Experimental Study of Double Pass water passage in Evacuated Tube with Parabolic Trough Collector

Sarah Bassem\textsuperscript{1} Jalal M. Jalil\textsuperscript{2} Samer Jaffer Ismael\textsuperscript{3}

Electromechanical Engineering Department, University of Technology, Baghdad Iraq
\textsuperscript{1} sarabassem38@gmail.com
\textsuperscript{2} 50003@uotechnology.edu.iq
\textsuperscript{3} 50240@uotechnology.edu.iq

Abstract. In this paper, a new design, fabricate and investigate the performance of the parabolic trough systems (PTC) by using double pass water passage in evacuated tube technology. This system can be used for heating water in winter season without assistive devices. The double-pass method utilizing to improve thermal performance for PTC by increasing the path of water flow in the evacuated tube and then increase the rate of the outlet temperature. Besides, the evacuated tube was used to decrease the thermal losses, which is caused an increase in thermal efficiency. The experiments were test and simulate the different solar radiation approximate to winter season and at many flow rates 0.00305, 0.0055 and 0.0083 kg/s. The higher temperature difference was 46 °C at minimum mass flow rate 0.00305 kg/s. The maximum thermal efficiency was 69.7 % at 0.0083 kg/s.

Keywords: parabolic trough collector; double pass; heating water; evacuate tube; thermal efficiency.

Nomenclature

| Symbols  | means                                | units         |
|----------|--------------------------------------|---------------|
| A_1      | Aperture Area of The Collector       | m\textsuperscript{2} |
| A_r      | Surface Area of The Receiver         | m\textsuperscript{2} |
| A_c      | Surface Area of The Concentrator     | m\textsuperscript{2} |
| D_o      | Diameter for Cylindrical Receiver    | m             |
| f        | Focal Length                         | m             |
| H_p      | Height Of The Parabola               | m             |
| S        | Curve Length Of Parabolic Surface    | m             |
| \phi_c   | Rim Angle                            | degree        |
1. Introduction

The main idea of the parabolic trough collector (PTC) systems is to polarize the sun light and convert it into heat which can be directly utilized in many applications such as solar cooker, water pumping, and water heating [1]. Some researchers in the field of PTC systems were summarized in this section: Solomon [2] modeled and simulated the parabolic trough collector. The mathematical model was carried out by showing the temperature distribution of hot water output. The water output temperature ranged from 80°C to 115°C during the summer season. At winter, the water temperature was less than 80°C. Mohamed [3] designed and studied the parabolic trough collector experimentally by using the stainless-steel layers as parabolic reflector and pipe which made from galvanized steel as receiver without tracking. It was found that the efficiency collector was about 37%. Al-Asfar, et al. [4] fabricated and tested the PTC system. The system length was 6 m, the aperture width was 1.67m, and the rim angle was 100°. Also, the reflector was made from stainless-steel layers and the operation of tracking was manually. The thermal efficiency was 22.4%. Huang, et al. [5] used many technologies as helical fins, dimples, and protrusions to increase heat gain of PTC system. It was observed that the dimples technique was the best option to make thermal improvement. These methods increase the surface area which is increased the heat rate from absorber tube and water. Reddy et al. [6] showed the influence of putting porous discs into receiver surface and enhance heat rate between fluid and tube. It was concluded that the heat rate between the receiver surface, fluid, and receiver cross-section was limited in porous disc case enhanced receiver compared with the conventional tubular-receiver. Fuqiang, et al. [7] clarified the utilization of asymmetric outward corrugated tube for PTC receiver. The results show that the corrugated tube caused increasing in heat rate and reduced the thermal strain of the metal tube. It was concluded that the system design utilized to improve turbulence in the metal tube. Tagle-Salazar, et al. [8] presented the thermal model of PTC system for heating applications by using nano-fluid. The experimental side was performed over a range of parameters by using alumina-water nano-fluid as working fluid. Akharzadeh [9] investigated of a PTC system with nine different tubes with corrugated shape. The friction factor is 1.84 times more than the plain tube. While, the higher thermal efficiency is 65.8% which is obtained for the PTC with a helical corrugated tube with a pitch length 3 mm and the roughness height 1.5 mm. In present work, focuses on designing, implementation, testing and experimental evaluation to the thermal system of high efficiency parabolic trough collector using double pass of water passage in evacuated tube, will be investigated with different mass flow rates and solar radiations. The essential purpose is to enhancement the thermal performance of parabolic trough collector, which can be used for water heating application.

2. Theory

The designed parameters were calculated from geometric of circular parabolic reflector with sun incident angle and investigated in this section [10], [11], [12] .

The concentration ratio which is given by:

\[ \text{CR} = \frac{\text{Aa}}{\text{Ar}} \]  

(1)

Where:

\[ \text{CR} = \text{Concentration ratio} \]

Rim angle is calculated as below
The thermal efficiency is calculated as follows:
\[ \eta = \frac{Q}{A \cdot I} \]  

Where:
A: area of aperture for collector (m²) 
I: radiation solar (W/m²) 

Q is heat gain useful (W) 
m: is a mass of water flow rate (kg/s) 
Cp: is a heat specific (J/kg. K) 
ΔT: Temperature variation between the output and input for water (°C)
3. Experimental Setup

In this work, the parabolic trough solar collector was designed with double pass evacuated tube and was tested indoor. Experiments were performed by two rows of halogen lamps, each contains 6 lamps so a total of 12 halogen lamps were used, each of which has 500 W of rated capacity. The distance between one lamp to another is 13 cm, and the distance between the two rows is 25 cm. The height between the parabolic trough collector and halogen lamps is 150 cm to ensure direct and uniform solar radiation distribution across the device. Dimmer had been employed to monitor the intensity of light from the halogen lamps.

The parabolic trough solar collector system consists of structure of the reflector, reflector and the double pass evacuated tube.

The structure of the reflector has a rectangular shape; the reflector proves inside the frame with rectangular shape. The reflector has 175.5 cm length, 100 cm width and 0.25cm height. The structure of the reflector is manufactured from the aluminum clips of a 4*4 cm square shape. The selected material would low cost.

The reflector was made of style steel because the reflectivity of style steel is very high, the reflector dimensions are listed in Table 1, The reflector is installed within the allotted temple to form a parabola trough. The appendages of the reflector are worked from both sides along the reflector to install the sides of the reflector on the structure using screws. The parabola is installed from the bottom with the structure using adhesive, in order not to deform the front surface of the reflector. Using screws for installation from the bottom will lead to deformation of the reflector surface. Figure (1) shows the reflector surface.

Table (1) system specification of PTC

| Parameter                                      | Value       |
|------------------------------------------------|-------------|
| Collector Aperture area                        | 1.73 m²     |
| Aperture width -Wa                            | 1 m         |
| Rim angle                                      | 90°         |
| Focal length                                   | 0.25 m      |
| Mirror reflectivity                            | 0.91        |
| Geometrical Concentration ratio                | 17          |
| Outer diameter of evacuated glass              | 5.5 cm      |
| Inner diameter of evacuated glass              | 4.5 cm      |
| Inner diameter of double pass pipe            | 6.35 mm     |
| Length of evacuated tube                       | 1.83 m      |
| Coating absorbance of double pass evacuated tube | 0.94      |
| Coating emittance of double pass evacuated tube | 0.06      |

The focal length is 0.25 m from the vertex V and rim angle 90° [13]. The aperture width of the system (Wa) is 1m. The double pass evacuated tube, consist of two-layered glasses evacuated tube that were fused jointly at one end, and selective coating absorbing deposited of outer surface for absorber tube. The length and outer diameters of outer glasses and absorber tubes are 183cm, 5.5cm, and 4.5cm, respectively. The double pass tube is welded inside evacuated tube. Double pass tube made of copper; the diameter selected of 0.635cm as shown in Figure (1). Water was used as a working fluid.
where it supplied from a tank which is placed higher than the collector position and open loop system is adopted for water circulation.

Figure (1) Parabolic trough collector system with double pass water passage in evacuated tube

4. Result and Discussion

The performance results for parabolic trough solar collector such as outlet temperature and thermal efficiency are obtained. Experimental results are obtained in different solar radiations and water flow rates. Figure (2) demonstrates the temperature inside the surface of evacuated tube at different water flow rates. The greater temperature inside the surface of evacuated tube is 145°C at 0.00305 kg/s because the heat extraction is low between tube and water at minimum water flow rate. The temperature of water difference increases with increase in solar radiations. The impact of solar radiations in the temperature difference at different mass flow rate was shown in Figure (3). Figure (4) illustrates the effect of mass flow rate on the temperature water difference. Both Figures (3,4) show decreasing in water flow rate and increasing in the solar radiations led to increase in the temperature difference because when the flow rate is low, the water flow is slow, thus prolonging the heating time of the water during the flow in the tube. Consequently, higher temperatures are
obtained, and vice versa. The maximum temperature difference reached 46 °C, at mass flow rate 0.00305 kg/s and solar radiations 780 W/m².

Figures (5, 6) display the difference of the thermal efficiency with mass flow rate at all values of solar radiation (300-400-500-600-780) W/m². The collector thermal efficiencies increase with an increase in water flow rate and reach maximum point and then decrease because of the decrease in the temperature difference at mass flow rate increases. Maximum thermal efficiency reached 69.70 % at water flow rate equal to 0.0083 kg/s meanwhile, minimum value reached 24.60 % at 0.00305 kg/s of water flow rate.

**Figure (2)** Difference of temperatures inside surface of evacuated tube with mass flow rate at different solar radiation

**Figure (3)** Difference temperatures with solar radiations at different values of mass flow rate
Figure (4) Difference temperatures with mass flow rate at different solar radiations

Figure (5) Difference of thermal efficiency with solar radiation at different values of mass flow rate
5. Conclusion

1- The results indicated that the system can be used for heating water in winter season without assistive devices, also can be used in factories and their applications, and in electrical stations to heat water before entering the steam boiler, which leads to a reduction in spent fuel.

2- The higher temperature difference between inlet and outlet is $46^\circ$ C at $0.00305 \text{ kg/s}$ and $780 \text{ W/m}^2$.

3- The maximum thermal efficiency is $69.7\%$ at $0.0083 \text{ kg/s}$ and $780 \text{ W/m}^2$.

4- The effect of mass flow rate on system efficiency is studied, can be concluded that the efficiency increases as the mass flow rate increase.

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