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THE EFFECT OF THERMAL EFFICIENCY ON THE ENERGY PRODUCTION OF A SOLAR PARABOLIC TROUGH SYSTEM IN AMMAN-JORDAN

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ABSTRACT

Interest in alternative energy sources is necessary nowadays due to the scarcity of traditional energy resources. Alternative energy is the most promising candidate to meet the energy needs of various practical applications. Solar energy is the strongest candidate for use among alternative energy sources due to its large availability and optimal distribution. Solar energy applications are divided into applications that operate with a direct conversion system of solar energy into electrical energy and applications that operate on the principle of indirect conversion of solar energy into electrical or thermal energy. In this work, the parabolic trough system was highlighted and the effect of the thermal efficiency of the parabolic trough on its ability to produce energy was studied. A thermal efficiency ranging from 25% to 75% was applied with an increase of 25% in each attempt. It was found from the results of the study that increasing the thermal efficiency of the parabolic trough plays a major role in increasing the energy production.

Keywords: solar energy; parabolic trough; thermal efficiency; energy conversion.

1. INTRODUCTION

Due to the limited supply of energy resources, one of the most significant issues of the contemporary period is energy security. [1-3]. Whereas, traditional energy sources, with their natural distribution, are insufficient to meet the world's energy needs for various needs. Most of the world's countries depend on importing enough petroleum products from the producing countries to meet their energy needs. Here it was found that importing energy burdens the importing countries with many financial obligations and burdens their economy [4-6]. From here start the search for alternative sources of energy instead of traditional energy sources. It was taken into account that alternative energy sources are sustainable, clean and available in various countries of the world of all kinds. Hence, we find that renewable energy is defined as inexhaustible energy and does not pollute the environment. Renewable energy includes many types, the most important of which are solar energy, wind energy, geothermal energy, tidal energy, hydrogen energy, nuclear energy and others [1-3, 5-47].

Renewable energy sources are considered the most important energy sources candidate to cover the shortage of energy sources [11-13, 23-27, 29-33, 35, 37-39, 42, 48]. The recent interest in renewable energy comes due to the sustainability of its sources and the cleanliness of its operation which are the two most important factors that make renewable energy the hope for the future. The sun is the main source of most renewable energy sources, as it leads to the movement of wind and thus provides the possibility of generating energy through the wind [15-19]. Solar energy is the most prominent among the renewable energy sources to meet the needs of different countries with the quantities of energy required for different needs. The reason behind the use and exploitation of renewable energy systems is the development of the technology related to exploiting renewable energy systems, especially solar energy. The development of renewable energy technology is noted through a number of factors, the most important of which are the low cost of construction and operation, the increase in the efficiency of resource utilization, and the ease of maintenance work for different systems, and others[21, 26, 27, 29-31, 40].

Solar energy is the greatest hope for many countries of the world because of its availability with a relatively long number of sunshine hours and an appropriate radiation intensity that makes its exploitation fairly productive and valuable. Solar energy systems are divided into two main types in relation to the way they are used. The first is photovoltaic cell systems (PV), which depend on the direct conversion of solar radiation into usable energy. The second type is concentrated solar power (CSP) energy systems that depend on converting solar energy into energy that is indirectly drawn from it through an intermediary such as turbines [37, 38].

CSP energy systems are one of the most important applications of solar energy because of the stability in production and producing high temperatures. CSP systems are divided into two types according to the system of receiving sun rays. The first type reflects the sun's rays to a specific receiver as a single point focus, and the second type reflects the sun rays to one or multiple lines. According to these divisions, many applications appear as examples of the first type, the most important of which are the solar dish, and the solar tower. The most important examples of the second type are the parabolic trough and Fresnel systems [23, 49-51].

The parabolic trough is a concentrated solar power energy system that reflects sunrays toward a line that is called a line focus. Parabolic trough systems are widely used mostly for two reasons: steam production and power production [52-55]. There are many factors that affect the ability of the parabolic trough systems to produce energy, the most important of which are the

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availability of solar radiation with appropriate radiation intensity rates, solar radiation incidence angles, manufacturing materials, and their efficiency [56-58].

Jordan is considered one of the poorest countries in the world in terms of energy sources, as it depends for at least 95% of its energy needs on energy imported from neighboring countries, especially the Arab Gulf countries. On the other hand, Jordan is one of the lucky countries in the world in possessing alternative energy sources, as there are more than 320 sunny days in Jordan with ideal solar radiation rates and suitable for exploiting solar energy for energy production purposes, and this is what Jordan recently directed [6-9, 11-19, 21, 27, 29, 30, 37, 39, 40, 45].

In this work, a comparison was made about the energy production of the parabolic trough system with using different thermal efficiency, starting from 25% to 75%, with an increase of 25% in each experiment. It was found that increasing the thermal efficiency of parabolic trough systems has a significant role in improving the energy production of these systems.

2. GEOGRAPHICAL AND METEOROLOGICAL DATA

Jordan is considered one of the countries in the solar belt, with sunshine days estimated at 320 days throughout the year equivalent to 3300 h/year with a high solar intensity as shown in the figure.1 below. Amman is the capital of Jordan which is located within a longitude and latitude 36° east and 32°to the north respectively.

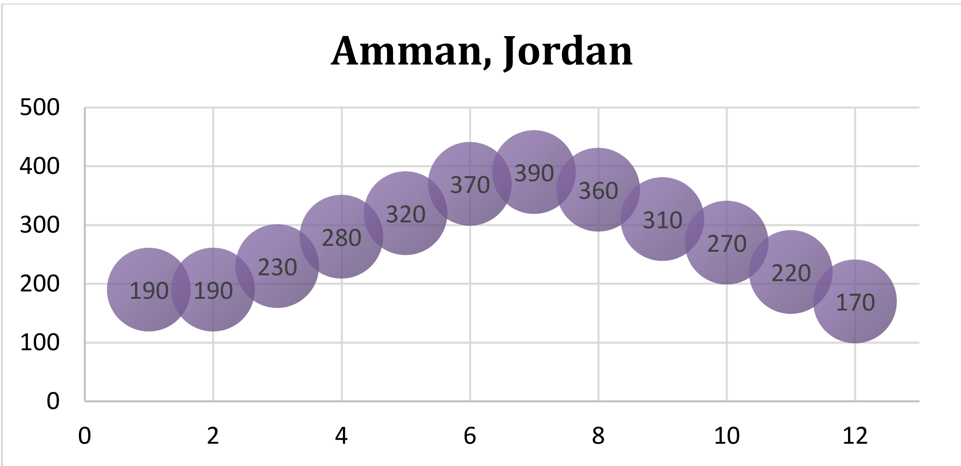

Figure-1. Sunshine hours in Amman, Jordan, throughout the year.

Figure-2 shows the average upper and lower limits temperature in Amman capital of Jordan throughout the year. The highest temperatures were recorded in June, July, August, and September, while the lowest temperatures were recorded during January, February, and December.

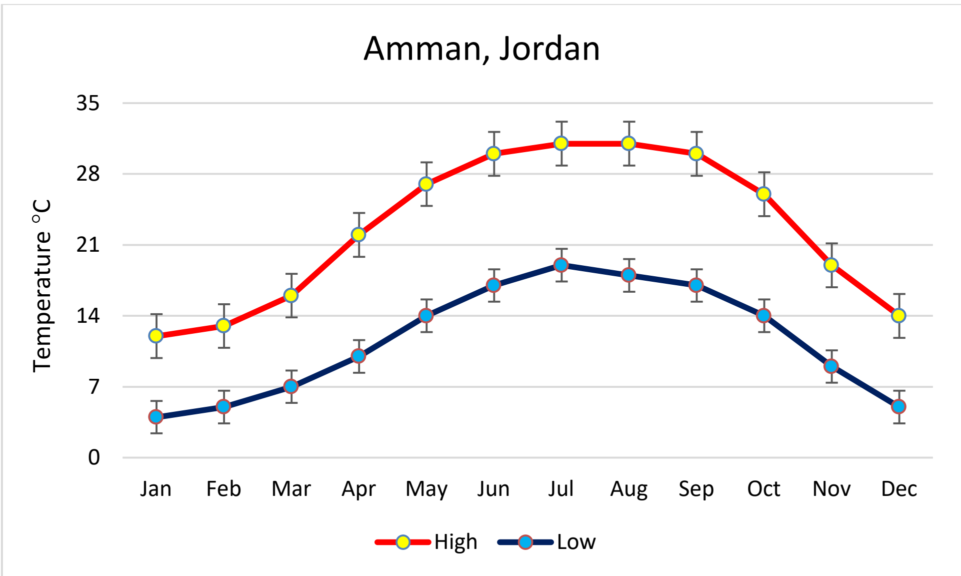

Figure-2. The average upper and lower limits temperature in Amman throughout the year.

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3. SOLAR CALCULATIONS

Solar energy calculations are considered one of the most complex engineering calculations because of the large number of variables implemented in the various calculations. In this work, some calculations in touch with solar energy will be mentioned as a method to explain the scientific results.

One of the highest solar radiations in the world was in Jordan. The average solar radiation in Amman is about 4-8 kWh/m² on a daily based which is equivalent to the amount of 1400-2300 kWh/m² on a yearly based. Based on the previous information Jordan has been divided into five regions according to the solar intensity namely, the southern, eastern, central, northern, and western regions, with solar radiation intensity rates of 6-7, 5.5-6, 4.5-5,5.5, and below 4.5 kWh/m² respectively.

Solar declination is defined as the angular position of the sun at solar noon, with respect to the plane of the equator with a value in degrees, and it is calculated based on formula (1)[15].

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \tag{1}$$

Where n represents the day of the year. Thus, the first of January is the first day of the year followed by counted in series till the 31 of December is the last day of the year i.e., 365.

The angular displacement (east or west) of the sun is related to the local meridian. It will be negative in the morning and positive during the afternoon which is called the Solar Hour Angle (SHA).

The sunset hour angle ws is defined as the symmetric solar hour angle with respect to the time during the sunset. It is calculated based on using formula (2).

$$\cos\omega_s = -\tan\phi \tan\delta \tag{2}$$

Where ϕ is the latitude of the site, and δ is the declination.

Extra-terrestrial radiation is the solar radiation outside the atmosphere. The daily extra-terrestrial solar radiation can be calculated by using the formula (3)

$$H_0 = \frac{24\times 3600 G_{sc}}{\pi}\left(1+0.033\cos\frac{360n}{365}\right)\times\left(\cos\phi\cos\delta\sin\,\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\,\delta\right) \tag{3}$$

Where Gsc is the solar constant and it is equal to 1367 W/m^2.

The weather factors and conditions can affect the solar radiation as not all the radiation reached the earth as well as the radiation which is reached the earth comes in different forms.

4. RESULTS AND DISCUSSIONS

The selected parabolic trough system specification is an assembly length of 48m, an aperture width of 6m, a focal length of 1.5 m, a module length of 4m, a pole height of 3m, an azimuth angle of 180 degrees, a mirror reflectivity of 90%, a receiver absorbance of 95%, and optical efficiency of 70%.

Figure-3 shows the selected parabolic trough rack for the study (A). The energy production from the parabolic trough rack at the 10th of December which is the worst day of the year in the solar radiation as well as the solar intensity where it effected by increasing the thermal efficiency as it is clear in Figure-3(B) as the total energy production from the parabolic trough rack are 117.7, 235.2, and 343.4 kWh for the selected racks which has a thermal efficiency of 25%, 50%, and 75% respectively. The energy production at the early morning and late-night hours reaches zero production due to the total absence of the sun from the parabolic trough system. Energy production begins to increase at the same time of each trial with the increase in thermal efficiency.

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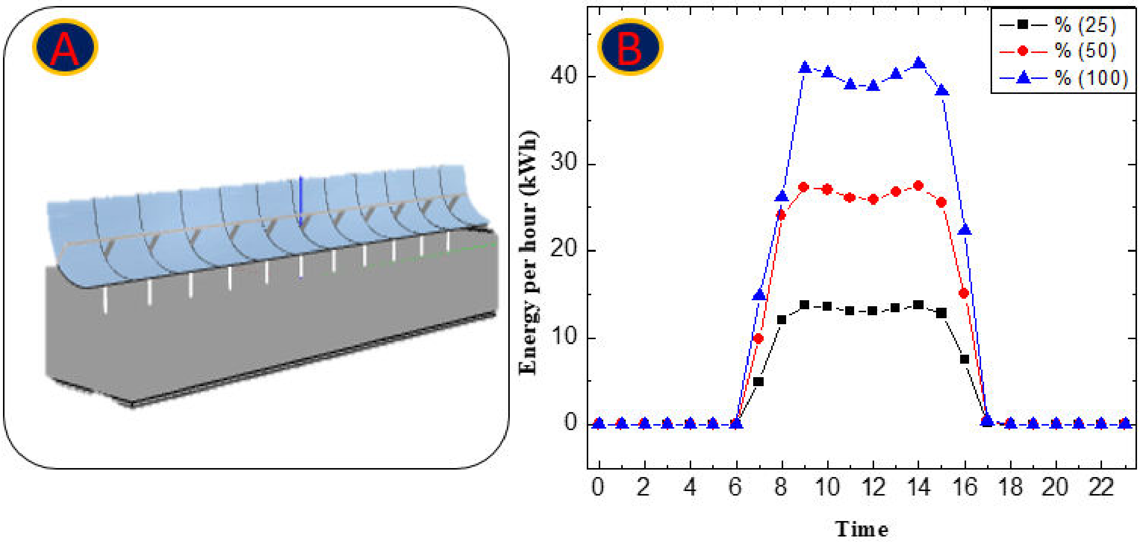

Figure-3. Parabolic trough system (A), and Energy production on the 10th of December of each trial.

Figure-4 shows the annual energy production from the parabolic trough system during the three study cases, which is represented by the increase in thermal efficiency from brother 25% to 75% by an increase of 25%. It is clear that with the increase in thermal efficiency, the amount of energy production over the year increases to almost double, so it was found that the amount of energy production from the parabolic trough system is 3165.5.kh, 6331.3, and 9492 kilowatt-hours throughout the year for thermal efficiencies of 25%, 50% and 75%, respectively. Also, it was found that the lowest amount of energy production over the three study cases is December with an energy production of 117.7, 235.4, and 353 kWh/year for 25%, 50% and 75% of the thermal efficiency respectively, and the highest energy production was during the July with an energy production of 414.8, 829.6, and 1244 kWh/year for 25%, 50% and 75% of the thermal efficiency respectively.

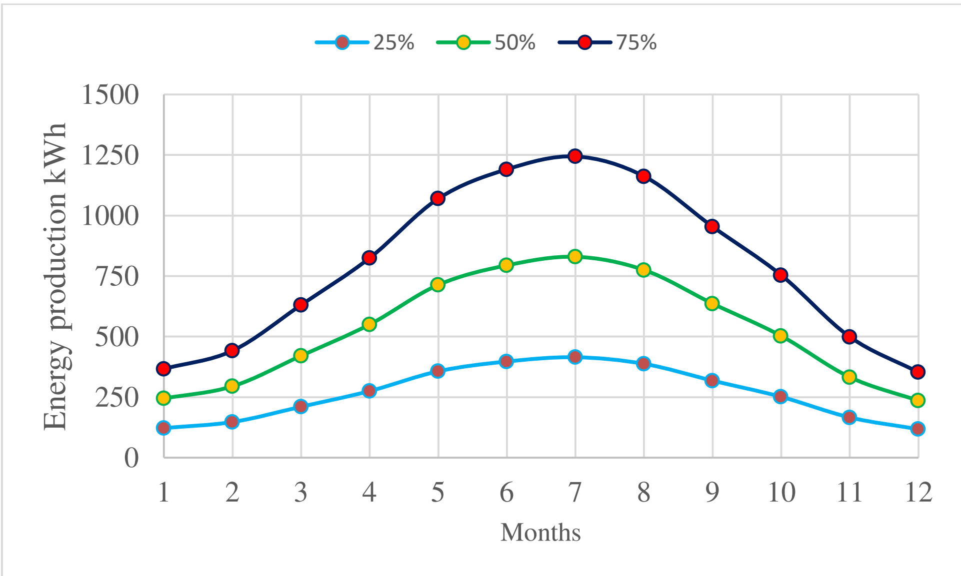

Figure-4. Energy production over the year in kWh/year.

Figure-5 shows the energy production from the parabolic trough system during the worst day of the solar radiation around the year which is the 10th of December. The energy production was 117.7, 235, and 353 kWh/day with respect to the thermal efficiency of 25%, 50%, and 75% respectively. The increase in thermal efficiency is a major reason for the increase in energy production from the parabolic trough system, knowing that with the increase in thermal efficiency, the temperature of the parabolic trough increases, and here this increase is not considered a problem, on the contrary, this is an addition to the concentrated solar energy power systems, in complete disagreement with the photovoltaic systems.

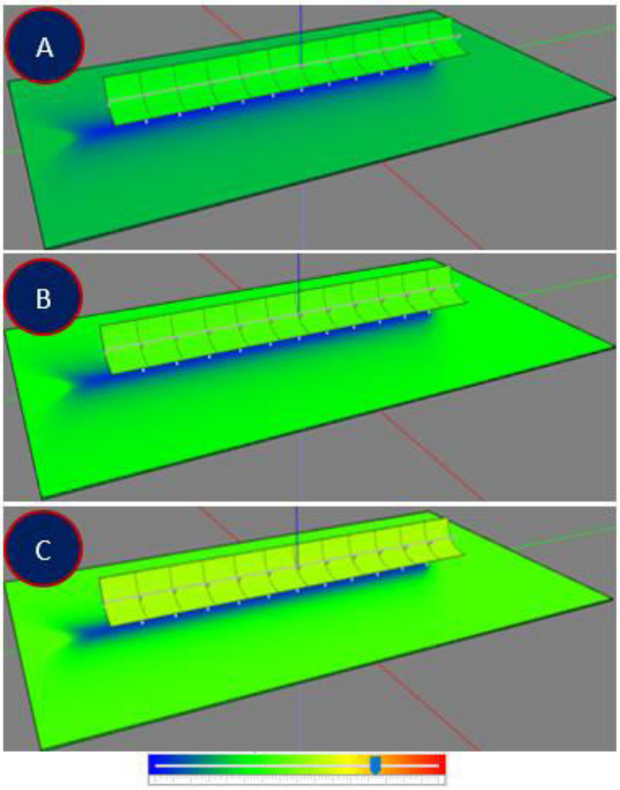

Figure-5. Energy production of the worst day of the year (10th of December).

5. CONCLUSIONS

The study aims to investigate the effect of increasing the value of the thermal efficiency of the parabolic trough system on the amount of energy production of it. The study analyzed the energy production over the worst day in solar radiation in Amman, Jordan, which is the 10th of December of each year. It was found that the amount of energy production increases with the increase in the thermal efficiency of the parabolic trough, as it was as follows: 117.7, 235, 353 kWh/day with respect to the increase in thermal efficiency of 25% and 50% % and 75%, respectively. The study as well analyzed the energy production over the year, and it was as follows: 3165.5, 6331.3, and 9492 kWh/year, with respect to the increase in the thermal efficiency from 25%, 50%, and 75%, respectively.

It can be concluded from the above that increasing the thermal efficiency of the parabolic trough system helps to increase its energy production and increase the operating temperature of such systems, which helps in maximizing the energy production for the various needs.

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