Influence of Nano-Fluid and Receiver Modification in Solar Parabolic Trough Collector Performance

M Dharani Kumar ¹, G Yuvaraj ², D Balaji ³, R Pravinraj ⁴, Prabhu Shanmugasundaram ⁵

Department of Mechanical Engineering, KPR Institute of Engineering & Technology, Coimbatore-07
¹ dd.dharan@gmail.com, ² yuvarajg75@gmail.com, ³ balaji.d@kpriet.ac.in, rajpravin394@gmail.com ⁴, ⁵ prabhumech094@gmail.com

Abstract—Utilization of natural renewal sources in India is very high over the past decades. Solar power is a prime source of energy available plenty in the world. In this work solar energy is modified into thermal energy by using copper absorber tube with fins. Due to low heat transfer coefficient results leading to higher thermal losses and lower thermal efficiency. In order to increase the heat transfer coefficient copper receiver tube with fins is used and as well as solid has higher thermal conductivity compare to fluid (Tio₂) nano fluid is used to improve the heat transfer rate. The analyses have been carried out and take the account of parameters such as solar radiation with time variation, mass flow rate of water, temperatures.

Keywords—Solar energy, Solar radiation, heat transfer, nano fluid, copper receiver tube with fins.

1. Introduction

Anderson T.Net.al.[1] discussed about the natural energy resources were declined day by day in order to fulfill the demand of growing population needs, should search for alternative energy resources, it costs is less for doing the setup of solar panel, because we have more than abundance of natural energy.

The rate of energy dissipating from the sun have been striking the earth more because of abundant content and weather conditions of earth, depends upon locality, it varies. According to the survey, the average radiation dissipated from the sun is 1000 W/m². Hence power production issue is not happen, sun rays directions will always perpendicular over the surface orientation. Solar collectors were used to utilize the sun energy in the focused manner and transfer the energy in another form of waves. There are various methods have to absorb and storable form of energy which suggested to use in many applications such as drying, agricultural resources, textile applications etc., also used for water heating purposes. Solar parabolic trough collector is the easiest way to convert the heat energy in the form of energy utilization energy. Many researchers had been carried out research work on solar parabolic trough collector heater with different receiver tubes with and without vacuum, different nano-fluids are used to improve the efficiency of the parabolic trough collector.
The application areas of solar energy can be categorized as follows:

- Architecture and urban planning
- Agriculture and horticulture

Solar thermal energy can be used for:

- Cooking/heating
- Drying/Timber seasoning
- Distillation
- Electricity/Power Generation
- Cooling and Refrigeration
- Process heating

Solar collector has been used in emanating and reflecting the radiation and transfers the fluid passing of various ports. Solar collector is fitted with solar absorber for effective transmission of energy into the usable form. It is divided into two category concentrating and non-concentrating type. In the non concentrating type, the size of absorber is always same than other system.

Martinez et al. [2] studied the 2.37 m aperture and 1.14 m long parabolic convertor of surface finish trough collector and they proved the effective reflection was done in the size of 0.3 x 0.6 m and it yields the size of reflectance around 86%. The focusing range is maintained up to 5.08 cm.

Thomas et.al. [3] have analysed the design aspects of the modification of thermal systems through concentrators. It also discussed about the existing system performance and compared with modified system.

Donald Jeremy Gaitan Cal Poly et.al.[4] have analysed the change in size of collector through different testing methods. Purpose of the research is to evaluate the Design and thermal system of Cal poly method. Systeam particularly designed to maintained the energy storage device performance. The test results were compared with a mathematical model drafted during the design stage.

Tadahmun Ahmed Yassen [5] discussed an experi-mental study carried out to demonstrate the solar parabolic trough effectiveness. In order to determine the thermal efficiency, they suggested to use the FORTRAN360 software and also dimensions were measured. It has been concluded the increase in mass flow rate gradually increases the thermal efficiency.

Omid Mahia.et.al [6] evaluated the utilization of nano fluids in practical applications with the help of thermal systems. Due to the shortage of fossil fuels, It is in need to improve the performance of solar operated systems. Nano fluids also suggested to use in the field of photo voltaic cells. Finally, utilization of nano fluids allowed to use in wide ranges were imbibed.

R. Saidur et.al.[7] investigated the pollution tackle methods produced by natural energy resources. In this study, the effect of nanofluid has been analyzed by using as working fluid for direct solar collector. They analysed the thermal coefficient of linear expansion using nano fluid in trough collector. With respect to Volume fraction, the extinction transfer coefficients were measured.

R. Taylor et.al [8] have discussed the parameters of optimization in thermal efficiency performance in all the systems wherever the utilization of nano fluids are possible. They concluded effectiveness of heat transfer improves the mass flow rate of nano fluids in thermal systems.

N. Castillo [9], have describes Titanium-di-oxide in the field of thermal sciences, it accepted universally due to increase in thermal conductivity of nano fluid. Also improve the fin efficiency essential reasons in the range of material properties and good corrosion resistance.

Jinghuan Zhang [10] done calcinations in order to improve the property of crystallinity in TiO2 form.

**Figure 1.** Line diagram of parabolic trough collector.
2. Synthesis of nano-material (TiO2) by ball milling method

2.1. Ball Milling
Small tungsten carbide balls are put in a container in the form of powder and allowed to rotate in central axis allowing them to strike the walls. The balls inside the container impart collision energy. 50 balls are used in a vial, two vials are used to produce the powder. Process is carried out by wet milling, one hour running and half an hour cooling with air circulation is shown in figure 2. Total timing of ball milling is 10 hours with 300 rpm.

![Figure 2. Wet Milling (TiO2) after ball milling.](image)

2.2. High Resolution Transmission Microscopy (HR-Tem):
HRTEM is a powerful tool to study properties of materials on the atomic scale, such as semiconductors, metals, nanoparticles. The TiO2 view of morphology at 400(=c) is observed by TEM is shown in figure 3.

![Figure 3. Photographic view of (TiO2) Nano-Particle.](image)

3. Receiver modification with fins
In parabolic trough collector receiver, gain heat energy from the trough (aperature) and heats the water is used for various purposes. Fins are used to increase the heat transfer rate because of its surface area increases heat gain is increasing.

Fins are placed in the receiver for the entire length in linear arrangement above the fins glass cover is covered to reduce the convective heat transfer losses. Fins are used because its increases surface area once surface area increases there is increase in the heat transfer rate. Due to the gain in the solar radiation in the fins, extra heat is added to the receiver tube to heat the water medium. Once heat gain is increases there must be increase in the heat transfer rate. Water medium is heated up hastily. Efficiency of the collector is increases with gaining of heat energy in the copper receiver fins is seen in figure 4 and the properties were discussed in table 1,2.

![Figure 4. Copper receiver tube with fins.](image)

The heat transfer fluid used should be high thermal conductive in nature, since it has transfer heat at a higher rate and also it should ensure that there is no much heat loss.
Table 1. Thermal Conductivity of different receiver material.

| SL.NO | MATERIAL  | THERMAL CONDUCTIVITY (W/mK) |
|-------|-----------|----------------------------|
| 1.    | Aluminium | 220                        |
| 2.    | Copper    | 400                        |
| 3.    | Steel     | 35-55                      |

Table 2. Design Parameter of Solar parabolic trough collector.

| Sl. No. | Parameters                        | Values  |
|---------|-----------------------------------|---------|
| 1       | Length of aperture, l             | 1.24 m  |
| 2       | Width , b                         | 1.24 m  |
| 3       | Receiver Outer Diameter           | 0.028m  |
| 4       | Receiver inner Diameter           | 0.025m  |
| 5       | Glass Outer Diameter              | 0.047m  |
| 6       | Glass Inner Diameter              | 0.042m  |
| 7       | Specular reflectivity of the concentrator surface (optical property) | 0.8     |
| 8       | (\(\tau\sigma_b\)) = transmissivity – absorptivity product for beam radiation (optical property) | 0.78    |
| 9       | \(F'\) (Collector efficiency factor) | 0.85    |
| 10      | Heat loss coefficient U           | 7.6 W/m² |
| 11      | Thermal conductivity of glass, \(K_g\) | 1.1 W/mK |
| 12      | Thermal conductivity of absorber, \(K_a\) | 400 W/mK |

4. EXPERIMENTAL STUDY:

Experiment was conducted by three ways.

(1) Without nano-fluid.

(2) With nano fluid concentration of 0.5 gram.

(3) With nano fluid concentration of 1 gram.

Volume fraction (0.05 gram for 100 ml = 1 g for 2 liters)

(0.5 g for 1000 ml) by varying two iterations.

M.N. Pantzali et.al. [11] Have describes the volume fraction of (TiO2) Straight copper tube. Heat transfer increases with nano particles volume fraction increases.

Figure 5. Modified parabolic trough with copper fin receiver tube.

Figure 6. Parabolic Trough Collector with tank arrangement.
4.1. Assumptions made:
- Heat transfer is assumed to be in steady state.
- One dimensional heat transfer.
- $F' = 0.85$ (Collector efficiency factor)

The collector used is a parabolic trough collector which is of concentrating type. Concentration ratio for parabolic trough collector is 2 –100, based on the application parabolic trough collector is designed.

4.2. Working Principle:

In concentrating collectors the term concentration ratio ($C$) is a very important parameter, as shown in figure 5, 6. It is defined as the ratio of the collector area at which radiation collects to the area (absorber) at which these radiations are concentrated. Concentration ratio is defined as the ratio of the collector area to the absorber area.

4.3. Instruments used:
- Pyranometer –To measure solar insolation (w/m²)
- Thermocouple –To measure temperature (°C)
- Water flow meter –To measure the mass flow meter (kg/s)

4.4. Mathematical Modeling:

4.4.1. Concentration ratio:
\[ C = \frac{\text{Effective aperture area}}{\text{absorber area}} = \frac{W - D_0}{\Pi D_0} \]
Where, $W = \text{Width of aperture in m}^2$  
$D_0 = \text{outside diameter of receiver tube in m}$

4.4.2. Heat Removal Factor:
\[ F_R = \left( m \times C_p \right) / \left( A_c \times U_L \times F' \right) \times \left[ 1 - e^{C - A_c} \right] \]
Where, $F_R = \text{Heat Removal Factor}$  
$m = \text{mass flow rate Kg/s}$

4.4.3. Absorbed radiation flux:
\[ S = \left( I_b \times R_b \right) \times (\rho) \times (\tau a) + \left( I_b \times R_b \right) \times (\tau a) \times \left( D_o / W - D_o \right) \]

4.4.4. $QU = \text{useful heat gain}$
\[ QU = (A_c \times FR) \times [I_b (\tau a) b - UL (To - Ti)] \]

Where, $T_i = \text{Inlet temperature in °C}$  
$T_o = \text{outlet temperature in °C}$  
$QU = \text{useful heat gain in w}$

4.4.5. Efficiency of the collector ($\eta$)
\[ \eta = \frac{QU}{A_c \times I} \]

5. Results and discussion

This paper describes the various results with changing the nano fluid concentration outlet temperatures are measured and without addition of nano fluid outlet temperatures are measured.
6. Conclusion
In this work, solar parabolic trough collector is studied experimentally with modified absorber tube with copper fins and using (TiO2) nano fluid with (0.5g and 1 g) concentration. It depends on the heat transfer rate and concentration ratio of collector. This research describes the outlet temperature increases with increases in nano fluid concentration shown in fig(7,8,9). Fin are used to increases the surface area so that heat transfer rate is increases.

7. Scope
Ultimate aim through this project is to provide an affordable access of the solar energy to heat the water for different applications. Energy that God gave us, the most renewable energy that we will ever see, and using it to replace our dwindling supplies of fossil fuels. In future this work is carried out by using various types of nano fluids to increases heat transfer rate and different receiver materials are used to study with vacuum and without vacuum.

REFERENCES
[1] Anderson T.N, Duke M, Morrison G.L, Carson J.K, “Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector”. Solar Energy 83 (2009) 445–455.
[2] Martinez, I, Almanza, R, Mazari, M, Correa, G: “Parabolic trough reflector manufactured with aluminum first surface mirrors thermally sagged”. Sol. Energ. Mat. Sol. C. 64(1), 85–96 (2000).
[3] Thomas, A, Guven, HM: “Parabolic trough concentrators—design, construction and evaluation”. Energ. Convers. Manage. 34(5), 401–416 (1993).
[4] Donald Jeremy GaitanCal Poly, San Luis Obispo, “Design, Construction, and Test of a Miniature Parabolic Trough Solar Concentrator CA”, Fall Quarter (2012).
[5] Tadahmun Ahmed Yassen,”Experimental and Theoretical Study of a Parabolic Trough Solar Collector”. Anbar Journal for Engineering Sciences (2012).
[6] OmidMahian,AliKianifar,Soteris,Kalogirou,Ioan Pop,Somchai Wongwises,”A review of the applications of nanofluids in solar energy”, International Journal of Heat and Mass Transfer 57 (2013) 582–594.
[7] R. Saidur, T.C. Meng, Z. Said, M. Hasanuzzaman, A. Kamyar, ”Evaluation of the effect of nano fluid-based absorbers on direct solar collector”. International Journal of Heat and Mass Transfer 55 (2012) 5899–5907.
[8] R. Taylor, “Thermal Energy Conversion in Nanofluids”. Phd Thesis Arizona State, University,( August 2011).
[9] N. Castillo, D. Olguin, A. Conde- Gallardo, S. Jiménez- Sandoval, “Structural and morphological properties of TiO2 thin films prepared by spray pyrolysis”, Revista Mexicana De Física (2004) 50 (4) 382.
[10] Jinghuan Zhang, Xin Xiao, Junmin Nan.”Hydrotermal hydrolysis synthesis and photocatalytic properties of nano-TiO2 with an adjustable crystalline structure”. Journal of Hazardous Materials 176, 617–622 (2010).
[11] M.N. Pantzali, A.A. Mouza, S.V. Paras, “Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE)”. Chem. Eng. Sci. 64 (2009) 3290–3300.