Evaluating the Performance of Solar Water Heating System

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Abstract- Applications of solar energy for domestic and industrial meeting purposes have been become very popular. However the effectiveness of presently used fixed flat plate collectors is low due to the moving nature of energy source. In the present work, and attempt has been made to evaluate the performance of the fixed flat plate solar water heating system by conducting experiments.

A flat plate water heater, is commercially available with a capacity of 100 liters per 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 were collected on fixed conditions for flat plate collector. The efficiency of solar water heating system was calculated at different mass flow rates and intensities. And the comparison shows that, there is an increase or decrease of efficiency with mass flow rates, intensities, useful heat gain, differences in temperatures.

Keywords – Declination angle, Hour angle, Day length, extra terrestrial irradiation

I. INTRODUCTION

RENEWABLE ENERGY SOURCES:

In countries like India most of the energy demand is meet by conventional energy sources which includes fossil fuels like coal, oil and natural gas. The increasing demand for supply of energy has put stress on existing fossil fuels which are depleting at fast rate on worldwide basis. This has led to the fear of exhaustion of these energy sources in the present century itself. Due to this the cost of the fossil fuels are also increasing day to day and these fuels also emitting large amount of harmful gases into the atmosphere which are affecting the environment.

The low generation capacity of the grid connected systems, especially in developing countries, and the load demand results in frequent power cuts. This has necessitated an urgent search for alternative energy sources (non-conventional energy sources) such as solar photovoltaic, wind energy, bio-mass, geo -thermal, hydropower, tidal energy etc.

The advantages of Renewable energy sources are:

(i) They do not pollute the atmosphere.
(ii) They are available in large quantities.
(iii) They are well suited for decentralized use.
(iv) They are non-depleting.

The non-conventional energy sources prove to be more advantageous in remote areas. One such energy source is the sun. The earth receives large amount of solar energy throughout the year.

The energy generated by the sun in the form of radiations can be converted directly or in-directly into other forms of energy such as heat and electricity.

SOLAR ENERGY:

The power from the sun intercepted by the earth is approximately 1.8 x 10 ^{11}MW, which are many thousands of time 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 Non-conventional energy sources.

The solar power where sun hits the atmosphere is 10^{17} watts, while the solar power on earth's surface is 10^{16}watts. The total worldwide power demand of all needs of civilization is 10^{13} watts. Therefore Sun gives 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times more power than world will require. Utilization of solar energy is of greater importance to India since it lies in a temperature climate of the region of the world where sun light is abundant for a major part of the year.

SOLAR ENERGY TECHNOLOGIES:

The solar energy generated by the sun in the form of radiations can be converted directly or in-directly into other forms of energy such as heat and electricity.

The solar energy technologies are classified as:

- Solar Thermal Technology
- Solar Photovoltaic Technology

SOLAR COLLECTORS:

Solar thermal technologies convert radiant energy from the sun to thermal energy. When the radiation strikes the surface, it is absorbed and transferred in to heat energy. This heat energy may be used to warm the water or air which is in contact with heated surface or circulated through it. Solar thermal technologies include a wide variety of devices to collect and absorb the sun's radiation.

TYPES OF SOLAR COLLECTORS:

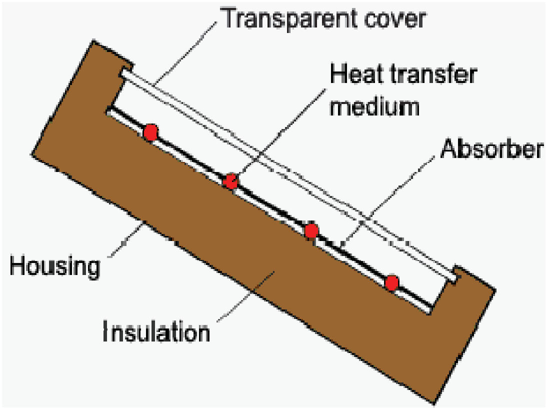
A wide variety of collectors are used in solar thermal conversion. They may be classified as,

1. Flat plate collectors(non-concentrating type)
    a) Liquid collector
    b) Air collector(solar air heater)
2. Concentrating collectors
    a) Focusing type:
        (i) Line focusing or cylindrical parabolic
        (ii) Point-focusing or parabolic (Dish type)
    b) Non-focusing type:
        (i) Flat plate collector with adjustable mirror

FLAT PLATE COLLECTORS:

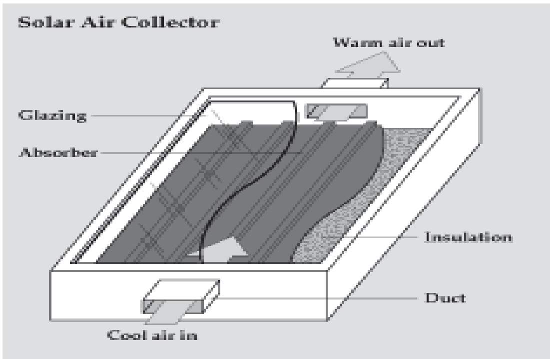
Flat plate collectors are used for low temperature services such as space heating and water heating. Flat plate collector is usually faced in the direction of sun and at some fixed angle of tilt from the horizontal. They are made in rectangular panel of about 1 to 2.9 sq.m. area. Flat plates can collect and absorb both direct and scattered solar radiation.

WATER TYPE COLLECTOR:



The radiation from the sun incident on transparent covers. They allow solar energy to reach the absorber plate and reduce the heat loss from the absorber. The absorber plate is usually made with copper, aluminum and coated with a black coke powder to enhance the absorption of radiation. The black surface absorbs the maximum radiation and plate heats up and in turns heats a fluid flowing through tubes which is an integrated part of the plate. The components of a collector are enclosed in a casing which is thermally insulated to prevent loss of heat from the absorber and fluid.

AIR FLAT PLATE COLLECTOR:

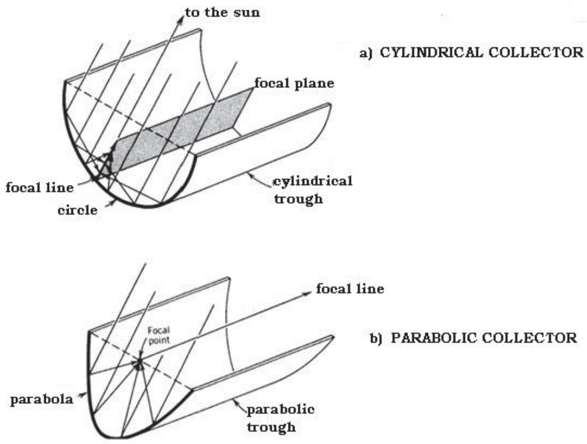


The conventional solar air heater consists of absorbing plate which is blackened to absorb more radiation. One or two absorbing plates are located above the absorbing surface. The radiation falling on transparent plates is allowed to reach the absorbing plate and absorbing plate heated up. The air flowing through the passage below the absorbing plate is heated to a required temperature. The insulation is provided at the bottom and besides the unit to minimize the heat loss.

CONCENTRATING COLLECTORS:

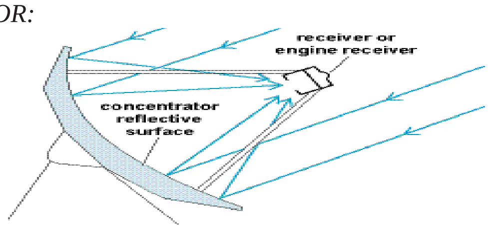
Concentrating collectors use optical system and can heat the fluids. They concentrate only direct radiation coming from a specified direction. Concentrating focusing collectors may be designed in two categories:

LINE FOCUSING COLLECTORS:



The solar radiation coming from a particular direction is collected over the area of the reflecting surface and is concentrated at the focus, F of parabola. Mostly cylindrical parabolic concentrators are used in which absorber is placed along the focus axis. It consists of a movable parabolic cylindrical mirror that focuses the direct radiation on a receiver tube. The receiver tube is located along the axis of the collector. The mirror rotates about its longitudinal axis, tracking the sun throughout the day. The solar energy focused on the receiver tube heats a fluid. A steam generator uses heat from the reservoir working fluid to generate steam for a steam turbine.

POINT FOCUSING COLLECTOR:



It consists of a reflecting parabolic dish of about 6.6 m diameter that tracks the sun, redirecting and concentrating the solar radiation on a receiver at the dish's focal point. The absorber located at the focus is a cavity made of a zirconium-copper alloy with the block chrome selective coating. In the receiver or absorber heat is absorbed by a working fluid. The fluid may be supplied to a power generating unit.

PERFORMANCE EVALUATION AND EXPERIMENTAL SETUP

ESTIMATING SOLAR RADIATION:

Flat plate systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day. So it is important to find the solar radiation following on the array surface and the actual output of a solar power varies substantial.

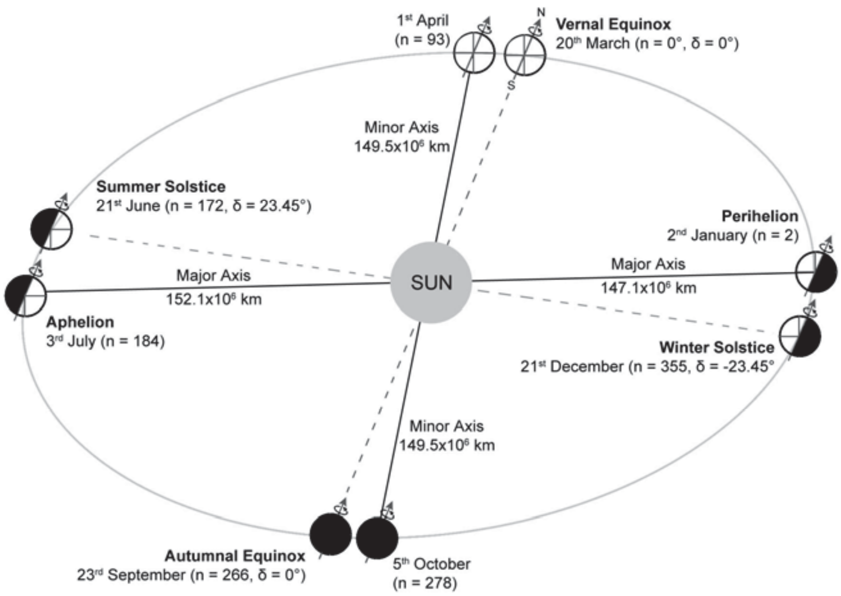
Before going in the details of solar radiation calculations we have to know about the sun, earth and the seasons.

SUN, EARTH, SEASONS:

Sun is a large sphere of very hot gases the heat being generated by various kinds of fusion reactions. Its diameter is 1.39e6 km while the earth is 1.27e4 km. the mean distance between the two is 1.50e8 km. The surface of the earth receives from the sun about 10e14 kW of solar energy which is approximately five times orders of magnitude greater than currently being consumed from all resources. It is evident that sun will last for 10e10 years. Even though the sunlight is filtered by atmosphere one square meter of land exposed to direct sunlight receives the energy equivalent of about 1 kW.

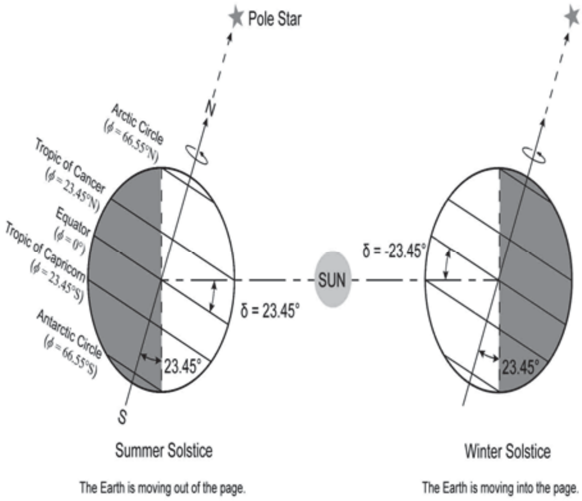
The Earth is an obligated sphere, meaning that it is a sphere that is flattened at the poles and bulges around the equator. For solar power calculations it is sufficient to treat the Earth as a simple sphere with a diameter of approximately 12,700 km. Points on the Earth's surface are defined in terms of longitude and latitude.

The axis of rotation is tilted at an angle of 23.45° with respect to the plane of the orbit around the Sun. The axis is orientated so that it always points towards the Pole Star and this accounts for the seasons and changes in the length of day throughout the year. The angle between the equatorial plane and a line joining the centers of the Sun and the Earth is called the declination angle (δ). Because the axis of the Earth's rotation is always pointing to the Pole Star the declination angle changes as the Earth orbits the Sun.

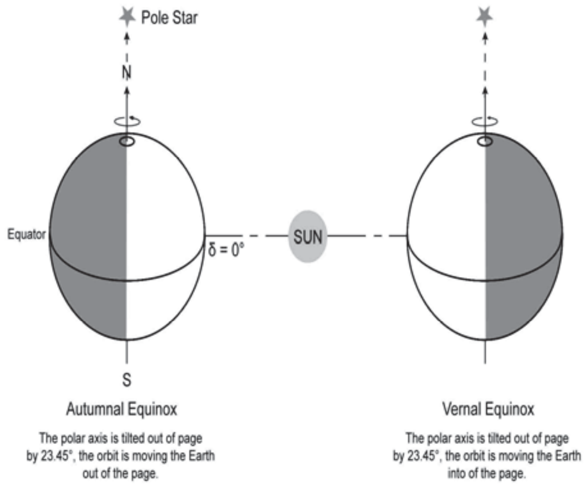


THE ORBIT OF THE EARTH AROUND THE SUN: N IS THE DAY NUMBER, WHERE ON THE 1ST JANUARY N = 1; IS THE DECLINATION ANGLE.

All points on earth ‘s surface north of 66.55°N latitude are in total darkness while all regions within 23.24° south pole receive continuous sunlight. At the time of summer solstice, the situation is reversed. At the time of two equinoxes, both poles are equidistance from the sun and all points on the earth’s surface have 12 hours of daylight and 12 hours of darkness. The sun’s ray passing through the centre of the earth lies in the equatorial plane at the time of equinoxes. From vernal equinoxes to autumnal equinoxes, the ray lies north of the equatorial plane. From autumnal equinoxes to vernal equinoxes, the ray lie south of the equatorial plane. The average direction of the sun’s rays from the entire year lies in the equatorial plane. Accordingly to intercept maximum amount of solar energy over the whole year, a solar collector in the northern hemisphere should be tilted and face due south.



THE SUMMER AND WINTER SOLSTICES. IS THE DECLINATION ANGLE AND V IS THE LATITUDE.



THE AUTUMNAL AND VERNAL WINTER SOLSTICES

SOLAR CONSTANT:

The Solar Constant (I_{SC}) is defined as the rate at which solar energy arrives at the top of the atmosphere.

Because of the sun's distance and activity vary throughout the year; the rate of arrival of solar radiation varies accordingly. The so called solar constant is thus an average from which the actual values vary about 3 % in either direction.

The distance between the earth and sun varies a little throughout the year. Because of this variation, the extraterrestrial flux also varies.

The solar radiation intensity falling on a surface is called irradiance and is measured in W/m^2 or kW/m^2. The solar constant can be used to calculate the irradiance incident on a surface perpendicular to the Sun's rays outside and the Earth's atmosphere on any day of the year (i.e. as the distance between the Sun and Earth changes thought the year):

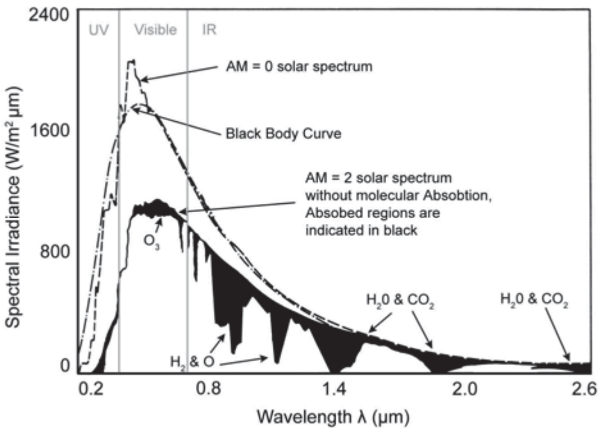
$$I_0 = I_{SC}\left[1 + 0.034\cos\left(2\pi\frac{n}{365.25}\right)\right] \rightarrow(1)$$

Where,
I_0 = extraterrestrial (outside the atmosphere) irradiance on a plane perpendicular to the Sun's rays (W/m^2),
I_{SC} = The solar constant is the average extraterrestrial irradiance at the edge of the atmosphere
I_{SC} = 1367 W/m^2
n = the day of the year such that for 1st January, n = 1.
Figure 4.4 shows the variation in I_0 over the course of a year. Most solar power calculations use I_0 as a starting point because, for any given day of the year it is the maximum possible energy obtainable from the Sun at the edge of the Earth's atmosphere.

SOLAR RADIATION AT EARTH'S SURFACE:

From the point of utilization of solar energy we are more interested in the energy received in the earth's surface than in the extra terrestrial energy. Solar energy received at the surface is entirely different due to absorption and scattering in atmosphere.

The atmosphere scatters and absorbs some of the Sun's energy that is incident on the Earth's surface. Scattering of radiation by gaseous molecules (e.g. O_2, O_3, H_2O and CO_2), that are a lot smaller than the wavelengths of the radiation, is called Rayleigh scattering. Roughly half of the radiation that is scattered is lost to outer space; the remaining half is directed towards the Earth's surface from all directions as diffuse radiation. Because of absorption by oxygen and ozone molecules the shortest wavelength that reaches the Earth's surface is approximately 0.29 µm. Other gas molecules absorbed difference wavelengths as indicated in figure



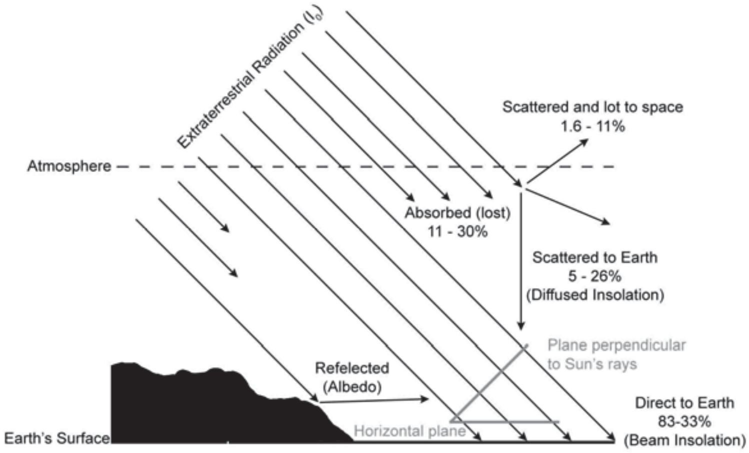
THE EXTRATERRESTRIAL SOLAR SPECTRUM (AM=0 SOLAR SRECTRUM), THE THEORETICAL BLACK BODY CURVE AND THE SOLAR SPECTRUM AT THE EARTH'S SURFACE FOR AM = 2 AND THE ABSORBED REGIONS SHOWN IN BLACK.

Scattering by dust particles larger than wavelengths of light is called Mie scattering. This process includes both true scattering (where the radiation bounces of the particle) and absorption followed by emission, which heats the particles. The amount of radiation scattered by this process will vary a lot depending on location and the weather blowing particles about. A form of Mie scattering called the Tyndall effect, that preferentially scatters shorter wavelengths is responsible for the sky being blue.

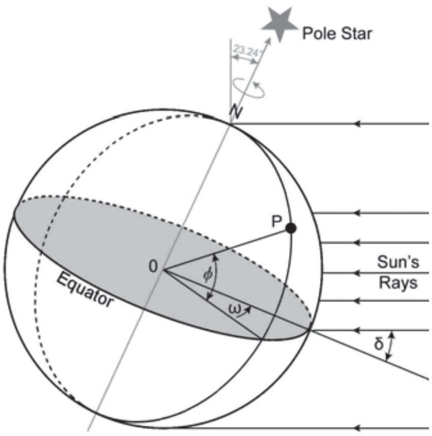
Clouds reflect a lot of radiation and also absorbed a little, the rest is transmitted through. Globally, clouds reflect a lot of radiation and help regulate the surface temperature.

The fraction of the total solar radiant energy reflected back to space from clouds, scattering and reflection from the Earth's surface is called the albedo of the Earth-atmosphere system and is roughly 0.3 for the Earth as a whole. Beam (or direct) radiation – coming straight through the atmosphere to hit the plane (very directional);

- Diffused radiation – scattered in all direction in the atmosphere and then some arrives at the plane on the earth's surface (not directional);
- Reflected radiation – beam and diffused radiation that hits the earth's surface and is reflected onto the plane.



The effect of the atmosphere on the solar radiation reaching the Earth's Surface.



THE DECLINATION ANGLE (□), LATITUDE (Φ) AND HOUR ANGLE (Ω) FOR POINT P.

SOLAR RADIATION GEOMETRY:

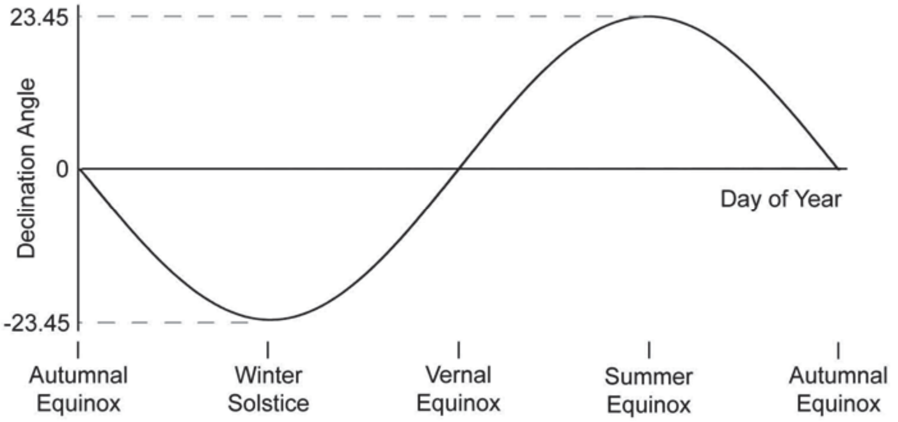
The position of the Sun in the sky as viewed from any point on the earth's surface can be defined using a variety of angles. The declination angle (δ) and the hour angle (ω) most easily defined from a view looking back at the Earth.

Declination Angle (δ): is the angle between the equatorial plane and a line joining the centre of the Sun and the Earth is called the declination angle (δ) and is the same for the whole Earth on any particular day.

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \quad \rightarrow(2)$$

Where:
δ = declination angle;

n = the day number, such that n = 1 on the 1st January.



THE VARIATION IN THE DECLINATION ANGLE THROUGHOUT THE YEAR.

The hour angle (ω): At a point P on the Earth's surface is the angle between the meridian containing point P and the meridian that is parallel to the Sun's rays. The hour angle is negative during the morning, reduces to zero at solar noon (when point P faces the Sun) and becomes increasingly positive as the afternoon progresses. Note that hour angle at any particular time is the same for all points on any particular meridian (i.e. points with the same longitude). Since the Earth completes one revolution every 24 hours, the hour angle changes by (360/15) 15° every hour.

$$\omega = (12\text{-}LST)*15^{o}$$

where, LST=Local Standard Time

The hour angles at sunrise and sunset (ω_S) are very useful quantities to know. Numerically these two values have the same value however the sunrise angle is negative and the sunset angle is positive. Both can be calculated from:

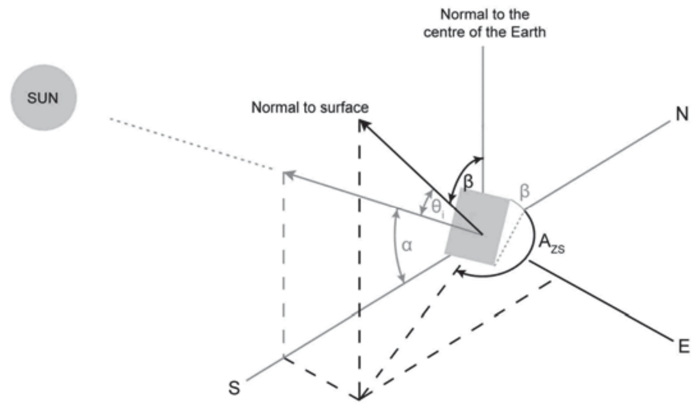
$$\cos \omega_S = - \tan \Phi \tan \delta$$

Day length: $N= 2\omega_S/ 15$

If a surface is tilted from the horizontal the Sun may rise over its edge after it has rise over the horizon. Therefore the surface may shade itself for some of the day. The sunrise and sunset angles for a titled surface (ω_S') facing the equator (i.e. facing due south in the northern hemisphere) are given by:

$$\cos \omega_S' = - \tan (\Phi-\beta) \tan \delta$$

where, β = the angle of inclination of the surface from the horizontal.



A TILTED SURFACE THAT IS NOT FACING THE EQUATOR.

ESTIMATION OF AVERAGE SOLAR RADIATION:

Calculate the irradiance intensity on a plane perpendicular to sun rays (I_0) on the edge of the atmosphere by correcting I_{SC} for Earth's elliptical orbit.

$$I_0 = I_{SC}\left[1 + 0.034\cos\left(2\pi\frac{n}{365.25}\right)\right] \qquad (W/m^2) \quad (1)$$

Calculate the extraterrestrial irradiance on a plane horizontal to the Earth's surface (I_{0h}) at the site's latitude.

$$I_{0h} = I_0 \cos\theta_Z \qquad (W/m^2)$$

Where, $\cos\theta_Z = \cos\delta \cos\Phi \cos\omega + \sin\delta \sin\Phi$

And,

$$\delta = 23.45\sin\left(2\pi\frac{284+n}{365}\right) \qquad (2)$$

$$I_0 = I_{SC}\left[1 + 0.034\cos\left(2\pi\frac{n}{365.25}\right)\right](\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta) \qquad (3) \quad (W/m^2)$$

To find the extraterrestrial irradiation energy falling on a plane horizontal to the Earth's surface throughout a whole day, integrate equation 3 with respect to time between sunrise ($\omega = -\omega_S$) and sunset ($\omega = \omega_S$). The resulting equation is:

$$H_{0h} = \frac{24}{\pi} I_{SC}\left[1 + 0.034\cos\left(2\pi\frac{n}{365.25}\right)\right](\cos\phi\cos\delta\sin\omega_S + \omega_S\sin\phi\sin\delta) \; (W/m^2)$$

Where,

$$\cos\omega_S = -\tan\phi\tan\delta$$

Monthly Average Daily Global Solar Radiation (H_g): is given by

$H_g = H_{oh}\,(a + b(S/S_{max}))$ (W/m^2)

H_{oh} = extraterrestrial irradiation energy falling on a plane horizontal

S = average daily hours of bright sunshine

S_{max} = maximum daily hours of bright sunshine

a,b are constants which depends upon the location

a = 0.352 cos Φ√P/Po

b = 0.3 (√P/Po)

√sin Φ

Where, Φ = latitude angle

P/Po = exp (-0.0001184*h)

h= altitude of the location

Monthly Average Daily Diffuse Solar Radiation (H_d): is given by

$H_d/H_g = 1.411 - 1.696 * H_g/H_{oh}$

Monthly Average Hourly Global Solar Radiation (I_g):

$I_g/H_g = I_o/H_{oh}*(a' + b' \cos\omega)$

$a' = 0.409 + 0.5016 \sin(\omega_{S-60})$

$b' = 0.6609 - 0.4767 \sin(\omega_{S-60})$

I_g = monthly average of hourly global radiation on horizontal surface (kW/m^2)

I_o = monthly average of hourly extra-terrestrial radiation on horizontal surface (kW/m^2)

Monthly Average Hourly Diffuse Solar Radiation (I_d): $I_d = I_o*H_d/H_{oh}$

Absorber Coating	Selectively Coated Continuous Electroplating of Black Chrome over nickel substrate on Copper sheet of 0.2mm thickness with heat treatment to withstand temperature up to 300^o c
ptical Properties	Absorptive = 0.92±0.02, Emissivity = 0.12± 0.02
Riser Tubes	Copper tube of diameter 12.5mm ± 0.5 mm, thickness 0.56 mm
Header Tubes	Copper tube of diameter 25mm ±0.5mm, thickness 0.71 mm
Bonding Between Riser & Header	Brazing
Bonding between Fin & Tube	Ultrasonic / Laser Welding
Back Insulation	Resin bonded Rock wool of $48/m^3$
Collector Box	100mm X 25mm Aluminum channel, Thickness 1.63mm
Collector Stand	Corrosion resistant Coated MS
Glazing	Toughened glass, Thickness 4mm with low Iron Transitivity> 85% @ near normal incidence
Retainer Angle for Glass	Aluminum Angle , size 25mmX 25mm X1.6mm
Beading for Glass	EPDM Rubber
Absorber Area	2sq. meter ± 0.2 sq. meter / Collector
Collector Tilt	24.5^o to HORIZON for places Located between 12^o North and 15^o South
Heat Transfer Medium	Water
Collector Area	2.03 sq meter
Number of Fins	9
Maximum Working Pressure	245 kpa(5 to 6 kg)
Dimensions	Length -2030mm, Breadth -1030mm, Height -100mm

SOLAR RADIATION ON TILTED SURFACE:

The total flux incident on a tilted surface has 3 components that is, beam component, diffused component and reflected component. These three components calculate the total flux incident on tilted surfaces in terms of horizontal surface flux.

Beam Radiation (r_b):

The ratio of the beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the tilt factor for beam radiation. It is denoted by the symbol (r_b).

$r_b = \cos\theta_i/\cos\theta_z = (\cos\delta \cos(\Phi-\beta) \cos\omega + \sin\delta \sin(\Phi-\beta))/ \cos\delta \cos\Phi \cos\omega + \sin\delta \sin\Phi$

Diffuse Radiation (r_d):

The tilt factor (r_d) for diffuse radiation is the ratio of the diffused flux on the tilted surface to that falling on horizontal surface.

$$r_d = \frac{1+\cos\beta}{2}$$

Reflected radiation (r_r):

The surrounding surface plays an important role for deciding the total flux on a tilted surface. Generally the reflectivity of the surrounding surface (ρ) is taken as 0.2 except snowy areas.

$$r_r = \frac{1-\cos\beta}{2} \times \rho$$

Flux on a Tilted Surface: The flux on a tilted surface at any instant is thus given by

$$I_t = (I_b * r_b)+(I_d * r_d)+(I_g * r_r)$$

CALCULATION OF EFFICIENCY:

Heat utilized = $m_w * Cp * (T_{out} - T_{in})$ KW
Velocity=length/time (m/sec)
Mass flow rate of water m_W = a*density*v(kg/s)
Inlet tank area (a)=$\pi/4*0.25^2=0.049$ m^2
Density of water=1000(kg/m^3)
Efficiency (η),

η = (useful energy required/energy collected from plate)

- T_1=Fluid inlet temperature, T_2=Fluid outlet temperature
- Where, radiation of incident energy = $A_p I_T$
- A_p = Collector area,
- I_T =Intensity of energy incident on the collector (W/m^2)

V. SOLAR WATER HEATING SYSTEM

SOLAR WATER HEATER:

Solar water heater is the most important of all low temperature solar energy applications. Solar water heater can be broadly classified into two types:

1) Natural circulation solar water heating
2) Forced circulation solar water heating

The reason behind using copper tube is its high conductivity i.e. 320W/mK.The glazing i.e. glass sheet is used to reduce reflection. The insulation is provided at the side walls and the bottom using glass wool whose conductivity is 0.04W/mK.The following tabular column shows the specifications of the panel.

NATURAL CIRCULATION SOLAR WATER HEATING:
CONSTRUCTION:
The following components of solar water heater are being used in natural convection:

1. Solar panel
2. Inlet and outlet tanks
3. Insulated pipes connecting collector & tanks

The main components of a flat plate solar collector are:

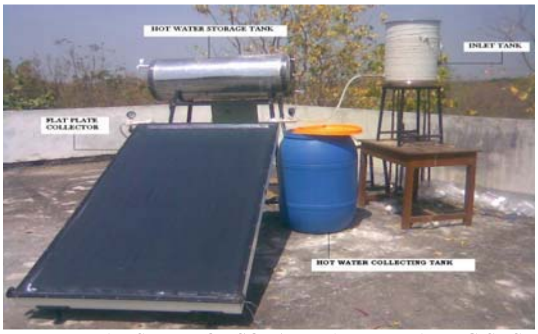
- **Absorber plate** made of any material, which will rapidly absorb heat from sun's rays and quickly transfer that heat to the tubes or fins attached in some manner, which produces good thermal bond.
- **Tubes or Fins** for conducting or directing the heat transfer fluid from the inlet header or duct to the outlet.
- **Glazing**, this may be one or more sheets of glass or a diathermanous plastic film or sheet.
- **Thermal insulation**, which minimizes the downward heat loss from the plate.
- **Cover strip**, to hold the other components in position and make it all water tight.
- **Casing**, which surrounds the foregoing components and keeps them free from dust, moisture etc.

In addition to the above components thermocouples are used for the measurement of temperature.

- The location of these thermocouples is chosen depending on the requirement and the locations are:

T_1=Fluid inlet temperature
T_2=Fluid outlet temperature
T_3=Glass temperature
T_4=Bottom surface temperature
T_5=Side surface temperature
T_6=Space between glass and bottom
T_7=Storage tank temperature

DATA LOGGER FOR MEASURING THE TEMPERATURES



EXPERIMENTAL SETUP OF SOLAR WATER HEATING SYSTEM

The setup is installed at an inclination of 18 ^{o} due north and the plate is installed at an inclination of 24.5 ^{o} with the horizontal. The device used for setting the direction is the magnetometer.

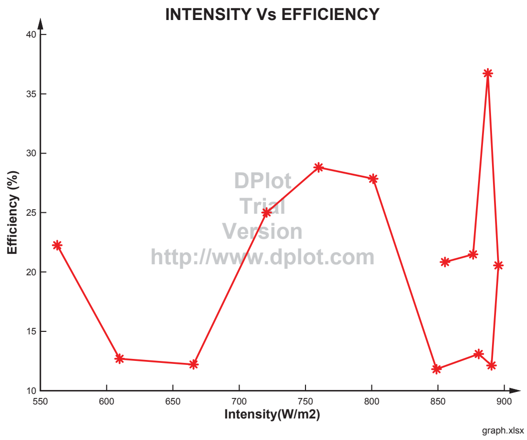
WORKING:

Experimental setup is shown in the above figure. It contains hot water storage tank, flat plate collector. Cold water from the over head tank enters the hot water storage tank. Water from the hot water storage tank enters the flat plate collector. Water gets heated in the risers of the flat plate collector and its density will decrease. The lighter density water move up and stored in the hot water storage tank. Higher density water from the bottom of the tank again enters the flat plate collector and gets heated and moves up and stored in the hot water storage tank and vice versa. Hot water can be drawn from the hot water storage tank for further applications.

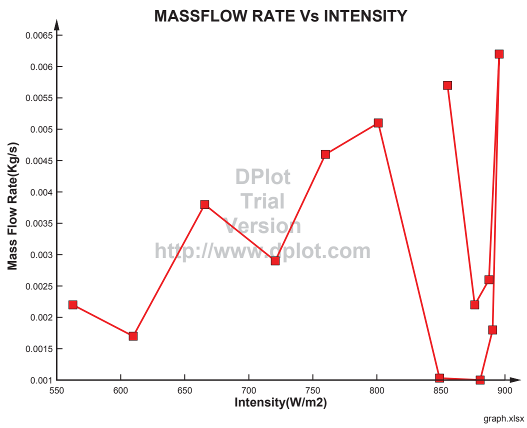
EXPERIMENTAL READINGS: Experimental readings of temperatures and respective flow rates are:

21st FEB, 2015/ Time	T_1 (^{O}C)	T_2 (^{O}C)	T_2-T_1 (^{O}C)	Mass Flow Rate (Kg/s)	Q_u (KW)	Intensity (W/m^2)	Efficiency (%)
11:00am	32.2	52.8	20.6	0.0057	0.493	855.23	20.84
11:15am	42.1	83	40.9	0.0022	0.382	876.43	21.48
11:30am	34.6	78.4	43.8	0.0026	0.459	887.57	36.73
12:10pm	36.9	83.2	46.3	0.0062	0.517	895.55	20.55
12:40pm	35.2	60.9	25.7	0.0018	0.373	890.37	12.13

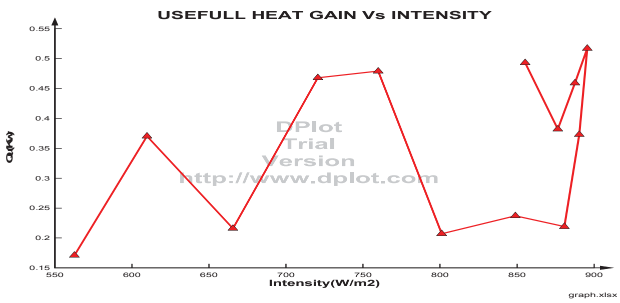
Experimental Investigations:



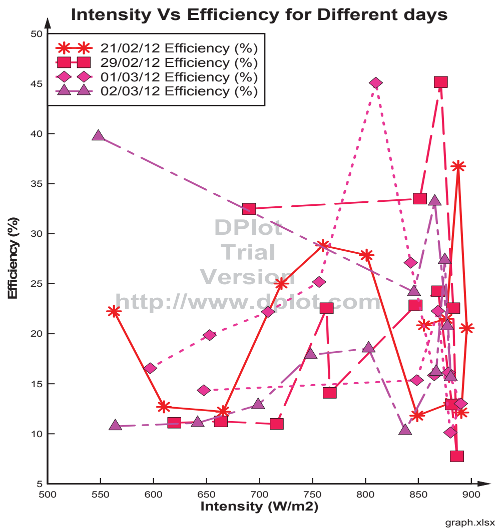
From the Intensity v_s Efficiency graph it is evident that the maximum efficiency 36% is obtained at an Intensity of 900 W/m^2.



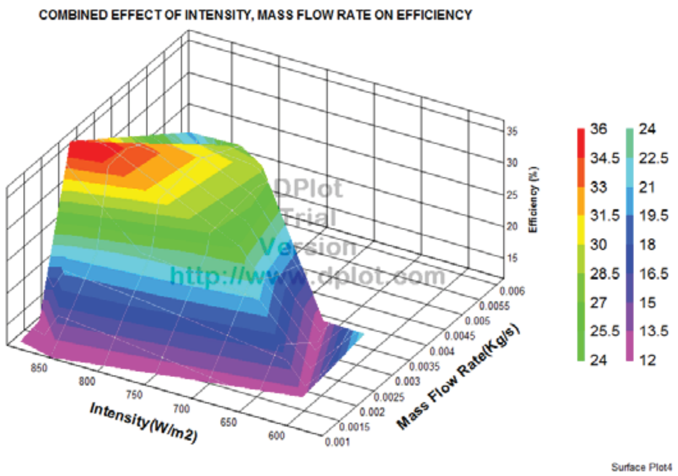
From the Mass flow rate v_s Intensity it is evident that the maximum mass flow rate is 0.0085kg/s is obtained at an intensity of $900W/m^2$.



From the Q_u v_s I_t graph it is evident that the maximum heat gain 0.52kw is obtained at an intensity of $900W/m^2$.



From the above graph the maximum efficiency is 45% on 29 feb 2012 at an intensity 870W/m^2.



The maximum efficiency is a factor of both intensity and mass flow rate.

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