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Design and Fabrication of Rotating Solar Collector

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Abstract – Rotating solar collectors are new types of concentrating collectors. It consists of two concentric tubes. The inner tube is called as Absorber Tube, which absorbs the solar energy and increase the temperature of the working medium or fluid. The outer tube is called as Cover, which is transparent and filled with air. The air acts as an insulation layer between the tubes. With the help of a prime mover (motor), the collector is rotated with speed of around 50-80 rpm, so as to prevent the heat transfer by convection in the insulating air layer between the absorber tube and the cover. These type of collectors can be used in power plants to increase the temperature of the feed water to boiler, so that the total coal consumption can be reduced thereby increasing the efficiency and saving the energy. This paper is the summary of the design and experimental work carried out on a rotating solar collector for domestic application.

Keywords - *Solar Collector, Convection, Absorber, Efficiency.*

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I. INTRODUCTION

As we know that the fossil fuel sources in the world are depleting day by day very fast and hence in the future, man has to rely on renewable energy sources. For developing countries like India, large demand of heat energy can be met by the utilization of non-conventional sources such as solar energy, wind energy, geothermal energy, biomass, tidal energy etc. The energy needs are going to increase significantly in the future. Keeping this fact in mind, it is absolutely necessary to make use of renewable energy sources. Out of all the non-conventional sources, solar energy has greatest potential. If a small amount of this form of energy can be used, it will be the biggest supplies of energy.

The applications of solar energy include Solar Water Heaters, Solar Drying, Solar Distillation, Solar Pumps, Solar Cookers, Solar Furnaces, Solar Photovoltaic Cells, Solar Steam Generators etc. Solar water heaters are commercially available and are used by millions of people across the world. Solar water heaters are having great importance especially in hotels, bungalows hospitals etc. For industrial applications, solar water heaters are widely used in textile, chemical, pharmaceutical, leather and other industries. Furthermore, if steam production is possible using solar energy, electric power generation can be feasible.

A lot of research is going on to develop efficient solar collectors. An efficient solar collector can be meant as the collector which has ability to produce high temperatures at low cost per surface area of the collector. In this work, a new type of design for the solar collector is proposed and it is evaluated both theoretically and experimentally. This collector is a rotating solar collector. It can be used to collect the solar thermal energy and use it for heating the various fluids. Wherever there is a requirement of steam, these collectors can be used to increase the temperature of feed water which is supplied to boiler. For example, in thermal power plants, sugar industry, dying industries etc., if the temperature of input feed water is increased from 35^{o}C to 75^{o}C using rotating solar collector, the coal consumption will be reduced, thereby decreasing the cost and saving the energy.

II. OBJECTIVES OF THE WORK

- To study the working of solar collectors
- To design and fabricate a rotating solar collector model to predict the performance
- To evaluate the theoretical and optical efficiency of rotating solar collector
- To determine losses due to convection and radiation
- To obtain best design of solar collector on the basis of maximum temperature and minimum cost

III. THEORY OF SOLAR COLLECTORS

A solar collector is a device which collects solar radiations and transfers the heat energy to a fluid passing in contact with it. Before designing a new type of collector, the existing methods of solar energy collection are studied. The solar collectors are mainly classified into two types i.e. Concentrating & Non-concentrating collectors.

1. Concentrating Collectors:-

In these collectors, solar rays are concentrated at a location or at a point using focusing devices like heliostats or mirrors. These collectors are efficient and produce high temperatures around 300 ^{o}C to 500 ^{o}C. Here, the orientation mechanism is necessary to track the sun. The common examples are Fresnel lens collector, Parabolic trough collector, Compound Parabolic concentrator etc.

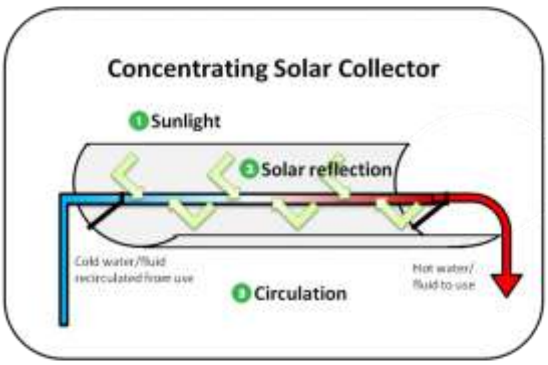

Figure 1. Concentrating Solar Collector

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2. Non-Concentrating Collectors:-

These collectors are also called as Flat-plate collectors. Here, the collector area is large and there is no tracking mechanism. It consists of an absorber plate generally made up of a black body with attached water tubes and a glass cover. The bottom surface and sides of collector are well insulated using materials like foam. The flat plate collectors are generally used for heating the water at low or moderate temperatures.

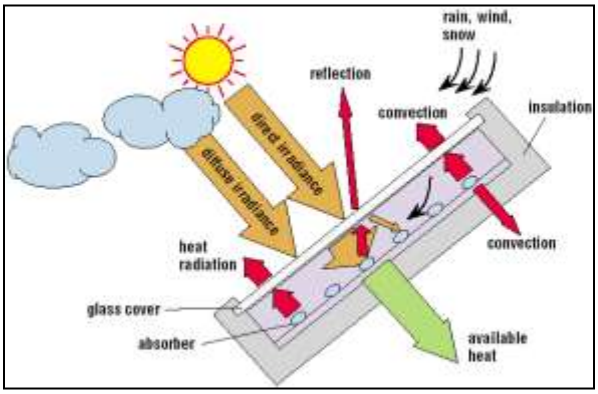

Figure 2. Non-concentrating or Flat plate Solar Collector

Now a days, there is a new type of solar collector invented called as Evacuated Tube Collector. It has of two concentric tubes made of borosilicate glass material. The vacuum between the two tubes is utilized for eliminating the losses due to conduction and convection. Evacuated tube collectors perform efficiently even in cold and overcast weather and are heavy and expensive. In these collectors, the temperatures of over 100°C are attainable and they can be used at higher temperatures than flat plate collectors. Evacuated tube collectors are having reflectors in order to utilize the total surface area of a round tube. The reflectors are steady and bend the light, so as to suit the geometry of the vacuum tube. The working of evacuated tube collected is somewhat similar to that of rotating solar collector.

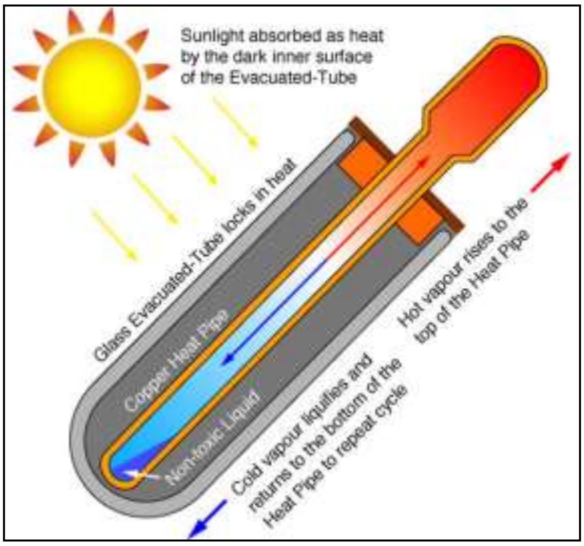

Figure 3. Evacuated Tube Solar Collector

IV. ROTATING SOLAR COLLECTOR – A NEW APPROACH

A new method of collecting the solar energy is invented, where by rotating the collector with a prime mover like small capacity electric motor, high temperatures can be obtained. Rotating collector has two circular concentric pipes. The various components of the rotating solar collector are explained as follows and shown in Figure 5.

1. Absorber Tube – The inner pipe is referred as Absorber Tube The absorber tube absorbs solar rays and transfers the heat energy to the working fluid. It is coated with a spectrally selective coating. There are two axles on ends of absorber to support it and transport fluid to and from the absorber tube.

2. Cover – The outer pipe is called transparent Cover. The transparent cover is filled with air. The air prevents heat loss by convection. It is generally made up of plastic or any transparent material. The cover surrounds the absorber and inflated in order to retain its shape by using air pump.

3. End Caps – They are used to support and insulate absorber tube and generally made from polyurethane foam.

4. Electric Motor – For rotating the assembly, small capacity electric motors are used which minimize heat losses. The capacity of these motors ranges from 8-12 W and rpm is 50-80.

5. Reflector – In order to maximize and concentrate the solar rays on absorber, reflectors are used.

V. EXPERIMENTAL SET UP

Figure 4. Experimental Test-Rig

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The experimental test-rig is shown in Figure 5. It is showing all the major components of rotating solar collector. The details of specifications and raw materials used for the fabrication of the set-up are as follows:

1) *Absorber Tube-*
   Length = 1.2m
   Diameter = 0.50m
   Material = Copper Sheet of 0.30mm coated with black paint
2) *Transparent Cover-*
   Length = 1.2m
   Diameter = 0.90m
   Thickness = 0.30m
3) *End Caps-*
   Material = Teak Wood & Foam
4) *Electric Motor-*
   Capacity = 12Volt D.C.
   Speed = 60rpm
   Bearings for support = 3Nos.
5) *Reflector-*
   Material = Galvanized Stainless Steel

The set-up is fabricated as per the following procedure:-

- The copper sheet is first cut into required dimensions and soldered to make a round drum. The drum is coated with a black paint, so that it will work as a black body and absorb maximum solar rays.
- Then, two round copper caps are welded to the drum and a hole is drilled on both end caps in the centre.
- A shaft is passed through both the holes.
- This whole assembly is fitted on a iron stand with the help of a pedestal bearings.
- The shaft is connected with the gearing arrangement which converts 950rpm to 60rpm with the help of chain drive.
- Then, two wooden end caps are fitted which act as insulation.
- A reflector of galvanized stainless steel is made curved in shape and fitted on the back of the arrangement.

VI. OBSERVATIONS & GRAPHS

The observations are noted for boundary conditions as,
Absorber Temperature = 70 ^{o}C & Cover Temperature = 30 ^{o}C

Time (in minutes)	*Rise in temp for water in stationary collector (in ^{c})*	*Rise in temp for water in rotating collector (in ^{o}C)*
5	35	45
10	38	51
15	41	54
20	44	62
25	47	65
30	50	69

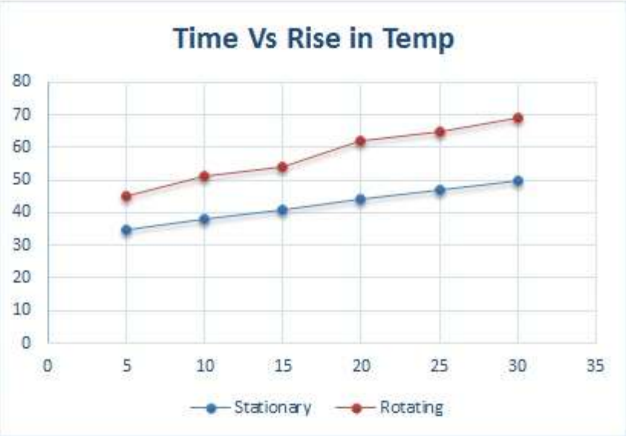

Figure 5. Comparison of Stationary & Rotating Collector for rise in temp

VII. CALCULATIONS & RESULTS

1. Weight of absorber = $2\pi R_a L d_a \rho_{cu}$

$= 2 \times 3.14159 \times 0.25 \times 1.2 \times 0.3 \times 8.96$

$= 5.06$ kg

Where R_a = Radius of absorber
L = Length of absorber
d_a = length of absorber
ρ_{cu} = Density of copper

2. Weight of Cover = $2\pi\ R_c\ L d_c \rho_{pvc}$

$= 2 \times 3.14159 \times 0.45 \times 1.2 \times 0.2 \times 1.39$

$= 0.94$ kg

Where R_c = Radius of Cover
L= Length of Cover
d_c = length of Cover
ρ_{pvc}= Density of PVC

3. Area of absorber $= 2\ R_a\ L$

$= 2 \times 0.25 \times 1.2$

$= 0.6\ m^2$

4. Calculation for RPM (N)

Main principle $\frac{Va^2}{Ra} = g$

If Ra= 0.25 g=9.81 m/s^2 then velocity =1.6 m/s

Now N= $\frac{V \times 60}{2\pi\ Ra}$

$= \frac{1.6 \times 60}{2\pi \times 0.25}$

= 60 rpm

5. Calculation for incident angle δ_i

$\delta_i = \sin^{-1}\left(\frac{Ra}{Rc}\right)$

$\delta_i = \sin^{-1}\left(\frac{0.25}{0.45}\right)$

$= 33.74^{0}$

Hence angle of incidence of solar radiation should be smaller than 40^{0} because the light transmission is fairly constant at incident angles under 40^{0}

6. Total conductive losses

$$\Phi c = \frac{2 \times l \times \lambda air \times \pi \times \Delta T}{\ln \left(\frac{Ra}{Rc}\right)}$$

Where λair = heat transfer coefficient of air
ΔT = Difference between temperature of absorber and cover

$$\Phi c = \frac{2 \times 1.2 \times 0.0298 \times \pi \times (343 - 303)}{\ln \left(\frac{0.45}{0.25}\right)}$$

$= 15.29\ W/m^2$

7. Maximum power entering system

$$\Phi_{in} = \Phi_{in}'' \times A_i \times (1+m)$$
$$= 800 \times 0.6 \times (1+2)$$
$$= 1440\ W$$

Where Φ_{in}'' = Solar influx= 800 W/m^2
A_i = Illuminated area of absorber
m = concentrating factor for reflector

8. Total power loss by radiation

$$\Phi_{rad} = A \times \sigma \times \varepsilon \times [(T_a^4 - T_c^4)]$$

Where σ= Stefan-Boltzman constant
ε= Emmision coefficient of absorber
T_a = Temperature of Absorber
T_c = Temperature of cover

$$\Phi_{rad} = 0.6 \times 5.67 \times 0.03 \times [(343^4 - 303^4)]$$
$$= 5.52\ W/m^2$$

9. Heat production,

$$\Phi_{prod} = \Phi_{in}'' \times A_i \times \zeta_h \times \alpha_{a,h} \times (1+m \times r) - (\Phi c + \Phi_{rad} + \Phi_{conv})$$
$$\Phi_{prod} = 800 \times 0.6 \times 0.916 \times 0.961 \times (1+2 \times 0.72) - (15.29+5.52+0)$$
$$= 1013.55\ W$$

10. Theoretical Efficiency

$$\eta = \Phi_{prod/}\Phi_{in}$$
$$= 1013.55/1440$$
$$= 70.38\%$$

11. Optical Efficiency

$$\eta_o = \zeta_h \times \alpha_{a,h} \times (1+m \times r))/(1+m)$$
$$= [0.916 \times 0.961 \times (1+2 \times 0.72)]/ (1+2)$$
$$= 71.6\ \%$$

VIII. CONCLUSION

The rotating solar collector is more efficient than conventional flat plate collectors due to prevention of convection by rotation. The air near the absorber tube is at higher temperature and hence lighter. Whereas air near the cover is at high temperature and denser. So, the heat transfer takes place between high temperature and low temperature air causing the absorber tube to cool down. But due to rotation, a centrifugal force is created which acts on air layer away from centre and forces the denser air outwards. So, the heat loss by convection is minimized thereby increasing the efficiency.

Also, with reference to cost estimation we observe that, rotating solar collectors are cheaper in cost. Therefore, it offers the potential of a sustainable energy.

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