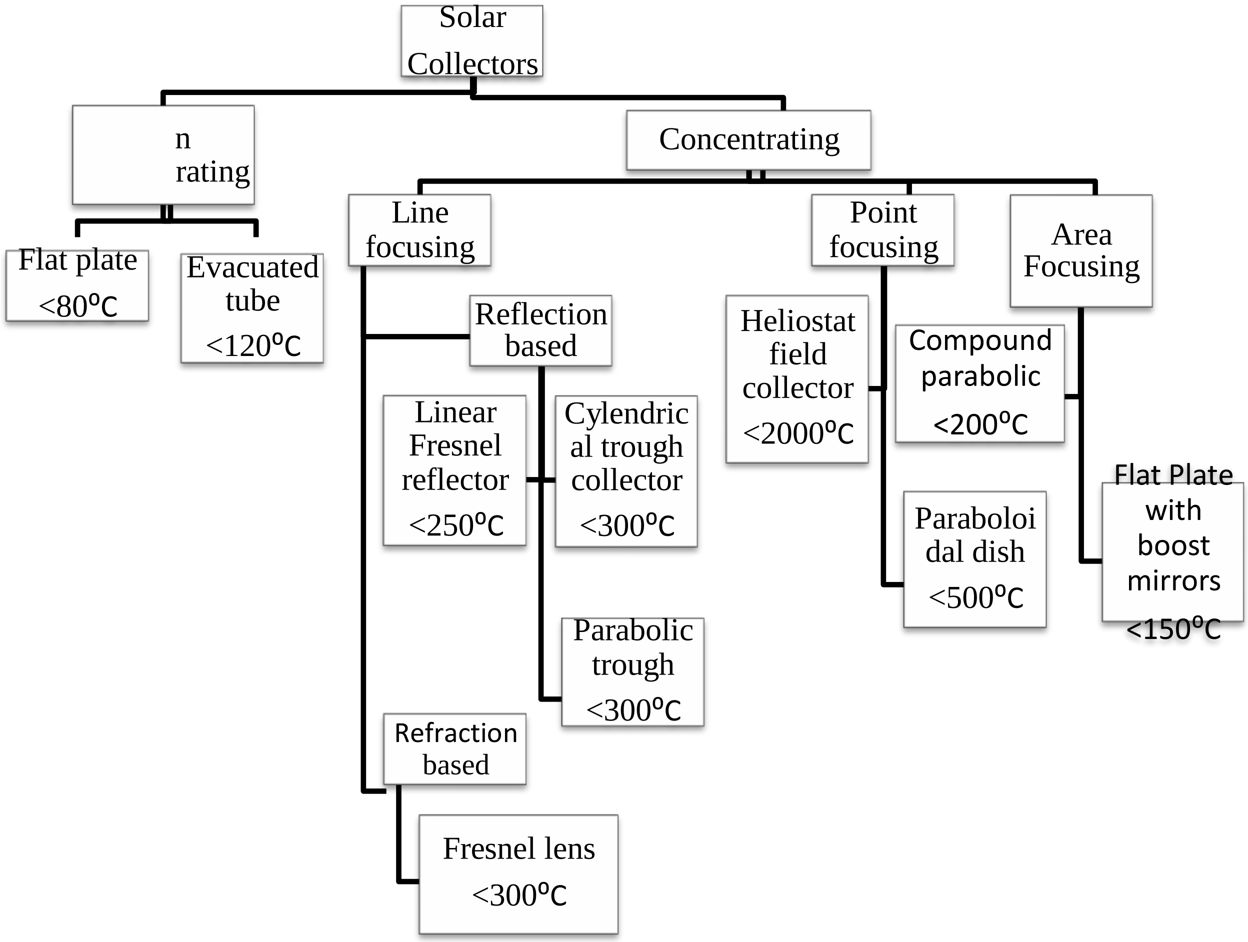


Fig 1.3 Types of Solar Collector

In non-concentrating type collectors' collector area is equal to absorber area. These are mostly used for low temperature (<120^{0}C) heating purposes for e.g. heating water in the houses and solar air heating for to preheat air in buildings. Non concentrating collector can produce high temperature but because of following reasons these are not used for high temperature application:

i. The cost of absorber higher than the cost of mirrors.
ii. The heat losses from the collector are proportional to the absorber area.
iii. Radiative losses are proportional to so there is great increase in radiative loss due to high temperature.

1.6.1 Flat plate solar collectors:

It is the non-concentrating type collector. This is used for low temperature heating applications. Domestic solar water heater is the main example of its use. These collectors are more reliable, simple in operation and low maintenance required. These collectors are widely used all over the world. The other applications of this collector are pool heating, laundry, space heating, drying agriculture products etc. Unglazed collectors are used for pool heating because of low temperature requirement. On the basis of type of fluid used for heat transfer flat plate collectors are classified as: liquid type flat plate solar collector and solar air heater. Fig.1.4. shows the different components of flat plate solar collector.

The solar energy collector with its associated absorber is the essential component of any system for the conversion of solar radiation energy into more usable form e.g heat or electricity. In the non-concentrating type the collector area is same as the absorber area. On the other hand in concentrating collectors the area intercepting the solar radiations is greater, sometimes hundred times greater than the absorber area.

Fig 1.4 Flat plate liquid solar collector [4]

1.6.2 Concentrating (focussing) type solar collector:

In concentrating collectors the solar radiations falling on large area (collector) are concentrated on the small area (absorber). Thus the energy falling per unit area increases on the concentrating surface as compare to any other surface. This increases the energy input rate per unit area due to which high temperatures can be achieved. So point focusing collectors are used for much higher temperature applications. The ratio of collector area to absorber area is the parameter decides the achievable temperature rise. The following table1.1 shows the different concentrating collectors with their achievable concentration ratios.

There are four basic types of concentrating collectors:

1) Parabolic trough system
2) Linear fresnel reflector
3) Parabolic dish
4) Heliostat Field Collector

1.6.2(a) Parabolic trough concentrator

A prototype parabolic trough concentrator (Fig.1.5) consists of a reflecting surface mounted on a reflector support structure having the profile of a parabola. A receiver assembly comprising a circular absorber tube with suitable selective coating and enclosed in a concentric glass envelope is centered along the reflector focal line. With suitable end supports, the PTC module is supported on triangular two base support. It is also provided with a precise manual tracking system in order to track the sun and, thus, to maintain focusing of solar radiation on the receiver assembly. The incident energy is absorbed by a working fluid, water, is circulating in tube.

Parabolic trough collectors (PTC) can effectively produce heat at temperatures between 50°C and 400°C for solar thermal electricity generation or process heat applications. Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these systems. Parabolic trough collectors are built in modules that are supported from the ground by simple pedestals at either end. Parabolic trough is a line focusing collector. The maximum concentration ratio achieved in case of this collector is . is the acceptance angle of the collector. The minimum value of this angle is the angle made by the sun on earth $1/2^0$. It is used for high temperature applications like steam generation, electricity production, industrial process heat etc. As per [Advances in Parabolic Trough Solar Power Technology] there are nine large solar power plants that are operating in the California Mojave Desert. These plants are developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS). Each plant is in the range 14–80 MW and represents 354 MW of installed electric generating capacity. There are two euro trough models ET100 and ET150 are developed with the optical concentration ratio 82:1 and achievable temperature of 500^0C [EuroTrough_Paper2002].

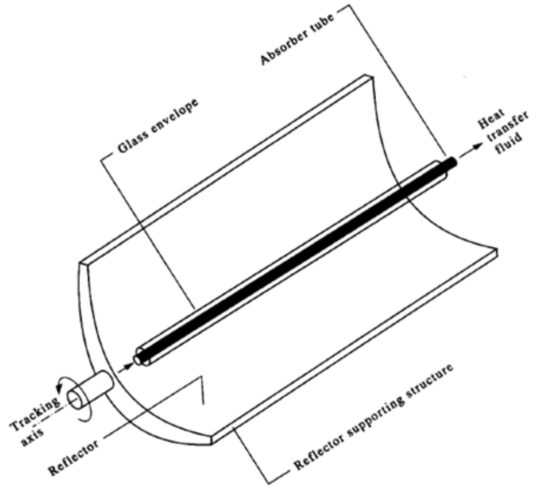


Fig1.5 Parabolic Trough Collector System [14]

The main components of parabolic trough are:

1) A **parabolic reflector** reflects and concentrates all the sun's rays to the receiver tube which is at the focal point of the parabola. The reflectors are parabolically shaped mirrors with a reflectivity of 93.5%. The mirror is a second surface silvered glass mirrors with reflective silver layer coating on the back side of the glass. A special multilayer paint coating protects the silver on the back side of the mirror for the effective steam generation.

2) An **absorber tube** is a linear receiver located at the focus line of parabolic reflective surface at the focus line of parabolic reflective surface, with means of transferring the absorbed solar energy to a heat transfer fluid. It has glass to metal seals and metal bellows to accommodate for differing thermal expansions between steel tubing and glass envelop. It has a vacuum type enclosure to reduce the heat losses. The selective coating on the steel tube has a good solar absorbance.
3) A **concentric tubular glass cover** surrounding the absorber with a gap of 1-2 cm with glass to metal seal to create vacuum so as to minimize the conduction and convection losses.
4) **Steel supported structure** is there in the back of the reflector mirror so as to provide mechanical strength to the collector to withstand the heavy wind loads.
5) A **Tracking mechanism** must be reliable and able to follow the Sun with a certain degree of accuracy, return the collector to its original position at the end of the day or during the night, and also track during periods of cloud cover. The use of tracking mechanism increases the amount of solar energy received by the collectors which results in the high power output. Commercially the one axis and two axis tracking mechanisms are available. Usually the single axis tracker follow the sun's east-west movement, while the two axis tracker also follows the sun's changing altitude angle.

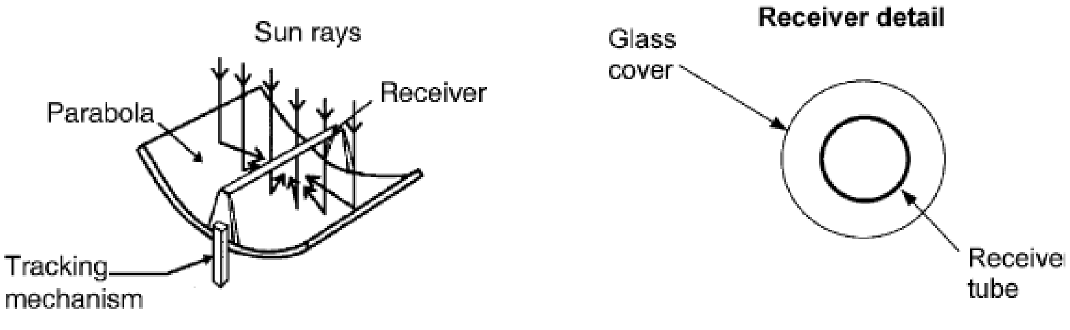


Fig. 1.6 Schematic diagram of a parabolic trough collector [14]

Advantages:

1) Higher operating temperatures 150-300ºC can be obtained.
2) High efficiency and low cost.
3) It can be used either for thermal energy collection, or for generating electricity.
4) There are unlimited number of location options
5) Flexible implementation
6) Possibility of thermal energy storage

1.6.2 (b) Linear Fresnel Reflector (LFR)

Linear Fresnel reflector (LFR) technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector , but unlike parabolic troughs, it doesn't have to be of parabolic shape, large absorbers can be constructed and the absorber does not have to move. A representation of an element of an LFR collector field is shown in Fig. (1.7). The greatest advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally these are mounted close to the ground, thus minimizing structural requirement.

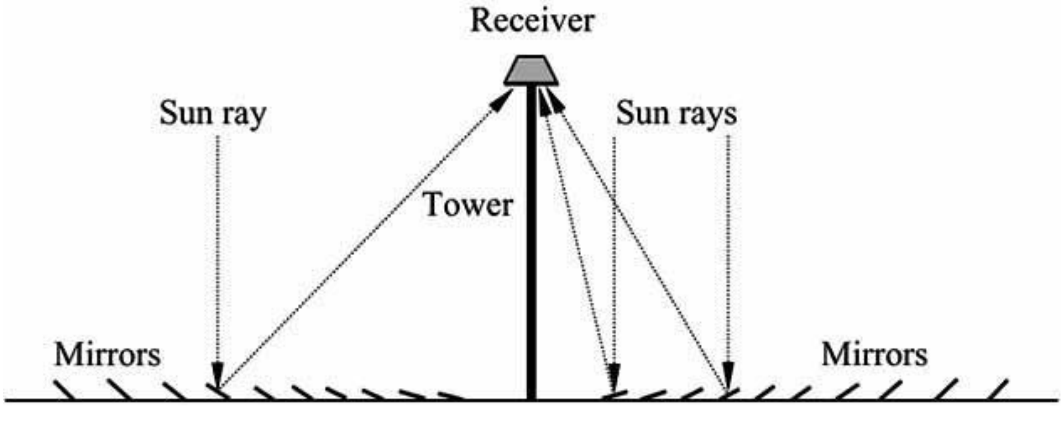


Fig.1.7 Schematic diagram of a receiver illuminated from an LFR field.[24]

1.6.2 (c) Parabolic Dish Reflector (PDR)

A parabolic dish reflector, shown schematically in Fig.(1.8), is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver. The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid. The thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system. Parabolic-dish systems can achieve temperatures in excess of 1,500°C. Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems.

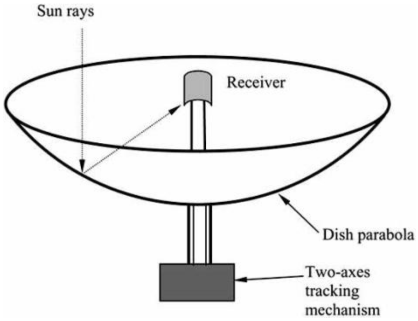


Fig.1.8 Schematic diagram of a parabolic dish collector [24]

1.6.2 (d) Heliostat Field Collector (HFC)

For extremely high inputs of radiant energy, a multiplicity of flat mirrors, or heliostats, using azimuth mounts, can be used to reflect their incident direct solar radiation onto a common target as shown in Fig. (1.**9**). This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure.

The concentrated heat energy absorbed by the receiver is transferred to a circulating fluid that can be stored and later used to produce power. Central receivers have several advantages

- They collect solar energy optically and transfer it to a single receiver, thus minimizing thermal-energy transport requirements.
- They typically achieve concentration ratios of 300 to 1,500 and so are highly efficient both in collecting energy and in converting it to electricity,

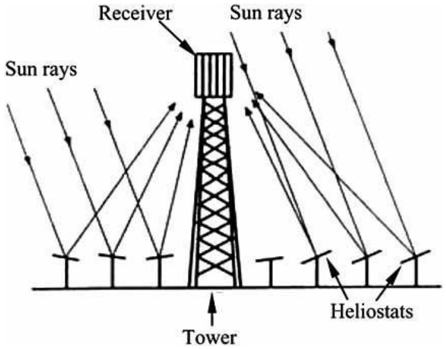


Fig. 1.9 Schematic diagram of heliostat field collector [24]

1.7 Comparison of different collectors

Table 1.1: Comparison of different collectors in Solar energy is given below 2:

Sr. No.	Name of collector	Type	Operating temp(ºC)	Concentr-ation ratio	Heat transfer medium	Application areas
1	Flat plate	Non-concentrating	30-80	1	Water or air	Air-heating and water-heating
2	Evacuated tube	Non-concentrating	50-200	1	Water or air	Water, oil, air Heating
3	Parabolic trough	Line-focussing	60-300	15-45	Water or thermal oil	Electricity production, water heating
4	Linear Fresnel reflector	Line-Focussing	60-250	10-40	Water or thermal oil	Water heating
5	Dish type	Point-focussing	100-500	100-1000	Thermal oil	Parabolic dish Engines

- The thermal losses in case parabolic trough are very small and increase only moderately as the operating temperature increase
- At peak conditions a parabolic trough collector can be expected to deliver more than 60% of incident radiations onto it even when taking into account the losses in the solar field piping.
- Also that the typically higher optical efficiency of the flat-plate collector compensates only partially for the higher thermal efficiency of the concentrators.
- The peak optical efficiency of a parabolic trough ranges from 60-70%.

CHAPTER 2

OBJECTIVE OF THE STUDY

The objective of present dissertation “Design, Fabrication and Experimental analysis of a prototype Parabolic Trough Collector using different reflecting materials for hot water generation” aim at obtaining optimum design and efficiency (in terms of reflective materials) of Parabolic Trough Concentrators that can be further used for different practical application like domestic hot water generation, process heating, air heating, steam generation etc.

The software “PARABOLA CALCULATOR 2.0” is used to generate design for Parabolic Trough Collector. Results suggested by software are used to fabricate Parabolic Trough Collector. Wood and Plywood is used as fabrication material due to its easy machinability and low cost. The dimensions of the collector are length: 1.20m, Collector width 1.20m, aperture area: 1.40 without glazing and 1.387m^2 with glazing having a glass cover tube with thickness 1mm. Absorber Tube used in present work is Copper Tube with and without Glazing (using a glass cover tube).In present study different Reflective Materials for reflective sun radiation on absorber tube is used vaz. Stainless Steel, Aluminium foil and Glass mirrors and comparison of efficiencies of PTC using these concentrators is analysed.

The main objectives of present dissertation are:

1. To design and fabricate prototype parabolic trough concentrator for Hot Water Generation and its feasibility in further applications.

2. To study different properties of reflective materials namely Stainless Steel, Aluminium Foil, Glass mirror and to find their optical efficiency in Prototype PTC.

3. Experimental analysis and comparison of different reflective material in terms of efficiency with Copper Tube (with and without glazing) and choosing the best reflective material for improved efficiency.

CHAPTER 3

LITERATURE REVIEW

The literature review is categorized on the basis of:

3.1 Performance
3.2 Design, Materials and economics
3.3 Application

3.1 Performance:

A.Valan Arasu *et al.(*2006) concluded the performance of a new parabolic trough collector hot water generation system with a well mixed hot water storage tank is investigated . The storage tank water temperature is increased from 35 °C at 9.30 h to 73.84 °C at 16.00 h when no energy is withdrawn from the storage tank. The average beam radiation during the collection period is 699 W/m^2. The useful heat gain, the collector instantaneous efficiency, the energy gained by the storage tank water and the efficiency of the system as a whole are found to follow the variation of incident beam radiation as these parameters are strongly influenced by the incident beam radiation. The value of each of those parameters is observed to be maximum around noon, when the incident beam radiation is maximum.

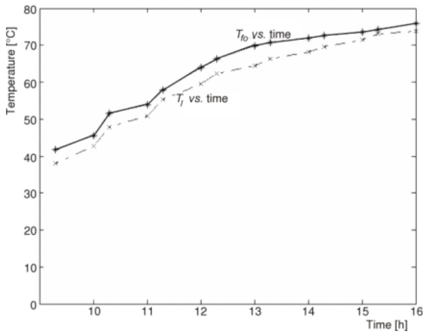


Fig. 1. Variation of collector water temperature, *Tfo* ,with time

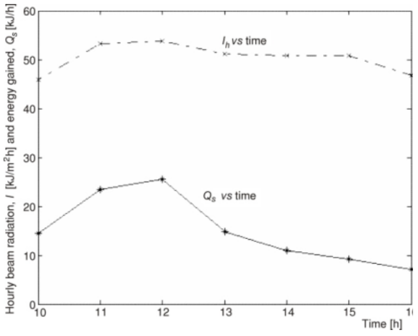


Fig. 2 Variation of Useful Heat gain with intensity

A.Valan Arasu *et al*.(2007) studied the modeling of a parabolic trough collector with hot water generation system with a well-mixed type storage tank using a computer simulation program is presented in this paper. This is followed by an experimental verification of the model and an analysis of the experimental results. The maximum difference between the predicted and the actual storage tank water temperature values is found as 9.59% only. This variation is due to the difference between the actual weather during the test period compared to hourly values and the convection losses from the collector receiver, which were not constant as accounted by the computer simulation program.

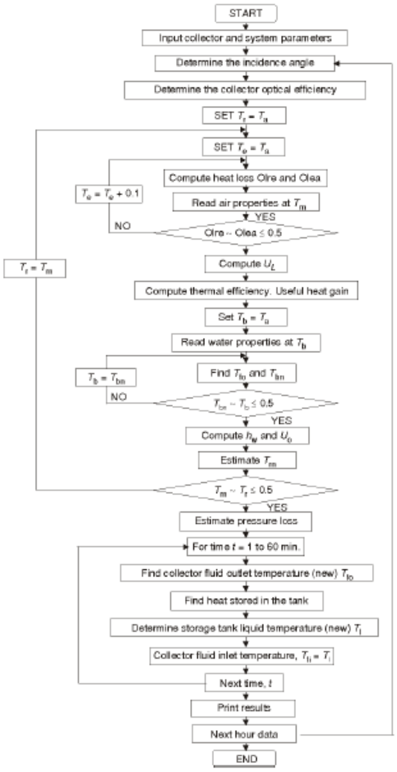


Fig.1 Simulation program for parabolic trough collector

K.S.REDDY *et al*.(2009) presented a thermal analysis of an energy efficient receiver for solar parabolic trough concentrator. Various porous receiver geometries are considered for the performance evaluation of a solar parabolic trough concentrator numerical models are proposed for the above receiver for internal heat gain characteristics and heat loss due to natural convection. The analysis is carried out on the basis of RNG-turbulent model and solved using FLUENT. The results showed the improvement in the heat transfer characteristics of the receiver with the introduction of porous inclusions but with a pressure drop as a penalty. The shorter fins were more favourable for improved heat transfer and pressure drop.

Isabel Llorente Garcı´a *et al*.(2011) describes a simulation model that reproduces the performance of parabolic trough solar thermal power plants with a thermal storage system. The aim of this model is to facilitate the prediction of the electricity output of these plants during the various stages of their planning, design, construction and operation. Model results for a 50MWe power plant are presented and compared to real data from an equivalent power plant currently operated by the ACS Industrial Group in Spain.

Najla El Gharbi, Halima Derbal *et al*.(2011) In this paper two optical technologies which showed promising results were compared, the first one is the Fresnel mirror and the second one is the parabolic trough. These two technologies are based on linear solar concentration. The main objective of this paper is to report the performance of these technologies by means of numerical analysis. A methodological analysis to design and evaluate the technical feasibility for the use of Fresnel mirror or parabolic trough in a Reflective Solar Power (CSP) system has been carried out. The influence of ambient conditions and the percent of different types of energy loss, etc., are analyzed Linear Fresnel reflectors are optical analogous to parabolic troughs. They are reflective reflectors with linear focus, where the parabolic reflective surface is obtained by an array of linear mirror strips which independently move and collectively focus on absorber lines suspended from elevated towers. The objective of this study is to reproduce the performance of parabolic troughs though with lower costs, this can be achieved with linear Fresnel reflectors (Häberle A et *al*. 2002). However with linear-Fresnel reflectors, optical quality and thermal efficiency is lower because of a higher influence of the incidence angle and the cosine factor. Because of that, this technology is not still much applied into ISCCS or in regenerative Rankine cycles.

M.J. Montes *et al*.(2010) in this work the contribution of solar thermal power to improve the performance of gas-fired combined cycles in very hot and dry environmental

conditions is analyzed in this work, in order to assess the potential of this technique, and to feature Direct Steam Generation (DSG) as a well suited candidate for achieving very good results in this quest. The particular Integrated Solar Combined Cycle (ISCC) power plant proposed consists of a DSG parabolic trough field coupled to the bottoming steam cycle of a Combined Cycle Gas Turbine (CCGT) power plant. For this analysis, the solar thermal power plant performs in a solar dispatching mode: the gas turbine always operates at full load, only depending on ambient conditions, whereas the steam turbine is somewhat boosted to accommodate the thermal hybridization from the solar field. To demonstrate this general effect of the ISCC systems, the particular selected arrangement is a DSG parabolic trough field which coupled to the high-pressure level of the steam turbine in the bottoming Rankine cycle. The DSG solar field fits very well to that pressure level. Besides that, this arrangement does not require of two critical elements for the DSG deployment: the thermal storage, as there is always a minimum load that is guaranteed by the fossil fuel, and the solar superheating section, because steam superheating
is accomplished in the HRSG.

A.El Fadar *et al*.(2008) suggests a numerical study of a continuous adsorption refrigeration system consisting of two adsorbent beds and powered a parabolic trough collector (PTC). Activated carbon as adsorbent and ammonia as refrigerant are selected. A predictive model accounting for heat balance in the solar collector components and instantaneous heat and mass transfer in adsorbent bed is presented. This paper concluded following points

An aim of the current work was to present a novel system, in which the solar parabolic trough collector has been introduced to the adsorption refrigeration purpose in order to achieve continuous cycles using two adsorbent beds. A theoretical model based on the heat and mass transfer in the adsorbent and on the heat balance equations in the collector components has been developed.

M J Brookes *et al*.(2007) tested a parabolic trough solar collected for development in a solar energy research programme. It was a low-temperature testing using water as a working fluid. Both an evacuated glass shielded and unshielded receivers were tested with which the peak thermal efficiencies of 53.8% and 55.2% were obtained respectively. The glass shielded element offered superior performance at the maximum test temperature. The high heat loss sensitivity of the unshielded receiver to the variation in wind speed with corresponding insensitivity of the glass-shielded receiver is determined.

Ming Qu *et al*.(2006) programmed a performance model for solar thermal collector based on a linear, tracking parabolic trough reflector focussed on a surface treated metallic pipe receiver enclosed in an evacuated transparent tube. The effects of solar intensity and incident angle, collector dimensions, material properties, fluid properties, ambient conditions, and operating conditions are considered on performance of the collector. The results from the model are as follows:

1. If the glass envelope is removed, conduction, convection losses enhances.
2. When a vacuum is present in the annulus between the receiver surface and the glass envelope then the losses are effectively eliminated.
3. With the increase in operating temperature the pressure drop decreases because the viscosity of the fluid reduces.
4. The flow rate does not have an impact on PTSC.
5. The efficiency of the collector decreases with the increase in wind speed.

P. Rhushi Prasad *et al*.(2010) compared the performance of fixed flat plate water heater with that of heater with tracking by conducting experiments. A flat plate water heater, which is commercially available with a capacity of 100 litres/day is instrumented and developed into a test-rig to conduct the experimental work. Experiments were conducted for a week during which the atmospheric conditions were almost uniform and data was collected both for fixed and tracked conditions of the flat plate collector. The results show that there is an average increase of 4oC in the outlet temperature. The efficiency of both the conditions was calculated and the comparison shows that there is an increase of about 21% in the percentage of efficiency.

Ricardo Vasquez Padilla *et al.*(2011) , observed that Solar parabolic trough collectors ( ) are currently used for the production of electricity and applications with relatively higher temperatures. A heat transfer fluid circulates through a metal tube (receiver) with an external selective surface that absorbs solar radiation reflected from the mirror surfaces of the PTC. In order to reduce heat losses, the received heat is covered by an envelope and the enclosure is usually kept under vacuum pressure. This paper concluded the following points.

A comprehensive heat transfer model for thermal analysis of parabolic trough solar receivers was developed. The proposed model included a detailed radiative heat transfer analysis and more accurate heat transfer correlations. The results obtained showed good agreement with the experimental data and in comparison with the other heat transfer models, the proposed model presented in general lower RMSE values and better performance.

N. Naeeni *et al*.(2006) In the present study heat transfer from a receiver tube of the parabolic trough collector of the 250kW solar power plants in Shiraz, Iran, is studied taking into account the effects of variation of collector angel of attack, wind velocity and its distribution with respect to height from the ground. The momentum equation contains buoyancy force when the buoyancy effect is high and force convection effect is low.Computation is carried out for various wind velocities and different collector orientations with respect to wind direction. For solution of the energy equation, temperature of the receiver tube is taken as 350K and ambient temperature is assumed to be 300 K. Various recirculation and temperature fields were observed around the receiver tube for different flow conditions. Effect of collector orientation on the average Nu number for the receiver tube was found negligible when the cover of the absorber tube is considerable.

S. D. Odeh, G. L. Morrison *et al*.(1999) described the thermal losses of the LUZ trough collector in terms of absorber emissivity, wind speed, absorber temperature and ambient temperature. A semiempirical equation was developed to predict the efficiency of the parabolic trough collector in terms of absorber wall temperature so that it can be used with any working fluid. The collector thermal loss when using synthetic oil as the working fluid was found to be higher than in the DSG collector. The direct steam generation collector efficiency has a maximum value when the dry steam generation region starts. The pressure drop analysis shows that the pumping power required for the DSG collector is similar to the pumping power for the existing collector (using oil).

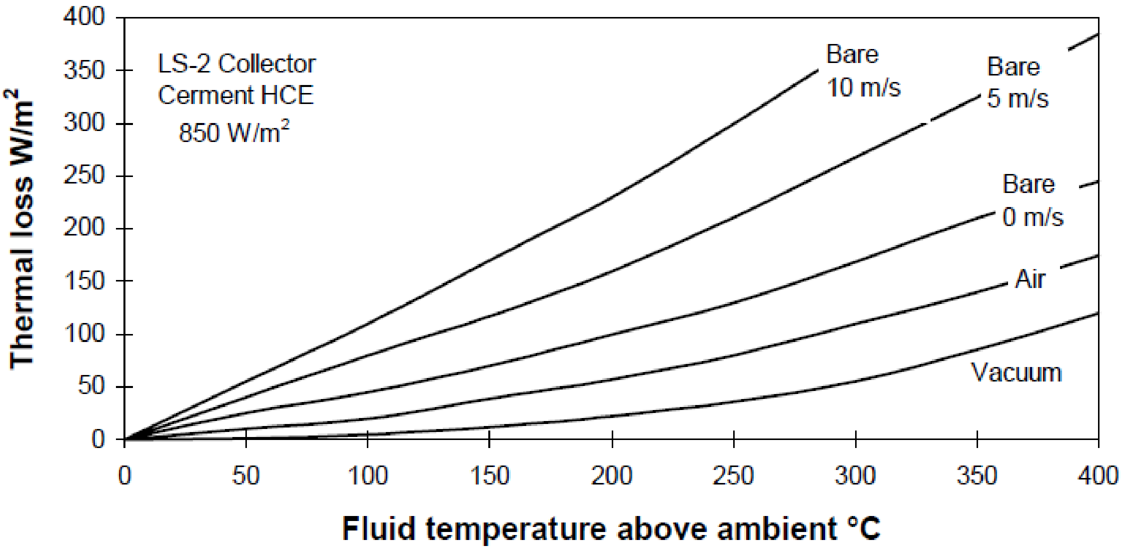


Fig 1. Collector thermal losses for vacuum, lost vacuum (Air),and broken glass (Bare) HCE (Cohen, 1993)

3.2 Design, materials and economics:

A.Thomas *et al*.(1992) studied that design parameters of a PTC can be geometric and functional. The geometric parameters of a PTC can be its aperture width and length, rim angle, focal length, diameter of receiver etc. The functional parameter can be its instantaneous efficiency, optical efficiency and overall thermal efficiency. These parameters are mainly affected by properties of material and optical errors associated with system. The instantaneous efficiency of a PTC (   ) can be calculated from an energy balance on the receiver tube. The instantaneous efficiency is defined as the rate at which useful energy is delivered to the working fluid per unit aperture area (divided by the beam solar flux (at the collector aperture plane

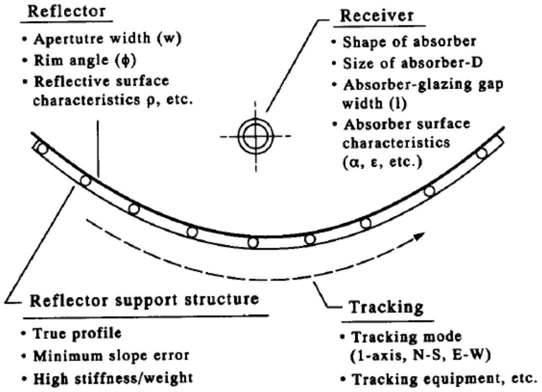


Fig. 2. Subsystem of a parabolic trough concentrator.

A.Valan Arasu *et al.(*2007) , described the design and manufacture of a smooth 90 rim angle fiberglass reinforced parabolic trough for parabolic trough collector hot water generation system by hand lay out method in this paper. The paper concluded the following points. The design and manufacture of a smooth 90 rim angle fiber glass reinforced parabolic trough for parabolic solar collector is presented. The cost of the fiber glass reinforced parabolic trough is 48US$ per square meter of aperture area and the cost of the wooden mould is 67US$.

A.Valan Arasu *et al.(*2007) studied experimentally a(n electronic embedded system controlled one axis automatic solar tracking system. It is designed and developed for parabolic trough collector employed for hot water generation. The electronic circuit diagram with detailed description and performance of the tracking system are presented. The position of Sun is successfully detected using light dependent resistors, with an accuracy of 0.1°. The accuracy is much greater than the required 0.5°, which is determined from the collector acceptance angle test. The tracking mechanism maximum error is found to be 0.18°. The tracking mechanism has proved to be sufficiently accurate for the present solar energy application *i.e.* hot water generation. Extensive testing of the parabolic trough solar collector hot water generation system proved that the tracking mechanism is very effective.

Randy Gee, Randy Brost *et al*.(2009) comprehensive analysis of the impact that reflector specularity has on the optical performance of parabolic trough solar collectors shows that beam spread from commercially available metalized polymer films results in a loss of approximately 1.5% for state-of-the-art parabolic troughs. This 1.5% loss contrasts markedly with the 5% loss indicated in a DLR-authored paper from Solar PACES 2009. The primary reason for this difference is that the former analysis did not account for the combined effect of the other optical errors in a parabolic trough system. To get accurate results, reflector specularity should be analyzed as just one factor in the optical system as a whole. It is also shown that the performance impact can be higher or lower than the 1.5%, depending on the concentration ratio of the trough concentrator being considered and the magnitude of the other optical errors of the parabolic trough solar collector. The analysis also indicates that reflector surfaces can be accurately characterized with two fundamental quantities: a) ρ2π, the solar-weighted hemispherical reflectance, and b) σspec, the rms of the reflected light distribution which is sometimes best represented as the combination of two Gaussian distributions. By describing the distribution of specularly reflected light, σspec can be used in combination with ρ2π to quantitatively, and fairly, compare various parabolic trough reflector surfaces in a way that incorporates the important system-level effects.

G.C. Bakos *et al*.(2000) observed that *are* the preferred type of a collector used for steam generation due to their ability to work at high temperatures with high efficiencies. The results produced from a simulation program, showing the variation of collector's efficiency as a function of the heat transfer fluid flux, pipe diameter, solar radiation intensity and active area of the PTC, are presented. This paper concluded the following points

1. When the flux of the heat transfer fluid is increasing, the efficiency is improving. Also the efficiency drops as the pipe length is increased.

2. The efficiency increases as the pipe diameter is reduced. This result was expected because the smaller diameter led to a greater solar radiation density on the active area of the pipe.

3. The efficiency increases with the increase of the mirror's active diameter and the intensity of solar radiation respectively.

Rafael Almanza, Genaro Correa *et al*.(2000) with the aim of developing a parabolic trough concentrator with first surface solar mirrors made over coated soda-lime glasses with concave geometry. In order to cover all the surface of the concentrator, whose measurements were 2.37m of aperture and This product works up to 8003C with a minimum deformation when it has been set and hardened. In order to sag the coated glasses, they were introduced in a furnace up to 6003C for about 2 h. Mirrors were made using sputtering technique with planar magnetron. The evaporation of aluminum "lm was about 1000As in thickness, while SiO2 was about 3000As . The specular reflectance of the mirrors was around 86%. The field test of focusing such a concentrator gave a size focus of about 5.08 cm, where over 90% of reflected beam solar irradiance arrived on a simulated pipe receiver with this diameter 1.14m long, 16 mirrors were built with sizes of 0.3]0.6m and they were put together like a mosaic set.

S.D.Odeh, G.L.Morrison *et al*.(1998) concluded, Solar Electric Generation System (SEGS) currently in operation are based on parabolic trough solar collectors using synthetic oil heat transfer fluid in the collector loop to transfer thermal energy to a Rankine cycle turbine via a heat exchanger. To improve performance and reduce costs direct steam generation in the collector has been proposed. In this paper the efficiency of parabolic trough collectors is determined for operation with synthetic oil (current SEGS plants) and water (future proposal) as the working fluids. This paper concluded the following points. The thermal performance of a trough collector in a SEGS plant was analyzed and a thermal model developed for evaluating the performance of a direct steam generation (DSG) collector. Thermal losses from the trough collector are described in terms of absorber emissivity, wind speed, absorber wall temperature and radiation level.

Balbir Singh, Mahinder Singh *et al.(*2003) look at the designing procedures of a solar thermal cylindrical parabolic trough concentrator (CPTC) by simulation. The designing effort starts off with the selection of certain parameters such as the aperture area and the diameter of the receiver to obtain the geometric concentration. Concentration ratios can be theoretically very high with the imaging concentrators of précised tracking in the range of 10 to 40 000. The process that is necessary to evaluate the performance of a solar thermal CTPC to use the processed data to design a simulated model by using the same meteorological data is evaluated. The results clearly showed that there is an equilibrium achieved between the increasing thermal losses with the increasing aperture area, and the increasing optical losses with the decreasing aperture area for the optimization of the long-term performance of the CPTC.

Maria Brogren *et al*.(2004) developed a newly aluminium-polymer-laminated steel reflector for use in solar concentrators was evaluated with respect to its optical properties, durability, and reflector performance in solar thermal and photovoltaic systems. The optical properties of the reflector material were investigated using spectrophotometer and scatterometry. The durability of the reflector was tested in a climatic test chamber as well as outdoors. Aluminium-laminated steel reflector has good durability in an outdoor environment, because of the plastic coating that protects the evaporated aluminium foil from moisture and air pollutants. However, the total reflectance decreased significantly and the light scattering became anisotropic when the material was exposed to damp heat and ultraviolet radiation in a climatic test chamber. It was found that the PET coating did not withstand the accelerated testing and that cracks in the PET layer caused the scattering. Therefore, the material may not be suitable as an internal reflector or in other applications where it may be exposed to high temperatures. However, the optical properties of the Al-on-steel reflector remained unchanged during one year of outdoor exposure in Sweden and the material showed potential as a cost-effective reflector in low-reflective solar thermal and photovoltaic applications.

H.R.Ghosh, N.C.Bhowmik *et al*.(2009) studied that The performance of a solar radiation conversion system is affected by its orientation and tilt angle with the horizontal plane. This is because both of these parameters change the amount of solar energy received by the surface of solar system. This paper concluded the following points.

The results demonstrated that a gain in the amount of solar radiation received by the surface mounted tilt angle at monthly tilt angle lied in the range of 0%-55% (average of 15% for whole year). Thus the output of solar energy utilizing system could be increased by 15% (if collector responses linearly with solar radiation) at almost no radiation if they could be installed at a slope equal to the mean monthly slope for the side of application and the slope adjusted once a month.

3.3 Applications:

M. M. Alkilani *et al*.(2009) presents a theoretical investigation of output air temperature due to
thermal energy discharge process from a phase change material (PCM) unit consists of inline
single row of cylinders contain a compound of paraffin wax with aluminium powder. This system consists of a single-glazed solar air collector integrated with a PCM unit which is divided into cylinders as an absorber-container installed in the collector in a cross flow of pumped air. The assumptions taken are:

1: Air behaves as an incompressible fluid.
2: The Stefan number is very low.
3: The heat loss assumed very low, and neglected.
4: The heat transfer process in every cylinder is radially symmetric;

The heat transfer in PCM is by conduction. To overcome the low thermal conductivity of paraffin wax they added a powder of material which has a good conductivity property such as copper or aluminium powder and paraffin wax with aluminium powder is used to decrease the system cost. A Matlab computer program has been developed to compute the air temperature; cylinder by cylinder along the duct, freezing time for each cylinder, and the time required to discharge all the thermal energy. Output air temperatures due to a discharge process in a solar air heater integrated with a phase change material have been predicted for eight different values of mass flow rate, and reached the maximum temperature (42°C), with mass flow rate (0.05kg/s). The phase change material consists of paraffin wax with mass fraction 0.5% aluminium powder to enhance the heat transfer, the freezing time for the phase change material unit has been predicted for each mass flow rate, The freezing time of the phase change material cylinders related inversely to the mass flow rate, and take longer time approximately (8 hours) with flow rate of 0.05 kg/s.

Soteris A. Kalogirou *et al*.(2006) presented a survey of the various types of solar thermal collectors and applications are presented. Initially, an analysis of the environmental problems related to the use of conventional sources of energy is presented and the benefits offered by renewable energy systems are outlined. A historical introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors in order to show the extent of their applicability. These include solar water heating, which comprise thermo syphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications.

S. Kalogirou *et al*.(2005) presented the modelling of a parabolic trough collector system for hot water production. This is followed by an experimental verification of the model and analysis of the experimental results. A proto type model was constructed and tested over four months. Hence the accuracy with which the simulation program predicts performance can be accessed. The simulation program can predict the parabolic trough collector system performance to an accuracy of about 7% and therefore the model can be successfully used for long term parabolic trough collector system performance prediction.

A. Scrivani *et al*.(2007) examined the concept of utilizing trough type solar concentration plants for water production, remediation and waste water treatment. This presented study is intended to find applications of the solar trough concentration technology beyond heat and refrigeration. A number of possibilities have been identified are related to clean water production by processes such as solar distillation, atmospheric condensation and waste processing. The fresh water thus obtained can be used for human consumption, but the free heat produced by trough plants makes for an easy way to obtain irrigation water from waste, refuse and landfills. The possibility of obtaining refrigeration without the use of electrical power opens up further possibilities for obtaining water, even from thin air. The possibility of utilizing this water for irrigation is a concrete step in the favour of agriculture in Mediterranean countries. The system is a low cost, no pollution, and alternative to incineration.

Lourdes García-Rodríguez *et al*.(1999) In this paper, the application of the direct steam generation into a solar parabolic trough collector to multieffect distillation is proposed and economically evaluated. The thermal fluid of the solar field is pure water, which boils as circulating along the solar collectors. The steam generated drives a multieffect distillation unit.

This solar distillation system is compared with multieffect plants connected to a conventional parabolic trough collector field, and with fossil fuel powered distillation plants. Different parameters are analysed, the plant capacity and performance ratio, the cost of conventional thermal energy, the cost of the solar collectors, and the annual average of the fresh water obtained per m2 of solar collector. Results obtained are useful in finding the most suitable conditions in which solar energy could compete with conventional energies in solar desalination.

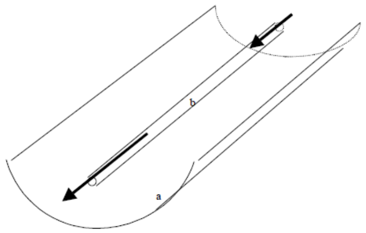


Fig.1. Diagram of a solar parabolic trough collector (PTC). A reflective surface (a) concentrates the solar radiation on to a cylindrical receiver (b). A thermal fluid is heated as it circulates into the receiver.

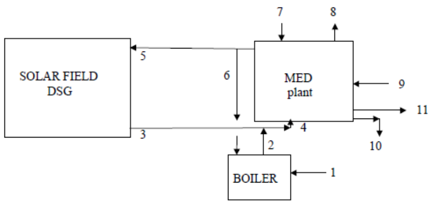


Fig. 2. The solar assisted desalination plant. 1, fuel; 2,3,4, steam supply; 5,6, condensed steam; 7, auxiliary energy; 8, cooling seawater output; 9, seawater input; 10, blowdown; 11, fresh water.

Hazim Mohameed Qiblawey *et al.(*2007) This paper describes several desalination technologies in commercial and pilot stages of development. The primary focus is on those technologies suitable for use in remote areas, especially those which could be integrated into solar thermal energy systems The use of solar energy in thermal desalination processes is one of the most promising applications of the renewable energies. Solar desalination can either be direct; use solar energy to produce distillate directly in the solar collector, or indirect; combining conventional desalination techniques, such as multistage flash desalination (MSF), vapor compression (VC), reverse osmosis (RO), membrane distillation (MD) and electrodialysis, with solar collectors for heat generation. Direct solar desalination compared with the indirect technologies requires large land areas and has a relatively low productivity. It is however competitive to the indirect desalination plants in small-scale production due to its relatively low cost and simplicity.

Daniel M. Blake, David Kearney *et al*.(2002) established that development of a thermal storage option and increasing the operating temperature for parabolic trough electric systems could significantly reduce the levelized electricity cost (LEC) compared to the current state of the art. Both improvements require a new heat transfer fluid if a direct storage system is to be used. The properties of a fluid that can be used for both heat collection and storage require a very low vapor pressure at the hot side operating temperature. This requirement can almost certainly only be met by an ionic fluid. Further, the piping layout of trough plants dictates that the fluid not be allowed to freeze which requires extensive insulation and heat tracing unless the fluid has a freezing point <25°C.
A recent study by Kearney and Associates under subcontract to SunLab has explored the potential for use of inorganic nitrate salts that freeze at about 120°C and documented the advantages of storage and higher operating temperature. As part of that study, the LEC achievable if an “ideal” fluid having the above properties was documented. It seems likely (but not certain) at present that this ideal fluid will have to be found among organic rather than inorganic salts. This paper summarizes the results of the first year of searching for heat transfer and storage fluids in this new domain and identifies the key issues that must be addressed in the development of a new fluid.

3.4 Literature summary and gap analysis:

Table 3.1: Literature summary

Sr. no	Author	Area of research	Contributions and applications of research
1	**G.C.Bakos et al.(2000)**	Design, Optimization And conversion efficiency determination Of A Line-Focus Parabolic Trough	The results produced from a simulation program, showing the variation of collector's efficiency as a function of the heat transfer fluid flux, pipe diameter, solar radiation intensity and active area of the PTC, are presented
2	**Maria Brogren et al.(2004)**	Optical Properties Aluminum-Polymer-Laminated Steel Reflector Solar parabolic trough	A newly developed aluminum-polymer-laminated steel reflector for use in solar concentrators was evaluated with respect to its optical properties.
3	**M J Brookes et al.(2006)**	Performance of parabolic trough Solar collector(PTSC)	The glass-shielded element offered superior performance at maximum test temperature reducing the overall heat loss coefficient by half.
4	**A. Valan Arasu et al.(2007)**	Design, Manufacture And Testing Of A Fiberglass Reinforced Parabolic Trough.	The design and manufacture of a smooth 90 rim angle fiberglass reinforced parabolic trough for parabolic solar collector is presented. The cost of the fiberglass reinforced parabolic trough is 48US$ per square meter of aperture area.
5	**Ming Qu et al.(2006)**	Performance of PTSC	Effects of glass cover, vacuum, pressure drop, incident angle, flow rate, and wind speed are calculated.
6	**A. Valan Arasu et**	Theortical analysis of PTC with hot water	The modeling of a parabolic trough collec- tor with hot water generation

	al.(2007)	generation	system with a well-mixed type storage tank using a com puter simulation program is presented fol lowed by an experimental verification of the model and an analysis of the exp.
7	**A.El Fadar et al. (2008)**	A Continuous Adsorption Refrigeration system Driven By PTC	The solar parabolic trough collector has been introduced to the adsorption refrigeration purpose in order to achieve continuous cycles using two adsorbent beds.
8	**S. D. Odeh et al.(2009)**	Thermal analysis of PTSC	The monthly average collector output at Darwin is almost steady during the year. The collector thermal loss when using synthetic oil as the working fluid was found to be higher than in the DSG collector.
9	**Y.J. Dai et al.(2009)**	Analysis On A Reflective Solar Collector Using Linear Fresnel Lens	The thermal efficiency of this collector can reach 52.1%, higher than the commonly used evacuated tube collector by 9%
10	**Hank Price et al.(2010)**	Alternative technologies to cut down cost of parabolic trough power plant	The various alternative technologies are given for the tracking mechanisms, reflector materials, heat collection elements thermal charateristics, heat transfer fluids and power cycle to reduce the cost of the plant
11	**M.Hussain et al.(2009)**	Determining Seasonal Optimum Tilt Angles	The results demonstrated that a gain in the amount of solar radiation received by the surface mounted tilt angle at monthly tilt angle lied in the range of 0%-55%

			(average of 15% for whole year).
12	**Michael Geyer et al.(2010)**	Cost efficiency	Cost reduction by simplification of the design, by improvement of the optical performance of the collector, by extension of collector length per drive unit. 14% solar field cost reduction are observed due to weight reduction and collector extension to 150 meters
13	**P. Rhushi Prasad et al.(2008)**	Comparison of fixed flat plate collector with that having tracking mechanism	There is an average increase of 4ºC in the outlet temperature and an increase of about 21% in the percentage of efficiency.
14	**J. Bartl et al.**	Effect of emissivity on the Surface temperature of the collector	Worked on the emissivity of Alloys of aluminium with magnesium and silicon and found that they are tough, have high electrical conductivity, high emissivity, but are still lower in comparison to other metals
15	**Randy Gee et al.(2007)**	Reflector specularity	Studied the Impact of reflector specularity on the optical performance of parabolic trough solar collectors. It is observed that the Metalized polymer reflectors are less specular than glass mirrors
16	**Maria Brogren et al. (2007)**	Properties of aluminium-polymer-laminated steel reflector	The optical properties, durability, and reflector performance is calculated and most importantly the cost-effectiveness of the reflector

17	**Soteris A. Kalogirou (2009)**	Survey of different solar collectors	Description of the various types of collectors and their optical and thermal analysis and environmental problems and their performance.
18	**S. Kalogirou et al.**	Performance prediction By simulation	Experimental verification of the PTC model and analysis of the experimental results for hot water production.
19	**A. Scrivani et al. (2009)**	Parabolic Trough use in different applications	Waste water treatment, solar distillation, refrigeration without electrical power

3.5 Gap Findings:

From the above literature review it is seen that a lot of research and work has been done in the steam generation using parabolic trough solar collector by different researchers regarding receiver tube, parabolic trough collector, their materials, heat transfer fluid and the performance of the whole system under varying conditions. It is observed that the main application of a parabolic trough solar collector is in the steam generation which further leads to the power generation with small use in water heating, waste water treatment and also in refrigeration. Cost analysis is an important area of research for this system as the cost of electricity from this type of system is still higher. A lot of research had been carried out on PTC regarding its design with different parameters, performance enhancement and area of application. In present study a Prototype PTC is designed, fabricated and Experimental analysis is carried out for hot water generation with different reflective materials for its feasibility. Use of different reflective material for thermal analysis in terms of improved efficiency is studied. Its a new concept as comparison of different reflecting materials for improving the efficiency of present prototype PTC and considering its feasibility for further practical application.

CHAPTER – 4

METHODOLOGY OF THE STUDY

4.1 General:

The present study aims at Design, Fabrication, Characterization, and Experimental analysis of prototype parabolic trough concentrator using different reflective materials Vaz. Stainless Steel, Aluminium Foil, Glass Mirrors. Different observation has been carried out to obtain best suitable reflective material in terms of its improved efficiency. Generally the efficiency of a PTC is given by

$$\eta = \frac{\quad}{\quad} \quad ^{[14]} \qquad \ldots(4.1)$$

Where = Heat removal factor

= Optical efficiency

= Heat loss coefficient

CR = Concentration ratio

It can be realized that the efficiency of a PTC depends on the optical efficiency ( ) which is determined by the optical properties of the various materials used in the construction of the collector. In equation (4.1) , , and can be identified as the three major design parameters which can be used to construct a three-parameter collector model for the preliminary design of PTC.

In present study we are using Copper tube (bare and glazed) as an absorber tube with different reflective materials and different testing are carried out. By these observations , we analyse the results obtained by experimental data and compared the different reflective materials in terms of their enhanced efficiency for present prototype PTC. Best material in terms of enhanced efficiency of prototype parabolic trough concentrator is obtained for its feasibility in further practical application like air heating, domestic water heating, steam generation etc.

METHODOLOGY OF STUDY

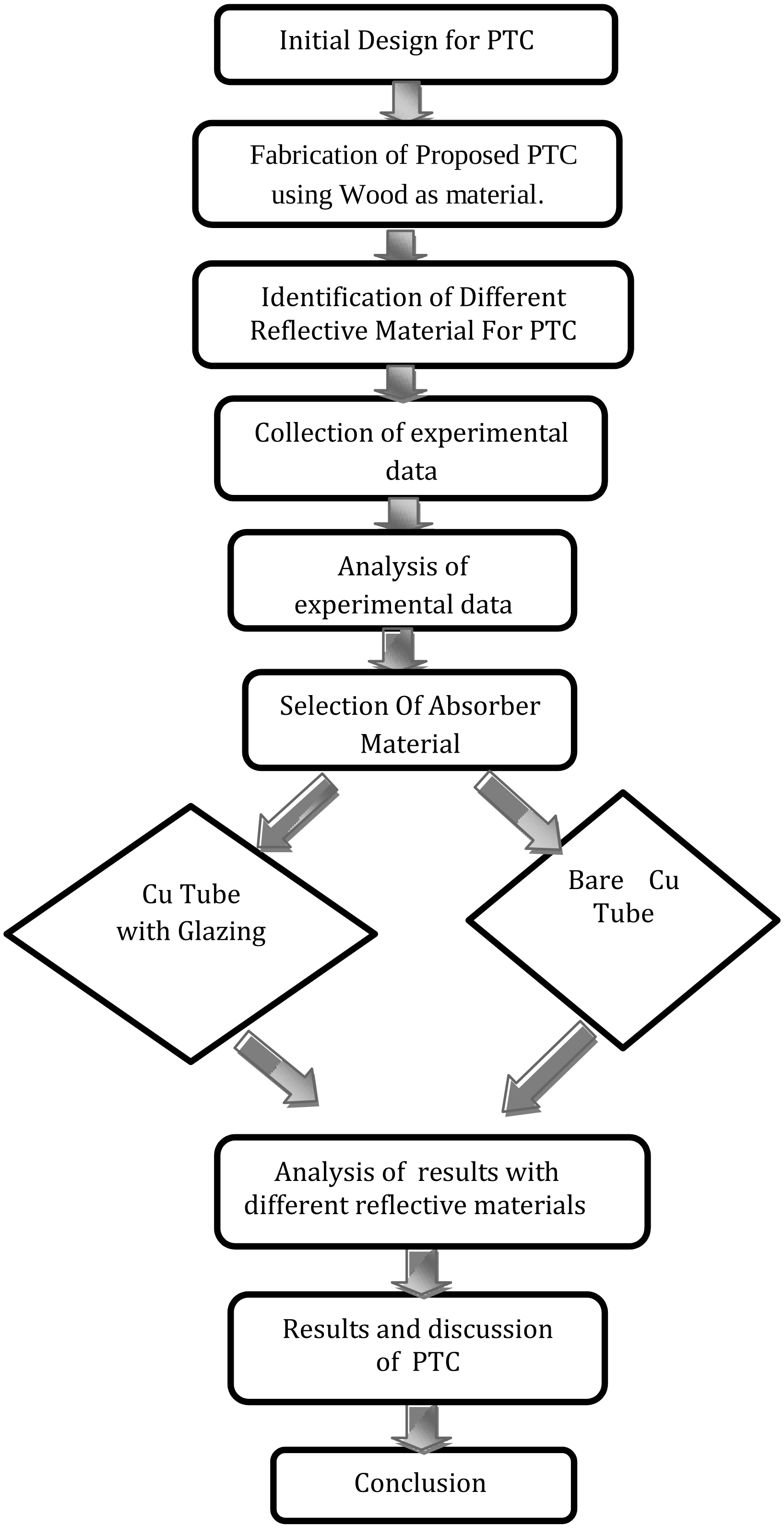


Figure 3.1

CHAPTER -5

STUDY AND THEORETICAL ANALYSIS OF REFLECTIVE MATERIALS

5.1 Characterization and theoretical analysis of different Reflecting materials:

The performance of a PTC depends on many parameters. One of them is the optical efficiency which is defined as the ratio the energy absorbed by the receiver to the energy incident on the concentrator aperture. The optical efficiency depends on the optical properties of the various materials involved, the geometry of the collector, and the various errors encountered in the construction of the collector. These errors affect the intercept factor which is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device (parabola). Its value depends on the size of the receiver, the surface angle errors of the parabolic mirror, and solar beam.

5.1.2 Importance of research topic:

The topic “Design ,fabrication and Experimental analysis using different reflective materials for hot water generation” has been selected for research to determine the best alternate reflective material for improved efficiency in prototype parabolic trough concentrator and to check its feasibility in further practical application like air heating, process heating, domestic water heating and steam generation. This will help in achieving economy in selecting reflective material in terms of improved efficiency. In present study different Reflective Materials for reflective sun radiation on absorber tube is used vaz. Stainless Steel, Aluminium foil and Glass Mirrors and comparison of efficiencies of PTC using these concentrators in feasibility of prototype Parabolic trough Concentrator is analysed for further practical applications like air heating, process heating, domestic water heating and steam generation.

The purpose of the study is to assess the best suitable Reflective Material for high efficiency and low cost for feasibility of prototype Parabolic Trough Concentrator.

.

5.2.1 Stainless Steel's Properties:

A Stainless steel sheet of dimensions (4ft x 5ft) is used to form the parabolic shape in prototype. The stainless steel sheet is used to provide the mechanical strength to the parabolic trough. The reflectivity of Stainless Steel in present work is 0.80.

Various properties of stainless steel are tabulated below and their theoretical analysis is carried out i.e.optical efficiency is found out.

Table 5.1: Various characteristics parameters for stainless steel

PARAMETERS	VALUES
Specular reflectivity of the concentrator surface	**.80**
Glass cover transmittivity for solar radiation)	**.88**
Absorber tube emissivity/absorptivity)	**.90**
Intercept factor)	**.95**

5.3.1 (a) Theoretical analysis:

Optical efficiency:

It is defined as the maximum heat radiation absorbed by aperture area when surface is at ambient temperature.

= (here =1) [1]

=

=0.8

= 0.609 or 60.9%

5.2.2 Aluminium Foil Properties:

Aluminium foil with dimensions (300mm x 4ft) is pasted on stainless steel sheet in such a way it form a shape of present parabola. The thickness of aluminium foil is approx.0.01mm.The reflectivity of aluminium foil used in present work is 0.88.

Various properties of aluminium foil are tabulated below and their theoretical analysis is carried out i.e. optical efficiency is found out.

Table 5.2: Various characteristics parameters for Aluminium foil

PARAMETERS	VALUES
Specular reflectivity of the concentrator surface	**.88**
Glass cover transmittivity for solar radiation)	**.88**
Absorber tube emissivity/absorptivity)	**.90**
Intercept factor)	**.95**

5.3.2 (b) Theoretical analysis:

Optical efficiency:

= (here =1) [5]

= [5]

=0.

= 0.6668 or 66.68 %

5.2.3 Glass Mirror Properties:

A piece of cotton cloth is then pasted on the sheet over which the mirror stripes which are 25 in number with dimensions (2in x 4ft) are pasted over the cloth. The mirror stripes are pasted in such a way that they do not affect the curve of the parabola. The mirror stripes are used because they have a very high reflectivity of 96%.

Table 5.3: Various characteristics parameters for glass mirror

PARAMETERS	**VALUES**
Specular reflectivity of the concentrator surface	**.93**
Glass cover transmittivity for solar radiation)	**.88**
Absorber tube emissivity/absorptivity)	**.90**
Intercept factor)	**.95**

5.2.3 (c) Theoretical analysis:

Optical efficiency:

= (here =1)[5]

= [5]

=0.9

= 0.703 or 70.3 %

CHAPTER 6

DESIGN AND FABRICATION

6.1 Design of prototype parabolic trough concentrator:

Parabolic trough collectors are structurally simpler than other types of collectors although some form of tracking (we have used manual tracking) must be employed and the parabolic surface must be accurate, to ensure efficiency. In order to be cost effective the parabola of the PTC must be produced in such a way so as to be low priced and accurate and the construction method must be amenable to a low labour and or a mass production manufacturing process.

6.1.1 Design Parameters

The design parameter of a parabolic trough collector can be classified as geometric and functional. The geometric parameters of a PTC are its aperture width and length, rim angle, focal length, diameter of the receiver diameter of the glass envelope and the concentration ratio.

The functional parameters of a PTC are optical efficiency, instantaneous and all day thermal efficiency and receiver thermal losses. These parameters are largely influenced by the absorptivity of the absorber. The errors are due to the defects in reflector material, support structure, location of the receiver with respect to the focal plane of PTC and misalignment of PTC with respect to the sun caused by the tracking errors.

6.1.2. Design of prototype PTC using PARABOLA CALCULATOR 2.0:

Initial specification for design of Parabolic Trough Concentrator is obtained by considering parabolic equation: $X^2 = 4aY$

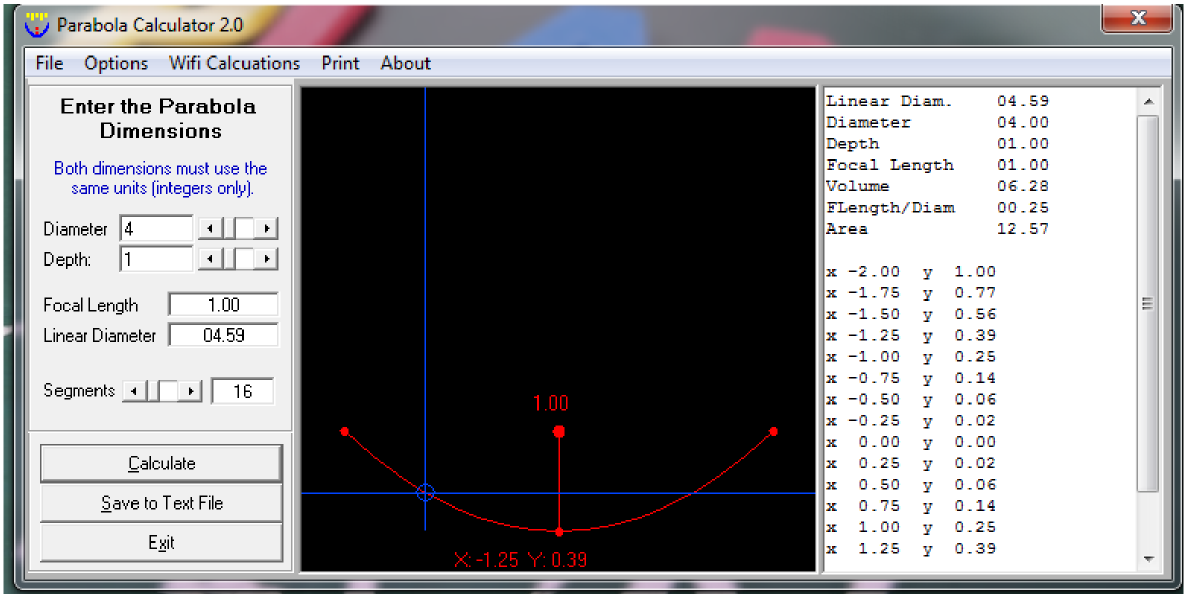
Where

Y-distance along vertical axis

a=focal length

X=distance along horizontal axis.

Corresponding points are obtained and we get a parabolic shape at different x,y. Some software are also available on internet as freeware free of cost for calculating parabola dimensions. One of such software we used for initial design of our prototype parabolic trough concentrator is “PARABOLA CACULATER 2.0”.PARABOLA CACULATOR 2.0 is shown below and data obtained is given in Table3.1 and 3.2.All dimensions are in feet (ft) as unit.



Both dimensions must use the same units (integers only).

Diameter: 4
Depth: 1
Focal Length: 1.00
Linear Diameter: 04.59
Segments: 16

```
Linear Diam.    04.59
Diameter        04.00
Depth           01.00
Focal Length    01.00
Volume          06.28
FLength/Diam    00.25
Area            12.57

x -2.00  y  1.00
x -1.75  y  0.77
x -1.50  y  0.56
x -1.25  y  0.39
x -1.00  y  0.25
x -0.75  y  0.14
x -0.50  y  0.06
x -0.25  y  0.02
x  0.00  y  0.00
x  0.25  y  0.02
x  0.50  y  0.06
x  0.75  y  0.14
x  1.00  y  0.25
x  1.25  y  0.39
```

Figure 6.1 PARABOLA CALCULATOR 2.0

Table 6.1:Design parameters for prototype parabolic trough collector

PARAMETER	DESIGN VALUE
LINEAR DIAMETER.	04.59 ft
DIAMETER	04.00 ft
DEPTH	01.00 ft
FOCAL LENGTH	01.00 ft
VOLUME	06.28 ft
FLENGTH/DIAM	0.25 ft
AREA	12.57 ft

X –HORIZONTAL AXIS	Y-VERTICAL AXIS
-2.00	1.00
-1.75	0.77
-1.50	.56
-1.25	.39
-1.00	.25
-.75	.14
-.50	.06
-.25	.02
.00	00
.25	.02
.50	.06
.75	.14
1.00	.25
1.25	.39
1.50	.56
1.75	.77
2.00	1.00

6.2 Fabrication of Prototype Parabolic Trough Concentrator:

In present thesis work consideration of cost is essential because we have considered cost analysis for best design and feasibility of proposed parabolic trough concentrator. Since trough should be capable of withstanding different loads like wind load , stress loads etc ,so it should be rigid body in design. In present work we have fabricate our PTC with wood as material. Stainless steel is used to form a parabolic shape in prototype. Carefully prepared aluminum sheet 0.635 cm (1/4in.) thick, were shaped consistent with the equation,

$$y = -$$

An aluminum sheet of aperture width 1.2m was bent into parabola with a focus at 0.3m using the formula the common equation for plotting parabola. The length of the concentrator was 1.2m and an aperture width of 1.2m. A manual tracker system was fabricated at the axis of absorber tube. 0.003m pin that was placed at the plane of aperture width would cast a shadow. The receivers were a cylindrical copper pipe painted black with appropriate black paint. The paint coat was kept as thin as possible so that there was minimum resistance of flow of heat through the coat through the pipe and to the heat transfer fluid. The collector was covered with a 0.001m thick glass cover.

To have a firm foundation we prepared a wood base as shown in following photos of prototype PTC. Different Components of Prototype PTC are shown in given pictures below :

6.2.1 Parabolic trough's reflective material:

In present PTC, we used different type of reflective material like Stainless Steel, Aluminium foil and Glass mirror for reflective solar radiation.

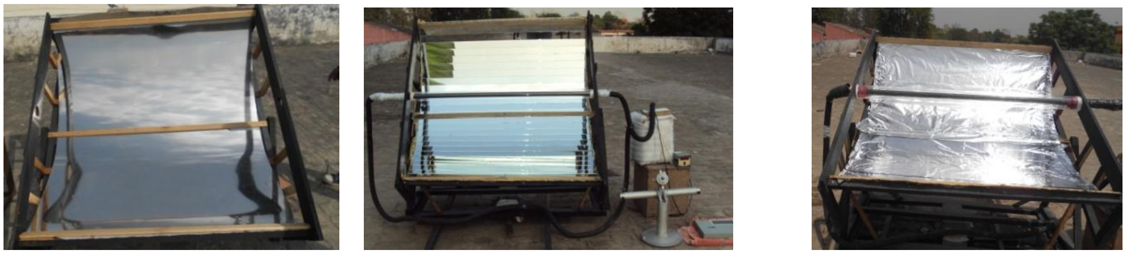


Figure 6.2 Pictorial PTC Reflectors (Stainless Steel, Glass Mirror, Aluminium Foil)

REFLECTORS:

6.2.2 Stainless Steel as Concentrator: A Stainless steel sheet of dimensions (4ft x 5ft) is used to form the parabolic shape in prototype. The stainless steel sheet is used to provide the mechanical strength to the parabolic trough. The reflectivity of Stainless Steel in present work is 0.80. The Prototype PTC is shown below with Stainless Steel As concentrator.

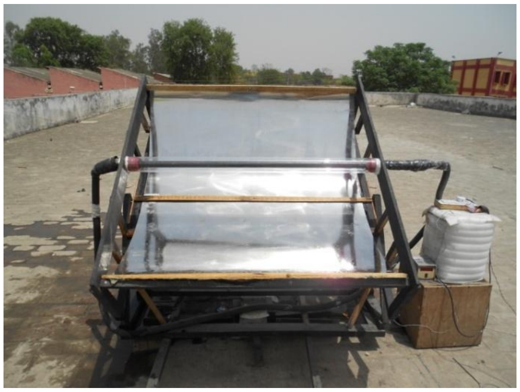


Figure 6.3 Pictorial view of PTC with Stainless Steel

6.2.3 Aluminium Foil as Concentrator:

As fig 6.4 shows Aluminium foil with dimensions(300mm x 4ft) is pasted on stainless steel sheet in such a way it form a shape of present parabola. The thickness of aluminium foil is approx.0.01mm. The reflectivity of aluminium foil used in present work is 0.88.Prototype Parabolic Trough Concentrator with Aluminium Foil is shown below.

Figure 6.4 Pictorial view of PTC with Aluminium Foil

6.2.4 Glass Mirror as concentrator:

A piece of cotton cloth is then pasted on the sheet over which the mirror stripes which are 25 in number with dimensions (2in x 4ft) are pasted over the cloth. The mirror stripes are pasted in such a way that they do not affect the curve of the parabola. The mirror stripes are used because they have a very high reflectivity of 93%. The reflector made up of mirror stripes pasted on a stainless steel substrate is shown below.

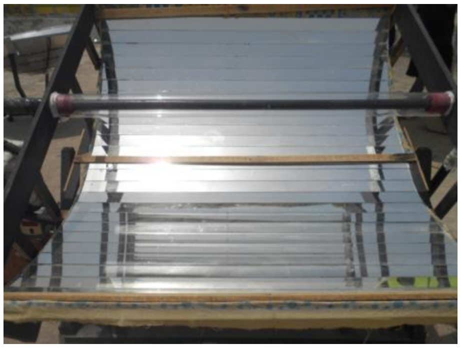
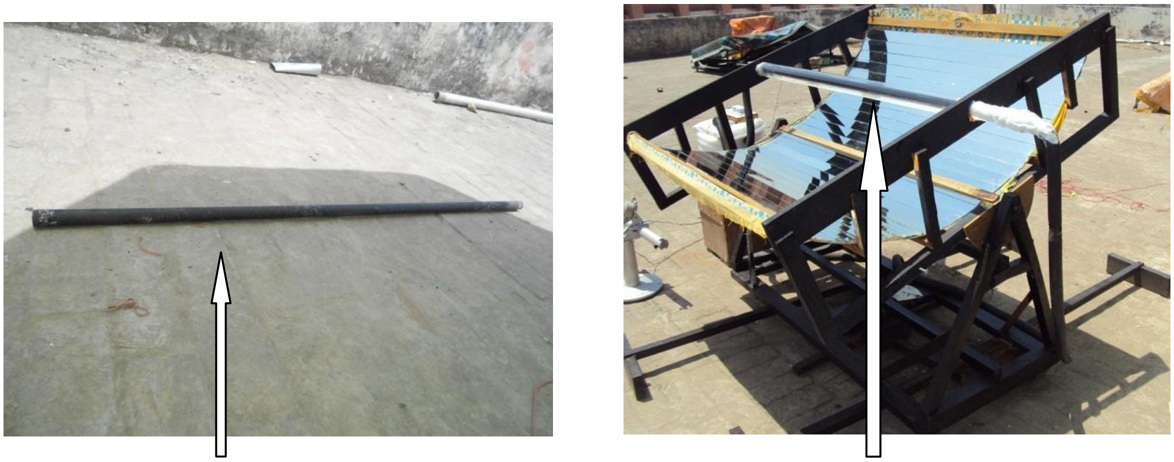


Figure 6.5 PTC with Glass Mirror

6.2.5 **Absorber Tube:** A copper tube with the glass cover tube on it joined by the glass to metal seals on both sides of the copper tube is used as an absorber tube. The glass cover tube is used so as to reduce the conductive, convective, and radiative losses from the copper tube. The copper tube with length 5ft and with inside and outside diameter of 31.5mm and 32.5 mm is used.



Bare Copper Tube

Copper Tube With Glazing

Figure6.6

6.2.6 **Storage Tank:** A container made up of steel of 15 lts capacity filled with water which is working fluid is used as a storage tank. The water is circulated from the container with the help of a small pump of power 24 W to the inlet of the absorber tube. Water after gaining heat from the absorber tube is dropped in the same container and is re-circulated again with the help of a pump. The inlet and outlet to the absorber tube is from the storage tank. The storage tank is insulated with glass wool and then wrapped in a thermocole sheet. Figure 3 shows the picture of the storage tank used in the experiment.

Figure 6.7 Storage Tank in PTC

6.2.7 Support Structure: The support structure for the PTSC is made up of wood. The selection of wood as a material for the support structure is because it is cheap, easy to maintain, lighter in weight and also it is very flexible to the changes if necessary. The support structure which is made up of wood is black painted. The support structure is fabricated in such a way that it could withstand wind loads, stress loads etc. It is also designed so that it could not affect the shape of the parabola and also to minimize the alignment errors. The provision of tracking is also there in the support structure

Figure 6.8 Support Structure For PTC

6.2.8 Insulation:

The SOFLON insulation is used on the pipes so as to minimize all the heat losses during the transport of working fluid from inlet to the outlet which is from the storage tank. This insulation is easily available from the market in the Air Conditioners and Refrigerators spare parts shop. Also glass wool is used for insulating the storage tank which is also easily available.

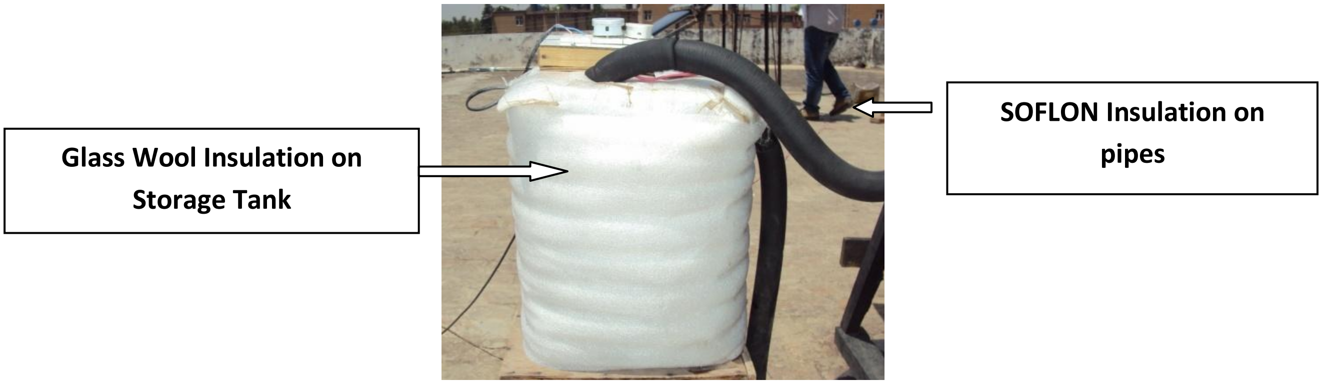


Figure 6.9 Storage Tank with Insulation

6.3 Manual Tracking System: :

For the utilization of the maximum solar intensity the Sun should be tracked throughout the day. The mechanism which is used to track the sun is called as tracking mechanism. Tracking can be done either automatically or manually. The PTSC is oriented in an East –West direction and sun’s trajectory is also from east to west, so a manual tracking is done from east to west. In this experiment manual tracking is done because it is comparatively cheaper as automatic tracking requires a motor and gear mechanism.

Manual tracking is done by rotating the parabolic trough by 10 degrees after every 1 hour by creating holes in a wooden ply of semicircular shape. A manual tracker system is fabricated using a circular ply of wood as shown in given pictures. Since the solar concentrator is operated under MODE 2(EAST-WEST TRACKING).As PTC is oriented in East –West direction and sun trajectory is also from east to west,so a manual tracking is done from east to west. A proper observation of sun trajectory is done(altitude angle, zenith angle etc.) and proper angle measurement(approx.10^0) of tracking is observed.

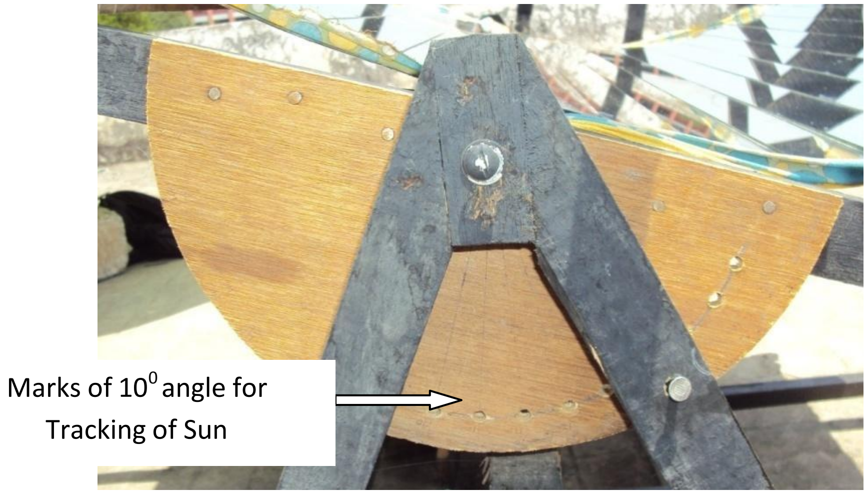


Figure 6.10 Fabricated prototype parabolic trough's manual tracking

6.4 Temperature and Intensity measurement: There are some instruments which are used to measure the temperature of the working fluid and the amount of solar intensity. These are:

a) **Pyranometer with digital display:**

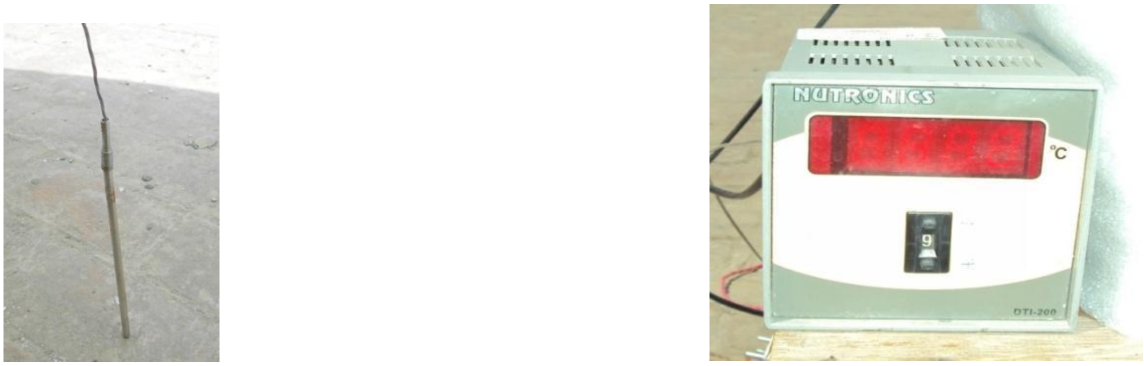
The Pyranomater is used to measure the solar intensity coming from the sun. It is used to measure both the beam and diffused radiations. There is a digital display which shows the amount the amount of solar intensity in (W/m^2). The Pyranometer and the digital display used in this experiment is shown in figure 6.11 .

b) **Thermocouple with DTI(Digital Temperature Indicator):**

The temperature of the working fluid i.e water is measured by the use of a thermocouple which is completely dipped in the container. The measured temperature is shown on the digital temperature indicator (DTI) which is called as RTD PT-100. Figure 6.11 shows the RTD PT-100 used to indicate the temperature of water in (^{0}C) in the storage tank.

Pyranometer (Kipp & Zonen)

Digital display unit



Thermocouple

RTD PT -100(DTI)

Figure 6.11 Temperature and Intensity Measuring Devices

Table 6.3 Prototype PTC specification after fabrication:

Items	Value
Collector aperture	1.2m
Collector length	1.2m
Aperture area	1.44 m^2
Rim angle	90^0
Focal distance	.30m
Receiver diameter	.034
Glass envelope diameter	.044
Concentration ratio	11.30
Water flow rate	.09kg/s
Storage tank capacity	15lt
Tank material	Stainless steel
Tank insulation material	Glass wool
Water pump	25W
Insulation on the pipes	Soflon

CHAPTER -7

EXPERIMENTAL ANALYSIS

7.1General:

The performance of the new PTC hot water generation system is determined by obtaining values of collector instantaneous efficiency and the system efficiency for different combinations of incident radiation, ambient temperature and inlet water temperature. The collector water outlet temperature (T_{fo}), ambient temperature (Ta) and storage tank water temperature (T_l) were recorded with the help of PT 100 – resistance temperature device (RTD) sensors.

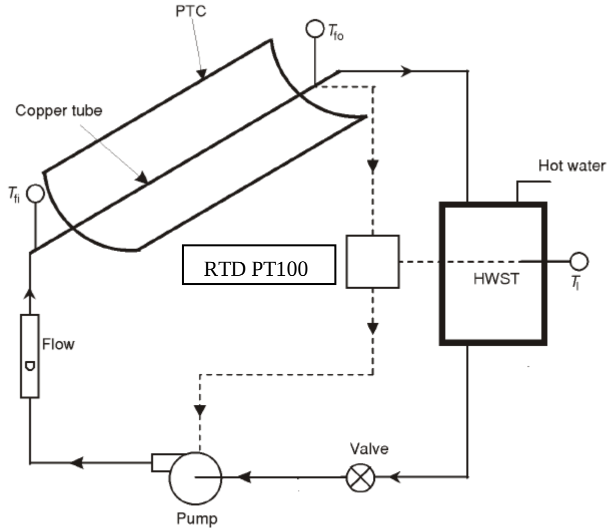


Fig. 7.1 Line Diagram of Parabolic trough collector with storage tank

The useful energy collected per unit time in a solar collector system employing solar concentrators may be written as :

= ———— [1]
(7.1)

It can also be expressed as

= ([1] **(7.2)**

The heat removal factor is given by

$$= \frac{\quad}{\quad} \qquad [1] \qquad \mathbf{(7.3)}$$

From equations (1)-(3),

$$(\qquad = \frac{\quad}{\quad} \qquad \frac{\quad}{\quad} \qquad \mathbf{(7.4)}$$

Which may be solved to give

$$= \quad + \frac{\quad}{\quad} + (\qquad \frac{\quad}{\quad} \qquad \exp(\qquad [1] \quad \mathbf{(7.5)}$$

7.2 Design analysis:

The instantaneous efficiency of a PTC ( ) can be calculated from an energy balance on the receiver tube. The instantaneous efficiency is defined as the rate at which useful energy is delivered to the working fluid per unit aperture area (divided by the beam solar flux (at the collector aperture plane

$$\frac{\quad}{\quad} \qquad - \frac{\quad}{\quad} \quad [1] \qquad \mathbf{(7.6)}$$

In equation (7.6) , , and can be identified as the three major design parameters which can be used to construct a three-parameter collector model for the preliminary design of PTC.

If the optical characteristics of the materials used can be assumed to be temperature independent, the optical analysis of the collector can be decoupled from the thermal analysis. Hence, the optical efficiency can be modeled and analyzed independently without knowledge of the thermal design and vice versa.

7.3 Optical analysis:

The optical efficiency can be expressed as

$$= \rho \qquad \cos\Theta \qquad \mathbf{(7.7)}$$

Where

ρ = average specular reflectance of the reflective surface

= effective transmittance-absorptance factor

= angle of the incidence of the sun’s rays on the collector aperture measured from the normal to the collector

= instantaneous intercept factor (defined as the fraction of rays incident upon the aperture that reach the receiver for a given incidence ϴ)

The optical efficiency, by equation (7.7), varies with angle of incidence between the aperture surface normal and the incoming radiation. There are several factors besides cosϴ that contribute to the decrease of optical efficiency with increasing incidence angle. These factors include the incident angular dependence of glazing transmittance and absorber absorptace. Also, the instantaneous intercept factor decrease with incidence angle.

7.4 Thermal analysis:

The primary function of the receiver subsystem of a PTC is to absorb and transfer the concentrated energy to the fluid flowing through it. In this process, however, the absorbing surface of the receiver will be heated, and its temperature will become considerably higher than that of the surroundings. For example, depending on the temperature requirements of the application, operating temperatures as high as 300 can be attained at the absorbing surface of the receiver during operation. Subsequently the temperature difference between the absorbing surface and the surroundings will cause some of the collected energy to be transferred back to the surroundings. The knowledge of heat loss from the receiver is important for predicting the performance and, hence, designing .

Proper qualification of the heat loss from the receiver is important for predicting the performance, and hence, designing .

These are

1. Heat transfer from the absorber tube to the working fluid.
2. Heat transfer between the absorber tube and the glass jacket (glassing).
3. Heat exchange between the glass jacket and the surroundings.

Since PTC will be optimized based on instantaneous or all-day efficiency, a steady-state thermal analysis of the receiver will sufficient for design studies.

7.5 Calculations for performance analysis:

A Prototype parabolic Trough Concentrator is located in Patiala operating in East-West tracking mode,is used for hot water generation .The concentrator has aperature area of 1.387m^2, length 1.20 m while the absorber tube(3.15cm inner diameter and outer diameter 3.25cm)has a concentric glass cover (4.3 cm inner and 4.4 cm outer diameter) around it.Values of other design parameters of concentrators are as follows (taking case of Glass Mirror):

Specular reflectivity of concentrator surface(Glass Mirror)	= 0.93
Absorptivity of absorber tube(α)	= 0.90
Glass cover transmitivity for solar radiation	= 0.88
Intercept factor(γ)	= 0.95

Values pof the operational and metrological parameters are as follows:

Date	=3 may,2012
Time	=12-1 pm
I_b	= 878 W/m^2
Ambient Temp.	=25^{0}C
Mass flow rate of water	=.09 kg/s
Outlet temperature	= 81.2^{0}C

1)The absorbed flux,S is given by:

$$\mathbf{S=I_b r_b \gamma \rho (\alpha\tau)_b} \qquad \mathbf{(7.8)}$$

$$S = 932.[.95*.93*.90*.88]$$

$$= 652.15 W/m^2$$

(2) Convective heat transfer coefficient:

Properties will be taken at a mean fluid temp. of 60 .

Thus, ρ = 1000kg/

= 4.2KJ/kg-K

ν = 0.475

k = 0.58W/m-K

Average velocity V = = = 0.1155m/s

Reynolds number = = = 7659

Prandt’l number = = =3.44

Nusselt number = 0.023

=0.023 (where n= 0.4 for heating)

= 48.27

Therefore =

= = 888.8W/

(3) Collector heat removal factor and Overall loss coefficient:

Assume = 12.82W/ , so the collection efficiency factor

F’ =

=

=0.98

So = = 232.32

Therefore, heat removal factor

=

= 232.32

= 0.9293

(4) Concentration ratio:

C =

(where is the outer diameter of glass cover)

=

=

= 11.32

(5) Optical efficiency:

= (**here =1)**

=

= 0.93

= 0.703 or 70.3%

(6) The useful heat gain rate:

$$= \quad ($$

$$\mathbf{=148.75\ W}$$

(7) Instantaneous Efficiency:

$$= \frac{\quad}{\quad} \quad \textbf{(here } r_b\textbf{=1)} \qquad \textbf{(7.9)}$$

$$= 4.31\%$$

(8) Thermal Efficiency of System (per Hour) :

Taking,

Mass of water ( ) = 15kg, specific heat of water (= 4.2KJ/kg-K,

$$\textbf{Efficiency } \eta = \frac{\quad}{\quad} \qquad \textbf{(7.10)}$$

$$=12.21\%$$

(9) Overall thermal Efficiency (average):

Taking,

Mass of water ( ) = 15kg, specific heat of water (= 4.2KJ/kg-K,

Time duration (t) =5 hours (8am-12pm), = aperture area = 1.387 .

$$\textbf{Efficiency } \eta = \frac{\quad}{\quad}$$

$$= \frac{\quad}{\quad}$$

$$= 20.55\%$$

7.6 The performance of a cylinderical parabolic solar concentrator:

The following procedure was used to perform the experiments:

(1) The collector was exposed to the sun at least 30 min before the experiment.

(2) In each experiment, for 30 min duration, the water mass flow rate passing through the absorber was maintained constant.

(3) The collector was tracked with the sun manually by inspecting the reflecting rays falling on the absorber.

(4) After the preparation of the apparatus, the following readings were recorded:

- Mean water inlet temperature.
- Mean water outlet temperature.
- Total and diffused radiation falling on the collector surface.
- Mass of collected water.

Figure 7.2 Parabolic trough collector with storage tank

7.7 Experimental readings for Stainless Steel with bare Copper tube:

Reflective material	=	Stainless Steel
Reflectivity of Mirror	=	0.80
Absorber Tube	=	Copper Tube
Diameter of Cu tube	=	34 mm
Area	=	1.40 m^2

Table 7.1: Variation of Temperature in Stainless Steel with Intensity (Bare Tube)

TIME (Hour)	INTENSITY (W/)	TEMP.OUT ^{o}C	TEMP. IN ^{o}C	ANGLE (degree)
8-9	296	32	25	170-160
9-10	512	41.4	32	160-150
10-11	656	47.6	41.4	150-140
11-12	712	52.1	47.6	130-120
12-01	696	55.8	52.1	110-100
01-02	650	59.5	55.8	90-80
02-03	636	57.4	59.5	70-60
03-04	496	54.6	57.4	50-40

Following readings has been taken on dated 15 April, 12 day is normal at the morning and noon.The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz.April 15, 2012 is shown in figure.7.3. The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 59.5 °C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature.

Table 7.2: Performance data in Stainless Steel concentrator (Bare tube)

Useful heat gain Q_u (W)	Instantaneous efficiency/(Δ°C T) inst.	System efficiency (Thermal Eff.) therm.	Overall Thermal Efficiency overall
$Q_{u(8-9)}$ =122.5	18.00 / (.2)	29.56	
$Q_{u(9-10)}$ =164.5		22.94	
$Q_{u(10-11)}$ =108.50	08.23 / (.1)	11.81	
$Q_{u(11-12)}$ =78.75		07.90	
$Q_{u(12-1)}$=64.75	03.85 / (.1)	06.64	
$Q_{u(1-2)}$ =64.75		05.56	12.28

The variation of beam radiation, I, and useful heat gain, Q_u, with time is shown in fig. 7.4. It is seen that a fairly smooth variation of beam radiation with the maximum (712 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

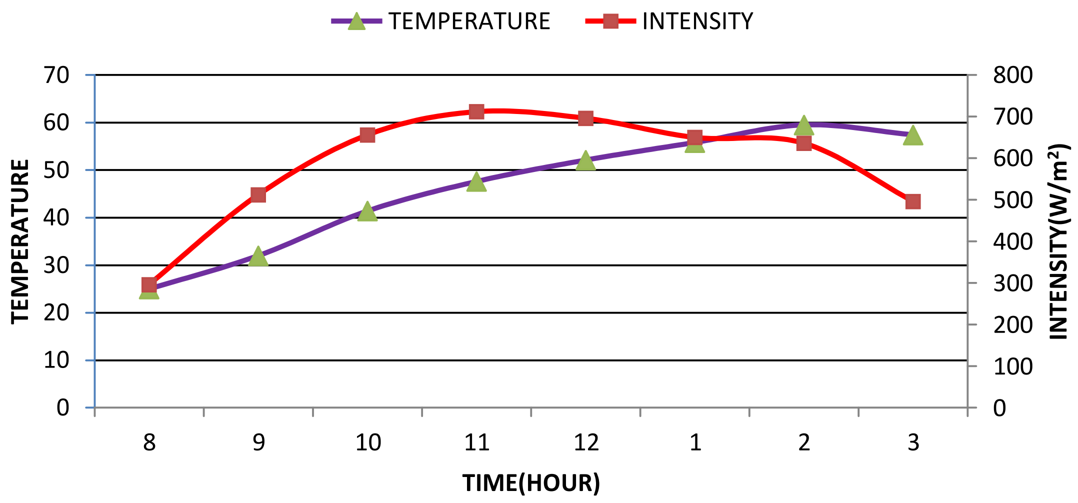


Figure 7.3

(Variation of collector water temperature, T_{fo} , and beam radiation I,with time)

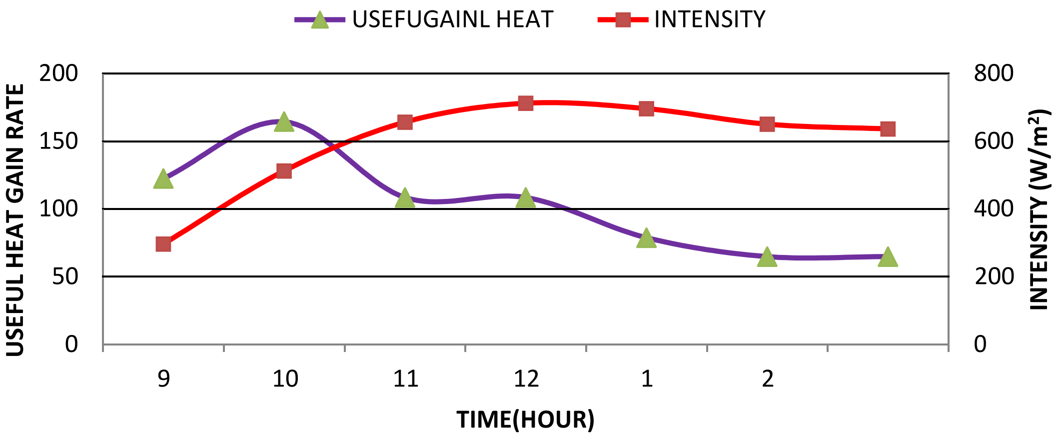


Figure7.4

(Variation of beam radiation, I, and useful heat gain, Q_u , with time)

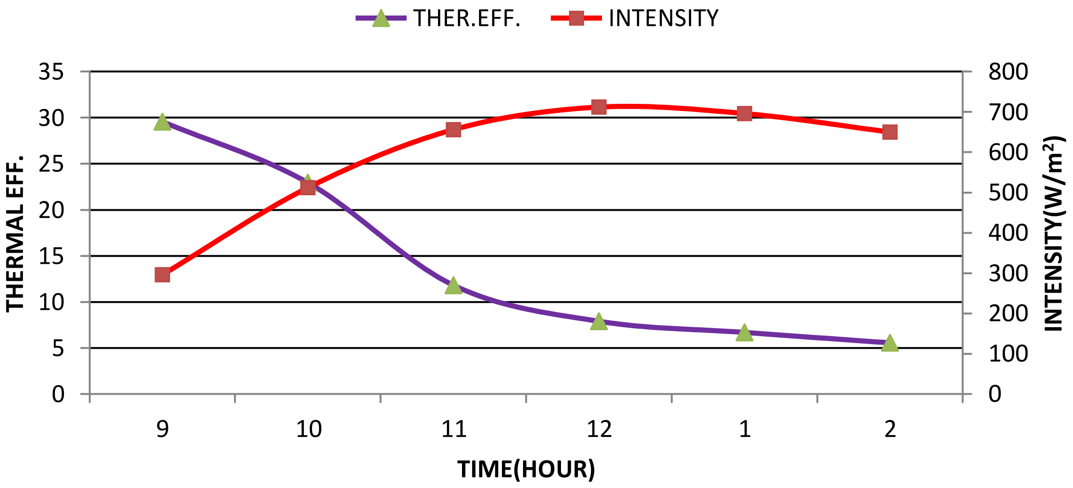


Figure 7.5

(Variation of collector Instantaneous Efficiency with intensity, I and time)

The collector instantaneous efficiency is computed using eq. (7.7). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.5. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

7.8 Experimental readings for Stainless Steel with Glazed Copper tube:

Reflective material = Stainless Steel

Reflectivity of Steel = 0.80

Absorber Tube = Copper Tube

Diameter of Cu tube = 34 mm

Glazing Material = Glass cover Tube

Glazing Diameter = 44 mm

Area = 1.387 m^2

Table 7.3: Variation of Temperature in Stainless Steel with Intensity (Glazed Tube)

TIME (Hour)	INTENSITY (W/)	TEMP.OUT ^{0}C	TEMP. IN ^{0}C	ANGLE (degree)
8-9	290	34.0	25.0	170-160
9-10	519	41.3	34.0	160-150
10-11	762	49.1	41.3	150-140
11-12	867	54.6	49.1	130-120
12-01	778	59.1	54.6	110-100
01-02	720	62.8	59.1	90-80
02-03	640	61.4	62.8	70-60
03-04	370	57	61.4	50-40

Following readings has been taken on dated 19, APRIL, 2012 day is normal at the morning and noon but become cloudy at evening. The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz. April 19, 2012 is shown in figure 7.7 .The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 63.4 °C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period.

At any instant, the collector water temperature is greater than the storage tank water temperature.

Table 7.4: Performance data in Stainless Steel concentrator (Glazed tube)

Useful heat gain Q_u (W)	**Instantaneous efficiency/(Δ^{o}C T) inst**	**System efficiency therm (Hourly)**	**Overall Thermal Efficiency overall**
$Q_{u(8\text{-}9)}$ =157.50	28.19 / (.2)	39.15	
$Q_{u(9\text{-}10)}$ =145.25		20.17	
$Q_{u(10\text{-}11)}$ =119.00	7.15 / (.2)	11.25	
$Q_{u(11\text{-}12)}$ = 96.25		08.00	
$Q_{u(12\text{-}1)}$ = 78.75	04.90 / (.1)	07.29	
$Q_{u(1\text{-}2)}$ = 64.75		06.48	12.30

The variation of beam radiation, I, and useful heat gain, Qu, with time is shown in fig. 7.8. It is seen that a fairly smooth variation of beam radiation with the maximum (867 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

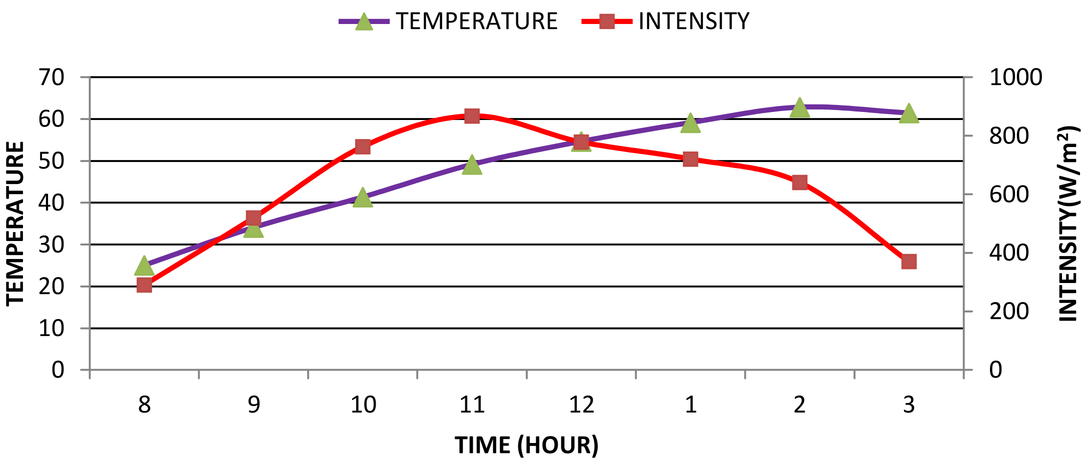


Figure 7.7.(Variation of collector water temperature, T_{fo} , and beam radiation I,with time)

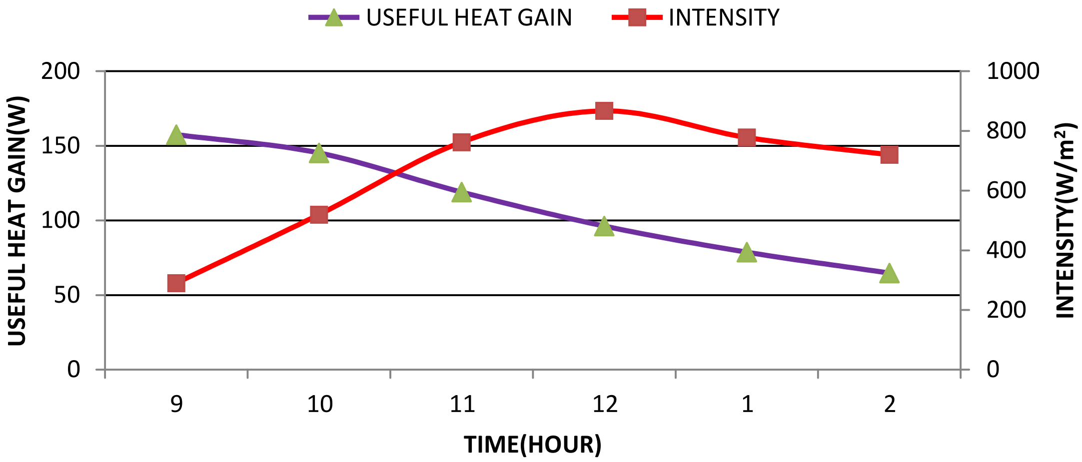


Figure 7.8

(Variation of beam radiation, I, and useful heat gain, Q_U , with time)

The collector instantaneous efficiency is computed using eq. (7.7). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

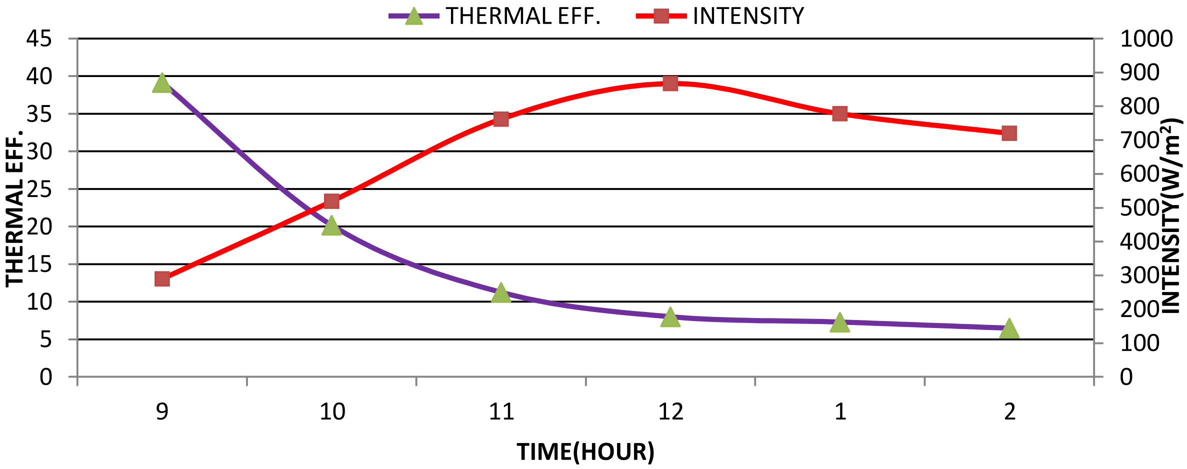


Figure 7.9

(Variation of system Efficiency (HOUR) with time and intensity I)

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.9. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

Discussion:

From above two experimental analysis following results are concluded:

1). Maximum temperature rise in Stainless Steel as concentrator using bare copper tube is 59.5^{o}C while in case of glazing it is 62.8^{o}C.

2). Useful heat gain and hence system instantaneous efficiency per hour is more in glazing as less losses are encountered(as shown in graph). Difference between peek instantaneous efficiencies in both cases is 4 % (more in case of glazing).

3). System efficiency (thermal efficiency) per hour is increased approximately by 24.49% comparing maximum efficiency in both cases.

4).Overall thermal efficiency of PTC is almost same in case of copper tube with glazing and bare copper tube.

7.9 Experimental analysis for Aluminium Foil with bare Copper tube:

Reflective material	=	Aluminium Foil
Reflectivity of Mirror	=	0.88
Absorber Tube	=	Bare Copper Tube
Diameter of Cu tube	=	34 mm
Area	=	1.40 m^2

Table 7.4: Variation of Temperature in Aluminium Foil with Intensity (Bare Tube)

TIME (Hour)	INTENSITY (W/)	TEMP.OUT ^{o}C	TEMP.IN ^{o}C	ANGLE (degree)
8-9	380	37.5	25	170-160
9-10	575	48.2	37.5	160-150
10-11	724	56.4	48.2	150-140
11-12	912	62.3	56.4	130-120
12-01	883	68.0	62.3	110-100
01-02	776	66.4	68.0	90-80
02-03	685	64.6	66.4	70-60
03-04	566	63	64.3	50-40

Following readings has been taken on dated 23 April, 12 day is normal at the morning and noon.

The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz. April 23,12 is shown in fig7.10. The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 68 °C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature.

Table 7.5: Performance Data in Aluminium Foil concentrator (Bare tube)

Useful heat gain **Q_u (W)**	**Instantaneous efficiency/(Δ^{o}C T)** **inst.**	**System efficiency** **therm (Hourly)**	**Overall Thermal Efficiency** **overall**
$Q_{u(8-9)}$ =218.75	21.60 / (.3)	41.11	
$Q_{u(9-10)}$ =187.25		23.26	
$Q_{u(10-11)}$ =143.50	07.45 / (.2)	14.15	
$Q_{u(11-12)}$=103.25		08.08	
$Q_{u(12-1)}$=99.75	3.05 / (.1)	08.06	15.58

The variation of beam radiation, I, and useful heat gain, Q_u, with time is shown in fig. 7.11. It is seen that a fairly smooth variation of beam radiation with the maximum (912 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

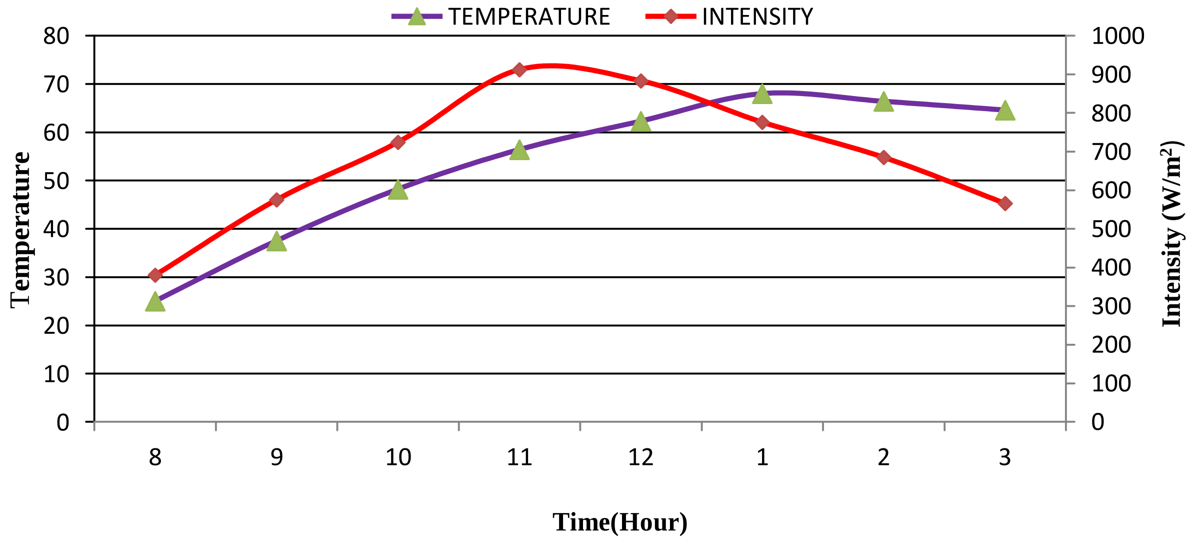


Figure 7.10

(Variation of collector water temperature, T_{fo} ,and beam radiation I with time)

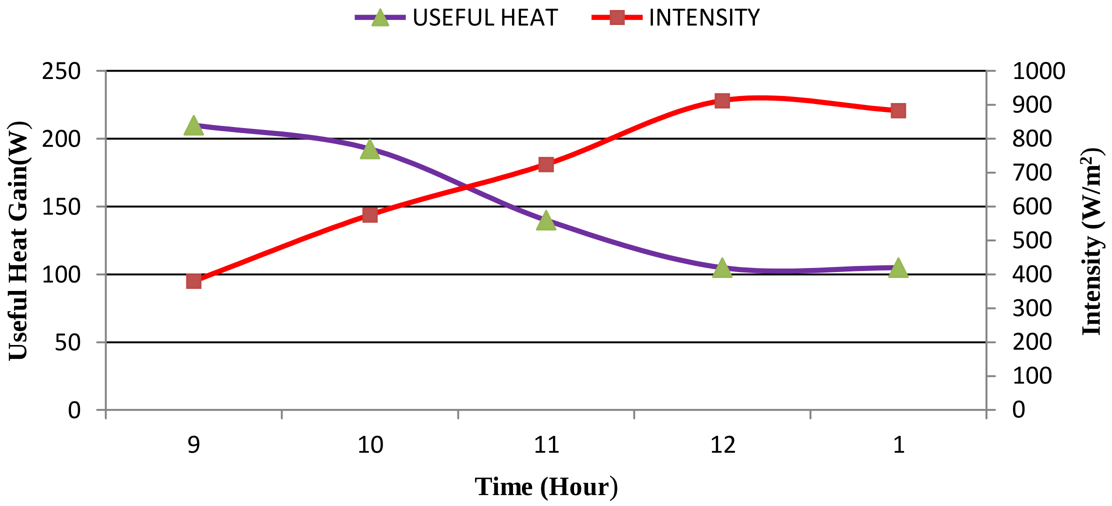


Figure 7.11

(Variation of beam radiation, I, and useful heat gain, Q_u, with time)

The collector instantaneous efficiency is computed using eq. (7.7). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

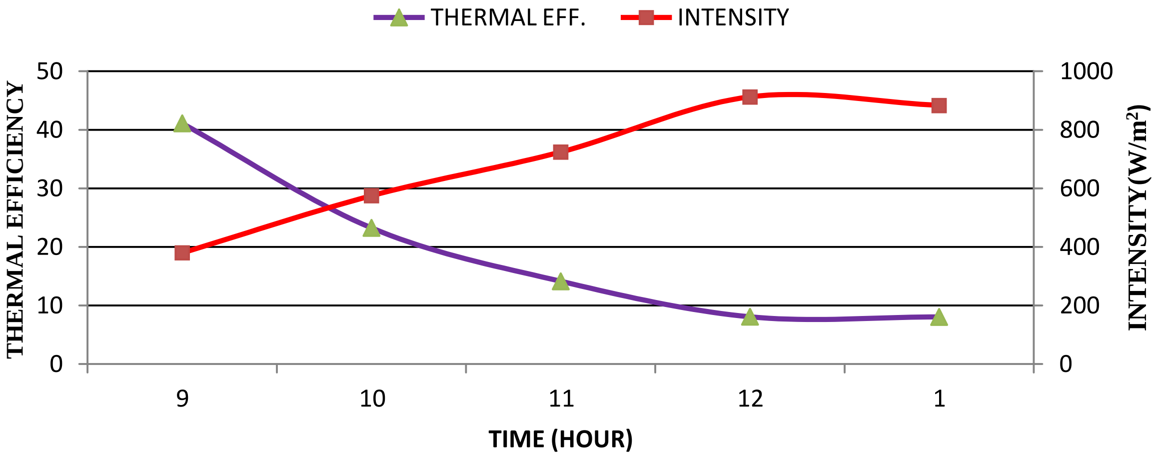


Figure 7.12

(Variation of system Efficiency (HOUR) with time and intensity I)

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.12. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously

7.10 Experimental readings for Aluminium Foil with Glazed Copper tube:

Reflective material = Aluminium Foil

Reflectivity of Steel = 0.88

Absorber Tube = Copper Tube

Diameter of Cu tube = 34 mm

Glazing Material = Glass cover Tube

Glazing Diameter = 44 mm

Area = 1.387 m^2

Table 7.6: Variation of Temperature in Aluminium Foil with Intensity (Glazed Tube)

TIME (Hour)	INTENSITY (W/)	TEMP.OUT ^{0}C	TEMP. IN ^{0}C	ANGLE (degree)
8-9	320	38.6	25	170-160
9-10	676	50.5	38.6	160-150
10-11	835	59.5	50.5	150-140
11-12	956	67.4	59.5	130-120
12-01	868	74.3	67.4	110-100
01-02	775	72.6	74.3	90-80
02-03	695	71.0	72.6	70-60
03-04	580	67.3	71.0	50-40

The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz. April 25, 2012 is shown in figure 7.15 .The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 75°C at 01.30 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature.

Table 7.7: Performance in Aluminium Foil concentrator (glazed tube)

Useful heat gain (W)	Instantaneous efficiency/(Δ^{o}C T) inst.	System efficiency therm (Hourly)	Overall Thermal Efficiency overall
$Q_{u(8-9)}$ = 238.00	34.066 / (.3)	49.68	
$Q_{u(9-10)}$ = 225.75		24.07	
$Q_{u(10-11)}$ =166.25	06.52 / (.3)	14.35	
$Q_{u(11-12)}$= 138.25		10.42	
$Q_{u(12-1)}$ =120.75	03.13 / (.1)	10.02	16.88

The variation of beam radiation, I, and useful heat gain, Qu, with time is shown in fig. 7.13. It is seen that a fairly smooth variation of beam radiation with the maximum (956 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

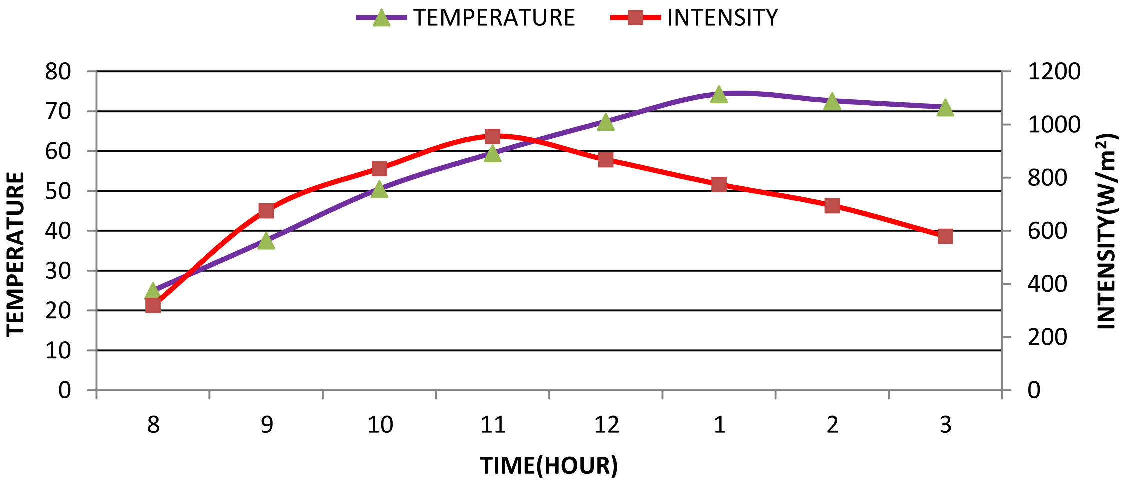


Figure 7.13.

(Variation of collector water temperature, T_{fo} ,and beam radiation I with time)

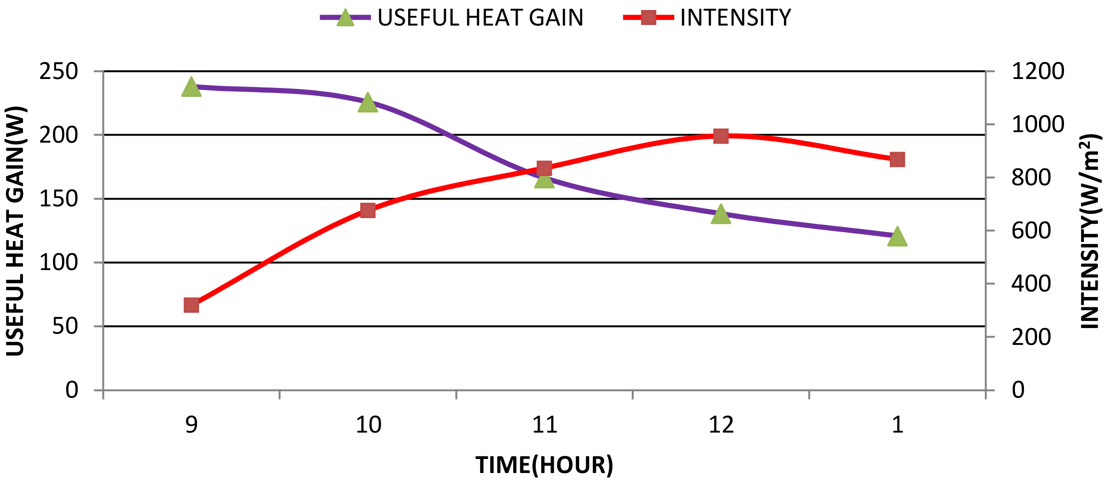


Figure 7.14

(Variation of beam radiation, I, and useful heat gain, Q_u, with time)

The collector instantaneous efficiency is computed using eq. (7.9). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

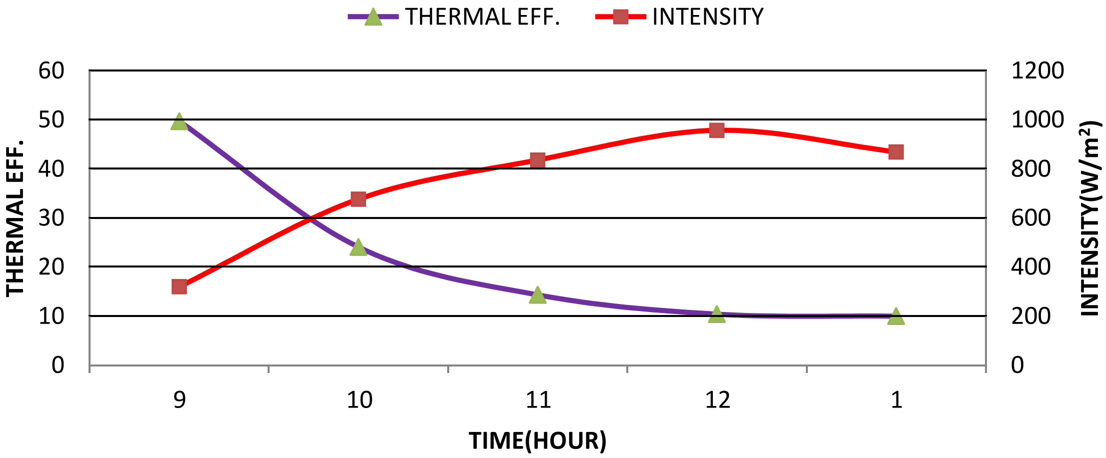


Figure 7.15

(Variation of system Efficiency (HOUR) with time and intensity I)

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.15. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

Discussion:

From above two experimental analysis and theoretical analysis following results are concluded:

1). Maximum temperature rise with Aluminium Foil as reflector in bare copper tube is 68^{o}C while in glazed copper tube it is 75^{o}C.

2). Useful heat gain and hence system instantaneous efficiency per hour is more in **glazing** as less losses are encountered(as shown in graph).Difference between peek instantaneous efficiencies is 36.56% (more in case of glazing).

3). System efficiency (thermal efficiency) per hour is increased approximately by 17.25 % comparing maximum efficiency in both cases.

4).Overall thermal efficiency of PTC with Aluminium Foil as concentrator is 7.7 % more in case of copper tube with glazing than bare copper

7.11 Experimental analysis for Glass Mirror with bare Copper tube:

Reflective material = Glass Mirror

Reflectivity of Mirror = 0.93

Absorber Tube = Bare Copper Tube

Diameter of Cu tube = 34 mm

Area = 1.40 m^2

Table 7.8*:* Variation of Temperature in Glass Mirror with Intensity (Bare Tube)

TIME (Hour)	**INTENSITY (W/)**	**TEMP.OUT ^oC**	**TEMP. IN ^oC**	**ANGLE (degree)**
8-9	315	38.3	25	170-160
9-10	565	51.2	38.3	160-150
10-11	717	61.0	51.2	150-140
11-12	932	69.4	61.0	130-120
12-01	896	75.0	69.4	110-100
01-02	780	74.0	75.0	90-80
02-03	647	72.3	74.0	70-60
03-04	520	70.7	72.3	50-40

Following readings has been taken on dated 1 May, 12 day is normal at the morning and noon.The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz. 1, May,12 is shown in figure. 7.16. The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 75°C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature.

Table 7.9: Performance data in glass mirror concentrator (Bare tube)

Useful heat gain **Q_u (W)**	**Instantaneous efficiency/(Δ^oC T)** **inst.**	**System efficiency** **therm. (Hourly)**	**Overall Thermal Efficiency** **overall**
$Q_{u(8\text{-}9)}$ =232.75	25.71 / (.3)	52.77	
$Q_{u(9\text{-}10)}$ =225.25		28.47	
$Q_{u(10\text{-}11)}$ =171.50	07.53 / (.2)	17.08	
$Q_{u(11\text{-}12)}$=147.00		11.26	
$Q_{u(12\text{-}1)}$ =98.00	03.01 / (.1)	07.81	18.38

The variation of beam radiation, I, and useful heat gain, Q_u, with time is shown in fig. 7.17. It is seen that a fairly smooth variation of beam radiation with the maximum (932 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

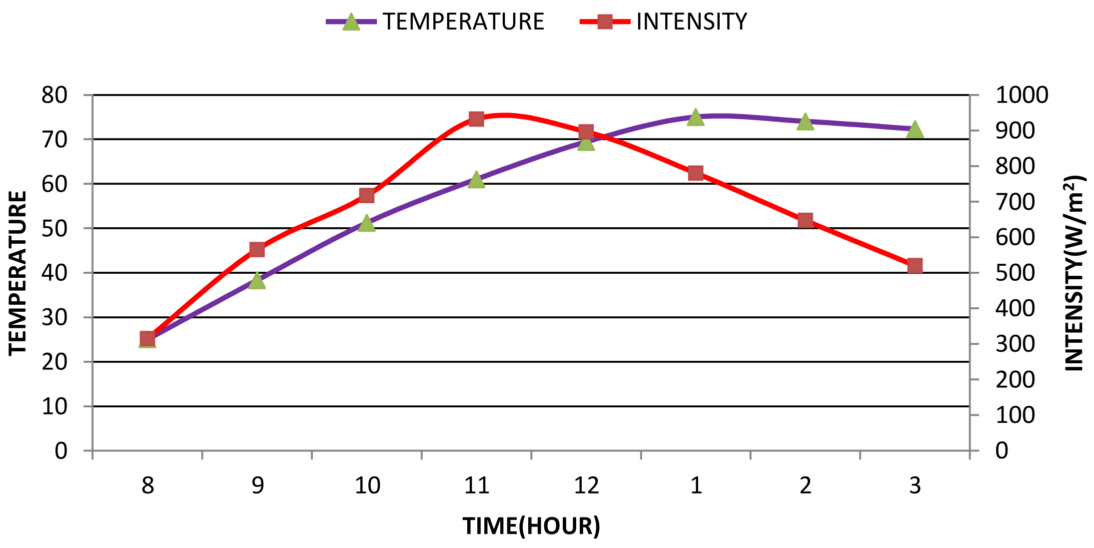


Figure 7.16

(Variation of collector water temperature, T_{fo} ,and beam radiation I with time)

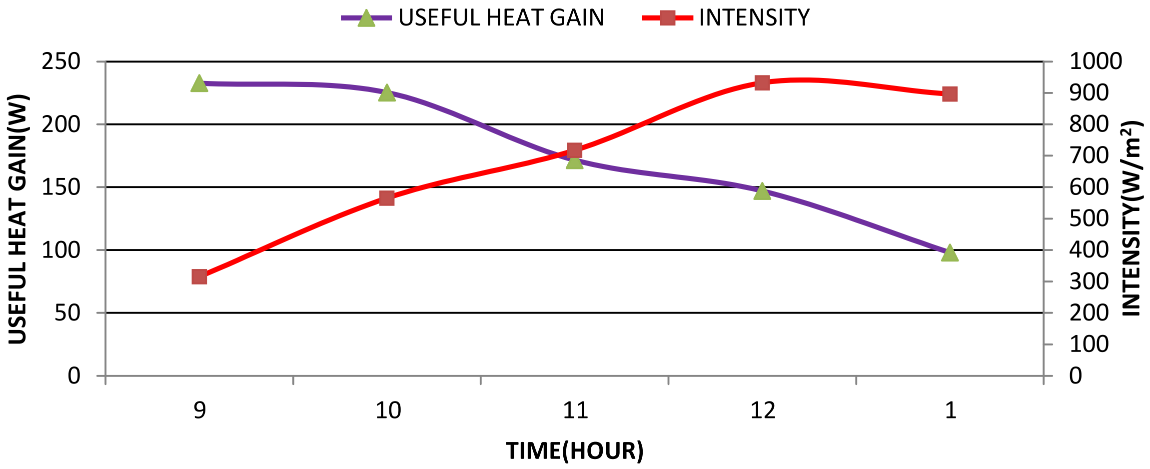


Figure 7.17

(Variation of beam radiation, I, and useful heat gain, Q_u, with time)

The collector instantaneous efficiency is computed using eq. (7.9). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

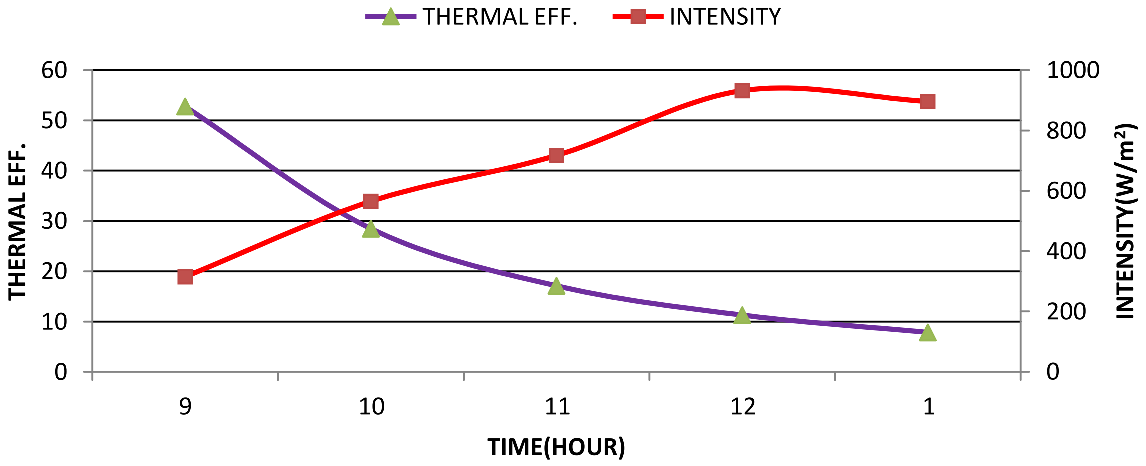


Figure 7.18

(Variation of system Efficiency (HOUR) with time and intensity I)

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.18. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

7.12 Experimental readings for Glass Mirror with Glazed Copper tube:

Reflective material = Glass Mirror

Reflectivity of Steel = 0.93

Absorber Tube = Copper Tube

Diameter of Cu tube = 34 mm

Glazing Material = Glass cover Tube

Glazing Diameter = 44 mm

Area = 1.387 m^2

Table 7.10: Variation of Temperature in Glass Mirror with Intensity (Glazed Tube)

TIME (Hour)	INTENSITY (W/)	TEMP.OUT ^{0}C	TEMP. IN ^{0}C	ANGLE (degree)
8-9	310	41	25	170-160
9-10	650	53.2	41	160-150
10-11	810	63	53.2	150-140
11-12	922	72.7	63	130-120
12-01	878	81.2	72.7	110-100
01-02	766	79.8	80.3	90-80
02-03	680	77.3	79.8	70-60
03-04	540	76.1	77.3	50-40

Following readings has been taken on dated 3,May,2012.day is normal at the morning and noon.The variation of collector water outlet temperature, T_{fo}, and beam radiation I with time on one day, viz. 3,May, 2012 is shown in figure 7.19 .The collector water temperature increases progressively with time, which varies from 8.00 am to 04.00 pm, Indian Standard Time (IST), as the water is recirculated through a hot water storage tank of capacity 15 litres. The mass flow rate of water through the collector is 0.0 9kgps. The storage tank water temperature increases steadily from an initial temperature of 25 °C at 8.00 h and touches a maximum value of 81.2°C at 01.00 pm, as no energy is withdrawn from the storage tank during the collection period. At any instant, the collector water temperature is greater than the storage tank water temperature

Table 7.11: Performance in glass mirror concentrator (glazed tube)

Useful heat gain Q_u (W)	**Instantaneous efficiency/(Δ^{o}C T) $_{inst.}$**	**System efficiency $_{therm}$ (Hourly)**	**Overall Thermal Efficiency $_{overall}$**
$Q_{u(8-9)}$ = 280.00	35.16 / (.3)	65.12	
$Q_{u(9-10)}$ = 213.50		23.68	
$Q_{u(10-11)}$ =171.50	06.72 / (.3)	15.26	
$Q_{u(11-12)}$ = 169.75		13.27	
$Q_{u(12-1)}$ =148.75	06.26 / (.2)	12.21	20.55

The variation of beam radiation, I, and useful heat gain, Q_u, with time is shown in fig. 7.20. It is seen that a fairly smooth variation of beam radiation with the maximum (922 W/m^2) occurs around noon. The useful heat gain first increases, reaches a peak value around noon and then decreases. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation.

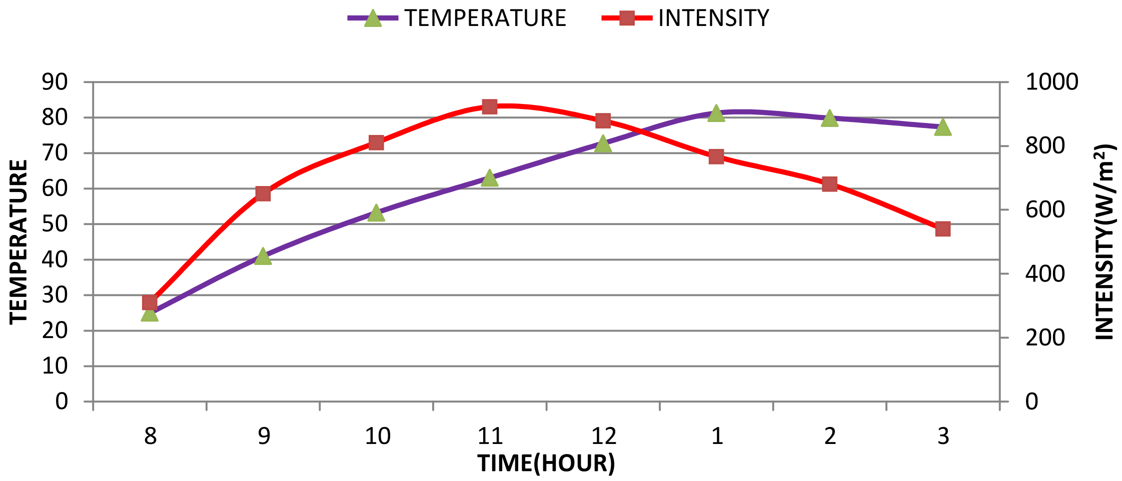


Figure 7.19

(Variation of collector water temperature, T_{fo} ,and beam radiation I with time)

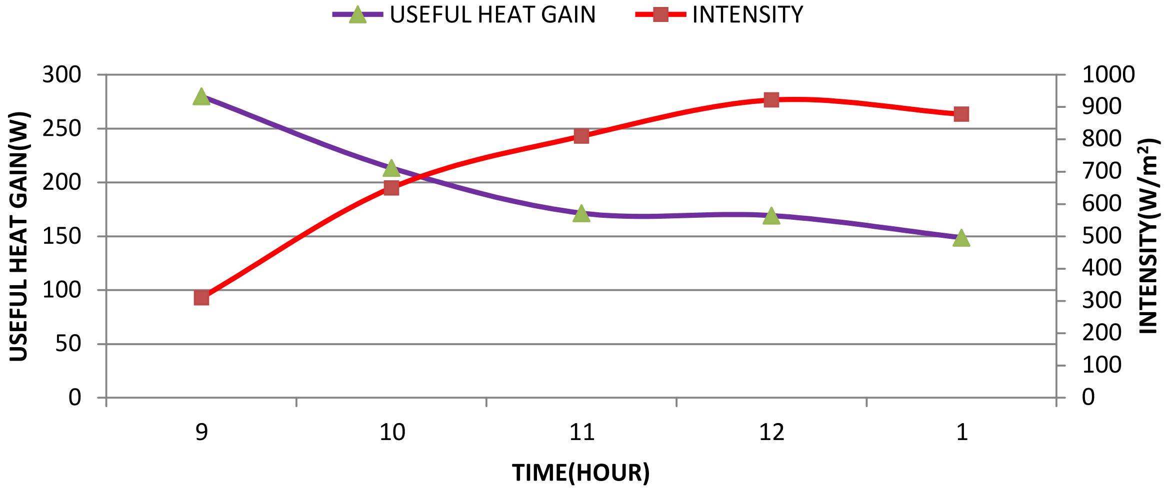


Figure 7.20

(Variation of beam radiation, I, and useful heat gain, Q_u, with time)

The collector instantaneous efficiency is computed using eq. (7.9). It will be noted that the general pattern of variation of efficiency over a day is the same as that of the useful heat gain because the value of efficiency depends on both the incident beam radiation and the useful heat gain.

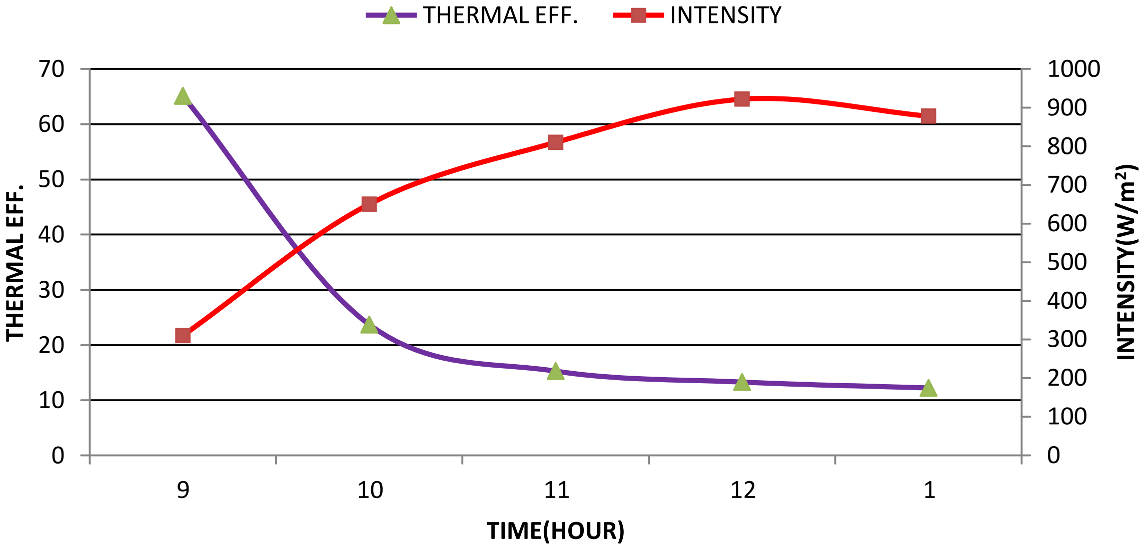


Figure 7.21

(Variation of system Efficiency (HOUR) with time and intensity I)

The variation of hourly thermal efficiency of the PTC hot water storage system is plotted against time and intensity in fig. 7.21. The hourly system efficiency (thermal efficiency) decreases per hour as useful heat gain decreases continuously.

Discussion:

From above two experimental and experimental analysis following results are concluded:

1). Due to glazing on Cu tube temperature rise is 81.2^0C in comparison to bare tube in which peak temperature is 75^0C using Glass Mirror as concentrator. This is because convective losses are minimized using cover glass tube.

2). Useful heat gain and hence system instantaneous efficiency per hour is more in glazing as less losses are encountered(as shown in graph).

3). System efficiency (Thermal efficiency) per hour is increased using glazing approximately by 18.96% comparing maximum efficiency in both cases.

4). Overall thermal efficiency of PTC is 9.25% more in case of copper tube with glazing than bare copper tube by taking Glass as concentrator.

CHAPTER 8

RESULTS AND DISCUSSION

8.1 General:

Thermal performance tests on a PTC are normally conducted to determine its instantaneous efficiency at solar noon and all-day efficiency. A common method of testing the efficiency of a solar collector employs an oil circulating system in which the temperature rise across the collector is measured under steady-state conditions. Along with the inlet and outlet collector fluid temperatures, the fluid mass flow rate and the instantaneous irradiance as measured as well.

Following above procedure in experimental analysis, performance data like maximum temperature rise, peak instantaneous efficiency, thermal efficiency per hour, useful heat gain and overall system efficiency of prototype parabolic trough collector are obtained.

These results are summarized in table 8.1 shown below.

Table 8.1: Tabulation of different performance parameters

SR NO.	**CONCENT-RATOR**	**ABSORBER TUBE**	T_{fo} **(MAX.)**	$\eta_{inst.}$ **(MAX.)**	η_{therm} **(MAX.)**	$\eta_{overall}$ **(MAX.)**
1.	STAINLESS STEEL	**BARE Cu TUBE**	59.5^{0}C	18.00	29.56	12.28
		Cu TUBE WITH GLAZING	62.8^{o}C	28.19	41.11	12.30
2.	ALUMINUM FOIL	**BARE Cu TUBE**	68 ^{o}C	21.26	39.15	15.58
		Cu TUBE WITH GLAZING	74.3 ^{o}C	34.66	49.68	16.88
3.	GLASS MIRROR	**BARE Cu TUBE**	75 ^{o}C	25.71	52.77	18.38
		Cu TUBE WITH GLAZING	81.2 ^{o}C	35.16	65.12	20.55

Table 8.2 shows the maximum temperature rise in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. Figure 8.1 and 8.2 shows the variation of temperature in different reflective materials with bare copper tube and glazed copper tube and with time .The maximum temperature rise is 81.2 ^{o}C in glass mirror as a reflective material in glazed copper tube. Minimum temperature is obtained in stainless steel as a reflector material.

Table 8.2: Comparison of Temperature in different reflecting materials

Sr.No.	CONCENTRATOR MATERIAL	ABSORBER TUBE (COPPER)	TEMPERATURE
1.	**Stainless Steel**	Bare Tube	Maximum temperature rise is 59.5^{o}C.
		Glazed tube	Maximum temperature rise is 62.8^{o}C.
2.	**Aluminium Foil**	Bare Tube	Maximum temperature rise is 68^{o}C.
		Glazed tube	Maximum temperature rise is 74.3^{o}C
3.	**Glass Mirror**	Bare Tube	Maximum temperature rise is 75^{o}C
		Glazed tube	Maximum temperature rise is 81.2^{o}C.

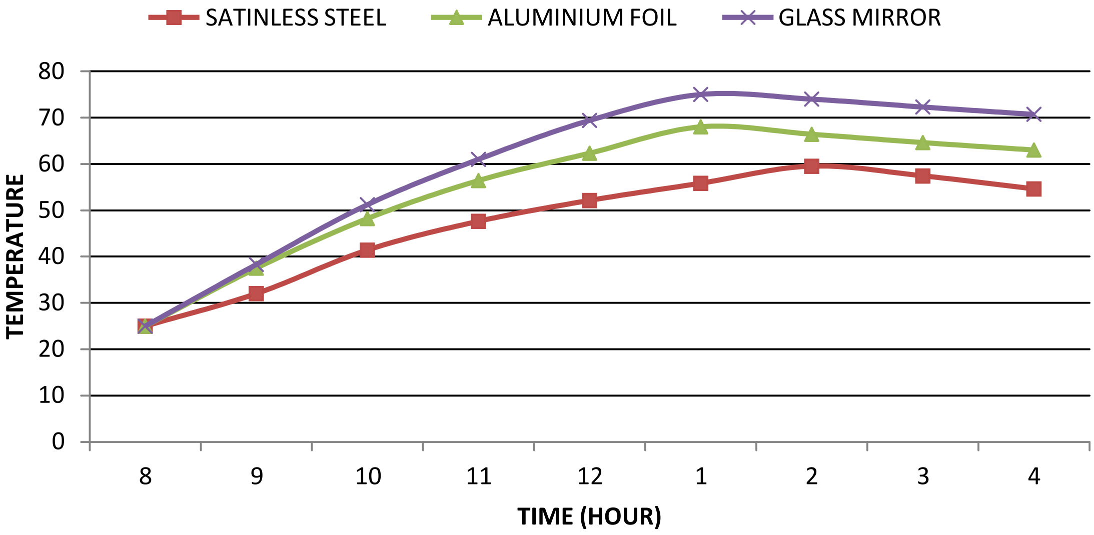


Figure 8.1

(Variation of temperature in different reflecting materials with bare copper tube)

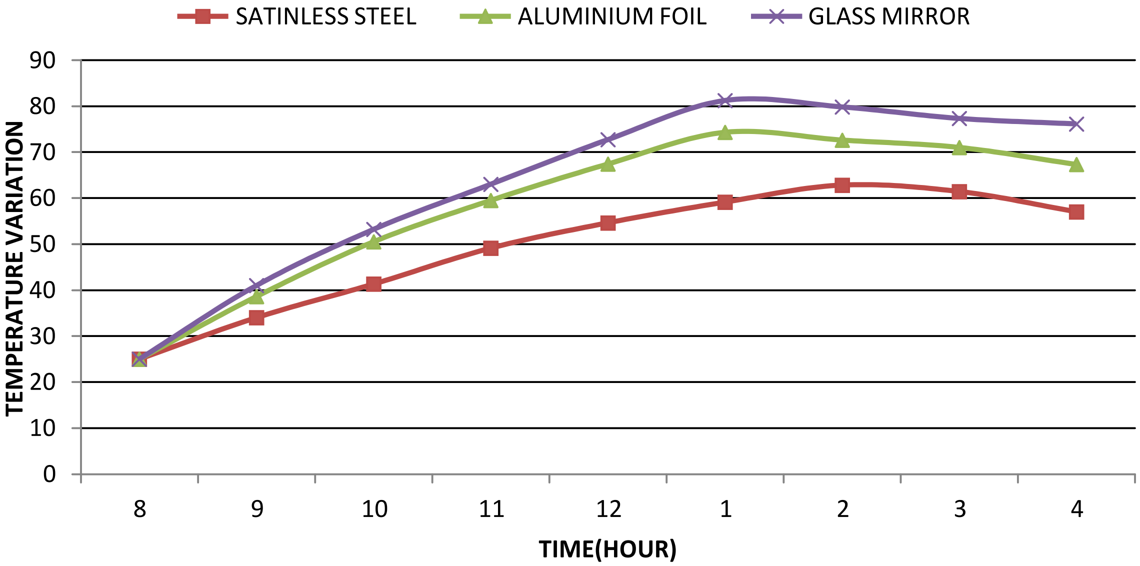


Figure 8.2

(Variation of temperature in different reflecting materials with glazed copper tube)

Table 8.3 shows the maximum Useful Heat Gain (W) in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. Figure 8.3and 8.4 shows the variation of Useful Heat Gain in different reflective materials considering bare copper tube and glazed copper tube and with time .The maximum useful heat gain is 280 W per hour in glass mirror as a reflective material in glazed copper tube. Minimum useful heat gain per hour is obtained in stainless steel as a reflector material (122.50 W per hour) in bare copper tube.

Table 8.3: Comparison of Useful Heat Gain (W) in different reflecting materials

Sr.No.	CONCENTRATOR MATERIAL	ABSORBER TUBE (COPPER)	USEFUL HEAT GAIN (W) per hour
1.	**Stainless Steel**	Bare Tube	Maximum Useful heat gain is 122.50 W.
		Glazed tube	Maximum Useful heat gain is 157.50 W.
2.	**Aluminium Foil**	Bare Tube	Maximum Useful heat gain is 218.75 W.
		Glazed tube	Maximum Useful heat gain is 238 W .
3.	**Glass Mirror**	Bare Tube	Maximum Useful heat gain is 232.75 W.
		Glazed tube	Maximum Useful heat gain is 280 W. .

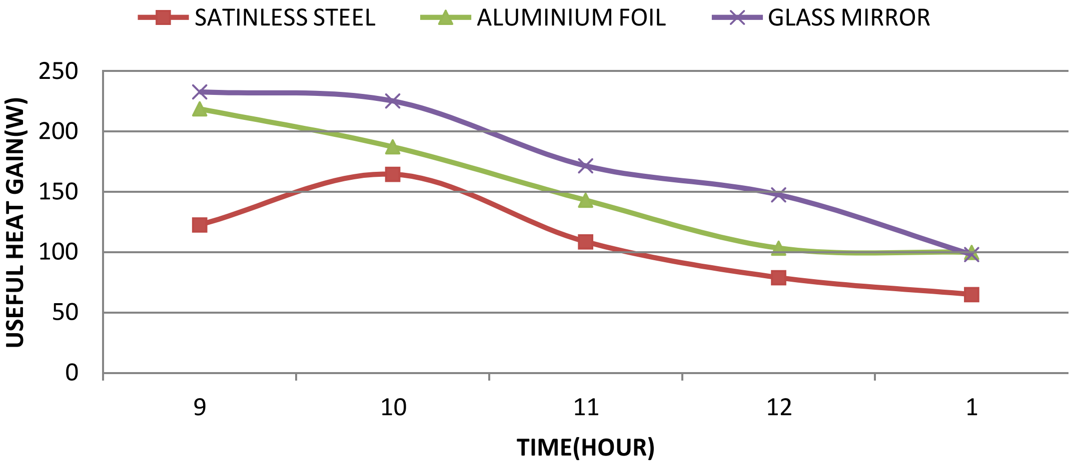


Figure 8.3

(Variation of useful heat gain (W) in different reflecting materials with bare copper tube)

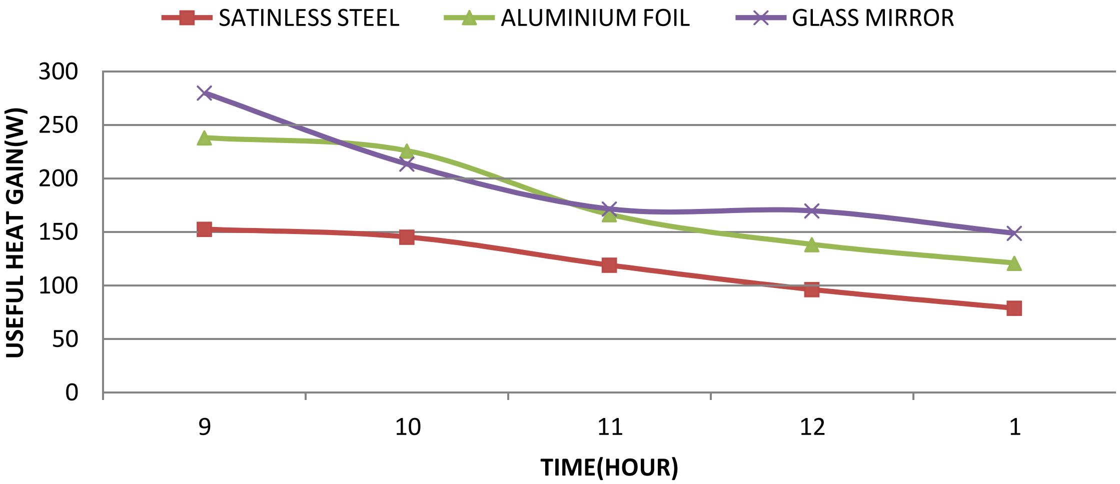


Figure 8.4

(Variation of useful heat gain (W) in different reflecting materials with glazed copper tube)

Table 8.4 shows the maximum Instantaneous Efficiency in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. Figure 8.4and 8.5 shows the variation of Instantaneous Efficiency in different reflective materials considering bare copper tube and glazed copper tube and with time .The maximum Instantaneous Efficiency is 35.16% in glass mirror as a reflective material in glazed copper tube. Minimum Instantaneous Efficiency is obtained in stainless steel as a reflector material 18% in bare copper tube.

Table 8.4: Comparison of Instantaneous Efficiency in different reflecting materials

Sr.No.	**CONCENTRATOR MATERIAL**	**ABSORBER TUBE (COPPER)**	**INSTANTANEOUS EFFICIENCY inst.**
1.	**Stainless Steel**	Bare Tube	Maximum instantaneous efficiency in bare tube is 18%
		Glazed tube	Maximum instantaneous efficiency in glazed tube is 28.19%
2.	**Aluminium Foil**	Bare Tube	Maximum instantaneous efficiency in bare tube is 21.60%
		Glazed tube	Maximum instantaneous efficiency in glazed tube is 34.06%
3.	**Glass Mirror**	Bare Tube	Maximum instantaneous efficiency in bare tube is 25.71%
		Glazed tube	Maximum instantaneous efficiency in glazed tube is 35.16%

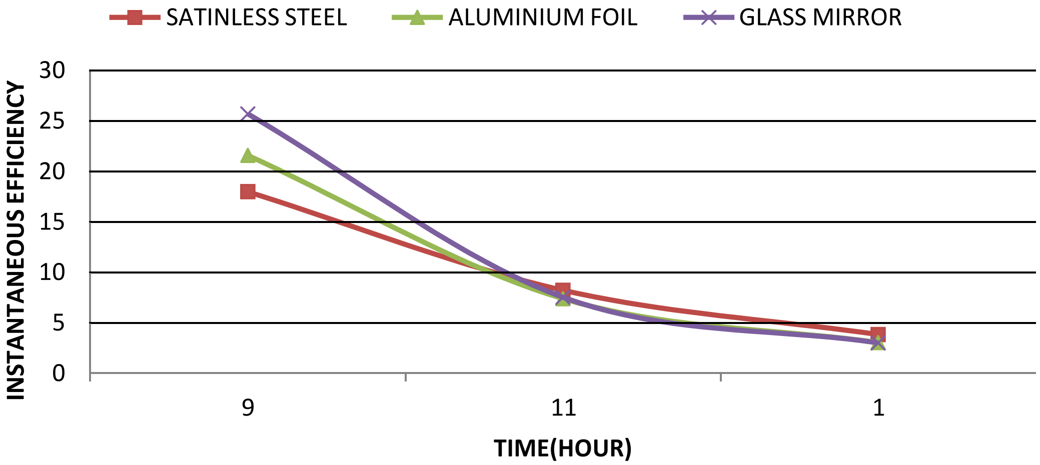


Figure 8.5

(Variation of Instantaneous Eff. in different reflecting materials with bare copper tube)

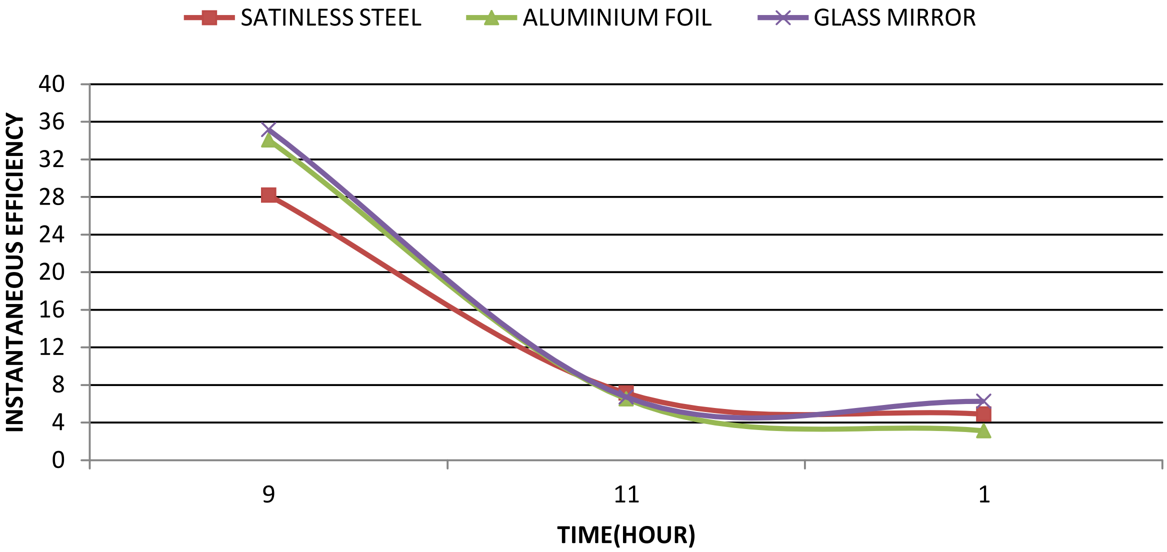


Figure 8.6

(Variation of Instantaneous Eff. in different reflecting materials with glazed copper tube)

Table 8.5 shows the maximum Thermal Efficiency per hour in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. Figure 8.6 and 8.7 shows the variation of Thermal Efficiency per hour in different reflective materials considering bare copper tube and glazed copper tube and with time .The maximum Thermal Efficiency per hour is 65.12% in glass mirror as a reflective material in glazed copper tube. Minimum Instantaneous Efficiency is obtained in stainless steel as a reflector material 29.56% in bare copper tube.

Table 8.5: Comparison of Thermal Efficiency per hour in different reflecting materials

Sr.No.	**CONCENTRATOR MATERIAL**	**ABSORBER TUBE (COPPER)**	**SYSTEM EFFICIENCY (THERMAL EFF.) THERM.**
1.	**Stainless Steel**	Bare Tube	Maximum thermal efficiency in bare tube is 29.56%
		Glazed tube	Maximum thermal efficiency in glazed tube is 41.11%
2.	**Aluminium Foil**	Bare Tube	Maximum thermal efficiency in bare tube is 39.15%
		Glazed tube	Maximum thermal efficiency in glazed tube is 49.68%
3.	**Glass Mirror**	Bare Tube	Maximum thermal efficiency in bare tube is 52.77%
		Glazed tube	Maximum thermal efficiency in glazed tube is 65.12%

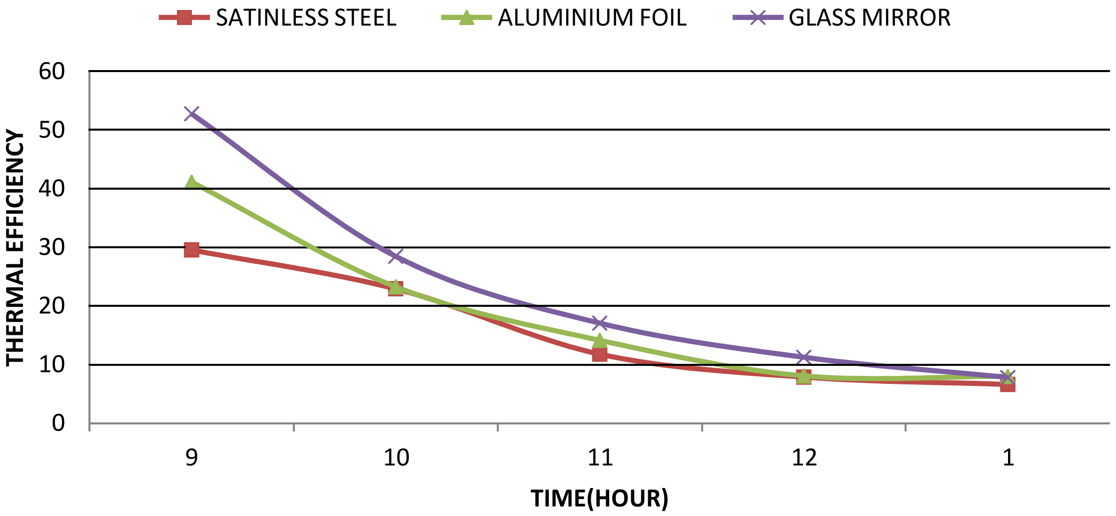


Figure 8.7

(Variation of Thermal Eff. in different reflecting materials with bare copper tube)

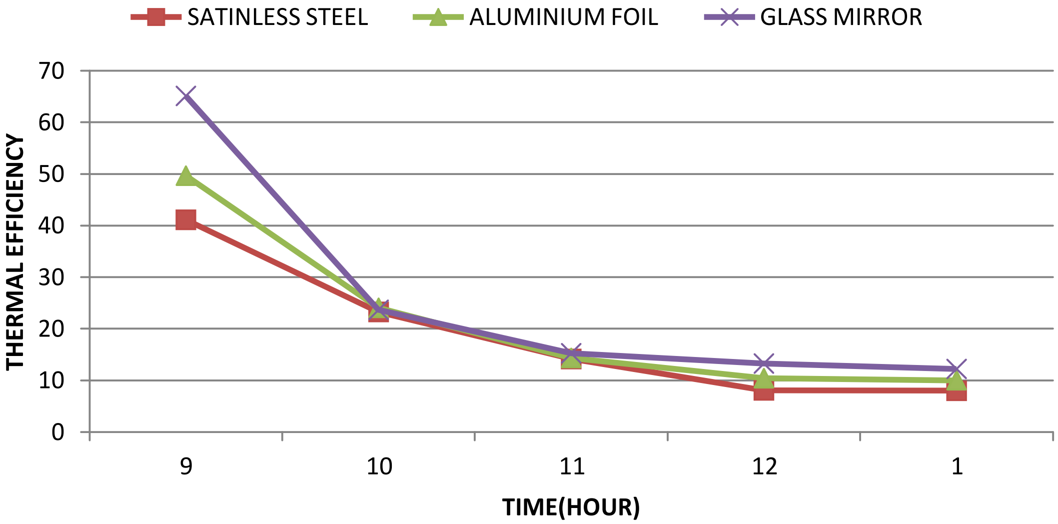


Figure 8.8

(Variation of Thermal Eff. in different reflecting materials with glazed copper tube)

Table 8.6 shows the maximum Overall system Efficiency in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. The maximum Overall System Efficiency is 20.55% in glass mirror as a reflective material in glazed copper tube. Minimum Overall system Efficiency is obtained in stainless steel as a reflector material 12.28% in bare copper tube.

Table 8.6: Comparison of Overall System Efficiency in different reflecting materials

Sr.No.	**CONCENTRATOR MATERIAL**	**ABSORBER TUBE (COPPER)**	**OVERALL SYSTEM EFFICIENCY** $_{\textbf{overall}}$
1.	**Stainless Steel**	Bare Tube	Maximum overall system efficiency in bare tube is 12.28%
		Glazed tube	Maximum overall system efficiency in glazed tube is 12.30%
2.	**Aluminium Foil**	Bare Tube	Maximum overall system efficiency in bare tube is 15.58%
		Glazed tube	Maximum overall system efficiency in glazed tube is 16.88%
3.	**Glass Mirror**	Bare Tube	Maximum overall system efficiency in bare tube is 18.38%
		Glazed tube	Maximum overall system efficiency in glazed tube is 20.55%

Table 8.7 shows the maximum System Optical Efficiency in different reflective materials namely stainless steel, aluminium foil and glass mirror with bare and glazed copper tube as an absorber tube. The maximum System Optical Efficiency is 70.3% in glass mirror as a reflective material in glazed copper tube. Minimum Overall system Efficiency is obtained in stainless steel as a reflector material 60.9% .

Table 8.7: Comparison of System Optical Efficiency in different reflecting materials

Sr.No.	**CONCENTRATOR MATERIAL**	**SYSTEM OPTICAL EFFICIENCY** **opticall**
1.	**Stainless Steel**	Maximum system optical efficiency in glazed tube is 60.9%.
2.	**Aluminium Foil**	Maximum system optical efficiency in glazed tube is 66.68%.
3.	**Glass Mirror**	Maximum overall system efficiency in glazed tube is 70.30%.

CHAPTER 9

CONCLUSION

The performance analysis of a prototype parabolic trough collector is evaluated experimentally using different reflecting materials. Also it includes, design, fabrication, study and characterization of reflecting materials. The different results are obtained using bare and glazed copper tube as an absorber tube. The concluded points of this work are as follows:

1. Maximum temperature rise is obtained in glass mirror as a reflector with glazed copper tube. Maximum temperature obtained is 81.2^0C where with stainless steel it is 63^0C.
2. Considering Instantaneous Efficiency, Glass mirror shows an improvement of 4-40% in comparison to Stainless Steel and Aluminium Foil as a reflector in PTC.
3. Considering Thermal Efficiency per hour, glass mirror shows 20-40% improvement in comparison to stainless steel and 5-35% improvement in comparison to Aluminium foil as a reflecting material.
4. Overall System Efficiency of prototype parabolic trough collector is improved by 40%.

   Glass Mirror shows the maximum improved overall system efficiency in comparison to Stainless Steel and Aluminium Foil as a reflective materials.
5. Optical Efficiency of present parabolic trough is maximum with Glass Mirror. Improved optical efficiency by using Glass Mirror as a reflecting material is 5-14% in comparison to Stainless Steel and Aluminium Foil as a reflecting Material.
6. There are also some demerits associated with present prototype parabolic trough collector such that manual tracking and high mass flow rate which restrict further improvement in its efficiency.
7. By eliminating the above said problems the improvement of collector efficiency can be achieved exceeding 50%.

In present work Feasibility of parabolic trough is analysed in further practical application like air heating, domestic water heating ,process heating etc. By using better tracking mechanism that can be governed by computer controls and flow meter devices the system efficiency can further be enhanced. The results obtained shows that the production of heating water using the sun flux is a viable undertaking.

FUTURE SCOPE

Area of application of Parabolic Trough collector is very wide. India’s Power scenario of solar energy as a renewable energy source is still under research. So, there is a necessity of further theoretical as well as experimental work, investigations to enhance the efficiency of solar collector and to obtain firm and authenticate results. In the present dissertation work, feasibility of a prototype parabolic trough collector is tested for hot water generation and further practical application like air heating, process heating and further steam can be generated with more area and length. However in present thesis work there are some demerits associated with its working. Hence there are lot of scope for further improvement and research which are summarized below:

- One of key improvement in present work is to modify tracking mechanism that is changing manual tracking mechanism with some automated gear mechanism which further improve the efficiency of system.
- System can be operated in two axis tracking mechanism and can be analysed for its effects on efficiency in practical applications.
- In present work, mass flow rate is also very high which has to be controlled by some suitable flow control mechanism for further improvement in its efficiency.
- Present prototype parabolic trough collector (PTC) can further be analysed for air heating, process heating, and steam generation .
- In present work, the production of heating water using the sun flux is a viable undertaking for prototype parabolic trough collector so it can be used as a domestic water heating appliance when there is fully commercialization of solar energy in India. Till now solar energy applications using PTC are still costly as it require high maintainance.

References

1) H.P. Garg, J Prakash "Solar Energy fundamentals and applications", Tata Mcgraw Hill ISBN No-07-463631-6.
2) A.ValanArasu "performance characteristics of the solar parabolic trough collector with hot water generation system" *10* (2006), 2, 167-174.
3) A.ValanArasu "Theortical Analysis and Experimental analysis of a parabolic trough collector for hot water generation" *11* (2007), 1, 119-126.
4) K. Ravi Kumar, K.S. Reddy "Thermal analysis of solar parabolic trough with porous disc receiver", Applied Energy 86 (2009) 1804–1812.
5) Najla El Gharbi, Halima Derbal, Sofiane Bouaichaoui, Noureddine Said "A comparative study between parabolic trough collector andlinear Fresnel reflector technologies" (2011) 565–572.
6) M.J. Montes, A. Rovira, M. Muñoz, J.M. Martíne, "Performance analysis of an Integrated Solar Combined Cycle using Direct Steam Generation in parabolic trough collectors" Applied Energy 88 (2011) 3228–3238
7) A. El Fadar, A. Mimet, A. Azzabakh, M. Pérez-García, J. Castaing, "Study of a new solar adsorption refrigerator powered by a parabolic trough collector", Applied Thermal Engineering 29 (2009) 1267–1270.
8) M J Brooks, I Mills, T M Harms, "Performance of a parabolic trough solar collector", Journal of Energy in South Africa Vol 17 No 3 August 2006.
9) Ming Qu, David H. Archer, Sophie V. Masson "A Linear Parabolic Trough solar collector performance model", ESL-IC-06-11-267.
10) P. Rhushi Prasad H.V. Byregowda P.B. Gangavati "Experiment Analysis of Flat Plate Collector and Comparison of Performance with Tracking Collector" ISSN 1450-216X Vol.40 No.1 (2010), pp.144 -155.
11) Ricardo Vasquez Padilla, Gokmen Demirkaya, D. Yogi Goswami, Elias Stefanakos, Muhammad M. Rahman, "Heat transfer analysis of parabolic trough solar receiver", Applied Energy 88 (2011) 5097–5110.
12) N. Naeeni, M. Yaghoubi, "Analysis of wind flow around a parabolic collector (2) heat transfer from receiver tube", Renewable Energy 32 (2007) 1259–1272.

13) S. D. Odeh, G. L. Morrison and M. Behnia, “thermal analysis of parabolic trough solar collectors for electric power generation”. 11 June 1997; revised version accepted 19 February 1998

14) A.Thomas and H.M.Guven “parabolic trough concentrator- design and evaluation” pp 401-416,1993.

15) A.ValanArasu “Design, manufacture and testing of fiberglass reinforced parabola trough for parabolic trough solar collectors” (2007) 1273–1279.

16) A.ValanArasu “design, development and performance studies of embedded electronic controlled one axis solar tracking system” Vol. 9, No. 2, pp. 163-169, June 2007

17) Randy Gee, Randy Brost, Guangdong Zhu, and Gary Jorgensen, “an improved method for characterizing reflector specularity for parabolic trough concentrators.

18) G.C. Bakos *, I. Ioannidis, N.F. Tsagas, I. Seftelis “Design, optimisation and conversion-efficiency determination of a line-focus parabolic-trough solar-collector (PTC)” (2000) 43-50

19) IvaHn MartmHnez, Rafael Almanza, Marcos Mazari,Genaro Correa “Parabolic trough reflector manufactured with aluminum first surface mirrors thermally sagged” 64 (2000) 85}96.

20) Balbir Singh Mahinder Singh!, Fauziah Sulaiman “designing a solar thermal cylindrical parabolic trough concentrator by simulation” 2003.

21) Maria Brogrena, Anna Helgesson, Bjorn Karlsson, Johan Nilsson, Arne Roosa “Optical properties, durability, and system aspects of a new aluminium-polymer-laminated steel reflector for solar concentrators”, Maria Solar Energy Materials & Solar Cells 82 (2004) 387–412.

22) H.R.Ghosh, N.C.Bhowmik “Determining seasonal optimum tilt angles, solar radiations on variously oriented, single and double axis tracking surfaces at Dhaka”Renewable Energy, Volume 35, Issue 6, June 2010, Pages 1292-1297

23) M. M. Alkilani, K. Sopian, Sohif Mat, “Output Air Temperature Prediction in a Solar Air Heater Integrated with Phase Change Material”, ISSN 1450-216X Vol.27 No.3 (2009), pp.334-341.

24) Soteris A. Kalogirou “Solar thermal collectors and applications” (2004) 231–295.

25) A. Scrivani, T. El Asmar, U. Bardi "Solar trough concentration for fresh water production and waste water treatment", Desalination 206 (2007) 485-493

26) Lourdes García-Rodríguez, Ana I. Palmero-Marreroa, Carlos Gómez-Camachob "Application of direct steam generation into a solar parabolictrough collector to multieffect distillation" (1999) 139–145

27) Hazim Mohameed Qiblawey*, Fawzi Banat "Solar thermal desalination technologies" (2008) 633–644

28) Daniel M. Blake, Luc Moensa, Mary Jane Halea, Henry Pricea, David Kearney, and Ulf Herrmannc "New Heat Transfer and Storage Fluids for Parabolic Trough Solar Thermal Electric Plants", September 4-6, 2002.

29) J. Bartl, M. Baranek, "Emissivity of aluminium and its importance for radiometric measurement", Institute of Measurement Science, Slovak Academy of Sciences 841 04, Bratislava.

30) http://www.parabolictrough.com

31) G.D Rai "Non-Conventional energy sources" ISBN No: 81-7409-073-8.

32) Avadhesh Yadav, V.K. Bajpai "An Experimental Study on Evacuated Tube Solar Collector for Heating of Air in India", World Academy of Science, Engineering and Technology 79 2011.