Parabolic solar water heater performance with optimum tracking system: Baghdad city case study.

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Abstract. The energy extracted from the solar is changing cording to seasons and the way of tracking. In this study, have been five tracking modes are North-South and East-West, which have been rotating over the seasons of the year. Also, the Baghdad city has been chosen to select the optimum tracking mode. A mathematical pattern has been used to solve numerically. From this study, deduced that all the tracking models performance is converging at the noon period of the North-South tracking mode. These will allow the highest solar energy collected is 34.15% from the East-West tracking rotating mode.

1. Introduction

The energy used in many applications related to the dangers of energy source depletion is increasing, and the consciousness of the climate global warming changes, many institutes, and organizations encouraged to minimize the release of Carbone dioxide and increase alternative green energy [1]. The inexpensive source of green energy worldwide is solar energy, which can be applied immediately for heating by utilizing a flat plate or parabolic solar heater or by converting it into electricity by using the photovoltaic cells. The greater solar density is getting by the efficient performance of the solar systems should be tracking the sun continuously or, stationary with appropriate direction and orientation relate to the sun. Many studies are embracing to investigate the performance and orientation of many solar energy-collecting devices. Jingyi et al. [2] recommended improving water heater technology by reducing the cost of manufacturing. Subhi et al. [3] performed a simulation study to carry out the performance of solar water heater by using numerical prediction, and they predicted that the performance of solar water heater is directly proportional to solar radiation. Tadahmun [4] studied the effect of seasonal changes on parabolic solar water heater efficiency, and the study observed that the thermal efficiency of a collector in summer is (2-5)% less than in winter. Other authors in [5-17] estimated the effect of tilted angle on the performance of PV-cell, the study show mathematically and experimentally that optimum photovoltaic cell performance which adopted with one tilted angle that is not equal to the latitude of operating locations. Mayur et al. [10] predicted experimental the amount of collected solar energy by a parabolic solar water heater, and they observed that the greater collection of energy will be at noon period. F. Jamadi [11] examined the effect of heating fluid rate of mass flow on collected heat thermal performance and obvious that the heating fluid mass flow rate has a positive effect on thermal efficiency, meanwhile, adversely affect on the collected solar energy. Rajamohan et al. [12] enhanced the performance of the solar water heating system by using a parabolic dish concentrator and conical absorber. The study concludes that using a parabolic dish concentrator contributes to increasing efficiency by 23.96 %. Maher et al. [13, 17] examined the effect of the tracking system on the collected energy of parabolic solar water heater heating located in Basra city. The study concludes that the North-
South rotating give the highest thermal performance from others. Miguel et al. [14] performed an analytic study by using software to investigate the effect of tracking or fixed arrangement on the energy collected by the compound concentrator parabolic. The study founds the varying tilted angle over all the year that will increase the collected energy by 22% than that of a fixed one.

2. Solar Radiation Geometry
To find the beam energy falling on the surface having an orientation, have been studying the performance of cylindrical parabolic solar water heater with different tracking modes. The covering equations of solar energy for finding the solar intensity should be obtained by the following equations [5][6]:

\[ I_c = I_o R_b \]

\[ I_d = H_d (\bar{a} + \bar{b} \cos \theta) I_o H_o^{-1} \]

\[ \bar{a} = 0.422 + 0.113 H_d H_g^{-1} \]

\[ \bar{b} = 2(1-\alpha) \sin \omega_s \cos \omega_s - 0.5 \sin 2\omega_s \]

\[ R_b = \cos \theta \cos \theta_z^{-1} \]

\[ \cos \theta_z = \sin \phi \sin \delta + \cos \delta \cos \phi \sin \omega \]

\[ \delta = 23.45 \sin [0.9863(284 + n)] \]

\[ H_g = (a + b) S S_{\text{max}}^{-1} H_o \]

\[ H_o = 24\pi^{-1} I_c (1 + 0.033 \cos (0.9863 n) + \omega_s \sin \phi \sin \delta + \cos \delta \cos \phi \sin \omega) \]

\[ a = -0.309 + 0.539 \cos \phi - 0.0693 E_t + 0.295 S_{\text{max}}^{-1} \]

\[ b = 1.527 - 1.027 \cos \phi + 0.0926 E_t - 0.359 S_{\text{max}}^{-1} \]

\[ \omega_s = \cos^{-1}(-\tan \phi \tan \delta) \]

\[ S_{\text{max}} = 0.133333 \omega_s \]

\[ I_g H_o = I_o (C + D \cos \omega) H_g \]

\[ I_o = 1.367 (1 + 0.033 \cos (0.9863 n)) \cos \theta_z \]

\[ C = 0.409 + 0.5016 \sin (\omega_s - 60) \]

\[ D = 0.6609 - 0.4767 \sin (\omega_s - 60) \]

3. Cylindrical parabolic solar heater tracking modes
A cylindrical parabolic collector was orienting with its focal axis pointed either in the East-West (E-W) or North-South (N-S) direction. In the East-West orientation, the focal axis is horizontal. While in the north-south orientation, the focal axis may be horizontal or inclined, as shown in Figure 1.
3.1. Tracking Mode 1

In this mode, the collector rotates around the E-W axis, so the tilted angle of the aperture plane depends on the location of the latitude and declination angle. For each day, there is a declination angle, so that the tilted angle should be daily adjusted (once per day). The tilted angle is equal to:

\[ \beta = \phi - \delta \]

The beam radiation incidence angle for this mode can be obtained by using the following:

\[ \cos \theta = \sin^2 \delta + \cos^2 \delta \cos \omega \]

3.2. Tracking Mode 2

In this mode, the collector rotates around the E-W axis. So the tilted angle of the aperture plane depends on the location of the latitude, declination angle, and the time. So for each day, the tilted angle should be hourly adjusted (once per hour). The tilted angle is equal to

\[ \tan(\phi - \beta) = \frac{\tan \delta}{\cos \omega} \]

The beam radiation incidence angle for this mode can be obtained by

\[ \cos \theta = (1 - \cos^2 \delta \sin^2 \omega)^{1/2} \]

3.3. Tracking Mode 3

In this mode, the collector rotates around the N-S axis. So the tilted angle of the aperture plane depends on the location of the latitude, declination angle and the time. So for each day, the tilted angle should be hourly adjusted (once per hour). The tilted angle is given by,

\[ \beta = \tan^{-1}(\cos \delta \sin \omega (\sin \phi \sin \delta + \cos \delta \cos \phi \cos \omega)^{-1}) \]

The beam radiation incidence angle for this mode can be obtained by

\[ \cos \theta = ((\sin \phi \sin \delta + \cos \delta \cos \phi \cos \omega)^2 + \cos^2 \delta \sin^2 \omega)^{1/2} \]

3.4. Tracking Mode 4

In this mode, the collector rotates around the N-S axis, so the tilted angle of the aperture plane depends on location latitude only so that the collector is fixed with a tilted angle according to location. This states,
For this mode, the beam radiation incidence angle is equal to a declination angle, as follows,

3.5. Tracking Mode 5

In this mode, the collector rotates around the N-S axis. The tilted angle of the aperture plane depends on the location of the latitude and declination angle. For each day, there is a declination angle, the tilted angle should be daily adjusted (once per day). The tilted angle is equal to

\[ \beta = |\varphi - \delta| \]

In this mode, the beam radiation incidence angle is equal to

\[ \cos \theta = 1 \]

Figure 2. Air mass variation for a different month.

4. Result and discussion

4.1. Effect of air mass on collected solar energy

Air mass is the path length, that sun rays take through the atmosphere normalized to the shortest possible path length, the air mass has an unfavourable influence on the collected energy by any tracking solar system. Figure 2 shows the air mass has higher values at the sunrise and sunset period. Because of the sun rays spend more path, the intensity of the solar energy at the sunrise and sunset is lower values of noon at any location.
4.2 **Spring season**

In the solar calendar, the spring season period is located from the 21 of March to the 20 of June. Figure 3 represents the collected energy of all five tracking modes. It has higher values at the noon period, and these values will be low at the sunrise and sunset period. This owing to the solar radiation is depleted during its passage through the atmosphere before reaching the earth’s surface. This depleting will increase with increasing the passaging path that represents the influencing of air mass that directly proportional to zenith angle variation, this shown in Figure 2. In light of Figure 3, the tracking mode 5 gives the highest collected solar energy, due to this mode is always tracking the sun rays, consequently from Figure 4 the beam solar radiation incident with angle approach to zero. That will reduce the reflected solar energy out of the collector.

![Figure 3. Tracking models performance over Spring season](image-url)
4.3 Summer season

The period of the summer is started from the 21 of June to 23 of September. Figure 5 shows two periods: the first one represented the first half of the Summer season. The highest collected energy happened in modes 3 and 5 more than others, because of the smallest incidence angle with an aperture plane, as shown in Figure 6. That will reduce the amounts of reflected energy.

Figure 5 represents the last half of the summer season. The collected energy values by E-W rotating of modes 5 and 4 are higher than 1, 2, and 3. Therefore, the incidence angle with an aperture plane of rotating E-W mode is smaller in Figure 6, so reducing the amount of reflected energy.
4.4 Autumn season

The period of the Autumn season, located from 24 September to 20 December, Figure 7 indicates the tracking model's performance over the Autumn season, the maximum collected solar energy was achieved with North-South tracking rotating mode (models 4 and 5). The other models (1, 2, and 3) are fewer values. From Figure 8, the incident angle for all models of the Autumn season, the incident angle is zero for models 4 and 5. Therefore, at this season the models 4 and 5 are better.
4.5 Winter season

The period of the winter season is from 21 December to 20 March. Figure 9 shows the tracking performance of the overall winter season; the maximum collected solar energy is achieving with North-South tracking rotating modes 4 and 5. Figure 10 indicates the incident angle for all modes. The reflected solar beam from the solar collector is reducing for modes 4 and 5, due to the smallest incidence angle associated with the aperture plane overall season. While, the other modes 1, 2, and 3 increased the reflected solar beam due to the increase of incident angle.
4.6 Over the year

In the light of Figures (4, 6, 8, and 10), the solar beam incident angle by mode 5 is always the lowest over all the months of the year. Figure 11-a leads to more collecting solar energy from other modes. The reflected energy of mode 5 is less due to move it in continuously. From Figure 11-b, the water heater that rotates with mode 5 has 34.15% collected solar energy more than that of E-W rotate modes (mode 1 and mode 2) over the year.

5. Conclusions

The following are summarized conclusions points can be dropped from this study:

1. The performance of the solar water heater of the present tracking modes is similar at noon due to the incidence angle is identical at this period.
2. At the moment of the sunrise and sunset, the amount of collected energy of any tracking mode is lower as compared with another period due to the effect of air mass that directly proportional to zenith angle variation.
3. The solar water heater performance with the tracking mode 5 gives the highest collected solar energy by 34% more than of E-W rotate modes (mode 1 and mode 2) over the year.
4. For a series connection of parabolic solar water heater and shaft arrangement, the tracking mode 5 is not suitable, so mode 4 is suitable for this type of arrangement.
5. The solar water heater with tracking mode 4 gives the collected energy reduced by 4% from mode 5.

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| Nomenclature | Definition |
|--------------|------------|
| $I_b$ | Hourly Beam solar radiation (kJ.m$^{-2}$) |
| $I_c$ | Hourly Concentration of solar radiation (kJ.m$^{-2}$) |
| $I_d$ | Hourly Diffusion of solar radiation (kJ.m$^{-2}$) |
| $I_o$ | Hourly extra-terrestrial solar radiation (kJ.m$^{-2}$) |
| $I_g$ | Hourly Global solar radiation (kJ.m$^{-2}$) |
| $H_d$ | Monthly average of Diffusion solar radiation (kJ.m$^{-2}$.day$^{-1}$) |
| $H_o$ | Monthly average of extra-terrestrial solar radiation (kJ.m$^{-2}$.day$^{-1}$) |
| $H_g$ | Monthly average of Global solar radiation (kJ.m$^{-2}$.day$^{-1}$) |
| $n$ | Day number of the year |
| $S$ | Monthly average of Day length (Hour) |
| $S_{\text{max}}$ | Monthly average of maximum Day length (Hour) |
| $E_L$ | Elevation above the sea level (km) |
| $R_b$ | The tilted factor for beam radiation |

| Greek symbols | Definition |
|---------------|------------|
| $\delta$ | Declination angle (°) |
| $\beta$ | The tilted angle of parabolic (°) |
| $\varphi$ | Latitude of location (°) |
| $\omega$ | Hour angle (°) |
| $\omega_s$ | Hour angle sunshine (°) |
| $\theta$ | Incidence angle (°) |
| $\theta_z$ | Zenith angle (°) |