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A Review of Parabolic Trough Collector Assisted with Mirror for low temperature Applications

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Abstract: The global energy demand is going to increase by over 60% in the upcoming decades. Thus, the alternative form of energy should be investigated. The only energy preferable will be a renewable form of energy which includes wind, solar, biomass, and waste generated through human activities. The most useful alternative to fossil fuels in generating clean energy is solar energy. However, the extraction of maximum energy from the sun is quite difficult. This paper includes a comprehensive review of simple parabolic trough collectors along with geometrical analysis, thermal efficiency, and applications. The applications of PTC include water desalination, water heating, increasing the performance that can be utilized for steam generation, etc.

I. INTRODUCTION

The excessive use of conventional sources of energy is creating the most serious threats such as global warming, and CO2 emissions into the atmosphere that are largely affecting the environment. This problem can be minimized by the use of renewable forms of energy such as wind, solar, etc. Nowadays, the most prominent form of energy is solar energy. Many countries have started the use of this clean and unpolluted energy for cooking, space heating, and desalination purpose.

Currently, the most useful thermal system based on solar energy are the concentrating collector. A solar collector absorbs the sun's radiation and convert it to heat energy, this energy gets converted to thermal energy into the working fluid such as water, air, oil, etc. Solar collectors are of different types such as Parabolic trough collector (PTC), flat plat collector and compound parabolic collector (CPC). Several efforts have been made by the researcher to improve the performance of PTC using various experimental and analytical parameters.

Parabolic collector is capable of providing higher concentration level as compared to flat plate collectors [1]. The performance of the PTC is greatly influenced by receiver absorptivity, heat transfer fluid, mirror reflectivity and among others [2]. Usually, the outer surface of the absorber is coated with matte black paint to minimize loss of thermal radiation and to improve solar absorption. There are many other methods to improve efficiency like utilizing turbulators, utilizing nanofluids as HTF, etc. (Kumaresan et al. 2017) [3]. The efficiency of the PTC can also be improved by incorporating the porous within the absorber (Ravi Kumar and Reddy 2009). The performance of the absorber tube can be improved by inserting metal foam, the reason behind is that it enhances the heat conduction from solid to fluid, disrupt fluid boundary layer and strengthen flow-mixing [4-5]. To generate hot water, a 90°- rim angle fiberglass- reinforced parabolic trough collector has been designed and developed by [1]. In PTC, many improvements have been made in heat transfer fluids. Nano- fluids as a heat transfer fluid is the most capable technique. Nanofluid improve the thermal performance of the base fluid by an improved volume-to-surface ratio and radiative properties. The most used nanoparticles are Al, Al_2O_3, Cu, SiO_2, TiO_2, Au, ZnO, Ni, Fe, and Fe_2O_3.

In this, review, we are focusing on applications, construction and working of a simple parabolic trough collector assisted with mirror for low temperature application.

A. Geometric Description

Geometrical analysis of simple parabolic trough collector.

The following formula describes the parabolic shape geometry:

$$y = \frac{x^2}{4f}$$

The rim angle (ϕr) is calculated by using the aperture (W) and the focal distance (f) as shown below:

ϕr = arctan [8 $\frac{f}{w}\frac{8(\frac{f}{w})}{16((\frac{f}{w})^2-1}$]

The total collector aperture (A_a) is the product of the width (W) and the length (L)

A_a = W · L

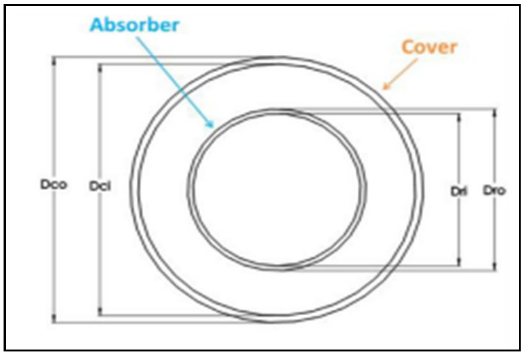
The absorber area (A_{ro}) is nothing but the outer area of the tube:

A_{ro} = π101D_{ro}L

The geometrical concentration ratio (C) is a ratio of the collector aperture (A_a) to the absorber area (A_a):

C = $\frac{A_a}{D_{ro}}$

Fig.1. Cross-section of the evacuated tube receiver



B. Thermal Description

The useful heat production from a PTC (Qu) is calculated using the fluid volume energy balance:

Q_U = m. c_p(t_{out}- t_{in})

The solar irradiation falling on the collector aperture (Qs) is the product of the aperture area (Aa) direct beam solar irradiation (Gb):

$Q_s = A_a \cdot G_b$

The thermal efficiency of the solar collector (η_{th}) is calculated by the ratio of the useful heat (Qu) to the available solar direct beam irradiation (Qs):

$\eta = \frac{Q_u}{Q_S}$

The thermal losses of the solar collector (Q_{loss}) can be calculated as shown, using the thermal loss coefficient (UL), the mean absorber temperature (Tr) and the absorber outer surface (A_{ro}):

$Q_{loss} = A_{ro} \cdot U_l \cdot (T_r - T_{am})$

The thermal losses of the absorber (Q_{loss}) are practically the radiation thermal losses of the absorber tube to the cover:

$$Q_{loss} = A_{ro} \cdot \sigma \cdot \frac{{T_r}^4 - T_c^4}{\frac{1}{\varepsilon_r}+\frac{1-\varepsilon_c}{\varepsilon_c}\cdot\frac{A_{ri}}{A_{co}}}$$

The parameter (σ) is the Stefan-Boltzmann constant whose value is equal to 5.67×10^{-8}W/m2K4. The thermal losses of the cover to the ambient (Q_{loss}) are assumed to be the same as the thermal losses of the absorber to the cover because the system is evaluated in steady-state conditions. Radiation and convection thermal losses from the cover to the ambient are present:

$$Q_{loss} = A_{co} \cdot \sigma \cdot (T_c^4 - T_{sky}^4) + A_{co} \cdot h_{out} \cdot (T_c - T_{am})$$

Where,

$A_{co} \cdot \sigma \cdot (T_c^4 - T_{sky}^4)$ = Radiation thermal losses,

$A_{co} \cdot h_{out} \cdot (T_c - T_{am})$ = Convection thermal losses.

In the previous calculation, the mean cover temperature (Tc), the ambient temperature (Tam) and the sky temperature (T_{sky}) are involved. The sky temperature (T_{sky}) can be estimated by the following equation:

T_{sky} = 0.0552 . $T_{am}^{1.5}$

The heat transfer coefficient between cover and ambient (h_{out}) can be calculated using the following formula:

h_{out}= 4 ·$V_{wind}^{0.58}$. $D_{co}^{-0.42}$

The above equation can be applied for cross-flow on cylindrical objects which uses the wind speed (V_{wind}) and the cover outer diameter (D_{co}). Value for the heat transfer coefficient is around 10W/m2K, for wind speeds close to 1 m/s.

II. EXPERIMENTAL SETUP AND WORKING

The factors to be considered while designing the PTC are stability, accuracy of the parabolic profile fabrication methods, material availability and strength. The parabolic curved focuses the direct sun radiation onto the absorber in the focal line of collector.

A. Construction

Experimental setup mainly consists of –

1) A Parabolic collector
2) A Receiver tube
3) Working fluid or Water.
4) Two surrounding mirrors

a) *Parabolic Trough Reflector:* It is a metal sheet usually made of steel bent in a form of parabola. For the experimental set up, a sheet of stainless steel can be used. It is of the Grade (SS 204). As it is used for the purpose of solar light reflection, the sheet can be coated with mirror, which makes the sheet surface highly reflective. The sheet is bent and supported by screwing it on round-cut plywood sheets.
b) *Wooden Supports For Trough Reflector:* The different materials can be used for support of the parabolic reflector. Usually, plywood sheets are used which provide the protection against wind to the reflector and are light in weight. The plywood sheets are cut in semi-circular shape for maintaining the bending support to the parabolic sheet. The stand below the reflector is also made up of the same material. The stand is made in such a way that it can be disassembled for transportation purpose.
c) *Receiver Tube:* Receiver tube is the most important part of a PTC. Its adjustment over the focal point requires quite attention. The material of the receiver tube affects the optical and thermal performance of the collector, glass cover protects the receiver, the gap between glass tube and receiver tube and reduces heat losses. The receiver tube is coated with a heat resistant PU-matte black paint.
d) *Mirrors For Surrounding:* In our prototype, we have introduced plane mirrors at the ends of the parabola to increase the reflecting surface.
e) *Instruments And Devices For Measurement:* For observing the operating performance of the set up various parameters are needed to be measured. For the sake of measurement, there is a need of a set of accurate instruments.

- Thermocouple for temperature and heat related parameters.
- Volume measuring container for mas flow rate measurement.
- Stopwatch for time related constraints.

B. Working

A PTC is a Line focusing type of reflector which focuses the sunrays falling on parabola shaped reflector in form of straight line. The solar radiation is focused on focal point of the parabola. The heat energy inside the solar radiations can be obtained by imparting a receiver tube at the focal point.

This receiver is made of material with a good thermal conductivity. It transfers heat energy from sunrays to the fluid inside it. Now, this superheated fluid is used to heat the water or gets converted into steam.

This whole set up is supported by metal or wooden stand. Also, the reflector is connected to tracking mechanism which is used to shift the acceptance angle of the reflector in order to receive maximum solar radiation.

The receiver is filled by the working fluid from one end and steam/hot water (based on application) can come out from another end.

III. CONCLUSIONS

This paper concludes a concise review of various geometrical and thermal parameters of parabolic trough collector. The most important parameter of the PTC is structure that can enhance efficiency and lower working cost. The second most critical parameter is working fluid i.e., Heat transfer fluid (HTF). Generally, water is use as a heat transfer fluid.

The reflector impact greatly on the performance of the PTC but it is costly. Some low cost-alternatives are Polished SS-204 sheet, Aluminium foil and Silver coated PVC sheet. The absorber should have low heat loss and high absorptivity. The PTC is versatile in performance and thus, can be used in various household and industrial applications. The thermal performance of PTC can also be improved by integrating mirrors to reduce solar radiation loss.

Based on literatures, it can be derived that nanofluid can be used for improving performance but it is still an emerging field and require research. The parabolic trough collector is replacing the old method of solar collector. It has the potential of replacing conventional method of water heating.

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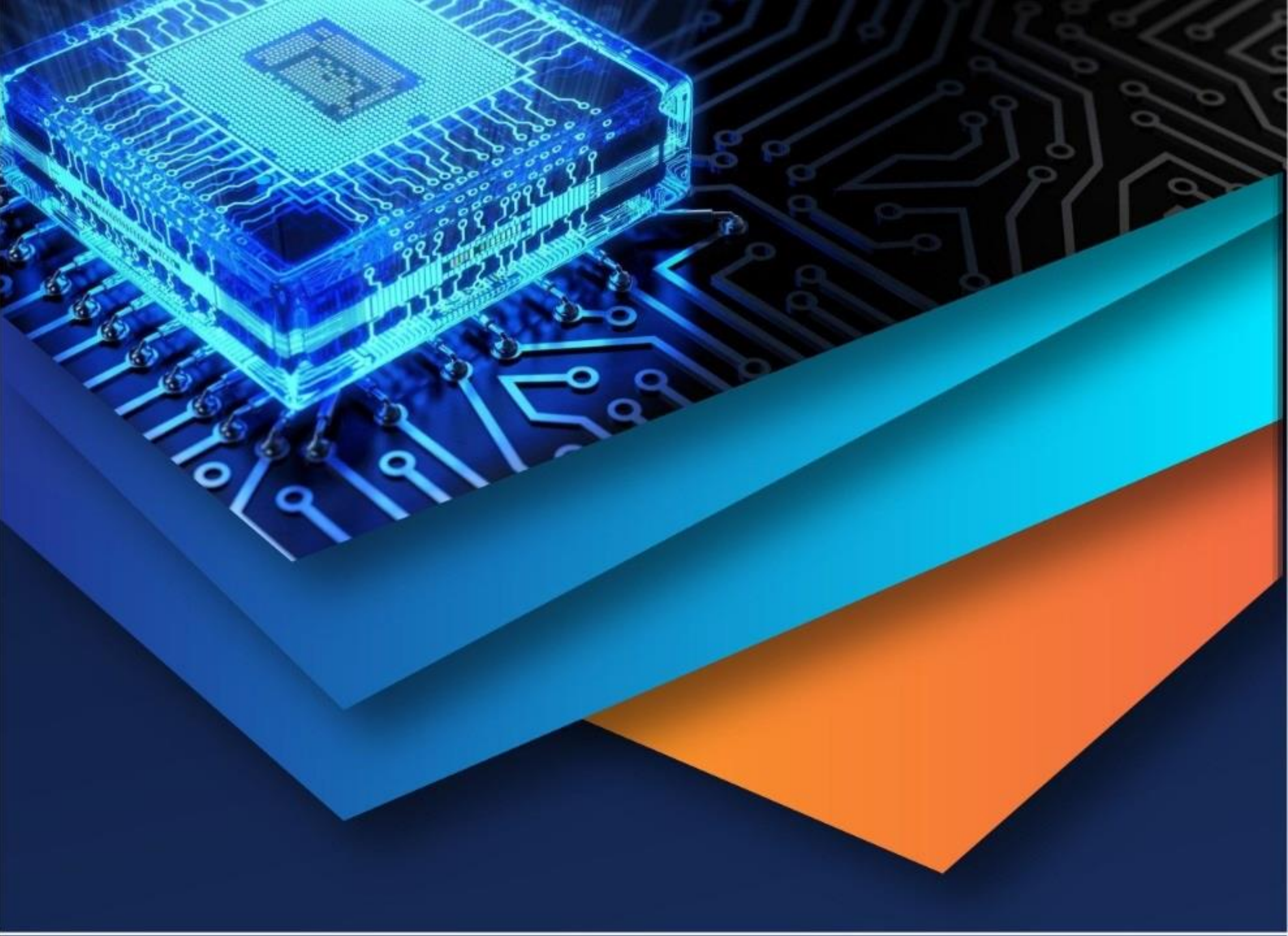

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