



Experimental Study of Concentrated Solar Power on Heat Feed Water Heaters in Steam Power Plants in Iraq

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Abstract:

For generating power, solar energy is counted a good exporter. Iraq is located in a hot zone with latitude from 32 degree N to 36 degree N. In Iraq, the average solar radiation is about 7 kilowatt hours / day.

In this work, central receiving tower was used to obtain steam using the available solar energy in summer and winter. To heat the feed water heater of South Baghdad Electrical Steam Power Plant, steam utilization for this purpose. In the project, manufacturing the central receiver tower, which is consisting of 150 mirrors fixed upon 75 manual tracking heliostats arranged for utilization the solar radiation concentrated on the central receiving tank (CRT). Pipes systems were used for hot water or steam exits from receiver. In this study, the central receiver tank (0.5m*1m) was filled with 157 liter of water. The experimental work was run for one year from June 2015 – May 2016. The outlet temperature of water from central tower receiver was steam for (July and August 2015) and hot water with high temperature for other months of the year. 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%. Temperature, power concentration factor and system efficient are greatly influenced by the number of heliostats used. A sample of calculations is used to evaluate the mathematical data of hot water and steam temperatures obtained from this study. These values are approximate with experimental data when compared together.

Keywords: Solar central tower, heliostat, steam generation, concentration system.

دراسة تجريبية لأستخدام الطاقة الشمسية المركزه على مسخنات مياه التغذية الحرارية في محطات توليد الطاقة البخارية في العراق

الخلاصة:

الطاقة الشمسية تعتبر مصدرا مهما لانتاج الطاقة، يقع العراق في منطقة حارة على خط عرض (32° – 36° شمالا) و ان معدل كمية الاشعاع الشمسي الساقطة على العراق تصل الى (7 كيلو واط باليوم). هذا البحث يتناول استخدام مجمع الطاقة الشمسية (برج الاستقبال المركزي) لانتاج الماء الساخن والبخار من الطاقة الشمسية. يستخدم الماء الساخن او البخار لتسخين مغذي مياه محطة جنوب بغداد الحرارية. صنع برج الاستقبال المركزي من مادة الستيل، وتتألف المنظومة من 150 مرآة مثبتة على هياكل حديدية تحرك يدويا لتركيز الاشعاع الشمسي على خزان الاستقبال المركزي. تم استخدام شبكة انابيب، واحدة لتزويد الخزان بالماء والاخرى لخروج الماء الحار او البخار منه. حجم الخزان المستخدم في هذا العمل هو ($0.5\text{ م} * 1\text{ م}$) ملء ب 157 لتر من الماء. وكانت التجارب العملية لمدة سنة من يونيو 2015 – مايو 2016. بعد عمل المنظومة تم الحصول على بخار لشهري (يوليو واغسطس 2015) وماء بدرجة حرارة عالية لبقية اشهر السنة. تظهر نتائج عمل المنظومة مساهمة الشمس لتسخين مغذي مياه محطة كهرباء جنوب بغداد الحرارية تصل الى 1.86% بمعدل مساهمة سنوي 1.03% . عدد المرات له تأثير كبير على حرارة الخزان، وعلى معامل التركيز وكفاءة النظام. كما تم عمل حسابات نظرية تقوم بحساب درجة حرارة المائع الخارج من المنظومة ومقارنته بالنتائج التي تم الحصول عليها من الجانب العملي.

1. Introduction

Solar energy is most abundant renewable power source which is readily available anywhere the sun shines [1]. Solar energy is easy to collect and use with relatively lower overall cost comparing with the other renewable energy sources [2]. Even though solar energy has benefits of being nonpolluting and minimal environmental impact, it does have limitations such as intermittent energy supply as the sun shines only at daytime, and energy conversion efficiency can be low [4].

Many applications of It is possible to obtain hot water, steam, heating and cooling by using clean energy, which is solar energy. Solar energy can be converted into electric energy or thermal energy. Flat panels and concentrators can be used to obtain electrical energy using high solar radiation density. [3]

For this work, 3- sizes for central receiver tanks that utilizing in this work that various ($1.2\text{m} \times 1.8\text{m} \times 1\text{m}$), ($0.5\text{m} \times 1\text{m} \times 1\text{m}$) and ($0.4\text{m} \times 0.6\text{m} \times 1\text{m}$). Many tests were accomplished for these sizes. The outlet temperatures of water from receiver in this system for three tests are various in 84.2°C , 111°C and 107°C , respectively.

2. Experimental Setup

Geographically, 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. The system manufactured the CRT, piping network, heliostat consists of 150 mirrors and heat exchanger. The solar radiation incidents upon the mirrors are reflected upon the surface of receiver tank to produce a hot water as shown in Figure (1)..



Fig. (1) The Central Receiver Tower project.

2.1. Central Receiver Tank (CRT):

The CRT was manufactured with (50cm) D and (100cm) L. Standing on top of a manufacturing structure. Four piping perforation were manufacturing for connecting piping, as shown in Figure (1).

2.2. Tower Steel Structure:

The structure of the tower was manufactured locally in the form of a letter from steel metal with the measurements (60*60*5) mm that the height of the tower is 2 meter.

2.3. Pipes Network:

The layout of piping system consists of a set of galvanized iron pipes that provide water with D 1.27cm, with pump ($Q_{\max} = 36$ L/ min, $H_{\max} = 30$ m , 2850rpm) that connect the water from the water storage tank to the CRT. Also plastic pipes with 1.27 cm D for provide

the water from CRT to exchanger and set of piping 1.27cm to return the hot water from heat exchanger to central receiver tank.

2.4. Heliostats:

Heliostat consists of a number of mirror, which is about 50 and the dimension is (50×50) cm hold upon the steel structure. The steel structure consists of rectangular frame (50×100) cm supported at height 65cm on checker plate (60×60) cm. The frame is manufacturing from aluminum with two plates (50×50) cm.

2.5. Heat exchanger:

A feed water heater in steam power plant for heating the water before entering the boiler by using solar energy was used. The test section is made of one pass shell and tube heat exchanger which is Bowman type(3740-6), having dimension of(1200 mm) $L_{overall}$, (1000 mm) L_{eff} , which contain (52) copper tube of (11 mm) ID and (13.5 mm) OD. The tubes are arrangement with a triangular staggered. The clearance between two adjacent tubes is (1.5 mm).

2.6. Measuring devices:

(1) Rotameter: 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.

(2) Temperature: for measuring temperature a thermocouples type K, and then transferred data into lap-top by using 1G-SD Card which connected with data logger system (Lutron-Model BTM-4208SD). Water temperature and the ambient temperature every hour are measured.

3. Mathematical Formulation

The useful energy delivered by the collector Q_u is given by the energy balance Equation (1).

$$\begin{aligned} Q_u &= Q_{abs} - Q_{loss} \\ &= Q_{solar} + Q_{dir} - [Q_{cond} + Q_{conv} + Q_{rad}] \\ &= C_R A_R I_a \tau \alpha + I_a \tau \alpha (A_t) - [Q_{cond} + Q_{conv} + Q_{rad}] \end{aligned} \quad (1)$$

The useful heat produced by concentrator is given by:

$$Q_u = \frac{m \cdot C_p}{\Delta t} (T_w^+ - T_w) \tag{2}$$

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

$$T_w^+ = T_w + \frac{\Delta t}{m \cdot C_p} [Q_{solar} + Q_{dir} - Q_{cond} - Q_{conv} - Q_{rad}] \tag{3}$$

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 .

$$CR = \frac{A_a}{A_r} \tag{4}$$

The heat gained and a heat loss from the central receiver tank is explained by Figure (2).

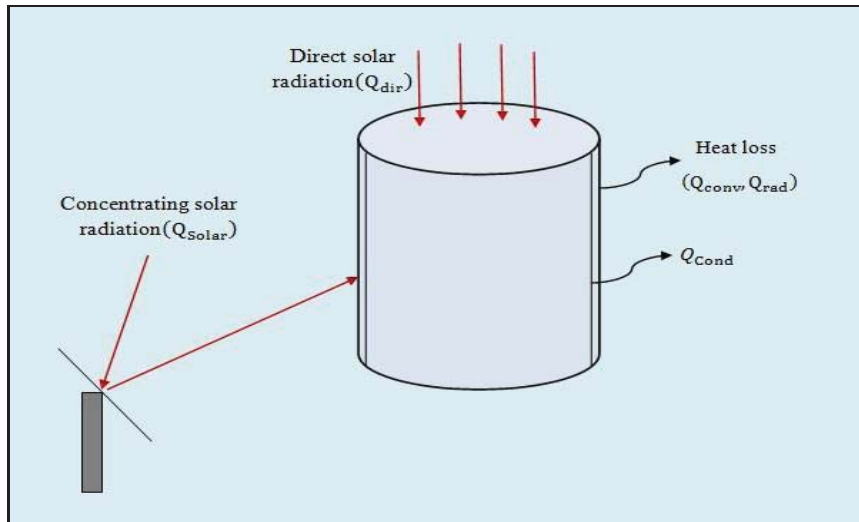


Fig. (2) The energy that loss from central receiver tower.

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

$$\eta_{thermal} = Q_{out}/Q_{in} = 1 - \frac{Q_L}{Q_{in}} \tag{5}$$

In this equation:

$$Q_{in} = Q_{solar} + Q_{dir}$$

$$Q_L = Q_{rad} + Q_{conv} + Q_{cond}$$

And

$$Q_{rad} = \sigma \times \epsilon \times A_s \times (T_s^4 - T_{\infty}^4) \tag{6}$$

$$Q_{conv} = h \cdot A_s \cdot (T_s - T_{ambient}) \tag{7}$$

The heat transfer coefficient (h) can be determined by using these equations:

$$h = \frac{Nu.K_f}{L_c} \quad (8)$$

$$Nu = 0.6(Gr.Pr)^{\frac{1}{5}} \quad (9)$$

$$Gr = \frac{g.\beta.(T_s - T_{amb}).L_c^3}{\nu^2} \quad (10)$$

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

$$X = \frac{\text{Energy loss}}{\text{Heat load}} \quad (11)$$

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

$$Y = \frac{(\text{Energy from solar collector})}{\text{Load}} \quad (12)$$

$$Y = \frac{(CR \times I \times A_r \times \tau\alpha + I \times A_T \times \tau\alpha) \times N}{L}$$

Δt : Time(sec) ($N \times 24 \times 3600$)

N = Number of days

I = Incident solar radiation (J/m^2)

A_T : reciver top surface area (m^2)

A_r : reciever project area (m^2)

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

$$f = (\Sigma FL / \Sigma L) \quad (14)$$

$FL = f \times \text{Load}$

4. Results and Discussions

The mathematical models in this work and experimental measurements for the CRT are summarized in Table (1) as shown below.

Table (1) Results of present work of central receiver tower

Year	Months	Properties of fluid exit from tank receiver	Inlet temperature of water	Outlet temperature of water
2015	June	Hot water	35 °C	98 °C
2015	July	Steam	38 °C	110 °C
2015	August	Steam	39 °C	118 °C
2015	September	Hot water	30.5 °C	95 °C
2015	October	Hot water	24 °C	80 °C
2015	November	Hot water	20.5 °C	61 °C
2015	December	Hot water	14 °C	45 °C
2016	January	Hot water	11.5 °C	38 °C
2016	February	Hot water	16.1 °C	50 °C
2016	March	Hot water	18.4 °C	65 °C
2016	April	Hot water	24 °C	78 °C
2016	May	Hot water	28.7 °C	89 °C

As shown before, the outlet temperatures of hot water will inlet to heat exchanger for exchanging heat with cold water for increasing its temperature to enhance the performance of feed water heater of steam power plants. The experimental data for the heat exchanger summarized in Table (2).

Table (2) Results of experimental data of heat exchanger

Year	Months	Flow rate of hot and cold water (L/min)	Thi (°C)	Tho (°C)	Tci (°C)	Tco (°C)
2015	June	7	98	78.1	30	47
2015	July	7	110	88.4	35	54.2
2015	Aug	7	118	94.7	38	58.8
2015	Sep	7	95	77.5	25	40.7
2015	Oct	7	80	64	21	34.2
2015	Nov	7	61	48.2	19	29.1
2015	Dec	7	45	37	15	21.5
2016	Jan	7	38	31.7	14	19.2
2016	Feb	7	50	40.3	18	25.9
2016	Mar	7	65	51.8	22	33
2016	Apr	7	78	63.4	28	40.8
2016	May	7	89	71	30	45.4

4.1. Monthly and Annual Solar Energy Contributions

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 (3). From South Baghdad Thermal Electrical Power Plant the thermal load was used is 5Mw (180000MJ).

Table (3) Result of Monthly and Annual Solar Energy Contribution.

Year	Months	Energy from solar collector (MJ)	Energy loss (MJ)	Load (MJ)	X	Y	F (%)
2015	Jun.	2013.6	1137.5	180000	0.0063	0.0111	1.6
2015	Jul.	2260.8	1328.2	180000	0.0073	0.0125	1.79
2015	Aug.	2312.7	1438.1	180000	0.0079	0.0128	1.86
2015	Sep.	1905.9	1005.8	180000	0.0055	0.0105	1.05
2015	Oct.	1555.1	841.1	180000	0.0046	0.0086	0.85
2015	Nov.	1188.2	599.8	180000	0.0033	0.0066	0.65
2015	Dec.	1028.7	406.3	180000	0.0022	0.0057	0.57
2016	Jan.	941	324.2	180000	0.0018	0.0052	0.52
2016	Feb.	1248	457.9	180000	0.0025	0.0069	0.69
2016	Mar.	1467.3	667	180000	0.0037	0.0081	0.81
2016	Apr.	1666.7	781.2	180000	0.0043	0.0092	0.92
2016	May.	1925.9	887.2	180000	0.0049	0.0107	1.06
Annual							1.03

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 as shown in Table (4).

Table (4) Annual contribution of solar energy when increase the surface area of the mirror and the size of the receiver

Mirror area(m ²)	CR	Receiver dimension (D×L)m	Load (MJt)	Annual Share (F) (%)
100	46.3	1.2×1.8	180000	16.3
200	92.6	1.2×1.8	180000	30
300	138	1.2×1.8	180000	43
400	185	1.2×1.8	180000	54.6
500	231	1.2×1.8	180000	65
600	277	1.2×1.8	180000	74
700	324	1.2×1.8	180000	83
800	370	1.2×1.8	180000	90

4.2. Comparison between theoretical data and experimental data:

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 (3-16).

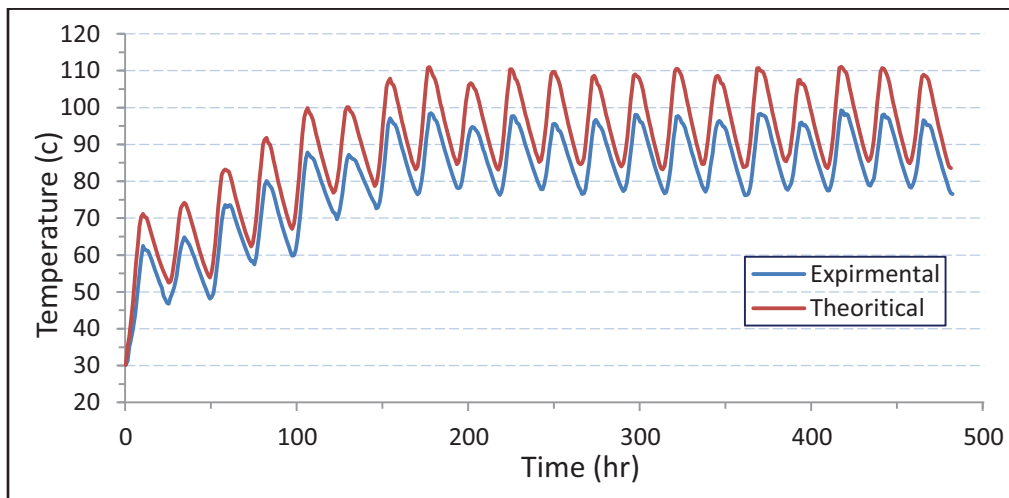


Fig. (3) Variation of hot water temperature with time for (20 day) in June 2015.

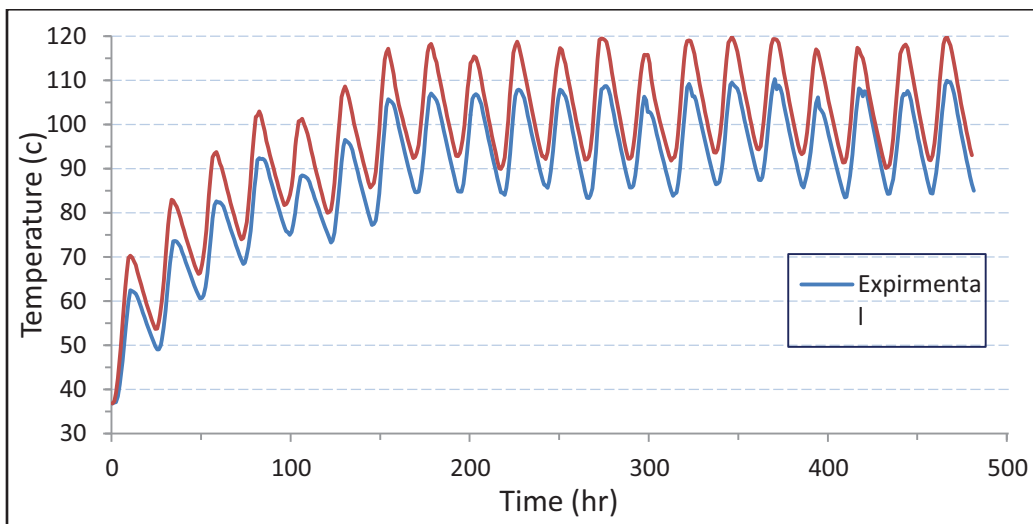


Fig. (4) Variation of hot water temperature with time for (20 day) in July 2015.

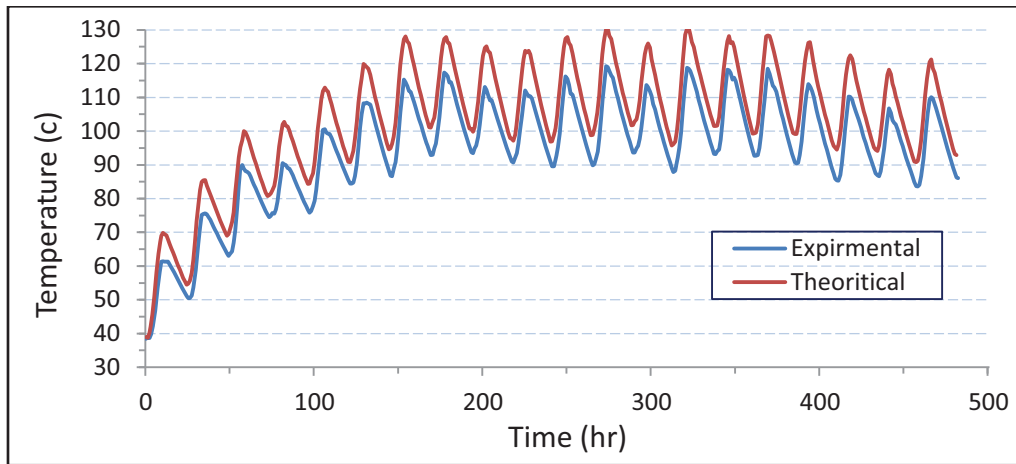


Fig. (5) Variation of hot water temperature with time for (20 day) in August2015.

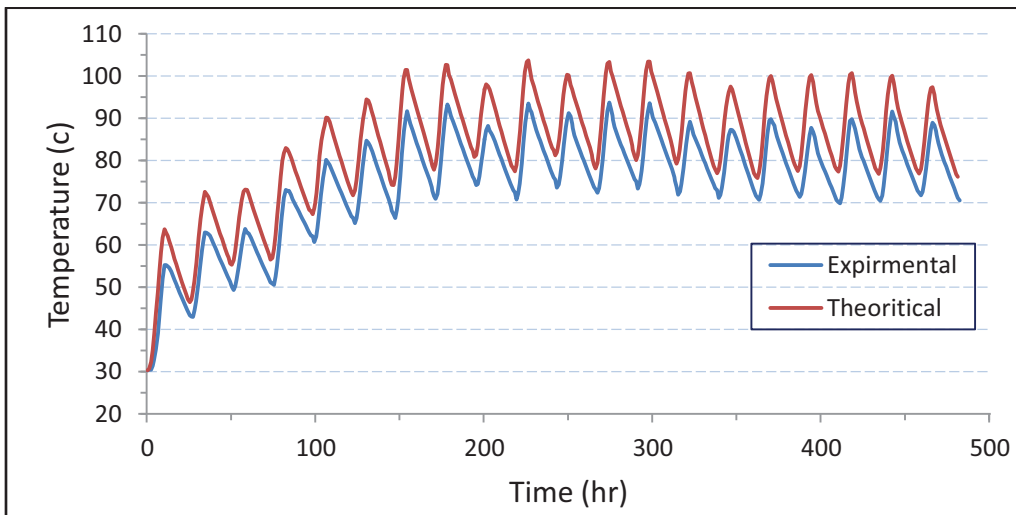


Figure (6): Variation of hot water temperature with time for (20 day) in September 2015.

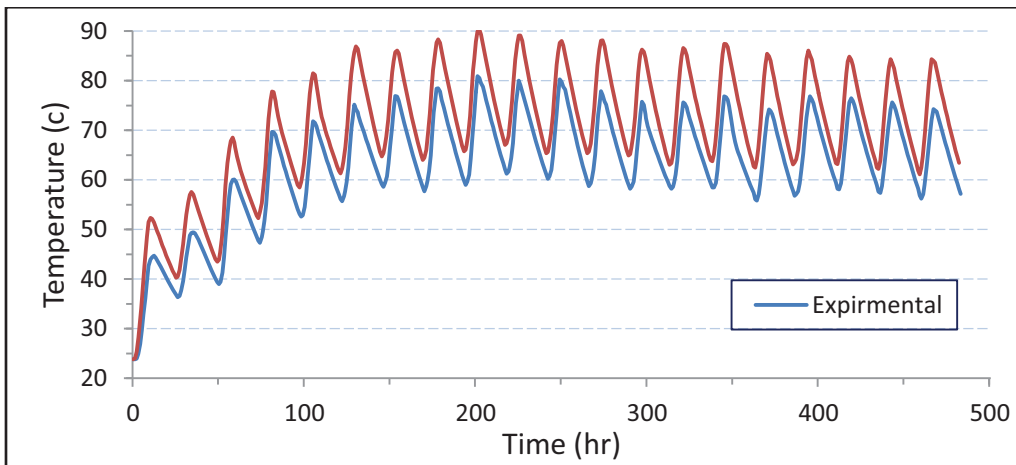


Fig. (7) Variation of hot water temperature with time for (20 day) in October 2015.

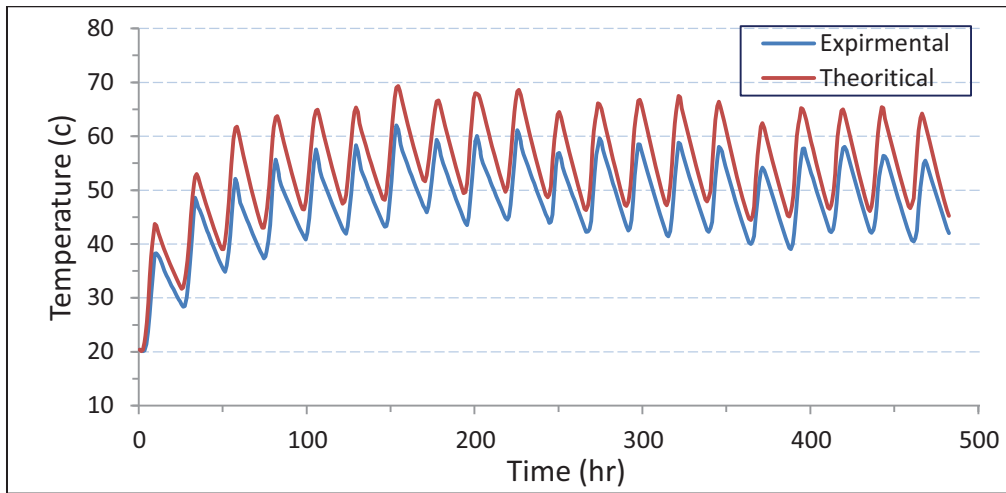


Fig. (8) Variation of hot water temperature with time for (20 day) in November 2015.

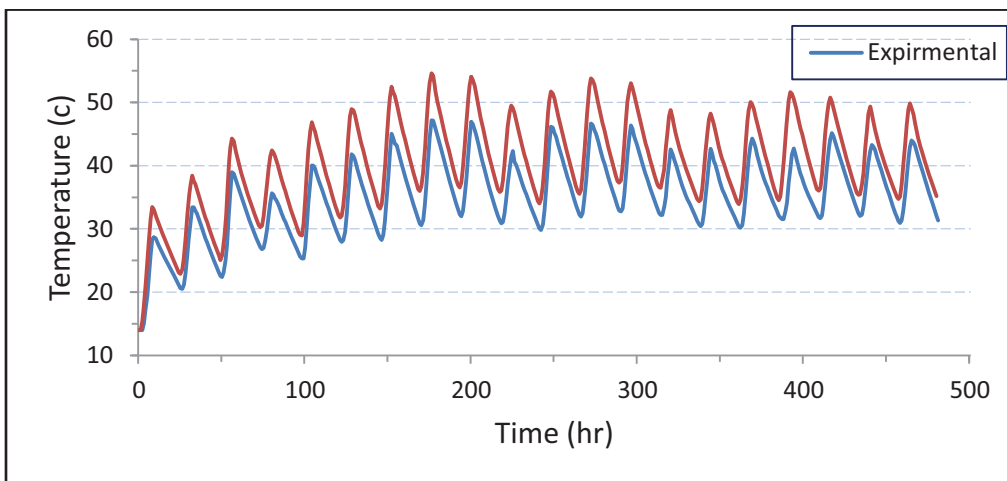


Fig. (9) Variation of hot water temperature with time for (20 day) in December 2015.

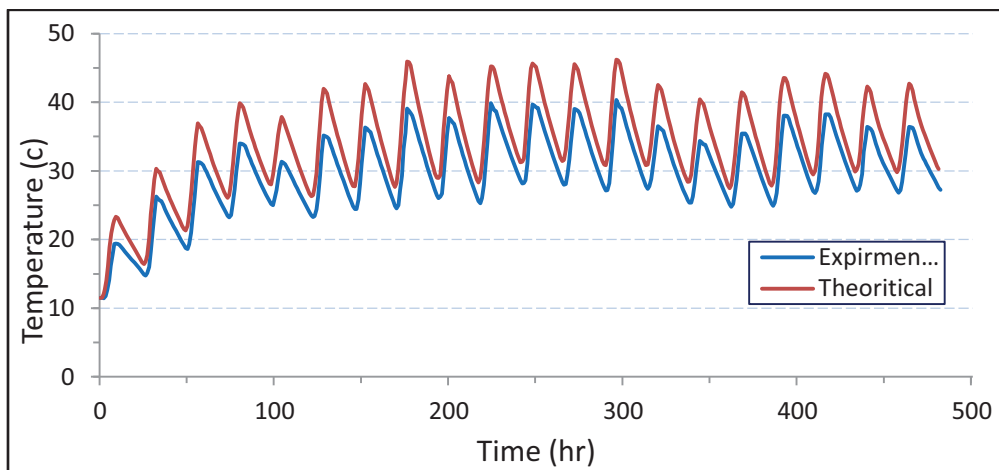


Fig. (10) Variation of hot water temperature with time for (20 day) in January 2016.

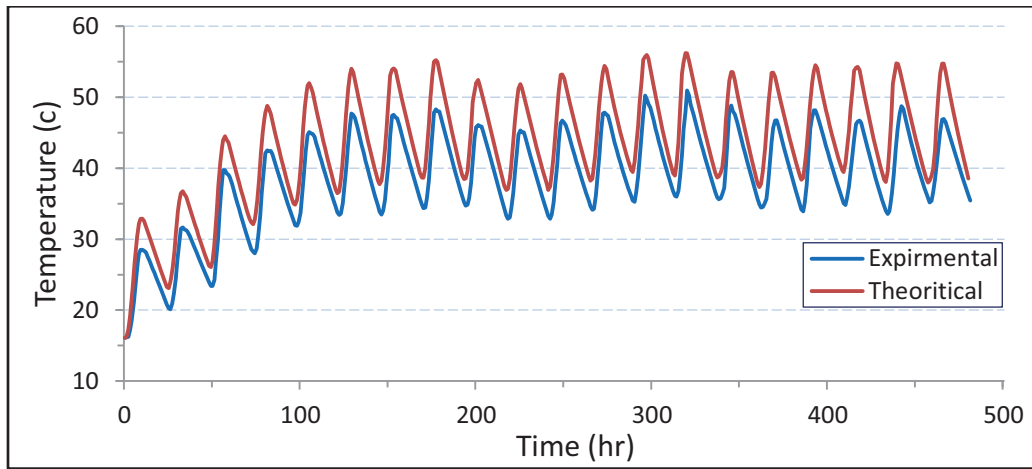


Fig. (11) Variation of hot water temperature with time for (20 day) in February 2016.

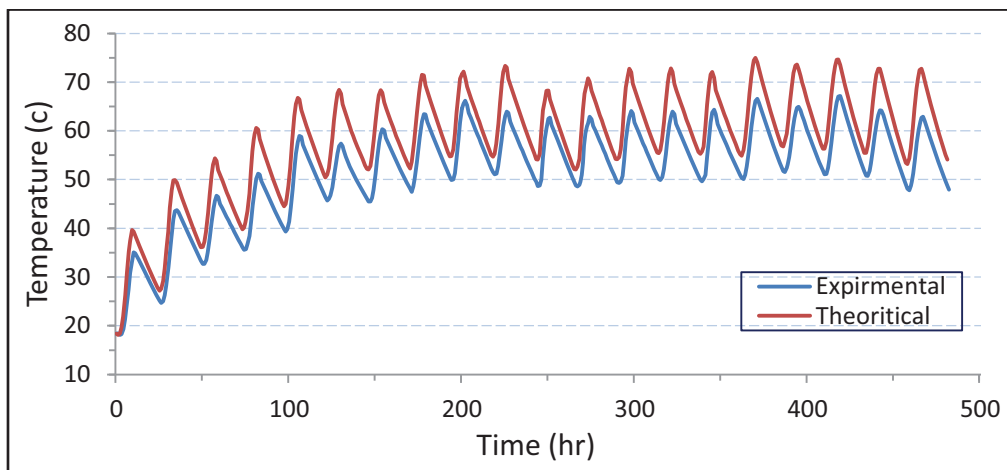


Fig. (12) Variation of hot water temperature with time for (20 day) in March 2016.

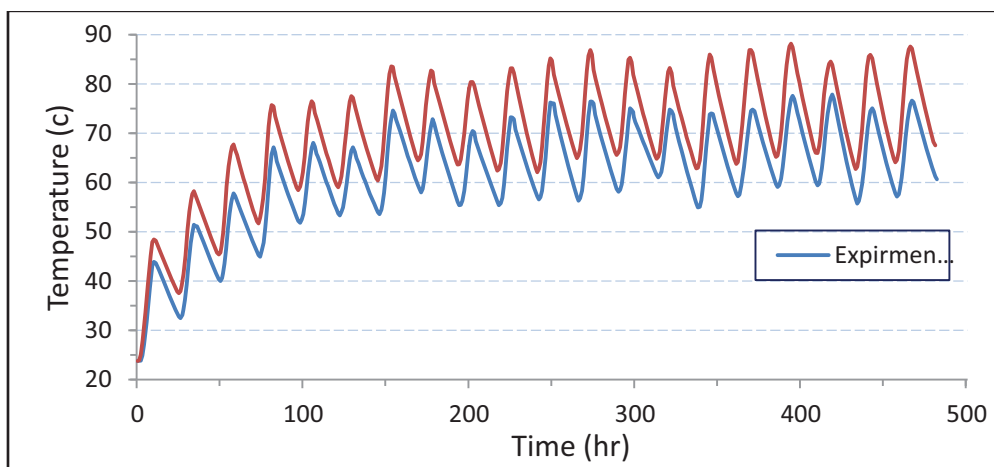


Fig. (13) Variation of hot water temperature with time for (20 day) in April 2016.

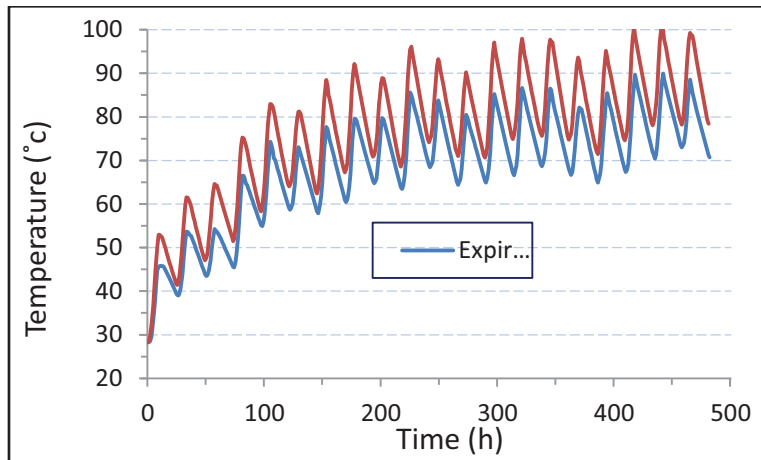


Fig. (14) Variation of hot water temperature with time for (20 day) in May2016.

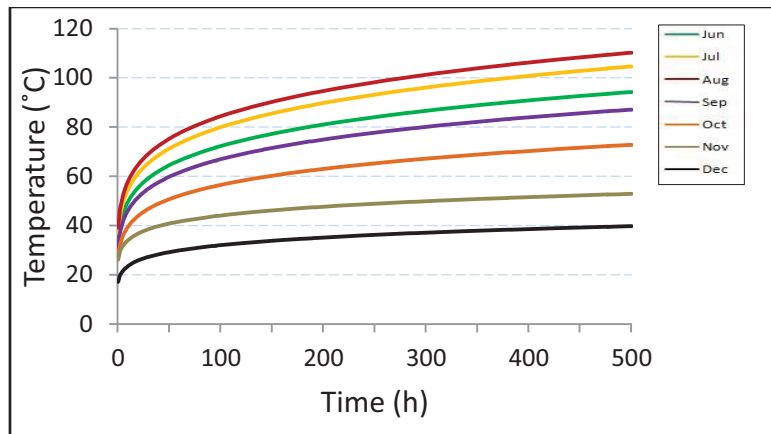


Fig. (15) Monthly average temperature of hot water in the storage tank from (June – December 2015).

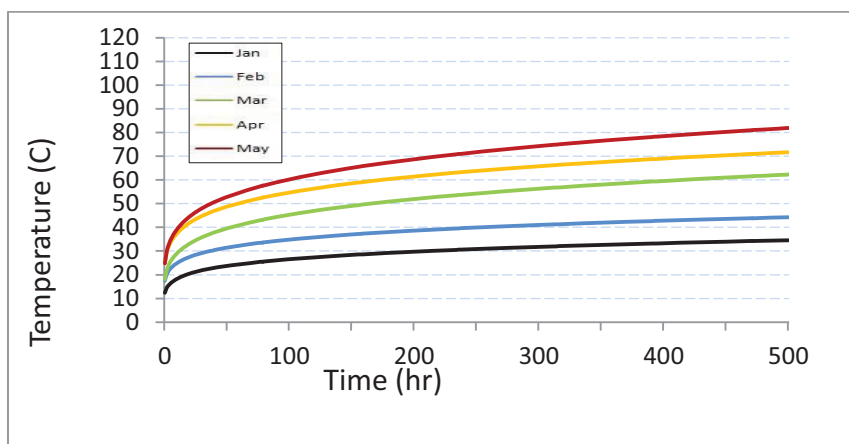


Fig. (16) Monthly average temperature of hot water in the storage tank from (January – May 2016).

5. Conclusions

The following conclusions are drawn:

1. The contribution of solar energy to heat feed water heater is increased by increasing the surface area of mirrors
2. Increasing the volume of water decrease the exit temperature but gives better contribution because of the high flow rate.
3. The highest exit temperature for water occurred in (June, July and August) due to the high intensity of solar radiation.
4. Although the sharing of solar energy in winter season is low, the load in this season also low, so the sharing of solar energy will be acceptable.
5. It can be design the concentrating solar collector in the form of groups to reduce the size of the receiver.

Nomenclature

Q_u	Useful energy (W)	σ	Stefan-Boltzmann constant ($W/m^2 \cdot K^4$)
Q_{solar}	Concentrating solar energy from the mirror (W)	ϵ	Emissivity of receiver
Q_{dir}	Direct solar energy to the receiver (W)	T_a	Ambient temperature ($^{\circ}C$)
Q_{in}	Energy incident on receiver (W)	T_s	Temperature of receiver surface (K)
Q_{out}	Energy absorbed by working fluid (W)	T_{∞}	Temperature of surroundings (K)
CR	Concentration ratio	T_f	Film Temperature ($^{\circ}C$)
A_a	Aperture area (m^2)	h	heat transfer coefficient ($W/m^2 \cdot K$)
A_r	Receiver project area (m^2)	Nu	Nusselt number
A_s	Surface area of receiver (m^2)	Gr	Grashoff number
I_a	Incident radiation (W/m^2)	K_f	Thermal conductivity of ambient fluid ($W/m \cdot K$)
m	Mass of the water (Kg)	L_c	Characteristic length of cylindrical receiver (m)
Δt	Time change for each hour (Sec)	β	Volumetric thermal expansion coefficient ($1/^{\circ}C$)
T_w	Temperature of the water ($^{\circ}C$)	ν	Kinematic viscosity (m^2/s)
T_w^+	Temperature of the water after one hour ($^{\circ}C$)		

References:

1. International Energy Agency, "Solar Energy Perspective", OECD/IEA, France, 2011.
www.iea.org/about/copyright.asp
2. Zhilei Jin, "Concentrated Solar Power Generation", M. Sc. Thesis, Arizona State University, USA.2013.
3. Rafid. M. Hannun, "Modeling of a Solar Thermal Power Plant", M. Sc. Thesis, University of Technology, Iraq. 2005.
4. Salah A. H. Saleh, "Impact of Urban Expansion on Surface Temperature in Baghdad, Iraq", Journal of Al-Nahrain University, Vol.13 (1), March, pp.48-59, 2010.
5. Davide Ferruzza, "Thermocline Storage for Concentrated Solar Power", M. Sc. Thesis, Royal Institute of Technology, Sweden. 2015.
6. Henry price, "Concentrating solar power system analysis and energy load", USA, DEC.2002.
7. S. Giuliano, R. Buck and S. Eguiguren, "Analysis of Solar Thermal Power Plants with Thermal Energy Storage and Solar-Hybrid Operation Strategy", M. Sc. Thesis, Institute of Technical Thermodynamics, Germany, 2011.
8. Seyed H. Madaeni, "How Thermal Energy Storage Enhances the Economic Viability of Concentrating Solar Power", IEEE Trans. On Magn, Vol. 201.
9. Björn Palm, "Exergoeconomic Analysis and Benchmark of a Solar Power Tower with Open Air Receiver Technology", M. Sc. Thesis, Royal Institute of Technology, Sweden. 2012.
10. M.T. Chaichan, K. I. Abaas and H. A. Kazem," The Effect of Variable Designs of the Central Receiver to Improve the Solar Tower Efficiency", Int.Journal of Engineering and Science, ISSN: 2278-4721, Vol. PP 56-61 1.2012.
11. Afreen Emad,"The Performance Assessment of a Concentrating Solar System in Iraq", M. Sc. Thesis, Al-Mustansiriya University, Iraq.2016.
12. Jonathan C. Tempies, "A Technical Evaluation of Concentrating Solar Thermal Power Generation Technologies for The Upington Area of South Africa", M. Sc. Thesis, University of KwaZulu-Natal, South Africa. 2012.