UTILIZATION OF SOLAR ENERGY FOR ENHANCEMENT EFFICIENCY OF STEAM POWER PLANT

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ABSTRACT

The present work deals with concentrating solar power (central receiver tower) to produce hot water or steam from solar energy. Hot water or steam is used to heat the feed water heater of South Baghdad Electrical Steam Power Plant. The central receiver tower (0.5m × 1m) was fabricated from steel material filled with 157 liter of water, consisting of 150 mirrors fixed upon 75 manual tracking heliostats arranged for focus the solar radiation upon central receiver tank. The experimental work was run for one year from June 2015 – May 2016. The results obtained from our system, solar shares for heating the feed water heater of South Baghdad Electrical Steam Power Plant up to 1.86 % and an annual average of 1.03%.

Nomenclature

\( Q_u \) Useful energy (W)
\( Q_{solar} \) Concentrating solar energy from the mirror (W)
\( Q_{out} \) Energy absorbed by working fluid (W)
\( CR \) Concentration ratio
\( A_a \) Aperture area (m²)
\( A_r \) Receiver project area (m²)
\( A_S \) Surface area of receiver (m²)
\( I_a \) Incident radiation (W/m²)
\( T_w \) Temperature of the water (°C)
\( T_{w_1} \) Temperature of the water after one hour (°C)
\( T_{r_1} \) Temperature of receiver surface (K)
\( T_{w_0} \) Temperature of surroundings (K)
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Key words: Solar central tower, heliostat, feed water heater, concentration system.


1. INTRODUCTION

The demand for fossil fuels has begun to rise; industries have been turning towards new, clean solutions to their energy needs. Solar energy has long been a potential solution to these needs. The power intercepted by the earth from the sun is estimated at about $1.8 \times 10^{11}$ MW. In fact, the sun provides enough energy in one hour to supply the earth with its energy needs for a whole year [1]. The method of using solar energy for produce steam is concentrating central tower receiver system, which consist of central receiver tank and a number of heliostat are arranged around it. The CSP technology saw its first development between 1984 and 1995 in concomitance with the oil shock of the ‘80s [2], but then no further commercial deployment was seen until 2005. The real birth as industry happened with the commissioning of the Solar Electric Generating System, which was based in California and accounted for 354 MWe.

The present work deals with concentrating solar power (central receiver tower) to produce hot water or steam from solar energy. Hot water or steam is used to heat the feed water heater of South Baghdad Electrical Steam Power Plant. The central receiver tank (0.5m × 1m) was fabricated from steel material, consisting of 150 mirrors fixed upon 75 manual tracking heliostats each heliostat has consisted of two (0.5 m × 0.5 m) mirrors, arranged around tank to focus the solar radiation upon central receiver tank as shown in Figure 1.

![Figure 1](image1.png)

**Figure 1** The central receiver tower system (a) Arrangement of heliostat around the central receiver (b) Feed water heater

2. MATHEMATICAL MODEL

The amount of solar radiation reaching the receiver is dependent on the amount of radiation available (sky conditions), the size of the concentrator, and several other parameters describing the loss of this radiation on its way to being absorbed. Heat loss from the receiver is separated into convection-conduction heat loss and radiation heat loss. The rate of heat loss increases as the area of the receiver and/or its temperature increases. This is why concentrators are more efficient at a given temperature than flat plate collectors, because the area in which heat is lost is smaller than the aperture area [3, 4]. The useful energy delivered by the collector $Q_u$ is given by the energy balance Equation (1).
The useful heat produced by concentrator is given by:

\[ Q_u = Q_{abs} - Q_{loss} \]  

(1)

\[ = Q_{solar} + Q_{dir} - [Q_{cond} + Q_{conv} + Q_{rad}] \]

\[ = C_R A_c I_a \tau A + I_a \tau A(T) - [Q_{cond} + Q_{conv} + Q_{rad}] \]

The useful heat produced by concentrator is given by:

\[ Q_u = \frac{m \cdot C_p}{\Delta t} (T_w^+ - T_w) \]  

(2)

The temperature of the water for each hour can be estimated by substituting equation (2) in (1) which results represented as:

\[ T_w^+ = T_w + \frac{\Delta t}{m \cdot C_p} [Q_{solar} + Q_{dir} - Q_{cond} - Q_{conv} - Q_{rad}] \]  

(3)

The concentration of solar radiation is achieved by reflecting or refracting the flux incident on an aperture area \( A_a \) onto a smaller receiver/absorber area \( A_r \) [5]:

\[ CR = \frac{A_s}{A_r} \]  

(4)

The thermal efficiency of a concentrator system \( (\eta_{thermal}) \) is given by [6]:

\[ \eta_{thermal} = \frac{Q_{out}}{Q_{in}} = 1 - \frac{Q_L}{Q_{in}} \]  

(5)

In this equation:

\[ Q_{in} = Q_{solar} + Q_{dir} \]

\[ Q_L = Q_{rad} + Q_{conv} + Q_{cond} \]

And

\[ Q_{rad} = \sigma \times \epsilon \times A_s \times (T_s^4 - T_\infty^4) \]  

(6)

\[ Q_{conv} = h \times A_s \times (T_s - T_{ambient}) \]  

(7)

The heat transfer coefficient \( h \) can be determined by using these equations [7]:

\[ h = \frac{\text{Nu} \cdot K}{\text{L}} \]  

(8)

\[ \text{Nu} = 0.6 (\text{Gr. Pr})^{\frac{1}{3}} \]  

(9)

\[ \text{Gr} = \frac{g \beta (T_s - T_{amb}) \cdot L^3}{\nu^2} \]  

(10)

Monthly and annual contribution of solar collector system is calculated by using F-chart method [4]:

\[ X = \frac{(Q_{rad} + Q_{conv}) \times \Delta t}{L} \]  

(11)

\[ Y = \frac{(\text{Energy from solar collector})}{\text{Load}} \]  

(12)

\[ \Delta t : \text{Time(sec) (N \times 24 \times 3600)} \]

\[ N = \text{Number of days} \]

\[ I = \text{Incident solar radiation (J/ m}^2) \]
A_r: receiver top surface area (m²)
A_p: receiver project area (m²)
L = total load (J)

F-chart for liquid

\[ f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \]  \quad (13)

For the annual system

\[ f = \frac{\sum F \cdot L}{\sum L} \]  \quad (14)

FL = f × Load

3. EXPERIMENTAL WORK

The system site is located in Baghdad at latitude 33.34° N and longitude 44.4° E, the site elevation is 39 m above sea level. It consists of a Central Receiver Tower, piping network, a number of individual mirrors called "heliostats" and feed water heater as shown in figure 1.

The central receiver tank was fabricated from steel material [50cm diameter and 100cm length]) was filled with 157 liter of water. Fixed on a steel structure and painted black color. 150 mirrors (0.5 m × 0.5 m) arranged around receiver tank to focus the solar radiation upon central receiver tank. The layout of piping system consists of a set of pipes supplying water to receiver tank, another set of pipes carrying the hot water from central receiver tank to feed water heater and return the hot water from heat feed water heater to central receiver tank. Two vertical variable area rotameters are used to measure the flow rates of the hot and cold water. For the hot and cold water circulation, a flow meter of (50 – 420) LPH range is used. A set of thermocouples type k fixed in many places such as mirror surface, water inlet to the central, water exit from central receiver tank , ambient temperature and inlet, outlet hot and cold water of feed water heater. The experimental work was run for one year from June 2015 – May 2016. Measured temperature of receiver tank at each hour recorded at the data logger system (Lutron-Model BTM-4208SD).

4. RESULTS AND DISCUSSION

The project was run by using water as the working fluid; the water (157 lit) filled the tank at 35 °C in June 2015. After concentrating the solar radiation to the central receiver tank, the temperature of water inside it started to increase, the heat accumulated inside water until generated the steam for (July and August 2015) and hot water with high temperature for other months of the year. The mathematical analysis and experimental data for the Central Receiver Tank results are summarized in table (1).

Table 1 Results of present work of central receiver tower

<table>
<thead>
<tr>
<th>Year</th>
<th>Months</th>
<th>Properties of fluid exit from tank receiver</th>
<th>Inlet temp. of water(°C)</th>
<th>Outlet temp. of water(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>June</td>
<td>Hot water</td>
<td>35</td>
<td>98</td>
</tr>
<tr>
<td>2015</td>
<td>July</td>
<td>Steam</td>
<td>38</td>
<td>110</td>
</tr>
<tr>
<td>2015</td>
<td>August</td>
<td>Steam</td>
<td>39</td>
<td>118</td>
</tr>
<tr>
<td>2015</td>
<td>September</td>
<td>Hot water</td>
<td>30.5</td>
<td>95</td>
</tr>
<tr>
<td>2015</td>
<td>October</td>
<td>Hot water</td>
<td>24</td>
<td>80</td>
</tr>
<tr>
<td>2015</td>
<td>November</td>
<td>Hot water</td>
<td>20.5</td>
<td>61</td>
</tr>
<tr>
<td>2015</td>
<td>December</td>
<td>Hot water</td>
<td>14</td>
<td>45</td>
</tr>
</tbody>
</table>
The previous results in table (1) of outlet temperatures of hot water will inlet to feed water heater for exchanging heat with cold water for increasing its temperature to enhance the performance of steam power plants.

Monthly and annual solar energy contribution for energy required to heat the feed water heater in the South Baghdad Thermal Electrical Power Plant were estimated by using the equations of F-chart method. The heat supplied by solar collector system that exists in Mechanical Engineering Department and it’s contributed shown in table (2). From South Baghdad Thermal Electrical Power Plant the thermal load was used is 5MW (180000MJ).

<table>
<thead>
<tr>
<th>Year</th>
<th>Months</th>
<th>X</th>
<th>Y</th>
<th>Load (MJ)</th>
<th>F (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Jun.</td>
<td>0.0063</td>
<td>0.0111</td>
<td>180000</td>
<td>1.6</td>
</tr>
<tr>
<td>2015</td>
<td>Jul.</td>
<td>0.0073</td>
<td>0.0125</td>
<td>180000</td>
<td>1.79</td>
</tr>
<tr>
<td>2015</td>
<td>Aug.</td>
<td>0.0079</td>
<td>0.0128</td>
<td>180000</td>
<td>1.86</td>
</tr>
<tr>
<td>2015</td>
<td>Sep.</td>
<td>0.0055</td>
<td>0.0105</td>
<td>180000</td>
<td>1.05</td>
</tr>
<tr>
<td>2015</td>
<td>Oct.</td>
<td>0.0046</td>
<td>0.0086</td>
<td>180000</td>
<td>0.85</td>
</tr>
<tr>
<td>2015</td>
<td>Nov.</td>
<td>0.0033</td>
<td>0.0066</td>
<td>180000</td>
<td>0.65</td>
</tr>
<tr>
<td>2015</td>
<td>Dec.</td>
<td>0.0022</td>
<td>0.0057</td>
<td>180000</td>
<td>0.57</td>
</tr>
<tr>
<td>2016</td>
<td>Jan.</td>
<td>0.0018</td>
<td>0.0052</td>
<td>180000</td>
<td>0.52</td>
</tr>
<tr>
<td>2016</td>
<td>Feb.</td>
<td>0.0025</td>
<td>0.0069</td>
<td>180000</td>
<td>0.69</td>
</tr>
<tr>
<td>2016</td>
<td>Mar.</td>
<td>0.0037</td>
<td>0.0081</td>
<td>180000</td>
<td>0.81</td>
</tr>
<tr>
<td>2016</td>
<td>Apr.</td>
<td>0.0043</td>
<td>0.0092</td>
<td>180000</td>
<td>0.92</td>
</tr>
<tr>
<td>2016</td>
<td>May.</td>
<td>0.0049</td>
<td>0.0107</td>
<td>180000</td>
<td>1.06</td>
</tr>
<tr>
<td>Annual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.03</td>
</tr>
</tbody>
</table>

To increase the contribution of solar energy for heating the feed water heater of South Baghdad Thermal Electrical Power Plant must increase the surface area of mirrors and the size of the receiver.

From the experimental work, the temperature of the exit fluid that recorded every hour daily was obtained. These data were calculated from the equations that mentioned in mathematical formulation. The calculated temperatures were higher than that measured (12%) percentage error. This was because of many reasons, such as diffusing the solar radiation, cloudy, dusty and heat losses because there is no insulation used, as shown in figures (2 -5).
Figure 2 Variation of hot water temperature with time for (20 day) in August 2015.

Figure 3 Variation of hot water temperature with time for (20 day) in January 2016.

Figure 4 Monthly average temperature of hot water in the storage tank from (June – December 2015).
Figure 5 Monthly average temperature of hot water in the storage tank from (January – May 2016).

5. CONCLUSION

We conclusion from this study:

- Increasing the volume of water decrease the exit temperature but gives better contribution because the high flow rate.
- The highest exit temperature for water occurred in (June, July and August) because the high intensity of solar radiation.
- The contribution of solar energy to heat feed water heater will increase by increasing the surface area of mirrors.

REFERENCES


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