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"Design and Fabrication of Parabolic Trough Collector"

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ABSTRACT

An evacuated tube solar collector using therminol D-55 / Transformer oil as heat transfer fluid coupled with parabolic trough is studied in this paper. An experimental set-up is to be constructed to study the performance of evacuated tube collector with therminol D-55 / Transformer oil as heat transfer fluid. The parabolic trough is coupled with evacuated tube collector for better performance. In the traditional solar collectors water is used as heat transfer fluid. The problems in using water as heat transfer fluid are addressed in detail in this paper. The temperature characteristics of heat transfer fluid and water in the storage tank and the heating efficiency is to be determined under various conditions. The efficiency of therminol based evacuated tube collector coupled with parabolic trough is 40% more than that of water based evacuated tube collector coupled with parabolic trough. This study projects the potential of therminol based evacuated tube solar collector coupled with parabolic trough in the instant hot water generation. Also a copper coil is incorporated in the collector through which the water is passed. This setup will help in achieving higher temperature at the outlet thereby increasing the overall thermal efficiency of the PTC.

Keywords: PTC – Parabolic Trough Collector, SCM – Solar Collector Modules, SCA – Solar Collector Assembly

I. INTRODUCTION

The evacuated tube is considered to be an important component in thermal application, particularly in solar water heating systems. The performance of evacuated tube solar parabolic collectors is better when compared to flat plate collector in high temperature applications. Different parameters like optical design, optimum operating conditions, heat transfer in tubes and performance studies of solar collectors have been studied by several researchers. Extracting heat from the evacuated tube is a major difficulty in evacuated tube solar collector applications. The fluid-in-glass and fluid-in-metal are the significant designs for better performance. Between the two, fluid-in-glass collector is widely used because of its low manufacturing cost and high thermal efficiency. Water is used as heat transfer fluid by many researchers. Morrison et al. studied the natural circulation of heat transfer fluid in fluid-in-glass evacuated tubes experimentally and numerically. Fluid-in-glass evacuated tube cannot withstand high pressures and hence it is suitable for applications where few metres of water head is available.

II. TECHNICAL SPECIFICATIONS

2.1 Parabolic Trough Collector-

A Parabolic Trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal mirror. The sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line where objects are positioned that are intended to be heated.A parabolic trough is made of a number of solar collector modules (SCM) fixed together to move as one solar collector assembly (SCA). A SCM could have a length up to 15 metres (49 ft) or more. About a dozen or more of SCM make each SCA up to 200 metres (660 ft) length. Each SCA is an independently-tracking parabolic trough.

A SCM may be made as a single-piece parabolic mirror or assembled with a number of smaller mirrors in parallel rows. Smaller modular mirrors requires smaller machines to build the mirror, reducing cost. Cost is also reduced in case of the need of replacing a damaged mirror. Such damage may occur due to being hit by an object during bad weather.The parabolic trough reflector can generate much high temperatures more efficiently than a single flat plate collector, since the absorber surface area is much smaller. The heat transfer fluid which is usually a mixture of water and other additives or thermal oil, is pumped through the tube and absorbs the solar heat reaching temperatures of over 200 ^{0}C. The hot water is sent to a heat exchanger where it directly heats a hot water storage tank for use in the home making this type of solar heating application a closed-loop active system. However, parabolic trough reflectors use only direct solar radiation to heat the receiver tube as diffused solar radiation cannot be focused onto the absorber making them less effective when the skies are cloudy or the sun is out of alignment.

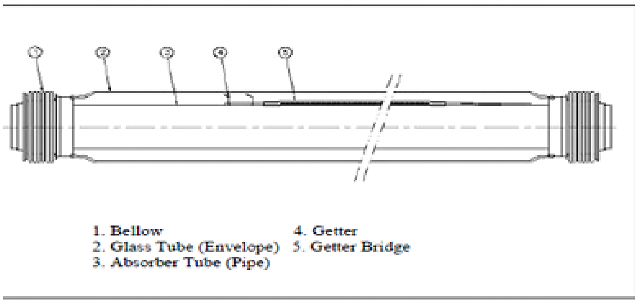
To overcome this problem, most concentrating collectors require some form of mechanical equipment that constantly orients the collectors towards the sun keeping the heat pipe absorber at the correct focal point. This is achieved by using a Tracking Solar Concentrator that aligns the trough with the sun throughout the day, maximising the solar heat gain.

The collector generally has a single rotation axis along the length of the trough which can be orientated in an east-to-west direction, tracking the sun from north to south, or orientated in a north-to-south direction and tracking the sun from east to west. Parabolic troughs are generally aligned on a north-to-south axis, and are rotated to track the sun as it moves across the sky each day from morning to night. The advantages of this type of tracking mode is that very little collector adjustment is required during the day resulting in the solar trough always facing the sun at noon time, but the collector performance early in the morning or late in the afternoon is greatly reduced due to the large incidence angles of the trough. Even though solar trough collectors use tracking systems to keep them facing the sun, they are most effective in sunnier climates where there are good solar resources. Like many other solar collectors, parabolic trough reflectors are modular, that is individual troughs can be connected together to give a larger surface area of absorber producing large amounts of solar hot water than can be created by an individual trough. Many single troughs connected together form a collector field were they are connected together in series and parallel rows.

2.2 Evacuated Tube –

The Evacuated tube collector consists of a number of rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate we saw in the previous flat plate collector. These glass tubes are cylindrical in shape. Evacuated tube collectors do not heat the water directly within the tubes. Instead, air is removed or evacuated from the space between the two tubes, forming a vacuum (hence the name evacuated tubes). This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation making the collector much more efficient than the internal insulating that flat plate collectors have to offer. With the assistance of this vacuum, evacuated tube collectors generally produce higher fluid temperatures than their flat plate counterparts so may become very hot in summer.

There are U-shaped copper pipes inserted in the evacuated tube with therminol—55 oil. The working fluid (in this case water) will be circulated in the copper pipes through a pump. The copper pipes will give the working fluid more time in the evacuated tube and also increases the thermal efficiency.



Schematic of an HCE (source: Solel Solar Systems Ltd.)

Figure 1

2.3 Therminol-55 –

Therminol 55 is a synthetic heat transfer fluid used in moderate temperature applications. Therminol 55 fluid is designed for use in non-pressurized /low-pressure, indirect heating systems. It delivers efficient, dependable, uniform process heat with no need for high pressures.

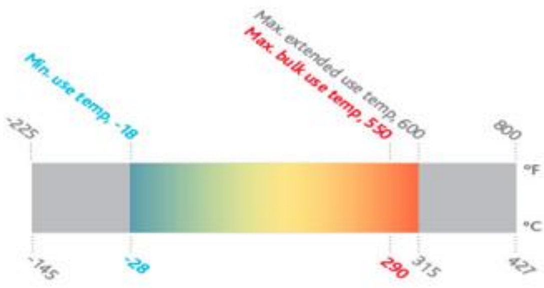


Figure 2. Temperature variation of Therminol – 55

PERFORMANCE BENEFITS –

Long Life – You will get years of reliable, cost effective performance, even when operating your system continuously at 290°C (550°F). This means you do not have to over specify your fluid.

Excellent resistance to fouling – Because Therminol 55 is a synthetic fluid, it resists the effects of oxidation 10 times better than mineral oils. Less oxidation and solids formation. For systems without nitrogen inerting, the performance advantages are significant.

Excellent Low Temperature Pumpability – Therminol 55 is still pumpable at -28°C (-18°F), compared to some mineral oils that will not pump at temperatures below -7°C (20°F). With Therminol 55, your heat transfer fluid system can start-up quickly and easily.

2.4 Use Of Copper Tube -

Copper has many desirable properties for thermally efficient.First and foremost, copper is an excellent conductor of heat. This means that copper's high thermal conductivity allows heat to pass through it quickly.Other desirable properties of copper include its corrosion resistance, biofouling resistance, maximum allowable stress and internal pressure, creep rupture strength, fatigue strength, hardness, thermal expansion, specific heat, antimicrobial properties, tensile strength, yield strength, high melting point, alloyability , ease of fabrication, and ease of joining.

Table 1. Thermal conductivity of some common metals

METAL	THERMAL CONDUCTIVITY	
	(Btu/(hr-ft-F))	(w/(m-k))
Silver	247.87	429
Copper	231	399
Gold	183	316
Aluminium	136	235
Yellow brass	69.33	120
Cast iron	46.33	80.1
Steelness steel	8.1	14.0

III. EXPERIMENT SETUP

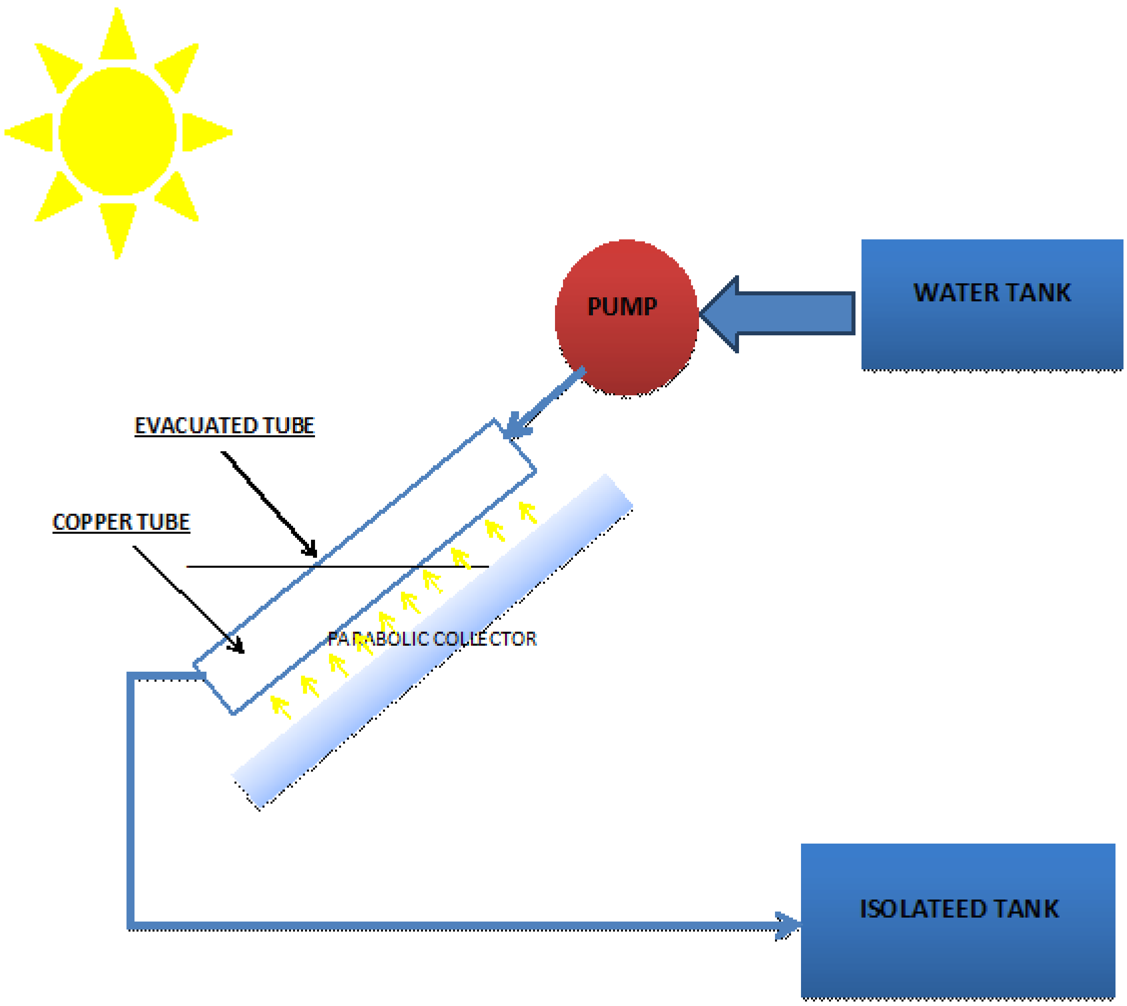


Figure 3

1. Design Calculations -

Equation of Parabola Y=0.041667 x^2(in inches)

Focal point at $\frac{1}{4a} = \frac{1}{4(0.041667)} = 6$ in above origin

Length of parabola from X_1 to X_2 ,"S"

Let t=2f and$q = \sqrt{t^2 + p^2}$, p is distance from y-axis to point X

$$S = [\frac{pq}{t} + t\ln(\frac{p+q}{t})]$$

p=12

t=2(6)=12

$$q = \sqrt{2.12^2} = 1.697 * 10^1$$

$$S = (\frac{12 + 16.97}{12} + 12\ln(\frac{12 + 16.97}{12}))$$

S=27.55in

Total length needed for sheet metal=27.55in

Trough length 42in and radius 12in

2. Thermal Calculations –

1. δ – Angle of Declination
2. W_s – The hour angle corresponding to sunset or sunrise
3. $\bar{S}$ – monthly average of the sunshine per hour per day at location
4. $\bar{S}_{max}$ – Monthly average of maximum possible sunshine per hour per day at location or day length on a horizontal surface.

5 .∅ - Latitude at which parabolic collector is being placed

6. I_{sc} - The rate at which the energy is received from the sun on a unit area perpendicular to the rays of the sun at the mean distance of the sun from the earth.

3. a_1,b_1 – constants obtained by fitting data .
4. E_l - Elevation of the location above mean sea level.
5. $\bar{H}_0$ – The monthly average of daily extraterrestrial radiation on horizontal surface at Location.
6. $\bar{H}_g$ – The monthly average of daily global radiation on a horizontal surface at a location.

a)Klen's Equation -

- Declination (δ) =23sin($\frac{360n}{365}$+(284+n))
  = -2.42
- $w_s = \cos^{-1}$ (-tan(latitude)* tan δ)
  = $\cos^{-1}$(-0.387169*-0.042262)
  = 90.93 ^{0} = 1.5870 radians
- $\bar{S}_{max} = \frac{2}{15} w_s = \frac{2}{15}\cos^{-1}$(-tan∅. tan δ)
  = 12.12 hours
- $\bar{S}/\bar{S}_{max}$ = 0.62
  Therefore, $\bar{S}$ = 7.6 hrs

- $\overline{H}_0 = \frac{24}{\pi} * I_{sc} * (1+0.33(\frac{360n}{365}))*w_s \sin\emptyset \sin\delta + \cos\emptyset \cos\delta \sin w_s$
  $= 34429.24$ kJ/m²day
- $\overline{H}_g/\overline{H}_0 = 0.4774$
  Therefore, $\overline{H}_g = 16436.519$ kJ/m²day

b) Gopinathan's Equation –

- $a_1 = -0.309 + 0.539\cos\emptyset - 0.0693\,E_l + 0.290(\overline{S}/\overline{S}_{max})$
  $= -0.309 + 0.539\cos(21.16487) - 0.0693(0.31) + 0.290\,(0.62)$
  $= 0.35956$
- $b_1 = 1.527 - 1.027\cos\emptyset + 0.0926\,E_l - 0.359\,(\overline{S}/\overline{S}_{max})$
  $= 1.527 - 1.027\cos(21.16487) + 0.0926\,(0.31) + 0.359\,(0.62)$
  $= 0.375426$
- $a_1 = 0.27$; $b_1 = 0.5$ (page no.90, table 3.2)

$\overline{H}_g/\overline{H}_0 = a+b\,(\overline{S}/\overline{S}_{max})$ (page no. 89)
$= 0.27+0.5(0.62)$
$= 0.58$

Therefore, $\overline{H}_g = 34429.24*(0.35956+0.375426(0.62))$
$= 20393.27$ kJ/m²day
$= 656$ W/m²

IV. CONCLUSION

This project work focuses on enhancing the heat transfer in order to increase effectiveness of parabolic trough collector. Design calculation and experimental setup will be fabricated. Experimentation will be carried out to see the effectiveness of trough collector by use of copper tubing insert inside evacuated tube. Experimental readings will be analysed and compared with existing setup.