Investigation of Thermal Performance of Evacuated Tube with Parabolic Trough Collector with and without Porous Media

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Abstract In this paper a new model has demonstrated that it operates in a moderate performance scale to generate hot water. In its early stage, the preliminary model, which built with double pass water tube inside evacuated tube, was investigated experimentally. The model was tested inside room under different operation conditions in terms of solar radiation 300, 400, 500 and 600 W/m² and water mass flow rates 0.00305 and 0.0083 kg/s. In the first case, there was a problem because of the air gap inside the tube and surrounding the double pass water tube, so In the second stage, two different filling medium inside the evacuated tube was proposed to modify the preliminary model. The mediums cases include porous media (stainless steel wire mesh and Aluminum fiber metallic). The results show that maximum efficiency without porous media was 62.4% at 0.0083 kg/s and heat flux 600 W/m², but after porous media applied, the efficiency reached 79.4% at 99.997% porosity of Aluminum fiber metallic and heat flux 600 W/m² with same water mass flow.

Keywords: Parabolic trough solar collector; Double pass tube; Evacuated tube; Thermal efficiency; Porous media

1. Introduction

The basic principle of the parabola trough collector (PTC) systems are to polarize sunlight into heat that can be instantly used for solar cooker applications or heating and water pumping. [1],[2]. Some researcher in the field of (PTC) systems were briefed in this section: Liang Zhang et al. [3] The thermal effectiveness of the receptor was found to be 0.472 in windy days in an experimental assessment of the heat losses of a U-type double-glazing solar receptor. Mohamed [4] Experiments conducted on parabolic troughs, stainless steel sheets and steel pipes were employed as recipients. The average collector effectiveness was around 37 percent without tracking. Chiad et al. [5] Enhanced efficiency in the design of PTSC, reduce heat losses and assist the mechanism of the sun tracker. The PTSC was made from a glass mirror in several pieces to make up the parabolic reflector. The experiments indicated that the median thermal efficiency was 50%, and the evaluation findings of a local PTSC were quite reasonable. Gong et al. [6] The parabolic trough receptor absorber tube with pin fin arrays inserted was fitted to increase the tube receptor's overall heat transfer performance for a parabolic solar system trough. The results show that heat transfer performance may be improved by up to 12.0 percent. Ghasemi et al.
investigated numerically 3-D turbulent flow for Syltherm 800 heat transfer fluid in the absorber tube of the solar system, the thermo hydraulic characteristics of solar parabolic trough collectors with porous rings. Computational Fluid Dynamics utilized to implement numerical simulation (CFD). The results show the heat transfer characteristic improves by lowering the distance between porous rings while increasing the inner diameter of the porous rings. Adel A. Eidan et al. [8] tested experimentally heat pipe evacuated tube solar collector (HP-ETSC) with various types of acetone based nano fluids, different values of ratios (40, 50, 60, 70 and 80%) and tilt angles (30°, 45° and 60°) are considered, the results show enhancement in thermal performance (20–54%). Singh et al. [9] investigated the experiment of a double pass converging finned wire mesh packing solar collector system, wire mesh enhance convective heat transfer to air by increasing the heat transfer region and air velocity at a given airflow rate. Subramanian et al. [10] tested a PTC with different absorber surface: i) Aluminum sheet ii) Aluminum foil iii) Mirror sticker, found that more heat absorption is obtained by using Aluminum sheet. Akbarzadeh et al. [11] The impacts on the thermal and exergy efficiency of PTC of the pitch by diameter and the ratio height to diameter of the corrugated tubes were examined. To do this, the PTC can achieve a maximum efficiency of 65%. 9 different helically corrugated tubes have been evaluated. Ahmed Amine Hachicha et al. [12] studied the influence of suspended industrial-grade multi-walled carbon nanotubes (MWCNTs) in distilled water (DW) on low to medium-temperature PTCs was investigated using numerical and experimental methods. The suspension of MWCNTs nanoparticles in water enhanced Nusselt number by 12 percent, 16 percent, and 21 percent. For flow rates less than 0.2 L/s, Nano fluid usage at low concentrations might improve thermo-hydraulic performance. Jalal M. Jalil et al. [13] investigated the effect of porous medium in the lower channel of double pass air heater solar collector, used stainless steel wire mesh and steel wool as porous medium, founded enhancement in thermal efficiency. the thermal performance of the double passage water in the evacuated tube in the parabolic trough collector is being studied by a variety of porous media, porosity, mass flow rates and solar radiation. The main objective is to increase parabolic trough collector thermal performance that may be utilized to heat water.

2- Theory

The useful heat gain was practically calculated:

\[ Q = m \cdot C_p \Delta T \]  

Where:
\nQ: useful heat gain (W) 
\nm: mass flow rate of water (kg/s) 
\nCp: specific heat (J/kg. K) 
\n\Delta T: Temperature difference between water outlet and inlet (°C) 

Thermal efficiency is calculated by:

\[ \eta = \frac{q}{A \cdot I} \]  

Where:
\nA: collector aperture area (m²) 
\nI: solar radiation (W/m²) 

Porosity [14]

\[ \phi = \frac{\nu \cdot v}{\nu t} \]  

Where:
\n\nu \cdot v \text{ the volume of vacuum is occupied by space}
\( \nu_t \) is the complete or bulk volume of material.

3. Experimental Setup

A parabola solar collector was created in this study using a tube with two passes evacuated and tested indoor. Two rows of halogen lights were conducted in experiments, each of which containing 6 lamps, the total of 12 halogen lamps with a nominal capacity of 500 W were utilized. It is 13 cm from one lamp to the other, and 25 cm from each of the two lanterns. The height between the parabola and the halogen lights is 150 cm, so that the sun radiation dispersion may be direct and homogeneous throughout the device. To monitor light intensity from halogen lamps, Dimmer was used.

The solar collector system comprises of a reflector structure, a reflector and an evacuated tube double pass.

The reflector's framework has a rectangular form and the reflector has a rectangular shape inside the frame. Length, width and height of the reflectors is 175.5 cm. The reflector structure is made from 4*4 cm square-shaped metal clips.

The outer diameters and length of the outer glass tube and absorber tube are 5.5 cm, 183 cm, and 4.5 cm, respectively. The tube with double pass is within the tube being discharged. Double pass copper tube; diameter chosen as indicated in illustration of 0.635 cm (1). Water was utilized as working fluid, supplied from a tank higher than collector location, and the water circulation system is open loop.

In this study, two types of porous media have been used, inserted inside evacuated tube and surround the double pass tube. The two types are; used stainless steel wire mesh with two porosities 99.996 and 99.995% and fiber metallic Aluminum with two porosities 99.997, 99.998%, as shown in Figures (2),(3) and (4).

![Parabolic trough collector system with double pass water passage in evacuated tube](image_url)

**Figure 1.** Parabolic trough collector system with double pass water passage in evacuated tube.
4. Results and Discussion
It is clear that when the porosity which is proportional to volume of void in the material is reduced, the voids are reduced and the porous media increases. Reducing the porosity increases heat transfer (reduces the air gap within the tube) and acquires heat from the porous media. Figures (5) and (6) show comparisons with and without a porous medium (steel wire mesh) at different radiation and different mass flow rate, also show the effect of porosity on the temperature difference. Outlet temperature increased with a decreased in porosity.

Solar collector with use of porous media in the tube of the collector enhances thermal efficiency as compared to collector without porous media. Figures (7) and (8) display the effect of porosity on the thermal efficiency. Maximum thermal efficiency is 67.4% at porosity 99.995%.

Low porosity increases heat transfer inside the tube. Figures (9) and (10) show comparisons between with and without porous media (Aluminum fiber metallic) at different solar radiation and at two porosities.

When efficiency is compared between stainless steel wire mesh at porosity 99.995% and Aluminum fiber metallic at porosity equal to 99.997%, it was found that the thermal efficiency for Aluminum is
higher than stainless steel due to thermal conductivity of Aluminum being higher than stainless steel. The maximum temperature difference when using steel wire mesh reaches 34 °C at porosity 99.995%, meanwhile, the maximum temperature difference when using Aluminum reach 41 °C at porosity 99.997% as shown in Figures (11) (12). The maximum efficiency when using steel wire mesh reaches 67.4% at porosity 99.995%, meanwhile the maximum efficiency when using Aluminum reaches 79.4% at porosity 99.997% as shown in Figures (13) and (14).

**Figure 5.** Comparison between with and without porous media at 0.00305 kg/s

**Figure 6.** Comparison between with and without porous media at 0.0083 kg/s
Figure 7. Effect of porous media and solar radiation on efficiency at 0.00305 kg/s

Figure 8. Effect of porous media and solar radiation on efficiency at 0.0083 kg/s

Figure 9. Comparison between with and without porous media at 0.00305 kg/s
Figure 10. Comparison between with and without porous media at 0.0083 kg/s

Figure 11. Comparison between steel wire mesh and Aluminum fiber metallic with solar radiation
Figure 12. Comparison between steel wire mesh and Aluminum fiber metallic with solar radiation

![Graph showing temperature difference vs. solar radiation for different materials.]

Figure 13. Comparison between steel wire mesh and Aluminum fiber metallic with solar radiation

![Graph showing efficiency vs. solar radiation for different materials.]

Figure 14. Comparison between steel wire mesh and Aluminum fiber metallic with solar radiation

![Graph showing efficiency vs. solar radiation for different materials.]
5. Conclusions

The maximum thermal efficiency without any material was 62.4% at 0.0083 kg/s and heat flux 600 W/m² and the maximum efficiency with porous media was 79.4% at 99.997% porosity of aluminum fiber metallic at 0.0083 kg/s and 600 W/m² heat flux. The porosity and thermal conductivity of porous media play an important role in the temperature difference. Decreasing in porosity and increasing thermal conductivity of porous media led to increasing outlet temperature. The outcomes showed that the system could be utilized for water heating in winter season without assistive devices.

6. References

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