Theoretical Efficiency and Practicality of the Solar Trough Collector / Tikrit-Iraq

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Abstract

An experimental and theoretical study was conducted to attain solar collectors' thermal efficiency. Testing was done during May of 2019 on a solar collector's surface at the Physics Department of the University of Tikrit. The absorbent tubes used had a length of 1.5 m, were painted black, made of copper, had an outer diameter of 0.03 m, internal diameter of 0.028 m, and a tank capacity of 40L. By entering these specifications along with those of the solar collector, the theoretical thermal efficiency was calculated. The findings showed that practical efficiency curves and useful thermal energy absorbed by the water contained goes down when using copper tubing. The results also illustrated that useful thermal energy and thermal efficiency increases along with increasing the mass flow rate of water.


Introduction

Solar energy is environmentally friendly and is the planet's main source of clean energy. It provides the energy necessary to maintain the presence of life on the Earth's surface. Within one-hour sufficient solar energy arrives the earth's surface to meet its clean energy requires for a whole year. Techniques have therefore been developed to capture it and are currently the most appropriate way to collect solar radiation. Researchers have studied different solar collector models, including solar trough collectors and parabolic dishes (Ayush, 2014; Mahmood, 2018; Messenger & Abtahi, 2017). This study is of the thermal transfer properties for the absorbent tubes of a solar collector through a receiver, using a three-dimensional digital simulation. The Monte Carlo model has been applied to calculate the solar radiation distribution the external surface of the receiving tube. It was noted that there was a great deal of heterogeneity in the distribution and spread of flow (Cheng, He, Xiao, Tao, & Xu, 2010; Senthil & Cheralathan, 2017). A practical study of a solar collector was also conducted. The collector was designed and manufactured from locally available materials within an area of 5.4m². Mirrors were used as a reflector for solar radiation, the receiver was made of steel, and oil was used for heat transfer. The practical results found the system's efficiency at 42% (Chiad et al., 2011). The theoretical thermal efficiency was reported by introducing the dimensions of the solar collector and its specifications to the FORTRAN 90 program. The findings from this showed that practical efficiency is less than theoretical efficiency and that the thermal efficiency increases along with an increased mass flow (Yassen, 2012).

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An automatic tracking system was also installed, as it was observed after several experiments that it is more effective and gives us greater efficiency than a manual tracking system (Singh & Kumar, 2013). It provided a basic mathematical model showing the thermal exchange between major units of the solar collector in the integrated solar cycle location (ISCC). The model obtained was used to achieve a simpler simulation of the studied system and to give developments for the heat move from one place to another inside the receiver tube. This model can be used to improve the collector design to the desired objectives (El Jai & Chalqi, 2013).

This study focused on the reasons behind the bending of the absorption tube which is undesired and often results from incorrect installation (Wu et al., 2014). Through parametric analysis of the solar collector, several elements were selected in the system, such as: the receiving tube diameter, the receiving tube material, and the heat transfer fluid. These were used to for the parametric analysis' study and evaluation of the system performance (Bharat, 2015). To evaluate the solar collector design's performance, its length was 5 m and the transfer medium for heat was made of iron and water. Simulated studies were conducted using an ANSYS program on the surface of the receiving tube to ensure design efficiency (Murtuza, Byregowda, & Imran, 2017). The aim of the study was to find and compare the solar collector’s practical and theoretical efficiency with the use of two types of absorbent tubes: iron absorbent tubes and a copper absorbent tubes. A speculative report has been hereby written outlining the difference in sun-controlled essentialness into warm imperativeness using an illustrative trough gatherer. The aim is to consider this gatherer's introduction to the North-West region of Morocco. The method is built on achieving warmth exchange conditions by a numerical multiplication. Matlab programming is used to study the introduction of the symbolic authority of the zone environment. This examination will allow for the separation of the temperature and imperativeness results gotten by the glow move fluid, using certified parameters (Leemrani, Marrakchi, Asselman, & Asselman, 2018). The trial testing demonstrates the development and testing of three trough sun-oriented gatherers (PTSC) with the objective of delivering moderate-temperature steam. The exploratory examination was completed on PTSC to test the warm presentation of the framework extended for 9 days over July and August, 2018. Various guideline of the PTSC framework have been chosen for measuring throughout this investigation. Measured variables include: the heat transfer liquid (HTF) type (pressure driven oil, ethylene glycol, and water), and three stream paces of the given liquid (1 LPM, 2 LPM, and 3 LPM). The steam age procedure occurs with a vapor temperature of 95.4°C, and a steam weight of 2.1 bar. The investigations demonstrate that the largest heat increases and highest proficiency occurs with pressure-driven oil, as does the most elevated estimation of liquid stream rate. The outcomes demonstrate that the greatest valuable warmth increase is about 1.035 kW, 0.879 kW, and 0.734 kW for using pressure driven oil, ethylene glycol-based water, and water individually, with an LPM stream average of 3 (Abbood & Mohammed, 2019b). The aim was to assess nanomaterial’s effect on thermal efficiency, entropy generation, enhanced heat transfer coefficient, and the pressure drop in PTCs. It has been explained that Nano fluids not only typically enhance thermal efficiency, thermal heat transfer coefficient, and system efficiency, but can also reduce system entropy generation. The sole obstacle in Nano fluid application in PTCs has been found to increase the pressure drop. This can be controlled by improving the fraction of nanoparticle size and mass flow rate (Olia et al., 2019).

Experimental Work

A solar trough with a manual one axis solar tracking system directed towards the south was used, as shown in Fig. (1). The solar trough was composed of stainless-steel sheets with thicknesses of 0.1mm, and was installed on an iron parabolic structure which was 1.5m long and 1m wide. To carry the structure of the collector, iron structures were manufactured with a thickness 0.2mm and height of 86cm. These were installed in the ground and were used with the copper absorbent tubes with a glass cover. The testing was conducted from 9:00 am until 2:00 pm on a clear day in May of 2018 at the University of Tikrit within the Physics Department building. During the test, the PTSC was placed vertically in the sun by moving the collector manually using a linear motor and two batteries (12 volt), like those used in satellite dishes. This is shown in Fig. (2). The water temperature was measured at the input and exit of the solar collector; the ambient temperature was measured using (k-Type) thermocouples and a thermometer; a solar
A meter was applied to report the solar radiation intensity; a flow meter was used to measure the mass stream average of water; and an anemometer was used to measure the wind speed.

**Fig. 1.** A+B. Shows the solar trough collector

**Fig. 2.** Linear motor for tracking system

### Thermal Analysis of a Solar Trough

The thermal losses from the absorbent tube has been evaluated in terms of the UL loss coefficient. Calculations included conductivity, radiation and convection. The total thermal loss coefficient was calculated from the following equation (Al-Hamadani, 2017):

\[
U_L = h_w + h_{rad,r-sky} \quad (1)
\]

\(U_L\) = Overall heat loss coefficient (W/m²·°C)

\(h_w\) = The wind heat transfer coefficient (W/m²·°C).

\(
h_{rad,r-sky}\) = Radiation heat transfer coefficient between absorbent tube and ambient (W/m²·°C)

\((h_w)\) is calculated from the following equation (Dheyab, 2017)

\[
h_w = 5.7 + 3.8 V \quad (2)
\]

\(V\) = Wind Velocity m/sec

The heat transfer coefficient of the radiation between the absorbent tube and the ambient was calculated using this equation [16]:

\[
h_{rad,r-sky} = \varepsilon_r \sigma (T_r + T_{sky}) (T_r^2 + T_{sky}^2) \quad (3)
\]

\(\varepsilon_r\) = Emissivity of absorber.

\(\sigma\) = Constant Stephan Boullmann 5.67x10⁻⁸ (W/m²·K²)

\(T_r\) = Absorbent tube temperature (°C)

\(T_{sky}\) = Sky Temperature (°C)

is calculated from the following equation:

\[
T_{sky} = 0.055 T_a^{1.5} \quad (4)
\]

\(T_a\) = Air temperature (°C).

The temperature of the absorbent tube was calculated from the following equation:

\[
T_r = T_{mf} + \frac{m \cdot C_p (T_{mf} - T_{fl})}{h_e \cdot A_{rt}} \quad (4)
\]

\(T_{mf}\) = Average water temperature (°C)

\(m\) = mass flow rate (kg/sec)

\(C_p\) = specific heat capacity at constant pressure of fluid (J/kg·K)

\(T_{fl}\) = outlet fluid temperature (°C).

\(T_{in}\) = inlet fluid temperature (°C).

\(A_{rt}\) = internal Surface area of absorbent tube

\(h_e\) = heat transfer coefficient inside absorbent tube (W/m²·°C).
The coefficient of the heat transfer within the absorbent tube was calculated from the following equation [10]:

\[ h_{c,i} = \frac{K_f}{D_{r,i}} \left[ \frac{N_u}{1 + 0.04 \left[ \frac{D_{r,i}}{L} \right] R_{a,1} P_{r1}} \right] \]  

(6)

\[ h_{c,i} = \frac{K_f}{D_{r,i}} \left[ 3.6 + \frac{0.0666 \left( \frac{D_{r,i}}{L} \right) R_{a,1} P_{r1}}{1 + 0.04 \left[ \frac{D_{r,i}}{L} \right] R_{a,1} P_{r1}} \right] \]  

(7)

L = the length of the collector

The number of Reynolds= the number of Brantel

The number of Reynolds \( (R_{e,f}) \) was calculated from the following equation (Dheyab, 2017):

\[ R_{e,f} = \frac{4 m}{\pi D_{r,0} U_L} \]  

(8)

\[ P' = \frac{1}{U_L} \left[ \frac{D_{r,0}}{R_{a,1} D_{r,i}} \right] \frac{D_{r,i} c_m \left( \frac{D_{r,0} - D_{r,i}}{D_{r,0}} \right) \frac{1}{2k}} {1 + 0.04 \left[ \frac{D_{r,i}}{L} \right] R_{a,1} P_{r1} \frac{R_{a,1}}{2k}} \]  

(9)

\( D_{r,0} \) = The external diameter of the absorbent tube

\( K_f \) = Thermal conductivity of an absorbent tube

The heat removal coefficient was calculated using this equation:

\[ F_R = \frac{m c_p F'}{A_{r,1} U_L} \left[ 1 - \exp \left( \frac{A_{r,1} U_L F' \ell}{m c_p F'} \right) \right] \]  

(10)

The theoretical efficiency was calculated using this equation (Ayush, 2014; Senthil & Cheralathan, 2017).

\[ \eta_{th} = \frac{Q_{u,th}}{U_L A_{r,1}} \]  

(11)

\[ \eta_{th} = \frac{F_R}{U_L A_{r,1}} \left[ \frac{U_L - U_L \left( T_f - T_{air} \right)}{U_L - U_L \left( T_f - T_{air} \right) \ell} \right] \]  

(12)

The practical efficiency was calculated using this equation:

\[ \eta_{exp} = \frac{Q_{u,exp}}{U_L A_{r,1}} \]  

(13)

\[ \eta_{exp} = \frac{m c_p F' \left( T_f - T_{air} \right)}{U_L A_{r,1}} \]  

(14)

**Results and Discussion**

Figure (3) shows the comparison of the experimental and theoretical results of thermal efficiency using a Copper absorbent tube. It shows that the theoretical thermal efficiency was almost constant, while the experimental thermal efficiency gradually increased with the increase of solar radiation from 9 am until peak time, wherein it reached the highest value and then decreased gradually until the last reading at (2:00) PM, with the lowest intensity of solar radiation. Experimental thermal efficiency was here less than the theoretical thermal efficiency because of the system’s thermal and optical losses, and the assumption that the weather conditions would be good, and the sky would be free of dust and clouds. In fact, there was a change in weather conditions, including the appearance of clouds and a change in wind speed. This affected the value of the experimental thermal efficiency and practical thermal efficiency in the copper absorbent tube, which had a higher flow of water (130 L/h) due to copper’s high thermal conductivity. A material’s ability to transfer heat depends on the degree of heat conductivity. When the thermal conductivity of the material increases, it becomes more efficient at thermal conductivity (Yassen, 2012).
Figure (4) shows that the water temperature when exiting the solar collector increased when using a copper absorbent tube along with an increase in solar radiation intensity, until peak time wherein it reached the highest value and then decreased gradually to the lowest intensity. The outgoing water temperature and incoming water temperature of the copper absorbent tube was higher than the outlet temperature at the mass flow of water (130 L/h), due to the high thermal conductivity of the copper tube. A material's ability to transfer heat depends on the degree of heat conductivity. When the thermal conductivity of the material increases, it becomes more efficient at thermal conductivity (Dheyab, 2017; Padilla, Demirkaya, Goswami, Stefanakos, & Rahman, 2011).

Figure (5) shows the useful energy absorbed by the water as this absorbed useful energy passed through a copper absorbent tube at the same water mass flow rate.

From the figure it is apparent that the useful energy absorbed by the water gradually increased with the increase in the intensity of solar radiation from 9:00 AM until reach the highest value at the peak time, before it decreased along with the lowest intensity of solar radiation at 2:00 PM. It can also be noted that the useful energy gained by the water when using a copper absorbent tube was greater than its iron counterpart because the thermal conductivity of copper is higher (Dheyab, 2017).
Figure (6) shows that the temperature of the copper absorbent tube was higher because of its higher thermal conductivity. A material's ability to transfer heat depends on the degree of heat conductivity. When the thermal conductivity of the material increased, it becomes more efficient at thermal conductivity (Abbood & Mohammed, 2019a; Tzivanidis, Bellos, Korres, Antonopoulos, & Mitsopoulos, 2015).

**Conclusions**

- Theoretical thermal efficiency is greater than practical thermal efficiency.
- Theoretical useful energy is greater than practical useful energy.
- The useful energy acquired by and practical thermal efficiency of copper absorbent tubes is greater than that of iron.

**References**


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