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Experimental study of a solar water heater for effect of solar radiation and mass Flow Rates

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الإهـــداء

إلى منارة العلم والإمام المصطفى .. إلى الأمي الذي علم المتعلمين . . إلى سيد الخلق أجمعين

.. محمد صلى الله عليه وسلم ..

إلى من جعلت الجنة تحت أقدامها .. أمي..

إلى من حرم نفسه فأعطاني .. أبي..

ثم إلى من أحبتهم وأحبوني في الله

.. إخوتي وأصدقائي..

إلى الذين لهم فضل كبير في تعليمنا وتبصير مسار عقولنا نحو التقدم والعلى

.. أساتذتنا الفضلاء .

نهدي لهم هذا العمل المتواضع

كلمـــــة شكـــر

الشكر لله أولاً وآخراً على نعمه التي لا تعد ولا تحصى

تتقدم بجزيل الشكر والتقدير إلى **الدكتور/ السنوسي ابوغرارة** المشرف على هذا البحث والذي أخذنا من وقته ومن علمه الكثير وكان لتوجيهاته القيمة الفضل الكبير في إنجاح هذا البحث وإظهاره بالشكل المطلوب

ونتقدم بالشكر أيضاً إلى كل من ساهم معنا بأية معلومة، أو عمل أو مساعدة في سبيل إتمام هذا البحث من أساتذة، ومهندسين والشكر موصول أيضاً لأعضاء هيئة التدريس بالكلية عامة وقسم هندسة الطاقة المتجددة خاصة.

كما لا يفوتنا أن نتقدم بجزيل الشكر والتقدير لأصدقائنا الذين شاركونا أجمل ذكريات الدراسة.

والله ولي التوفيق

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Symbol	Name of the parameter	Unit
U_L	Overall loss coefficient	W/m²ºC
Aa	Aperture area	m²
A_ρ	Area of the flat plate	m²
$A_{a\rho s}$	Area of the absorber plate	m²
$T_{\rho m}$	Average temperature of the absorber plate	ºC
q_t	Rate at which heat is lost from top	W
q_b	Rate at which heat is lost from bottom	W
q_s	Rate at which heat is lost from sides	W
$h_{\rho\text{-}c1}$	Convective heat transfer coefficient between the absorber plate and first cover	W/m²ºC
$h_{c1\text{-}c2}$	Convective heat transfer between first and second covers	W/m²ºC
T_a	Ambient temperature	ºC
$T_{c1,c2}$	Temperature attained by tow covers	ºC
T_{sky}	Effective temperature of the sky with which the radiative exchange takes place	ºC
L_1	Length of the absorber plate	m
L_2	Breadth of the absorber plate	m
L_3	Height of the collector casing	m
L_s	Thickness of the insulation	m

Chapter 1

INTRODUCTION

1. Introduction:

Sun is a constant source of energy. Every day, the sun enriches the earth with uncountable amounts of solar energy, most of which comes in the form of yellow light. All around planet earth, sunlight is by far the most important source of energy for all living things[1]. Without it, earth is lifeless. Solar energy has been used since prehistoric times, but in a most primitive manner. Before 1970, some research and development was carried out in a few countries to exploit solar energy more efficiently, but most of this work remained mainly academic. After the dramatic rise in oil prices in the 1970s, several countries began to formulate extensive research and development programs to exploit solar energy. Solar energy is the most readily available source of energy. It is also the most important of the non-conventional sources of energy because it is non-polluting and, therefore, helps in lessening the greenhouse effect. Solar light can be a free source of renewable energy for everyday jobs such as cooking, heating water or warming up homes. Solar energy can also be used to meet our electricity requirements. Through Solar Photovoltaic (SPV) cells, solar radiation gets converted into DC electricity directly. This electricity can either be used as it is or can be stored in the battery. This stored electrical energy then can be used at night. SPV can be used for a number of applications such as:

- domestic lighting,
- village electrification,
- water pumping,
- desalination of salty water, and
- Railway signals.

If the means to make efficient use of solar energy could be found, it would reduce our dependence on non-renewable sources of energy and make our environment cleaner[2].

Energy received from the sun can be categorized:

1. in the form of heat (or thermal energy), and

2. in the form of light energy.

Solar thermal technologies use the solar heat energy to heat substances (such as water or air) for applications such as space heating, pool heating and water heating for homes and businesses. There are a variety of products on the market that uses solar thermal energy. Often the products used for this application are called solar thermal collectors and can be mounted on the roof of a building or in some other sunny locations. The solar heat can also be used to produce electricity on a large utility-scale by converting the solar energy into mechanical energy.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Passive solar techniques include selecting materials with favourable thermal properties, designing space that naturally circulate air, and referencing the position of a building to the Sun. Passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

Active solar techniques are photovoltaic panels and solar cells to convert sunlight into useful outputs. [2]

1.1 Solar Energy:

Because, it is ultra clean, natural and a sustainable source of energy that one can utilize for generating electricity, solar heating appliances, solar cooling appliances and also solar lighting appliances.

On the global front, making use of solar energy seems to be one of the best options available. The worldwide climate change is a serious threat to our planet that is causing much of the problems. The emission levels of carbon dioxides that we generate by the constant use of fossil fuel are literally killing our planet. The usage of solar energy will only provide us with a clean environment, a life where we will not have to constantly worry about the ever so reducing natural resources. With net meeting, the ever so reasonably priced solar technology and the ultimate willingness

To change this situation around, you can augment the energy competence of your home, and in due course accomplish net zero fossil fuel expenditure and utilization. You will also save the planet from dying out by using solar energy.

Another key aspect of using solar energy is that it has massive financial benefits. On the whole, the planet is being drained of its oil resources and energy prices are only bound to go up. To only mend your own personal cost of energy needs is probably one of the smartest things to do and not to forget a very valuable future investment, when measured up to the unavoidable rise in the cost of energy in recent times as well as the not so far future. [3]

Generation of Energy in Sun and Its Way towards Earth

For better understanding about how it is generated we need to know bit more about Sun which provide us with this amazing source of energy. Solar energy is radiant energy which emitted by sun.

This huge ball is full of gases like hydrogen and helium, hydrogen atoms however is present on larger scale. Energy is formed because of nuclear fusion reaction when hydrogen atoms combine to form helium. This entire process takes place in the core of the sun which is the hottest part.

One helium atom is formed when four nuclei of hydrogen are fused together; however a helium atom poses lesser mass than four hydrogen atoms. During the nuclear fusion reaction some of the matter is lost which is release into the space, this matter comes out into space as radiant energy.

Sun surface is about 109 times bigger than surface of earth. Our mother earth is about 149.63*10^6 kilometers away from the sun and light takes about 8 minutes and 31 seconds to reach to surface of the earth. Light from the sun travels 186,262 miles per second to reach to earth. Energy emitted from the sun which reaches earth is in massive amount and can be extremely dangerous for mankind if direct exposure is made.

Earth possess layer of Ozone which filters all harmful radiant energy and allows only that light and heat energy to the surface of the earth which benefits living organisms.

1. The energy which finally reaches earth is very low to the amount of energy filtered, yet this amount of energy is sufficient to provide enough electricity to the earth for entire year. Some portion of energy is reflected back into space,

some amount of energy is utilizes by land, oceans and plants, still rest of the energy is up for us to and utilize effectively. [2], [3]

1.2 Advantages of Solar Energy:

There are plenty of excellent reasons that equate to advantages in using solar energy. Here are some advantages in using solar energy .

(i) Solar energy is non-polluting.

Solar energy is excellent alternative for fossil fuels like coal an petroleum because solar energy is practically emission free while generating electricity. With solar energy the danger of further damage to the environment is minimized. The generation of electricity through solar power produces no noise. So noise pollution is also reduced.

(ii) Accessibility of solar power in remote locations. Solar power can be generated electricity of matter how remote the area as long as the shines there. Even in areas that are inaccessible to power cables, solar power can produce electricity.

(iii) Available Free of Cost.

Sunlight is totally free. There is of course the initial investment for the equipment. After the initial capital outlay you won't be receiving a bill every month for the rest of your life from the electrical utility.

(iv) Solar energy is getting more cost effective.

The technology for solar energy is evolving at an increasing rate. At present photovoltaic technology is still relatively expensive but the technology is present photovoltaic technology is improving and production is increasing. The result of this is to drive costs down. Payback times for the equipment's are getting short as five years.

(v) The abundance of solar energy.

Even in the middle winter each square mater of land still receives a fair amount of solar radiation. Sunlight is everywhere and the resource is practically inexhaustible. Even during cloudy days we still receive some sunlight and it is this than can be used as a renewable resource.

(vi) Solar energy system is virtually maintenance free.

Once a photovoltaic array is setup it can last for decades. Once they are installed and setup there are practically zero recurring costs. If needs increase solar panels can be added with ease and with no major revamp.[2],[3]

1.3 Disadvantage of Solar Energy:

(i) High initial capital investment.

The initial cost of installing a solar energy system can be prohibitively high for some budgets. The cost of buying and installing solar panel arrays is a bit steep. Payback times may reach from ten o fifteen years before you can even break even with your initial investment.

(ii) Doubtful reliability.

It is obviously to power your home with a solar array at night if you don't have a system in which to store power. This means batteries at our present level of technology. So one probably need to draw electricity from the local utility grid.

iii) Position of the surface on which sunlight falls.

The position of your solar array is obviously of major importance in the generation of electricity. This means that some houses will not be ideally suited for conversion or for installing a solar energy system.

(iv) Polluting materials used in solar panels.

The majority of photovoltaic panels are made from silicon and other metals that are potentially toxic like mercury, lead and cadmium. This is the dirty secret of this “clean” technology.

(v) low efficiency.

The current efficiency rate of most solar panels is just 40%. This means that 60% of the sun's energy is wasted. The solar panels that can reach a maximum efficiency of 80%. [2],[3]

Chapter-2

LITERATURE REVIEW

2. Literature review:

The present world energy condition focuses on the development of various renewable energy. The most easily and readily available energy on the Earth is the radiation energy of the sun. This radiant energy is harnessed by solar collectors and used for various domestic or household purposes, even for a few industrial sectors. The use of solar energy not only puts less pressure on the current sources of energy present but also shows a light of hope in solving the current energy crisis. Solar water heating or solar energy usage is on rise mainly for three reasons firstly ,the increase of price of available fossil fuels like oil, gas etc. secondly, the world is getting concerned over the fact that fossil fuel is gradually being replenished from the Earth and thirdly, the use of renewable energy reduces pollution as well as demand on electricity[4],[5].

A solar collector works on the greenhouse effect principle. It absorbs the radiation of shorter wavelength and keeps it trapped to heat the collector plate. The long wave radiation is usually reflected back or remains unabsorbed[6].

A solar collector varies according to its design. A flat plate solar collector has the same intercepting area as its absorbing area whereas a concentrated or curved surface collector has a smaller receiver area compared to the interceptor area[7].

In this report, a review of the solar flat plate collector is provided which is organised as follows:

• A brief introduction about the types of solar collectors' present.

• The construction, working procedure and application of a flat plate solar collector.

• Thermal analysis and performance improvement of flat plate collector[8],[9].

performed an experiment where the experimental rig was a full-scale model, located in a small temperature controlled room. The collector they designed was constructed from timber ply and uses low iron, anti-reflective glass, of the type used in a standard flat plate collector, for the glass cover. Three 1KW element type heaters, sandwich between two sheets of 2mm thick aluminum plate, are used to model the absorber plate. The heaters were connected to variable voltage power supply through Al-go due UPM30 digital power meters that measure the power input to the heaters.

The power meters were connected in turn to a computer via RS232 connection. Thirty T-type thermocouples were used to measure:

a) The surface temperature on the heater plates,

b) The surface temperatures on the walls of the concentrators,

c) The temperature gradient across the glass cover, and

d) The ambient temperature [2].

The analysis of thermal performance of the flat-plate collector includes parameters such as solar intensity, ambient temperature and configuration of flat-plate collectors etc. A Solar Water Heater are devices which are provides hot water for bathing, washing, cleaning, etc. using of solar energy. It is generally installed where sunlight are available. The solar energy is the most capable of the alternative energy sources. Solar energy is considered an attractive source of renewable energy that can be used for water hearing in both homes and industry[10].

Work of Hottel and Woertz in 1942 and by Hottel and Whiller in1958 can be looked as a first work on solar flat plate collector. Theyhad developed the collectors consisting of a black flat plate absorber, a transparent cover, heat transfer fluid and an insulating case[11][12].

designed and constructed PTC and evaluation of the PTC were presented as a demonstrative prototype. The efficiency obtained was lower than the reported investigations. This was found due to the optical properties of the absorber pipe`s coating; in this case carbon soot with an absorbing capacity ˜0.90 was used. Nevertheless, the useful energy was not the one expected, due to the way it was applied; it left some irregularities on the surface. Finally, it is important to mention that the thermal efficiency of the collector is strongly related to the atmospheric conditions, like the direct solar radiation, the room temperature and the cloudiness[13].

presented reports on results of quasi steady state efficiency measurements on parabolic trough collector. Additionally, first measurements on the heat loss of the collector were reported. The investigations aim at a possibility to characterize the thermal performance of parabolic trough collectors - and more generally concentrating collectors - by a combination of measurements and heat loss measurements (without radiation). First results with regard to this aspect are positive[14].

Chapter 3

SOLAR ENERGY MEASURING DEVICES

3. Solar energy Measuring Devices:

3.1 Pyrheliometer:

A pyrheliometer is an instrument for measurement of direct beam solar irradiance. Sunlight enters the instrument through a window and is directed onto a thermopile which converts heat to an electrical signal that can be recorded. The signal voltage is converted via a formula to measure watts per square meter [2]. It is used with a solar tracking system to keep the instrument aimed at the sun. A pyrheliometer is often used in the same setup with a pyrometer. Fig. 3.1 represents a Pyrheliometer

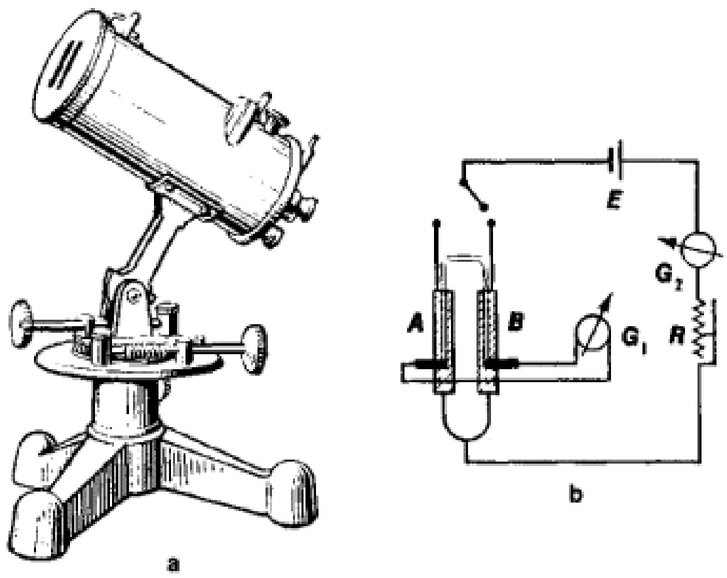

Figure 3.1: Pyrheliometer

3.2 Pyrometer:

A pyrometer is a type of actinometer used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m2) from the hemisphere above within a wavelength range 0.3 μm to 3 μm. The solar radiation spectrum that reaches earth's surface extends its wavelength approximately from 300 nm to 2800 nm. Depending on the type of pyranometer used, irradiance measurements with different degrees of spectral sensitivity will be obtained. Fig. 3.2 represents a Pyranometer[2].

Figure 3.2: Pyranometer

3.3 Pyrgometer:

pyrgeometer is a device that measures near-surface infrared radiation spectrum in the wavelength spectrum approximately from 4.5 µm to 100 µm. It measures the resistance/voltage changes in a material that is sensitive to the net energy transfer by radiation that occurs between itself and its surroundings (which can be either in or out). By also measuring its own temperature and making some assumptions about the nature of its surroundings it can infer a temperature of the local atmosphere with which it is exchanging radiation. A pyrgeometer consists of the following major components:

- A thermopile sensor which is sensitive to radiation in a broad range from 200 nm to 100 µm
- A silicon dome or window with a solar blind filter coating. It has a transmittance between 4.5 µm and 50 µm that eliminates solar shortwave radiation.
- A temperature sensor to measure the body temperature of the instrument.
- A sun shield to minimize heating of the instrument due to solar radiation. Fig. 3.3 represents a Pyrgeometer[2].

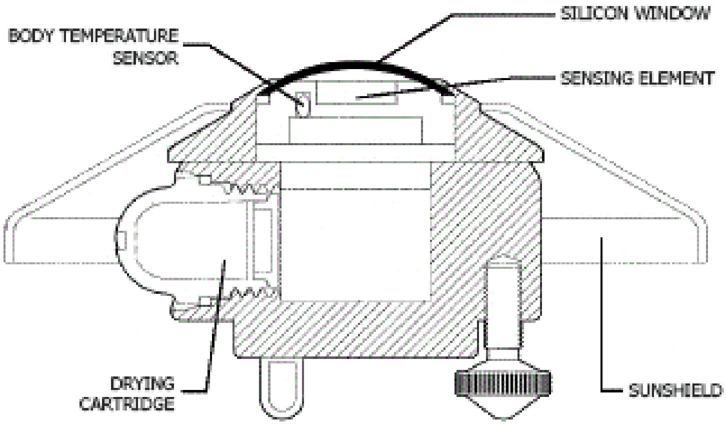

Figure 3.3: Pyrgeometer

3.4 Thermocouples:

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor. Thermocouples are widely used in science and industry. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered major appliances. Certain combinations of alloys have become popular as industry standards. Selection of the combination is driven by cost, availability, convenience, melting point, chemical properties, stability, and output. Different types are best suited for different applications. They are usually selected on the basis of the temperature range and sensitivity needed. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions. Other selection criteria include the chemical inertness of the thermocouple material and whether it is magnetic or not. Standard thermocouple types are listed below with the positive electrode followed by the negative electrode [2].

3.4.1 Nickel-alloy thermocouples:

Type E (chromel–constantan) has a high output (68 μV/°C), which makes it well suited to cryogenic use. Additionally, it is non-magnetic. Wide range is −50 °C to +740 °C and narrow range is −110 °C to +140 °C.

- **Type J**

Type J (iron–constantan) has a more restricted range (−40 °C to +750 °C) than type K but higher sensitivity of about 50 μV /°C [27]. The Curie point of the iron (770 °C) [28] causes a smooth change in the characteristic, which determines the upper temperature limit.

- **Type K**

Type K (chromel–alumel) is the most common general-purpose thermocouple with a sensitivity of approximately 41 μV /°C [29]. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C (−330 °F to +2460 °F) range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a deviation in output when the material reaches its Curie point, which occurs for type K thermocouples at around 185 °C[29].

They operate very well in oxidizing atmospheres. If, however, a mostly reducing atmosphere (such as hydrogen with a small amount of oxygen) comes into contact with the wires, the chromium in the chromel alloy oxidizes. This reduces the emf output, and the thermocouple reads low. This phenomenon is known as green rot, due to the colour of the affected alloy. Although not always distinctively green, the chromel wire will develop a mottled silvery skin and become magnetic. An easy way to check for this problem is to see whether the two wires are magnetic (normally, chromel is non-magnetic)[29].

Hydrogen in the atmosphere is the usual cause of green rot. At high temperatures, it can diffuse through solid metals or an intact metal thermowell. Even a sheath of magnesium oxide insulating the thermocouple will not keep the hydrogen out[11]**.**

- **Type M**

Type M (82%Ni/18%Mo–99.2%Ni/0.8%Co, by weight) are used in vacuum furnaces for the same reasons as with type C (described below). Upper temperature is limited to 1400 °C. It is less commonly used than other types[29].

- **Type N**

Type N (Nicrosil–Nisil) thermocouples are suitable for use between −270 °C and +1300 °C, owing to its stability and oxidation resistance. Sensitivity is about 39 μV/°C at 900 °C, slightly lower compared to type K. Designed at the Defence Science and Technology Organisation (DSTO) of Australia, by Noel A. Burley, type-N thermocouples overcome the three principal characteristic types and causes of thermoelectric instability in the standard base-metal thermo element materials:

1. A gradual and generally cumulative drift in thermal EMF on long exposure at elevated temperatures. This is observed in all base-metal thermo element materials and is mainly due to compositional changes caused by oxidation, carburization, or neutron irradiation that can produce transmutation in nuclear reactor environments. In the case of type-K thermocouples, manganese and aluminum atoms from the KN (negative) wire migrate to the KP (positive) wire, resulting in a down-scale drift due to chemical contamination. This effect is cumulative and irreversible.
2. A short-term cyclic change in thermal EMF on heating in the temperature range about 250–650 °C, which occurs in thermocouples of types K, J, T, and E. This kind of EMF instability is associated with structural changes such as magnetic short-range order in the metallurgical compo
3. A time-independent perturbation in thermal EMF in specific temperature ranges. This is due to composition-dependent magnetic transformations that perturb the thermal EMFs in type-K thermocouples in the range about 25– 225 °C, and in type J above 730 °C[30].

The Nicrosil and Nisil thermocouple alloys show greatly enhanced thermoelectric stability relative to the other standard base-metal thermocouple alloys because their compositions substantially reduce the thermoelectric instabilities described above. This is achieved primarily by increasing component solute concentrations (chromium and silicon) in a base of nickel above those required to cause a transition from internal to external modes of oxidation, and by selecting solutes (silicon and magnesium) that preferentially oxidize to form a diffusion-barrier, and hence oxidation-inhibiting films[17].

- **Type T**

Type T (copper–constantan) thermocouples are suited for measurements in the −200 to 350 °C range. Often used as a differential measurement, since only copper wire touches the probes. Since both conductors are non-magnetic, there is no Curie point and thus no abrupt change in characteristics. Type-T thermocouples have a sensitivity of about 43µV/°C. Note that copper has a much higher thermal conductivity than the alloys generally used in thermocouple constructions, and so it is necessary to exercise extra care with thermally anchoring type-T thermocouples[29].

3.5 solarimeter (or silicon cell pyrometer):

solarimeter is an instrument used for measuring the flow of solar radiation. It uses the photovoltaic effect to measure the amount of solar radiation reaching a given surface. A solar meter that uses the photoelectric effect has the same response as a photovoltaic system: it produces an electrical signal as a function of incident light.It responds mostly to visible light and its production depends on cell temperature. It captures light wavelengths from approximately 330 nm to 1100 nm. To obtain an independent temperature reading, the values measured by the photovoltaic solar meter must be corrected to compensate for the temperature. This measurement can be made thanks to a thermocouple. The adjustment factor should have high accuracy levels.

The instrument consists of a solarimeter fitted with a hemisphere of heat-absorbing glass. By this means, a well-tried instrument, already widely used in meteorological stations for the measurement of total incident radiation, is converted into an instrument suitable for measuring photosynthetically active radiation. The good angular response is preserved by using a hemispherical filter. With a commercial electronic microvoltmeter the instrument is sensitive enough for use in phytotrons, and if photosynthetically active radiation is assumed to be bounded by the wavelengths 0.4 and 0.7µ, calculations show that it compares irradiances of common light sources with daylight, in these units, with an error of not more than 20%, reducible to 10% with an improved filter glass. Arguments are presented for specifying and measuring light directly in such units, here called “plantwatts/m2”, rather than using illumination units and a conversion factor for each light source. Daylight measurements with a filtered and an unfiltered solarimeter over several months have shown that the number of plantwatts/m2 is not a constant proportion of the total irradiance but varies (in one locality) from 48 to 65%. Moreover, the variation is systematic, the highest proportions occurring during the dullest weather, presumably because water vapour is the chief absorber involved. A systematic error would, therefore, be introduced by measuring with an unfiltered solarimeter and assuming that the proportion of photosynthetically active radiation in daylight is constant[24].

Chapter 4

TYPES OF SOLAR COLLECTORS

4. Types of Solar Collectors:

Solar energy collectors are special kind of heat exchanger that transforms solar radiation energy to internal energy of the transport medium.

The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat and transfers this heat to a fluid (usually air, water or oil) flowing through the collector.

The solar energy is thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days[8].

There are basically two types of collector based on intercepting area:

- Non concentrating or stationary
- Concentrating

4.1 Collectors are further as classified as:

4.1.1 Tracking concentrator:

i. One axis tracking concentrator (MODERATECONCENTRATION):
- Cylinder parabolic concentration (FMSC)
- Linear Fresnel lens/reflector

ii. Two axis concentrator (HIGH concentration)
- Parabolic disk concentrator
- Central tower receiver
- Circular Fresnel lens
- Hemispherical bowl mirror

4.1.2 Non tracking concentrator:

i. Flat receiver with booster mirror
ii. Tabor Zimmer circular cylinder
iii. Compound parabolic concentrator
iv. V trough

4.1.3 Reflecting/Refracting concentrator

- **i.** One piece/composite
- **ii.** Single stage/Two stage
- **iii.** Symmetric/asymmetri**c**

4.1.4 Imaging/Non imaging

4.1.5 Line focussing/point focussing

4.2 Brief Description About Solar Collectors:

4.2.1 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 as shown in the Fig. 4.1. 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[5],[8].

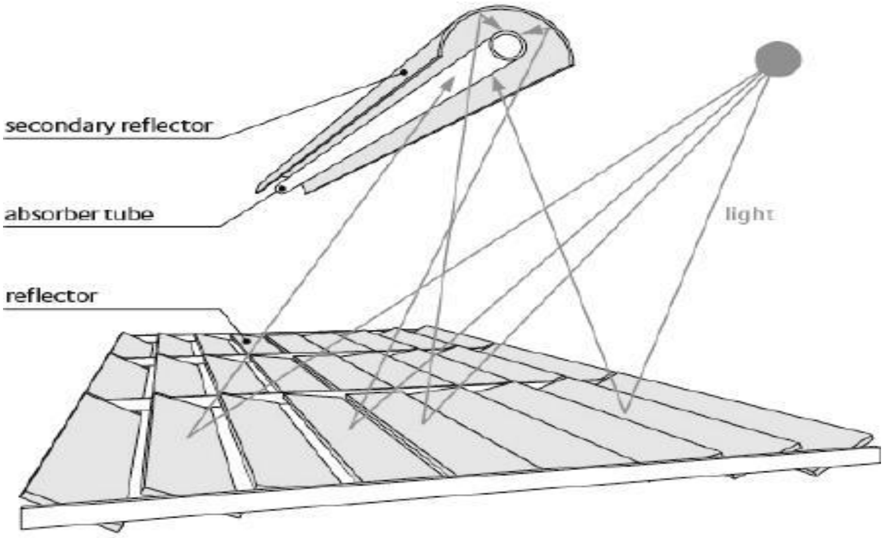

Figure 4.1: Linear Fresnel Collector (LFC)

A representation of an element of an LFR collector field is shown in the Fig. 4.1.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 requirements. One difficulty with the LFR technology is that avoidance adjacent of shading and blocking between reflectors. Blocking can be reduced by increasing the height of the absorber tower, but this increases cot. Alternatively, Compact Linear Fresnel Reflector (CLFR) technology can be used. The classical LFR system has only one receiver and there is no choice about the direction and orientation of a given reflectors reflect solar radiation. This provides the means for much more densely packed arrays, because patterns of alternating reflector orientation can be such that closely packed reflectors can be positioned without shading and blocking. The arrangement minimises beam blocking by adjacent reflectors and allow high reflector densities and tower heights to be used[5],[8][31].

4.2.2 Evacuated Tube Collector (ETC):

Evacuated heat pipe solar collectors (tubes) consist of a heat pipe inside a vacuum sealed tube, as shown in the fig. Evacuated tube collectors have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses so the collector can operate at higher temperature (150^oC). Both direct and diffuse radiation can be collected. Evacuated tube collectors use liquid vapour phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate) Protruding from the top of the tube is a metal tip attached to the sealed pipe (condenser). The heat pipe contains a small amount of fluid (e.g. methanol) that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid and the vapour travels to the hat sink region where it condenses and releases its latent heat. The condenser combines the vacuum insulation and nonimaging stationary concentration into a single unit. For high temperature application, a tracking ICPC may be used. Fig. 4.2 represents an evacuated tube collector[5],[8],[32].

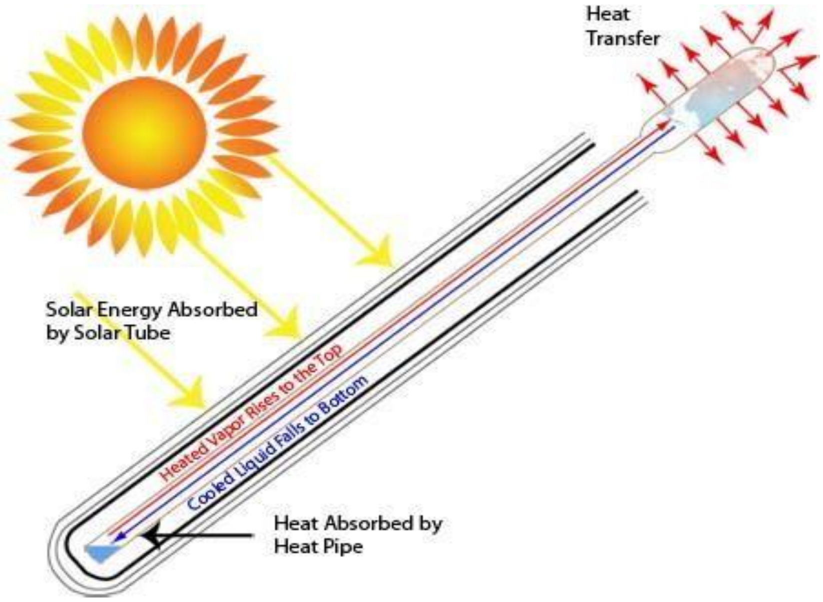

Figure 4.2: Evacuated tube collector (ETC)

4.2.3 Parabolic Dish Concentrator:

Parabolic dish concentrating systems use parabolic dish shaped mirrors to focus the incoming solar radiation onto a receiver that is positioned at the focal point of the dish, like it's illustrated in the Fig. 4.3. The fluid in the receiver is heated to very high temperatures of about 750^{o}C. This fluid is then used to generate electricity in a small Stirling engine, or Brayton cycle engine, which is attached to the receiver. Parabolic dish systems are the most efficient of all the solar technologies, at approximately 25% efficient, compared to around 20% for other solar thermal technologies. Fig. 4.3 represents a parabolic dish collector[5],[8].

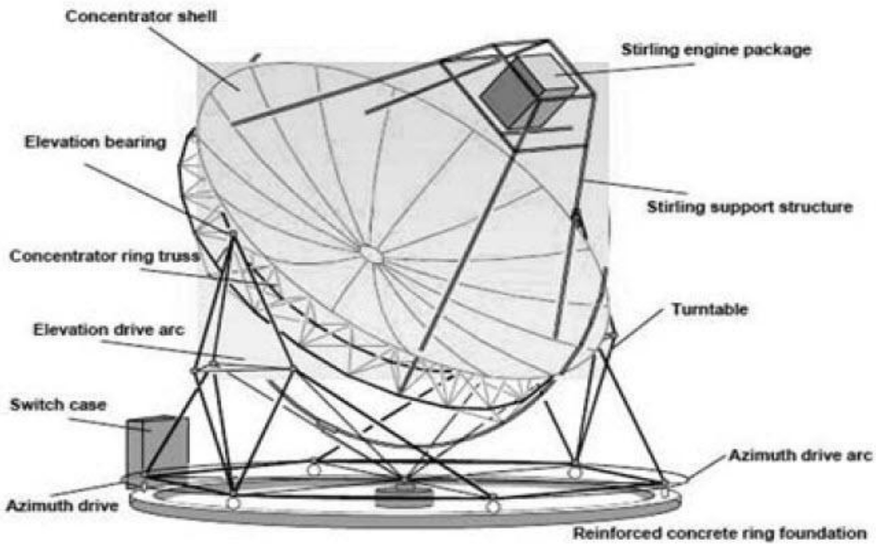

Figure 4.3: Parabolic dish collector

4.2.4 Central Tower Receiver:

The solar power tower, also known as 'central tower' power plants or 'heliostat' power plants or power towers, is a type of solar furnace using a tower to receive the focused sunlight. It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target). Concentrated solar thermal energy is seen as one viable solution for renewable, pollution free energy. Early designs used these focussed rays to heat water, and used the resulting steam to power a turbine. Newer designs using liquid Sodium have been demonstrated, and systems using molten salts (40% Potassium Nitrate, 60% Sodium Nitrate) as the working fluids are now in operation. These working fluids have high heat capacity, which can be used to store the energy before using it to boil water to drive turbines. These designs allow power to be generated when the sun is not shining. Fig. 4.4 represents a central tower receiver[3],[5],[8].

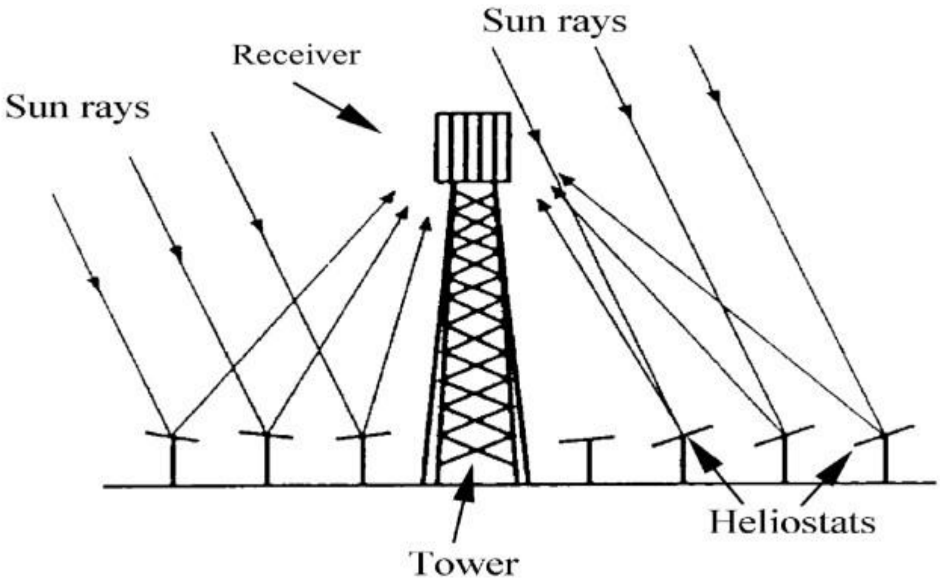

Figure 4.4: Central Tower Receiver

4.2.5 Hemispherical Bowl Mirror Concentrator

It consists of a hemispherical fixed mirror, a tracking absorber and supporting structure as shown in Fig. 4.5. All rays entering the hemisphere after reflection cross the paraxial line at some point between the focus and the mirror surface. Therefore, a linear absorber pivoted about the centre of curvature of the hemisphere intercepts all reflected rays. The absorber is to be moved so that its axis is always aligned with the solar rays passing through the centre of the sphere. This requires two-axis tracking. The absorber is either

driven around a polar axis at a constant angular speed of 15^o per hour or adjusted periodically during the day. This type of concentrator gives lesser concentration, owing to spherical aberration than that obtained in parabolic concentrator[3],[5],[8].

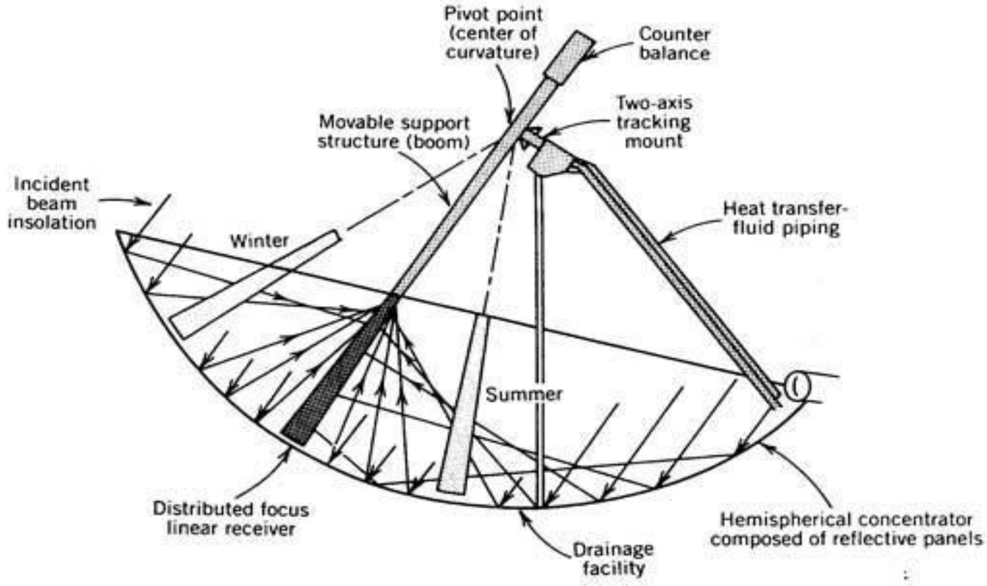

Figure 4.5: Hemispherical Bowl Mirror Concentrator

4.2.6 Compound Parabolic Concentrator:

Compound Parabolic Concentrator (CPC) is a special type of solar collector fabricated in the shape of two meeting parabolas. It belongs to the non-imaging family, but is consider among the collector having the highest possible concentrating ratio. Also because of its larger aperture area, only intermittent tracking is required. It is one of the collectors which has the highest possible concentration permissible by thermodynamics limit for a given acceptance angle. Its large acceptance angle results in intermittent tracking towards the sun. The Parabolic concentrator only accepts rays of light that are perpendicular to the entrance aperture. The tracking of this type of concentrator must be more exact and requires expensive equipment. The Compound Parabolic Concentrator accepts a greater amount of light and needs less accurate tracking. Fig. 4.6 represents a compound parabolic concentrator[3],[5],[8].

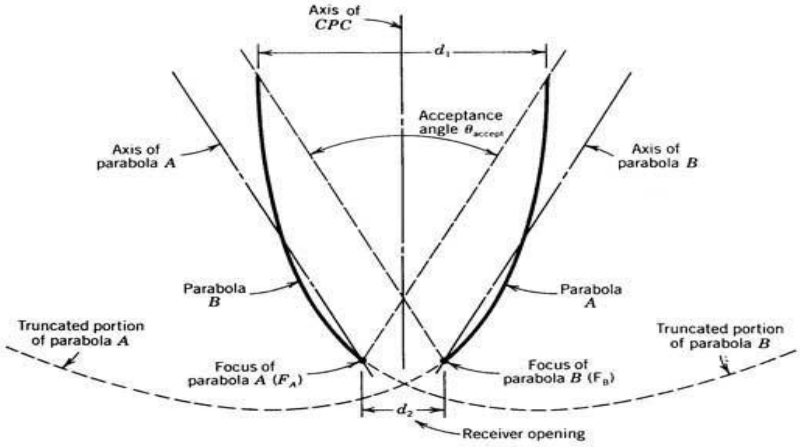

Figure 4.6: Compound Parabolic Concentrator

4.2.7 Concentrating Parabolic Collector:

It consists of a cylindrical parabolic trough reflector and a metal tube receiver at its focal line as shown in Fig. 4.7. The receiver tube is blackened at the outside surface to increase absorption. It is rotated about one axis to track the sun. The heat transfer fluid flows through the receiver tube, carrying the thermal energy to the next step of the system. This type of collector may be oriented in any one of the three dimensions: east-west, north-south or polar. The polar configuration intercepts more solar radiation per unit are as compared to other modes and thus gives best performance. The concentration ratio in the range of 5-30 may be achieved from these collectors[33].

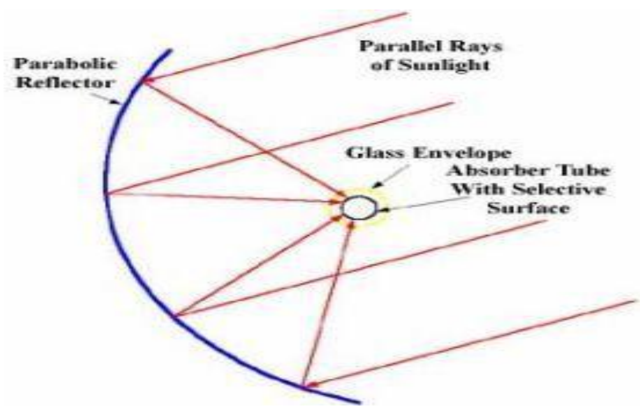

Figure 4.7: Concentrating Parabolic Collector

4.2.8 Flat Plate Collector:

A typical flat-plate collector is a metal box with a glass or plastic cover (called glazing) on top and a dark coloured absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal- typically Copper or Aluminium- because the metal is a good heat conductor. The main use of this technology is in residential buildings where the demand for hot water has a large impact on energy bills. This generally means a situation with a large family, or a situation in which the hot water demand is excessive due to frequent laundry washing. Fig. 4.8 represents a flat plate collector.

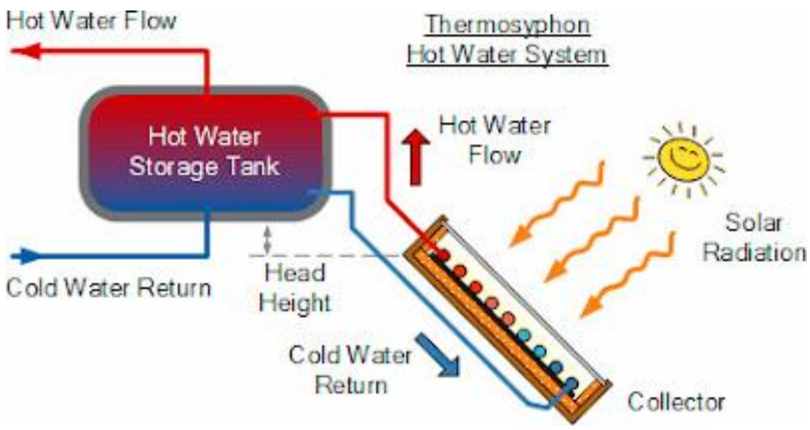

Figure 4.8: flat plate collector and Tank,(Thermosiphon systems)

The typical components of a flat plate collector are: -

a) **Absorber Plate:**

The absorber plate is a rectangular sheet made of high heat conducting material, especially copper or aluminium because of their high heat conductivity. It is usually painted in black and coated with absorptive material to get the maximum absorption of solar radiation[6]. This thin layer is highly absorbent to shortwave solar radiation but comparatively translucent to long wave radiation. Another thin layer is provided below the coating with high reflectance to long wave radiation. The absorber plate absorbs the sun's heat energy and transfer that to the working fluid with minimum heat loss[8],[16],[5],[18],[19].

b) **Headers:**

Tubes of large diameter are placed at the top and bottom of the absorber plate for the entrance and discharge of fluid. The header pipes are made of copper for maximum heat conduction from the absorber plate[6]. These header pipes are connected to the copper tubes by welding[8],[16],[5],[20].

c) **Tubes:**

Several tubes made of copper are placed on the absorber plate. The working fluid flows through the tubes where they are heated. The copper tubes are positioned parallelly on the absorber plate. (John Twidell, 2015)The liquid tubes are connected at both ends by large diameter header tubes. These are soldered and brazed to the absorber plate so that smooth heat transfer takes place between them by getting maximum surface contact[6],[8],[16],[5],[18].

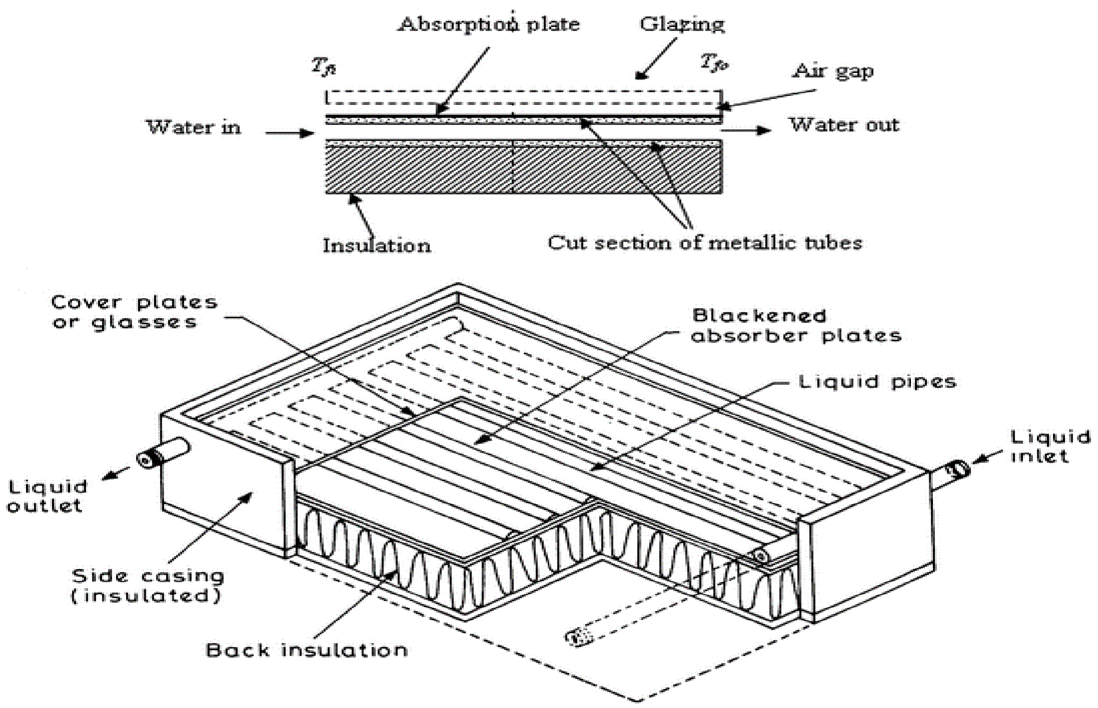

Figure 4.9: Parts of a flat plate collector

d) **Glazing:**

Glazing refers to covering with glass or plastic having radiative properties. A flat plate collector has single, double or multiple layers of glazing above the blackened absorber plate. Low iron glass is mainly used for glazing having high transmissivity of short-wave radiation and low or zero transmissivity of long-wave radiation[6]. The main purpose of glazing is to allow as much as solar radiation possible and create an insulation of the absorber plate with the environment by entrapping radiation to reduce convective losses as well as radiative losses. Transmission of short-wave radiation can also be increased by antireflective coating and surface texture. The glazing materials doesn't absorb heat like absorber plate[8],[5],[18].

e) **Insulation:**

Insulation is provided to the sides and bottom of the flat plate collector to reduce heat loss. Different insulating materials like rubber, cotton, wool is used for this purpose. Insulating substances decrease heat loss from the absorber plate and helps in heating the tubes as well as the plate[8],[5].

f) **Casing:**

A steel or wooden casing is used to hold the parts together. In the casing a layer of insulation is provided at the bottom. The absorber plate is placed after that with copper tubes incorporated in it. The sides are also insulated for the reduction of heat loss through convection[6]. Finally, the glazing is done with glass to provide air gap between absorber and the atmosphere. All the parts are soldered, brazed or welded properly to get maximum surface contact and high heat transfer. Casing protects the parts from environmental influences like dust particles, rainfall, moisture etc[5],[18].

Working:

A solar collector works as a water heater and is based on the transformation of the absorbed solar radiation to thermal energy. In general, solar collector works by absorbing solar radiation which incidents on the collector plate passing through the glazed glass. The absorbed heat is then transferred to the working fluid flowing through the connected copper tubes with minimum heat loss. The heated fluid is then moved to the place of its use or to a storage tank for later use[6].

A solar collector heating system is two types- active or direct and passive or indirect.

Active or direct solar collector is basically an open-loop system. In this system, a differential temperature sensor is used to compare the temperature of the water to be heated. The heat collected by the collector is transferred to the working fluid which goes directly to the storage tank and then supplied to the household needs. A heat pump is used which draws cold water from the bottom of the storage tank and circulates it through the solar collector. As a result, the heated water is circulated through the tanks directly from the collector [8],[18],[21].

Open-loop system is of two types- drain-down system and the recirculating system.

In the drain-down system a valve is used to allow the solar collector to fill with water when the collector reaches a certain temperature.

In the recirculating system water is pumped through the collector when the temperature in the storage tank reaches a certain critical value.

Passive or indirect system is a closed-loop system. In this system, a heat transfer fluid called glycol is used to circulate through the solar collector. Glycol after absorbing radiant heat from the collector is passed to a heat exchanger where it heats the working fluid through heat transfer. Glycol works as anti-freezing substance and can operate efficiently at freezing temperature. The working fluid after being heated from the heat exchanger is transferred to a storage tank for after use[22],[23].

Thermo-siphon system is a kind of passive system which consists of an insulated storage tank set above the collectors. The heated fluid moves to the storage tank by convective process and stored there. In response, the cold fluid circulates to the collector and gets heated up. In this system, flow of fluid is slow. This system is simple and uses no energy and requires comparatively low maintenance[9],[4].

Air flat plate collectors works on the same principle but is used for conditioning of household or commercial premises. It works by natural or forced convection of depending on absorbed heat. In air heating systems, boiler is used to heat the air before using for space heating. Blower or fan may also be used for forced flow of air in other applications[25].

Applications:

Solar collectors are primarily used for heating water for household purposes to reduce the usage and of energy and fossil fuel. Typical application of flat plate solar collector includes the following:[6],[8],[19].

- Water heating for household and residential use like washing clothes, bathing, washing other equipment as well as drinking warm water is done by solar collectors
- Industrial application of solar water heating includes the use of warm water in leather industry, textile industry, food and beverage industry etc.
- Laundry shops use warm water for washing clothes by using either active or passive collector
- Water of swimming pool is heated using solar collector
- Solar collectors are used in desalination plants for evaporation of water by heating it to high temperature
- Solar concentrators are used for solar distillation by heating copper boilers filled with water
- Solar powered electricity is generated from the radiant energy of the sun using solar collectors
- Air heater is used for space heating in household and commercial zones
- Crop drying for agriculture industry is done by forced flow of air using air heaters

- **Advantages of a Flat Plate Collector**

Some advantages of a flat plate collector include

1. A Flat plate collector facilitates the collection of direct energy from all directions and diffuses thermal radiation.
2. It is a clean, pollution-free system of energy generation.
3. The power utilized by FPCs is natural & renewable.
4. Flat plate collector devices have relatively low maintenance costs and longer working life.

5. It is easy to fabricate and economical.
6. It can be installed effortlessly. FPCs are fixed to a mounting structure *in* tilt and orientation in which they receive maximum sunlight.

With FPCs, more energy can be generated even at low temperatures[8],[5],[6].

- **Overall loss coefficient and heat transfer correlations**

It is convenient from the point of view of analysis to express the heat loss from the collector in terms of an overall loss coefficient, defined by the equation-[6],[18],34]

$\boldsymbol{q_u = U_c A_{abs}(T_c - T_a)}$ **……………..(4.1)**

The heat lost from the collector is the sum of the heat lost from the top, the bottom and the sides. Thus,

$\boldsymbol{q_{total} = q_t + q_b + q_s}$ **……………..(4.2)**

Each of these losses is also expressed in terms of coefficient called the **Top Loss Coefficient, Bottom Loss Coefficient** and **Side Loss Coefficient** and can be defined by the equations[34].:

$\boldsymbol{q_t = U_t A_p(T_{pm} - T_a)}$ **……………..(4.3)**

$\boldsymbol{q_b = U_b A_p(T_m - T_a)}$ **……………..(4.4)**

$\boldsymbol{q_s = U_s A_p(T_{pm} - T_a)}$ **……………..(4.5)**

The definitions of each of the coefficient is based on the area $\mathbf{A_p}$ and the temperature difference$\mathbf{(T_m\text{-}T_a)}$. This is done for convenience and helps in giving the simple additive equations:[34]

$\boldsymbol{U_r = U_t + U_b + U_s}$ **……………..(4.6)**

- **T_{op} Loss Coefficient**

The T_{op} loss coefficient U_t is evaluated by considering convection and re-radiation losses from the absorber plate in the upward direction.

In a steady state, the heat transferred by convection and radiation between: The absorber plate and first cover.

Hence,

$$\frac{qt}{Ap} = h_{p-c1}(T_{pm} - T_{c1}) + \frac{\sigma(T_{pm}{}^4 - T_{c1}{}^4)}{\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} + 1} \quad \text{.................(4.7)}$$

$$= h_{c1-c1}(T_{pm} - T_{c2}) + \frac{\sigma(T_{c1}{}^4 - T_{c2}{}^4)}{\frac{1}{\epsilon_c} + \frac{1}{\epsilon_c} + 1}$$

$$= (T_{c2} - T_a) + \sigma(T_{c1}{}^4 - T_{sky}{}^4)$$

- **Bottom Loss Coefficient**

The bottom loss coefficient U_b is evaluated by considering conduction and convection losses from the absorber plate in the downward direction through the bottom of the collector. It will be assumed that the flow of heat is one-dimensional and steady. Thus neglecting the convective resistance:[6],[35],[36]

$$U_b = \frac{ki}{\delta b} \quad \text{.................(4.8)}$$

Where, $\mathbf{k_i}$ = Thermal conductivity of the insulation,
b= Thickness of the insulation.

- **Side Loss Coefficient**

In case of side loss coefficient, it will be assumed that the conduction resistance dominates and that the flow of heat is one dimensional and steady. The one dimensional approximation can be justified on the ground that the side loss coefficient is always much smaller than the top loss coefficient. Thus[6],[34].

$U_s = (L_1 + L_2)L_3k_i/L_iL_2$ ……………..**(4.9)**

- **Effects of Various Parameters on Performance of solar collector**

A large numbers of parameters influence the performance of a liquid flat-plate collector. The parameters are the selectivity of the absorber surface, the number of glass cover, the spacing between the covers, the tilt of the collector, the fluid inlet temperature, thetransmissivity of the glass and dust settlement on the top glass cover.

1. **Selective Surfaces:**

Absorber plate surfaces which exhibit the characteristics of a high value of absorptivity for incoming solar radiation and a low value of emissivity for outgoing re-radiation are called selective surfaces. Are desirable because then maximize the absorption of solar energy and minimizes the emission of the radiative loss. If a surface has a high absorptivity for wavelengths less than 4μm and a low emissivity for wavelength greater than 4μm can be prepared, it would have the characteristics desirable for an absorber plate surface to act in a selective manner, the characteristics desired for an ideal selective surface. The selectivity of the surfaces is achieved by having a polished and cleaned metal base and depositing on it a thin layer which is transparent to have large wave lengths, but highly absorbing for small wavelengths solar radiations. The layer is less than 1nm in thickness, and is deposited by a variety of methods like electroplating, chemical conversions, anodic oxidation, rf-magnetron sputtering[5],[8].

2. **Number of Covers:**

As the number of covers increases, the value of both (ʊα) b and (ʊα) d decreases. Thus the flux S absorbed in the absorber plate decreases. The addition of more covers also causes the value of Ut, and hence the heat loss, to decrease. Thus, the useful heat gained (consequently the efficiency) goes through a maximum value with a certain number of covers5[8],[18].

3. **Spacing:**

The proper spacing to be kept between the absorber plate and the first cover or between two covers has been the subjects of considerable discussion. From the point of view of the heat loss from the top, it is evident that the spacing must be such that [8],[6].

.

4. **Effects of Shading:**

The main problem associated with the use of large spacing is that shaping of the absorber plate by the side walls of the collector casing increases. Some shaping always occurs in every collector and need to be corrected for. It is estimated that for most designs, using spacing of 2-3 cm between the covers, shading reduces the radiation absorbed by about 3%. It is recommended that absorber flux S can be calculated in the usual manner but with a multiplying factor of 0.97[5]**.**

5. **Collector Tilt**

Flat plate collector are in one position and do not track the sun[13].

6. **Mass Flow Rate**

The flow rate affects system efficiency and operating temperature. Slower flow rates keep the solar fluid in the collectors longer, so it comes out hotter, but overall efficiency decreases when heat is transferred more slowly. Higher flow rates do the opposite: more fluid is pumped around the system to improve efficiency, but the overall temperature is lower. It's important to understand what your project requires, so you can choose the right pump. Do you need a lot of low temperature water for domestic supply or do you need less at a higher temperature for solar cooling[2]**.**

7. **Solar Rediation**

Solar radiation provides a positive relationship with temperature changes in the solar collector. The temperature inside the solar collector is strongly influenced by solar energy.

Chapter 5

Experimental and Constructional Details of the Setup

5. Experimental and Constructional Details of the Setup:

The Computer Controlled Thermal Solar Energy Unit, is a system that transforms solar energy into usable thermal energy. It uses the thermosiphon solar system to heat water or the traditional pumping system. In both cases, the absorbed thermal energy is given by the simulated solar radiation; in our case, it is done using a panel with powerful luminous sources. As showed in the Figure 5.1

The EESTC unit mainly consists of the following elements:

- Thermal solar collector.
- Accumulator tank.
- Solar simulator.
- Pumping system.

The solar collector is mounted on an aluminum frame and the fluid (water) flows through cooper tubes. It has been developed in such a way that the geometrical shape of the surface allows the most efficient absorption.

The accumulator tank is protected with an anti-corrosive material. It has a computer controlled heating element with a safety device to prevent over-temperatures.

Lamps of the solar simulator emit radiation similar to the sun radiation, which is measured by a radiation sensor. The light is converted into heat in the solar collector and transferred to the heat transfer fluid. Three different configurations can be simulated with the solar simulator: all the lamps are turned on, half of the lamps are turned on in zigzag, or only one lamp is turned on.

Besides, the unit includes a computer controlled pump to perform a forced convection of the heat transfer fluid through the accumulator tank.

The unit is fitted with sensors and meters to record the relevant parameters (temperature, flow and radiation) and are included safety valves for overpressure protection.

This Computer Controlled Unit is supplied with the EDIBON Computer Control System (SCADA), and includes: The unit itself and a Control Interface Box a Data Acquisition Board and Computer Control, Data Acquisition and Data Management

Software Packages, for controlling the process and all parameters involved in the process**.**

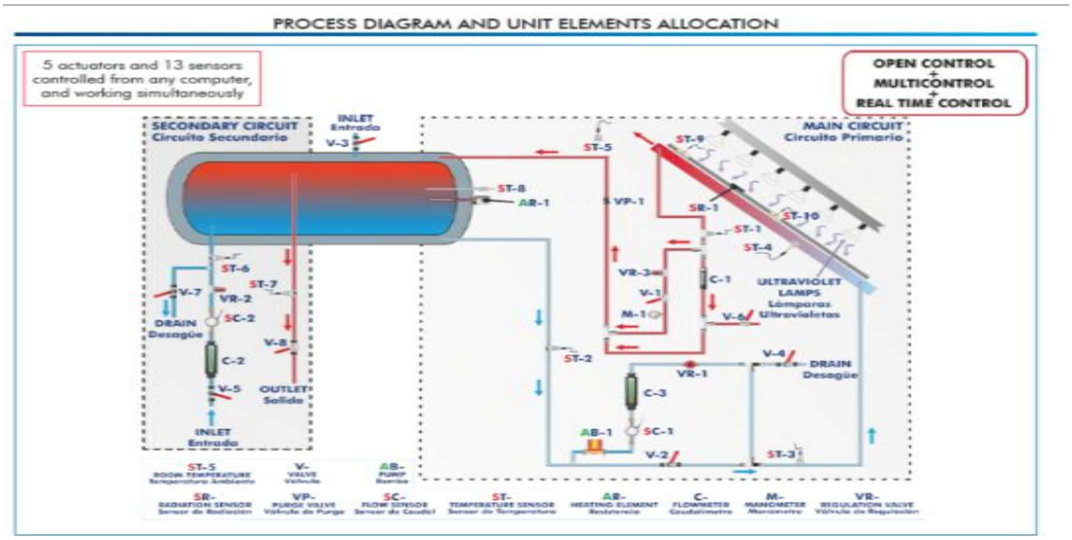

Figure 5.1: EESTC

The EESTC is a system built to transform solar energy into thermal energy.

Practical possibilities:

1.Study of the thermosiphon operation

2- Study of the lamp luminosity profile

3- Study of the output of the solar panels

4- Free circulation: influence of the tilt angle on the efficiency of the unit

5- Relationship between flow and temperature

6- Energy balance of the solar panel

7- Experimental study of the output

8- Influence of the angle of incidence on the temperature

9- Energy balance in the accumulation tank.

Solar simulator. (Lamps)

Aluminium frame with adjustable height.

Sixteen ultraviolet lamps of 300W each.

Control interface or console, depending on the mode

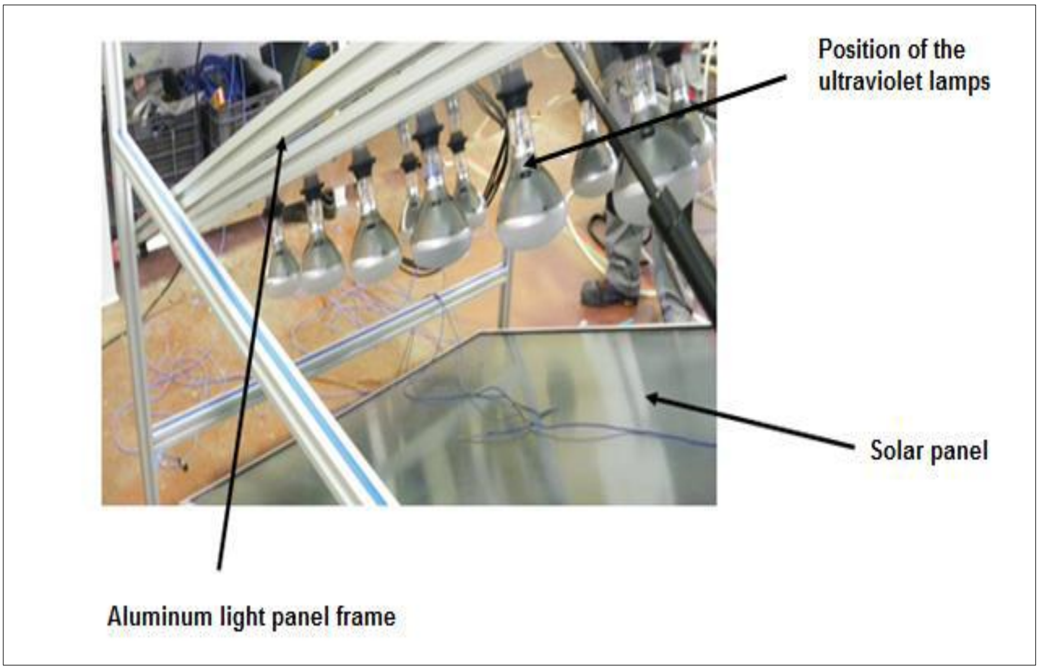

Figure 5.2 Solar Simulator

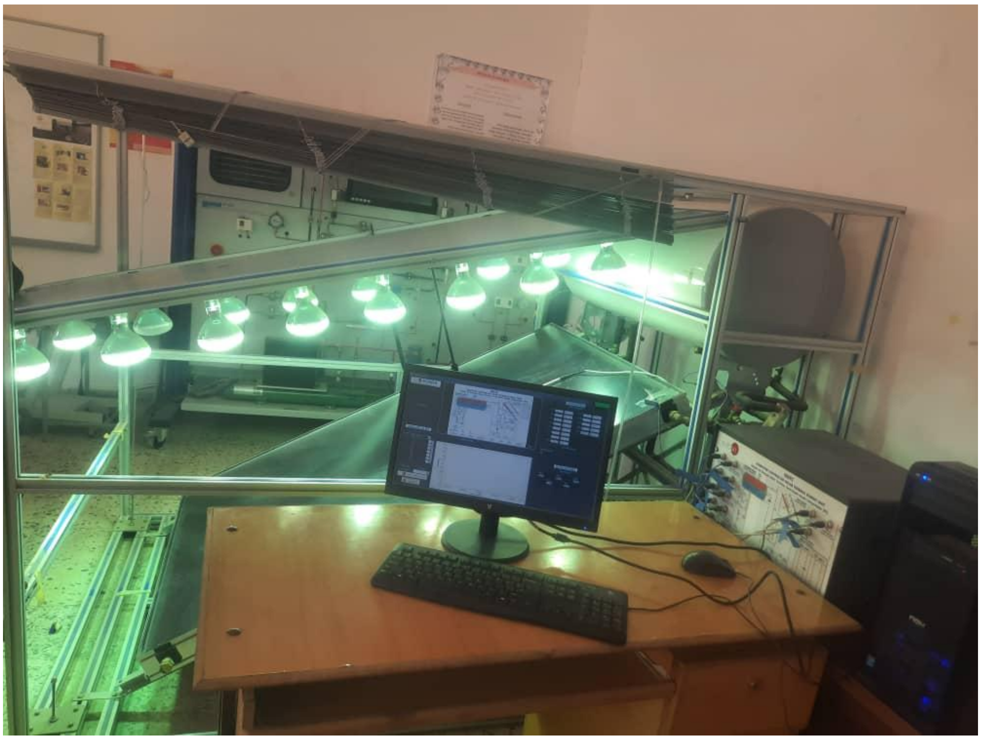

Figure 5.3 EESTC

The Computer Controlled Thermal Solar Energy Unit, "EESTC", is a system that transforms solar energy into usable thermal energy

Figure 5.4 Absorber, sensors Using solarimeter, To measure the intensity of radiation

Figure 5.5 Flow rate measuring

finely control and regulate water flow and pressure. The precision is achieved through the fine movement of the shaft,

Practical procedure of experimental:

Place the lamps panel parallel to the solar collector, adjusting the height of the panel with the height regulators, so that the lamps panel and the solar collector are parallel to each other. This process must be very carefully executed, so none of the lamps are damaged. Turn on a line of lights and write down the temperatures of the primary circuit, as well as of the solar collector. Than Check that when it reaches a certain temperature, the water of the primary circuit starts to circulate by itself and transfers heat to the accumulator. Write down the temperature, and flow values during regular intervals of time. Perform the same practical exercise with all the lights on. Than calculate the efficiency

$\eta = \dot{m} * C_p(T_o - T_i)/(A*I)$

Ta=34C°   Solar radiation. = 400W/m²   A=2 m^2 C_p= 4190 J/Kg.K

Table 5.1: Solar radiation. = 400W/m²

Mass flow m³/min	T_{out} C°	$T_{out} - T_{in}$ C°	Efficiency η
0.015	**37**	**3**	**23**
0.02	**37**	**3**	**31.4**
0.026	**37.2**	**3.2**	**43.5**
0.03	**36.2**	**2.2**	**34.5**

As shown in figure 5.6: The relationship between flow rate and efficiency, as the flow rate increases, the efficiency increases to 0.026. We notice a decrease in efficiency as a result of reducing the efficiency of the device and the value of the solar radiation on used.

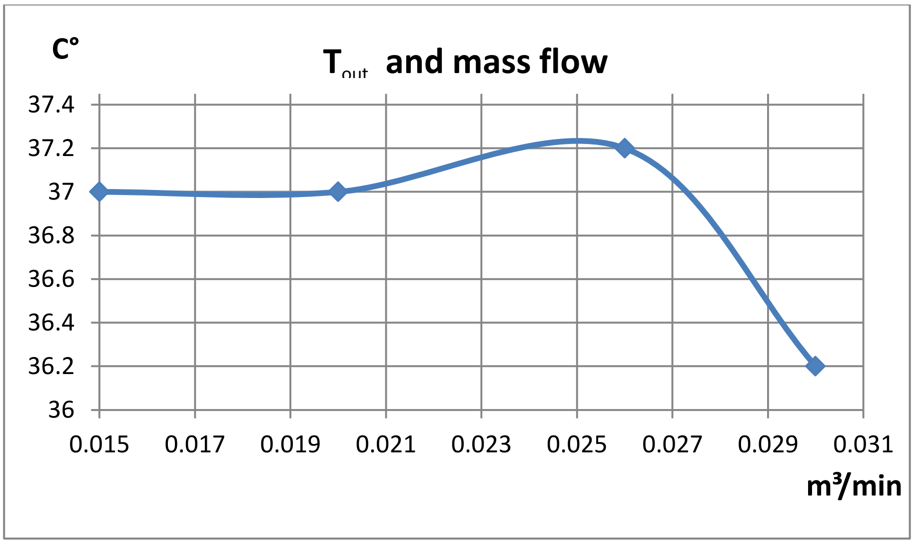

Figure 5.6: T_{out} and mass flow

As shown in figure **5.7:** The relationship between (the difference between the inlet and outlet temperatures) and the flow rate of the fluid, whereby when the value of the flow rate reaches 2.6, the two temperatures begin to decrease as a result of the capacity limit of the solar collector.

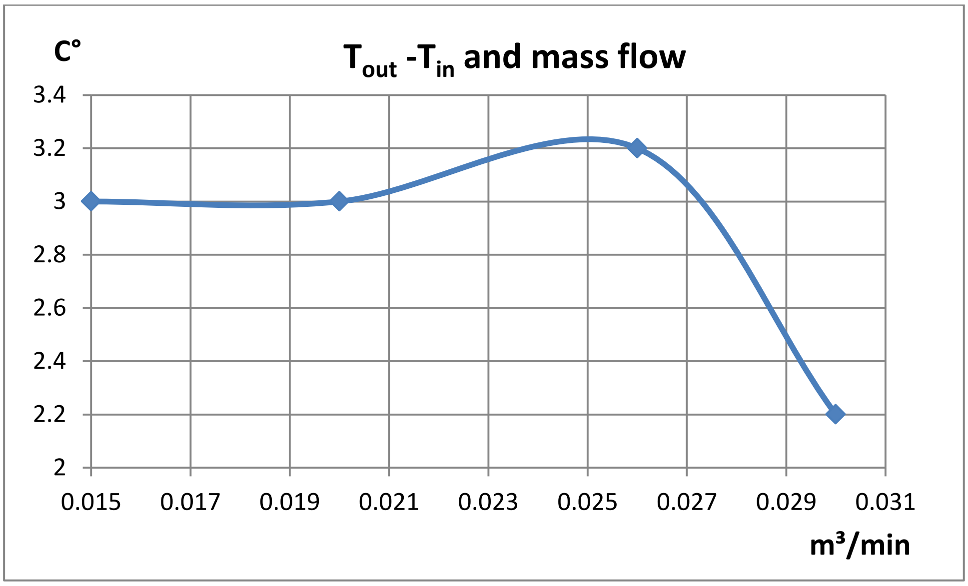

Figure 5.7: T_{out} -T_{in} and mass flow

As shown in figure **5.8:** The relationship between outlet temperature and flow rate, We notice from the curve that as the flow rate increases, the outlet temperature increases, until we reach a certain flow rate of 2.6. The outlet temperature begins to decrease as a result of the solar collector not absorbing thermal energy, and this is normal because the solar collector has a limited capacity.

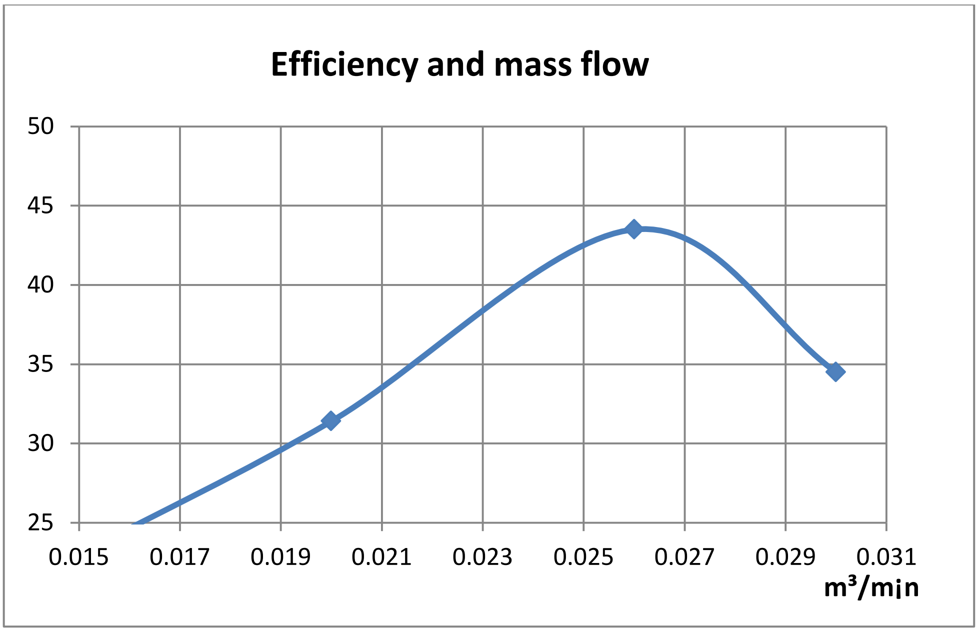

Figure 5.8: Efficiency and mass flow

$\eta = \dot{m} * C_p (T_o - T_i)/(A * I)$

C° **T_a=34Mass flow rate =0.026 m³/min C_p=4190 J/Kg.K**

A=2 m^2

Table 5.2: Mass flow rate =0.026 m³/min

Solar radiation W/m²	T_{out} - T_{in} C°	T_{out} C°	Efficiency
100	0.4	34.4	21.0
150	0.8	34.8	29.0
200	1.1	35.1	30.0
250	1.4	35.4	30.5
300	1.9	35.9	34.5
350	2.4	36.4	37.0
400	3.0	37.0	40.0

As shown in figure **5.9:** The relationship between solar radiation and efficiency. At 400 solar radiation, we notice that the greater the radiation, the greater the efficiency, and this is based on the direct relationship.

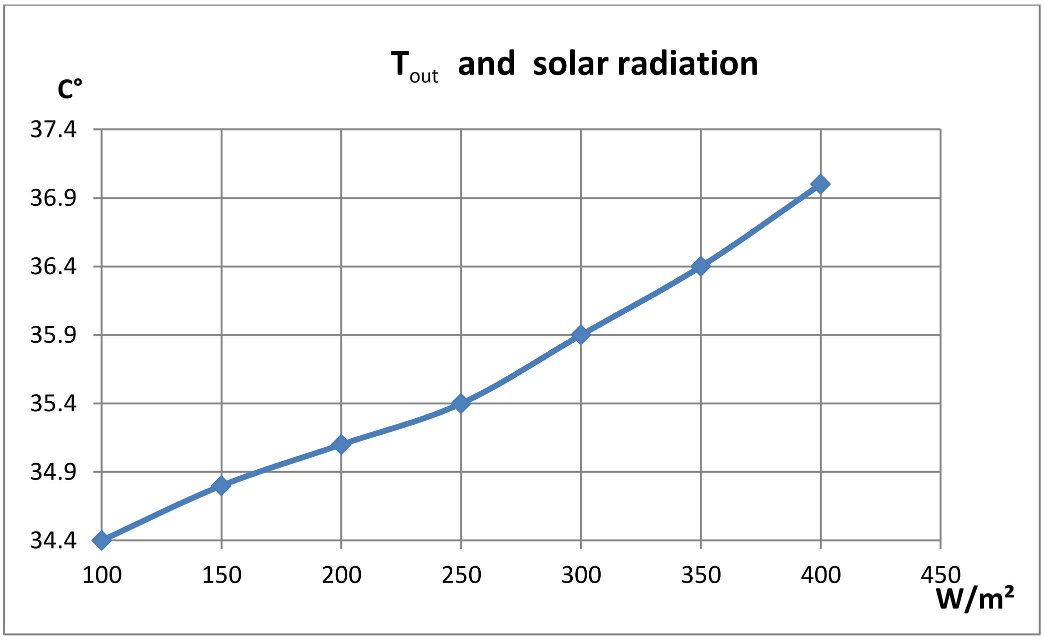

Figure 5.9: T_{out} and solar radiation

As shown in figure **5.10:** The relationship between solar radiation and (difference between inlet and outlet temperatures) and as we notice, both sides increase, this is due to natural conditions.

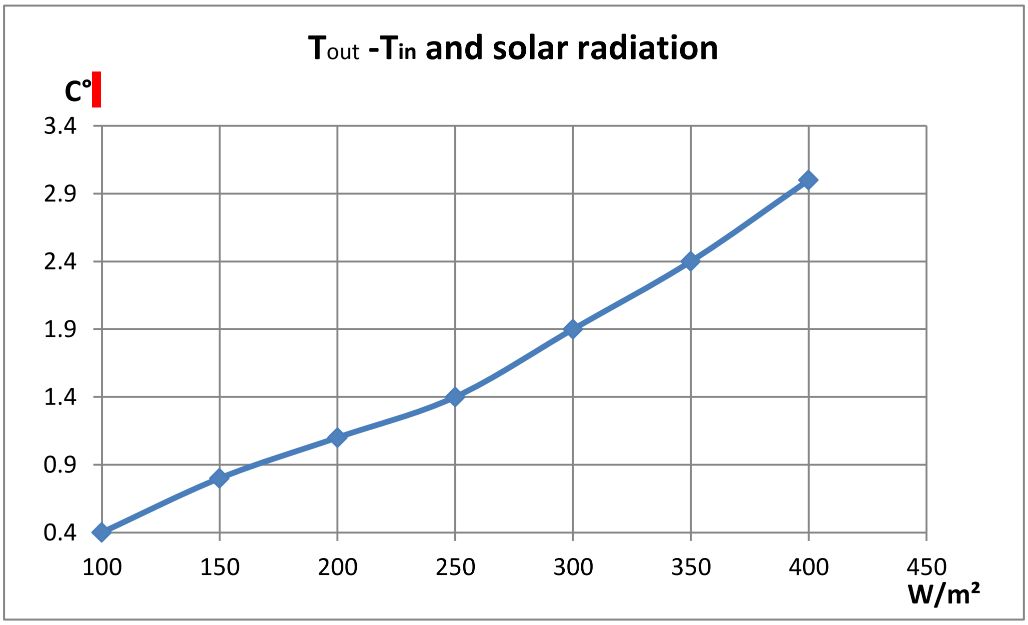

Figure 5.10: T_{out} -T_{in} and solar radiation

As shown in figure **5.11:** We note the relationship between outdoor temperature and solar radiation

. The increase in the value of both parties, and this degrades the direct relationship

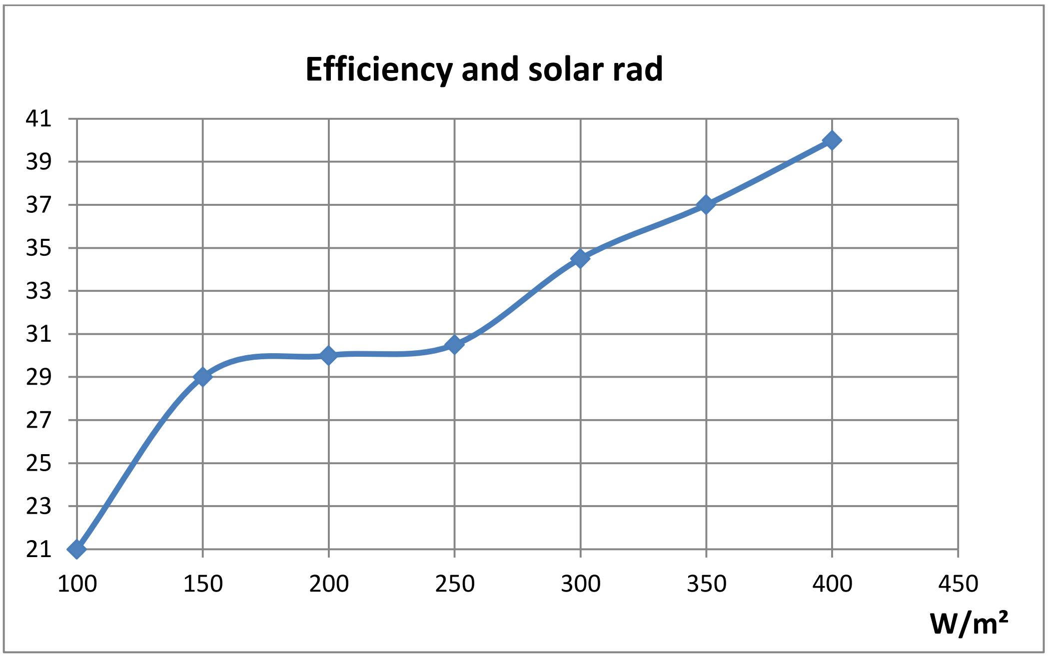

Figure 5.11: Efficiency and solar radiation

The thermal efficiency of the solar water heater has been studied experimentally by Computer Controlled Thermal Solar Energy Unit, "EESTC". This study is done to measure the performance of the solar water heater of thermal energy capability,

The optimal flow rate is determined in order to reach the maximum efficiency is 0.026 m/min.

Conclusion:

The Experimental measurements indicate that the water in the tank was heated by the solarimeter to absorbed by the solar collector. Moreover, the water temperature measurements at different points. Solar water heating utilizing thermosiphon is attractive, because it eliminates the need for a circulating pump. Results indicate that the design of the thermosiphon solar water heating system was a success. Furthermore, the experimental apparatus described in this project is a valuable addition to the laboratory. The experimental apparatus is portable, and it can be used as an instructional experimental apparatus for demonstrating basic heat transfer principles and thermo-siphon concept

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