Journal of Solar Energy research Vol 3 No 3 (2018) 227-236

ICESE

Journal of Solar Energy Research (JSER)

Journal homepage: jser.ut.ac.ir

Experimental Energy and Exergy Analysis of a Flat Plate Solar Water Heater to Find Optimum Collector Mass Flow Rate

S. Khanmohammadi [a*], F. Veysi [b], S. Amini [b]

[a] *Department of Mechanical Engineering, Kermanshah University of Technology, Kermanshah, Iran; *Email: shoaib_270@yahoo.com*
[b] *Department of Mechanical Engineering, Faculty of Engineering, Razi University, Kermanshah, Iran*

ARTICLE INFO

Received: 31 Aug 2018
Received in revised form: 25 Oct 2018
Accepted: 05 Dec 2018
Available online: 05 Dec 2018

Keywords:
SWH; collector flow rate; exergy efficiency; optimum flow rate

A B S T R A C T

This paper presents the experimental study of a flat plate solar collector to find the optimum flow rate of collector with variation of daily solar radiation intensity. The procedure of ASHRAE standard was used for testing the thermal performance of flat-plate solar collector. Results show that using optimal collector flow rate can improve energy and exergy efficiency of SWH. Furthermore, results show that in no load on storage tank overall energy efficiency can improve between 0.25 % and 7 %. In addition, calculations show an increment between 0.18 % and 1.12% for overall exergy efficiency. In the 36 L/h, and 52 L/h and 72 L/h thermal load on storage tank overall energy and exergy efficiency show a reasonable increment with using optimum flow rate of collector. Finally, these experimental analysis results can be a base for design a collector flow rate controller to have a more efficient SWH.

1. Introduction

There is an increasing interest for using solar water heater (SWH) because of their inexpensiveness, no need of fuel and environmental friendly aspects. In a SWH, collector is the main part of the system. Therefore, optimization of collector has the great effect on performance of the system. Although the radiation characteristics of solar collector such as absorptivity, emissivity are highly important, the fluid flow characteristics such as flow regime inside pipe and flow rate of collector has the substantial effect on thermal performance of system. There are many paper deals with experimental and theoretical study of SWH systems. In order to find the thermodynamic optimization of flat plate solar collector Mahanta D.K. and Saha S. K. [1] carried out a thermodynamic analysis. The optimization was a method based on minimized entropy generation. Nurdil Eskin [2] performed a simulation study on a solar heating system. She also used an experimental set up to evaluate exergetic performance of unsteady system. Viorel Badescu [3] implemented a direct optimal control method to find the best operation strategies for an open loop flat plate solar collector system. He finds that the optimum mass-flow rate is well correlated with global solar irradiance during the warm season. Tyagi S.K. et. al. [4] investigated exergetic performance of concentrating type of solar collector by parametric study using hourly solar radiation. Their results include variation of exergy output, thermal and exergetic efficiency with variation of concentration ratio in a given mass flow rate. In other research Hekmit Esen [5] performed an experimental energy and exergy analysis of a double-flow solar air heater. He evaluates four types of double flow solar air collectors under a wide range of operating conditions. Farahat S. et. al. [6] carried out an exergy analysis to find the optimum performance of a flat plate solar collector. In their study, a simulating program developed for thermal exergetic calculations. Their findings show that increasing wind speed and ambient temperature rapidly decreases the exergetic efficieny of system. Moreover, increasing incident solar energy per unit area of the absorber plate, increase exergy efficiency. Luminosu and Fara [7] investigated optimal performance flat plate collector using exergy analysis. They assumed that the fluid inlet temperature equal to ambient temperature in order to eliminate random variation in fluid inlet temperature. Results gave optimal values for the characteristic quantities of flat plate solar collector with open circuit. Valladares O. G. et. al. [8] conducted an experimental study on a domestic SWH. They carried out a set of experimental study on various solar systems in a similar solar radiation, ambient temperature, and initial condition. In addition, they find that temperature profile and mean temperature of storage tank, average efficiency of system, and exergy destruction during nighttime. Viorel Badescu [9] discussed the optimal control of flow in solar collector systems with fully mixed water storage tanks . Two design configurations proposed and comprehensive analysis carried out to find the better configurations. In addition, an optimal operation strategy include variation collector flow rate is investigated. Mousa S. Mohsen et. al. [10] studied a SWH in different local climatic conditions. Their experimental study reveals that temperature increment in a collector with single glass cover a few more than a collector with two glasses cover does and it is more effective to maintain hot water temperature in higher level. More paper can be found in Refs.[11, 12]

Since solar radiation intensity varies during a daytime, finding the optimum flow rate of collector in each solar radiation bandwidth can improve the performance of SWH. The literature reports show that optimum flow rates with variation solar radiation intensity not include the pervious study. The aim of current research is to develop an experimental study to find the optimum flow rate of collector in a SWH based on energy and exergy analysis. Results of this research can be a base to design an efficient controller for mass flow rate to have a more efficient SWH.

The SWH used in this experimental study composed of a solar flat plate collector, a storage tank and two circulation pumps. The area of solar collector is 2 m^2 and collector plates made of six parallel strips that are manufactured in copper pipe rolling method. The schematic of this solar collector is shown in Figure 1 also in the Table 1 specificatin is given.

2. Experimental set up

The schematic of experimental set up is shown in Figure 2 The SWH selected for experimental study is manufactured by Gunt, which is a German company. The solar collector (f in Figure 2) was experimentally investigated at the Razi University of Kermanshah, Iran.

Figure 1. The experimental set up front view

The relative collector position is shown in Figure 1. The tilt angle of flat plate collector is 45°. An electrical pump (b in Figure 2) circulates water in storage tank (a in Figure 1) circuit. The capacity of storage tank is 140 Liter. The system includes an expansion tank (d in Figure 1) and a relief valve (e in Figure 2), too. The solar controller (TDIC) with three thermostat provided for regulate the temperature. Four thermocouples measure temperature in collector inlet and outlet and heat exchanger inlet and collector circulating pump outlet. These sensors connected to a four-channel data logger (Testo 177-T4) which measure temperature with 0.01 ℃ uncertainties. In addition, a thermocouple was used to measure ambient temperature. A TES-1333R solar meter type records solar radiation. Accuracy of solar meter for radiation intensity below 1000 W/m^2 is $\leq 0.001\, W/m^2$.

3. Testing method

ASHRAE Standard 86-93 [13] for testing the thermal performance of collectors is certainly the one most often used to evaluate the performance of the flat-plate and concentrating solar collectors. The thermal performance of the solar collector is determined by obtaining the values of instantaneous and average efficiency for different combinations of incident radiation, and inlet fluid temperature.

This requires experimental measurement of the rate of incident solar radiation as well as the rate of energy addition to the working fluid as it passes through the collector, all under steady state or quasi-steady-state conditions.

Table 1. The specifications of the experimental set up.

Specifications	Value	Unit
Collector		
Dimensions	2065*1225*103	mm^3
Weight	42	kg
Volume of fluid	1.4	Liter
Absorptivity	95	%
Emissivity	5	%
Pipe diameter	8	mm
Storage tank		
Dimensions	850*750*600	mm^3
Volume	140	Liter
Allowable pressure	3	bar
Performance Temp.	95	℃
Heat exchanger		
Maximum performance pressure at 135 ℃	Inside circuit:45 outside circuit:45	bar bar
Minimum Temp.	-196	℃
Maximum Temp.	225	℃
Plate material	cupper	-
Storage tank pump		
Flow rate	5	m^3/h
Head	6	meter
Ambient Temp.	0 to 40	℃
Working fluid temp.	-10 to 110	℃

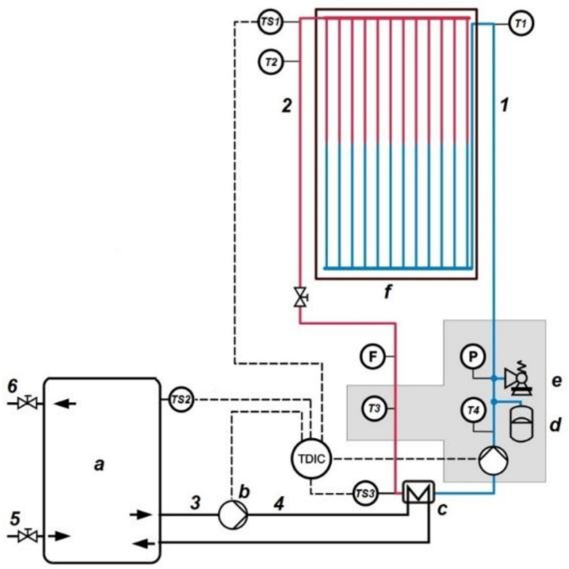

Figure 2 Schematic diagram of SWH model HL 313

3.1. Data collection

Based on ASHRAE standard 15 minutes time duration needs in order to system reach steady state after each variation in collector flow rate. In a working day from 8:55 to 16:55 about 32 series of data is obtained. Flow rate measure by a Rotameter.

3.2. Efficiency calculation

3.2.1. Energy efficiency

To calculate SWH energy efficiency the useful energy gain should be calculated. As the inlet and outlet fluid temperatures and the mass flow rate of water were measured, the useful energy can be calculated using Eq. (1). The useful energy can also be expressed in terms of the energy absorbed by the absorber and the energy lost from the absorber as given by Eq.(2):

$$Q_u = \dot{m}_1 C_p (T_2 - T_1) \tag{1}$$

$$Q_u = A_p F_R [S - U_L (T_1 - T_a)] \tag{2}$$

where Q_u is the rate of useful energy gained, $\dot{m}_1$ is the mass flow rate of fluid flow, C_p is the heat capacity of working fluid T_0 is the outlet fluid temperature of solar collector, A_p is the surface area of solar collector, F_R is the heat removal factor, S is absorbed radiation heat flux, U_L is overall heat loss, and T_a is the ambient temperature. F_R can be calculated from below:

$$F_R = \frac{\dot{m}_1 C_p}{U_L A_p}[1 - \exp(-\frac{F' U_L A_p}{\dot{m}_1 C_p})] \tag{3}$$

In the above equation F' is collector efficiency factor. It can be calculated from collector geometrical parameters and fluid flow characteristic in collector pipe. More detail can be found in Ref. [14]. From optical analysis, the radiation absorbed heat flux can be calculated [15].

$$S = (\tau\alpha) I \tag{4}$$

Where $\tau\alpha$ is the effective transmittance-absorptance coefficient that is equal with the optical efficiency (η_0). Regards to the obtained equations the energy efficiency of SWH can be written as follows:

$$\eta_{en} = \frac{Q_u}{I * A_p + W_{pump}} \tag{5}$$

3.2.2. Exergy efficiency

Exergy is defined as the maximum theoretical useful work that can be obtained as a system interacts with an equilibrium state [16]. One can find the formula for exergy balance as:

$$\dot{E}_{f,in} + \dot{E}_{f,out} + \dot{E}_{Q,in} + \dot{E}_s + \dot{E}_{loss} + \dot{E}_D = 0 \tag{6}$$

Where $\dot{E}_{f,in}$, $\dot{E}_{f,out}$, $\dot{E}_{Q,in}$, $\dot{E}_s$, $\dot{E}_{loss}$, $\dot{E}_D$ are the inlet flow exergy, outlet flow exergy, absorbed solar radiation exergy, stored exergy, exergy loss, and exergy destruction rate, respectively. The inlet flow exergy rate is given by [17]:

$$\dot{E}_{f,in} = \dot{m} C_p \left(T_{in} - T_a - T_a \ln\left(\frac{T_{in}}{T_a}\right)\right) + \frac{\dot{m}\Delta P_{in}}{\rho} \tag{7}$$

The outlet flow exergy rate can be given by [17].

$$\dot{E}_{f,in} = -\dot{m}C_p\left(T_{out} - T_a - T_a \ln\left(\frac{T_{out}}{T_a}\right)\right) + \frac{\dot{m}\Delta P_{out}}{\rho} \quad (8)$$

In equation 7 and 8 ΔP_{in} and ΔP_{out} are the pressure difference between dead state pressure and working fluid in inlet or outlet. The absorbed solar radiation exergy can be defined as follow:[6, 8]

$$\dot{E}_Q = \eta_0 I_t A_p(1 - \frac{T_a}{T_s}) \quad (9)$$

Where T_s is the apparent sun temperature that is equal with 75 percent of the black body temperature of the sun [18]. The stored energy in the steady state condition is zero. The exergy loss rate that is due to energy loss to ambient from a control volume is given by [19]:

$$\dot{E}_{loss} = -UA_c(T_c - T_a)(1 - \frac{T_a}{T_c}) \quad (10)$$

The exergy destruction rate composed of three terms. The first one due to temperature difference between the control volume and the sun temperature [19]

$$\dot{E}_{D,\Delta TS} = -\eta_0 I_t A_{CV} T_a(\frac{1}{T_{CV}} - \frac{1}{T_s}) \quad (11)$$

The second term is due to pressure drop in the path of flow:

$$\dot{E}_{D,\Delta P} = -\frac{\dot{m}\Delta \mathrm{P}}{\rho}\frac{T_a \ln(\frac{T_{out}}{T_a})}{T_{out} - T_{in}} \quad (12)$$

Moreover, the third term is caused by temperature difference between control volume surface and the working fluid that can be written as follow:

$$\dot{E}_{D,\Delta T_f} = -\dot{m}C_p T_a(\ln\left(\frac{T_{out}}{T_{in}}\right) - \frac{T_{out} - T_{in}}{T_{surr,CV}}) \quad (13)$$

Considering exergy efficiency definition and the aforementioned exergy equations the second law efficiency of SWH system (Figure 2) can be states as follows:

$$\eta_{ex,sys} = \frac{1}{I_t A_p\left(1-\frac{T_a}{T_s}\right)W_{pump}}\{\left[\dot{m}_1 C_p\left(T_1 - T_2 - T_a \ln\left(\frac{T_1}{T_2}\right)\right) - \frac{\Delta P_{col}}{\rho}\right] - \eta_0 I_t A_p\left(1 - \frac{T_a}{T_s}\right) - U_L A_p(T_p - T_a)\left(1 - \frac{T_a}{T_p}\right) + \eta_0 I_t A_p\left(1 - \frac{T_a}{T_s}\right) - U_L A_p(T_p - T_a)\left(1 - \frac{T_a}{T_p}\right) - \eta_0 I_t A_p T_a\left(\frac{1}{T_p} - \frac{1}{T_a}\right) - \frac{\dot{m}_1 \Delta P_{col}}{\rho}\frac{T_a ln\frac{T_2}{T_1}}{T_2 - T_1} + \dot{m}_1 C_p T_a ln\frac{T_2}{T_1} - \frac{T_2 - T_1}{T_p} + \left[\dot{m}_1 C_p\left(T_3 - T_4 - T_a \ln\left(\frac{T_3}{T_4}\right)\right)\right] + \frac{\dot{m}_1 \Delta P_{col}}{\rho} - \eta_{el}\eta_{mec}\dot{W}_{pump} + \dot{m}_1 C_p\left(T_2 - T_3 - T_a \ln\left(\frac{T_2}{T_3}\right)\right) - \frac{\dot{m}_1 \Delta P_{exe}}{\rho} - \dot{m}_1 C_p\left(T_2 - T_3)T_a(\frac{2}{T_5 + T_6} - \frac{2}{T_2 + T_3}\right)\} \quad (14)$$

3.2.3. Average energy and exergy efficiency

The average energy efficiency of solar water heater system can be calculated from:

$$\eta_{en,ave} = \frac{\sum_{j=1}^{n} \dot{m}_2 C_P(T_{6j} - T_{5j})\Delta t_j}{\sum_{j=1}^{n}(I_j A_p + \dot{W}_{pump})\Delta t_j} \quad (15)$$

The average exergy efficiency of solar water heater system can be calculated from equation (16):

$$\eta_{ex,ave} = \frac{\sum_{j=1}^{n} \dot{m}_2 (C_P\left(T_{6j} - T_{5j} - T_{aj}\ln(\frac{T_{6j}}{T_{5j}})\right) - \frac{\dot{m}_1 \Delta P_{tj}}{\rho_j})\Delta t_j}{\sum_{j=1}^{n}\left(I_{Tj} A_p(1 - \frac{T_{aj}}{T_s}) + \dot{W}_{pump}\right)\Delta t_j} \quad (16)$$

4. Results and discussions

The experimental investigation includes the performance test of flat plate solar collector to find the optimum flow rate of collector. A set of data carried out and a comparison between energy and exergy efficiency has made. Experimental investigation has done in two parts, in the first part, data obtained in the case no load on storage tank and in the second one there is 36 L/h, 54 L/h and 72 L/h load on storage tank. For each part, result is presented in two ranges of solar radiation intensity. In the first range the temperature difference between inlet and outlet water of storage tank is low and the solar intensity radiation is increasing, and in the second range the temperature difference between inlet and outlet water in storage tnak is high and the solar intensity radiation is decreasing. These two ranges equal before noon and after noon performance of solar water heater.

4.1. No thermal load

The experimental data in Figure 3 show the characteristic curve of collector for no thermal load on storage tank. Figure 3 represents energy efficiency of collector against a reduced temperature $(T_i - T_a)/I$ for various collector flow rate in no load on storage tank. It can be found that for reduced temperature more than 0.02 the slope of 120 L/h curve is lower than others. These mean that for reduced temperature more than 0.02 the energy losses is low.

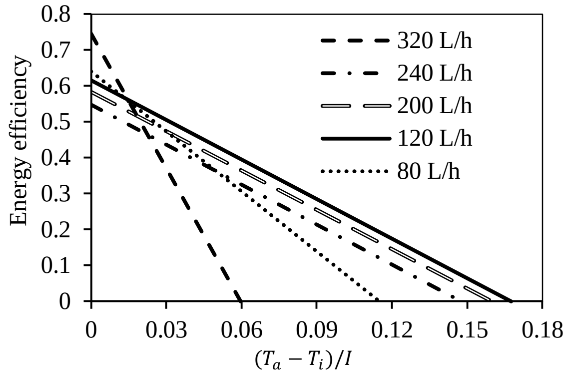

Figure 3. Characteristic curve against reduced temperature for various collector flow rate without thermal load

4.1.1. Energy analysis

Figure 4 shows the energy efficiency versus solar radiation intensity for various collector flow rate. Figure 4 (a) represents energy efficiency variation with solar thermal variation when water inlet temperature to collector is low and solar intensity radiation is increasing. Results show that in the low inlet temperature to collector and increasing solar radiation intensity, for radiation between 400 W/m2 and 600 W/m2, collector flow rate of 50 L/h and for intensity between 600 W/m2 and 900 W/m2, collector flow rate of 120 L/h shows better energy performance.

It should be mentioned that working fluid used in the experimental set up includes water and antifreeze. Since the Rotameter is calibrated for water, a correction factor should be considered for Rotameter. The optimum flow rate should be multiple by 0.8422 to give actual flow rate. Table 1 gives more detail for optimum flow rate of collector.

It can be found that in the case low inlet water temperature and increasing solar radiation intensity, 80 L/h collector flow rate has the better performance and in the case high inlet water temperature and decreasing solar radiation intensity 120 L/h collector flow rate has the best performance. Experimental data show that in the higher temperature difference between inlet and outlet to collector the flow rate of collector should be high to have higher efficiency.

4.1.2. Exergy analysis

Exergy analysis can give better insight to analysis of thermal systems. Figure 5 shows exergy efficiency versus solar radiation intensity. Table 2 represents the actual optimum flow rate in the case of no load on storage tank from exergy analysis point of view.

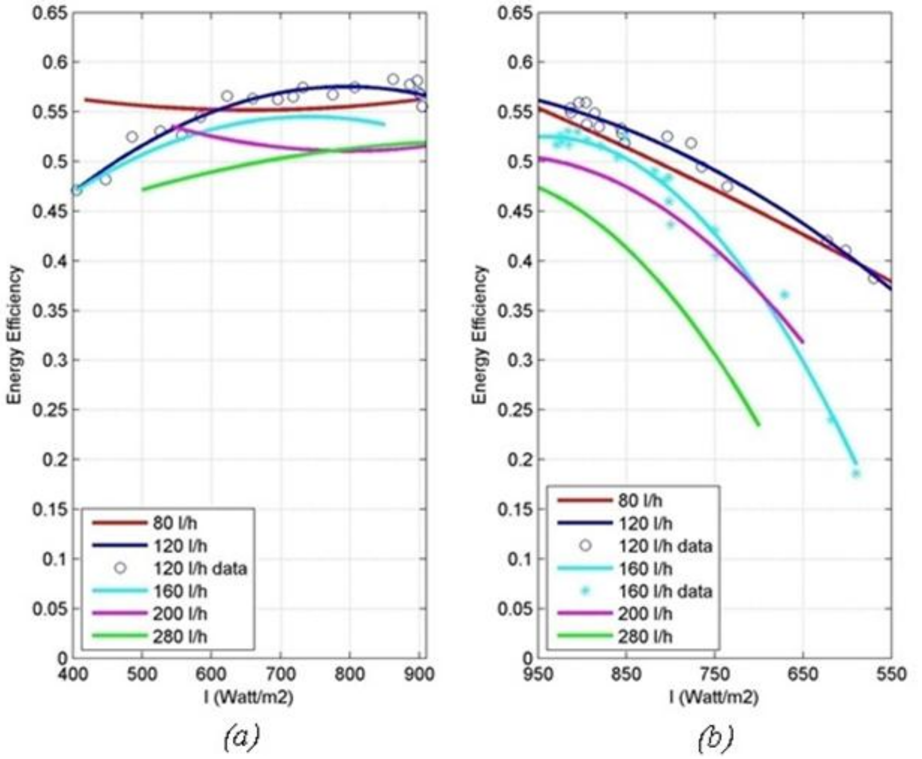

Figure 4. Energy efficiency for various collector flow rate in variation solar intensity radiation with no load in storage tank

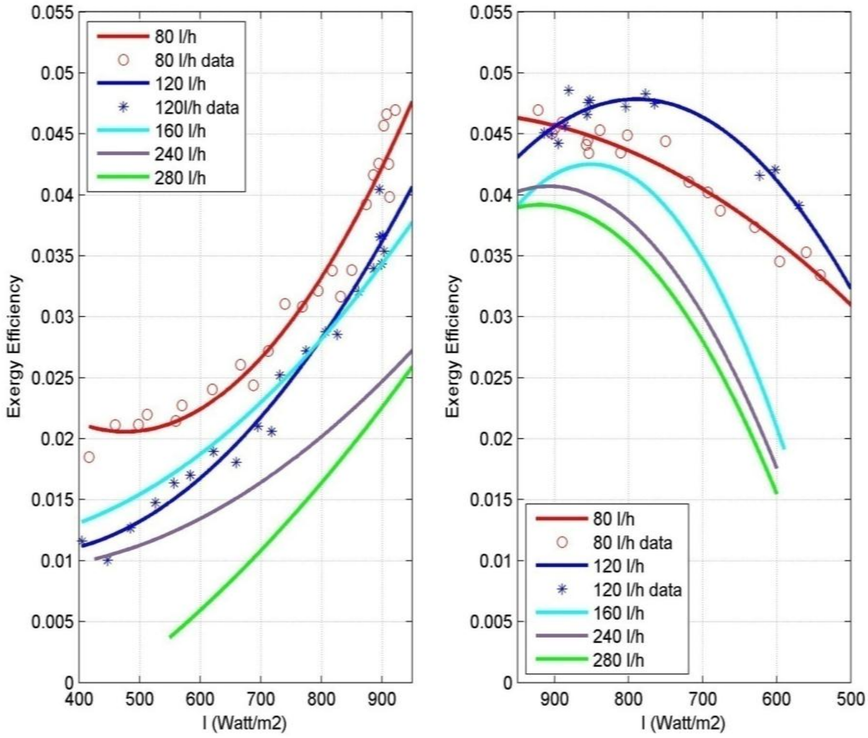

Figure 5. Exergy efficiency for various collector flow rate in variation solar intensity radiation with no load in storage tank

Daily average efficiency of solar collector system for various collector flow rate can illustrate potential of improvement of energy and exergy efficiency. Table 3 show daily average energy and exergy efficiency of collector for various collectors flow rate and optimum value of collector flow rate. Results show that overall energy efficiency of solar collector system with optimum flow rate can improve between 0.25 % and 7%. Furthermore, it can be found that overall exergy efficiency of collector with optimum flow rate can be improved between 0.18 % to 1.12%. More detail is given in Table 3.

Thermal load on storage tank is a key parameter in performance of solar flat plate collector and in finding optimum flow rate of collector. A set of experimental study conducted to find effect of thermal load on optimum flow rate.

Table 1. The optimum flow rate of flat plate collector based on energy analysis for no load in storage tank

Radiation bandwidth (W/m^2)	Increasing radiation intensity From 400 to 600	Increasing radiation intensity from 600 to 900	Decreasing radiation intensity from 900 to 450
Optimum flow rate (L/h)	80	120	120, 80
Optimum flow rate with Rotameter correction factor (L/h)	67.37	101.06	101.06, 67.37

Table 2. Optimum flow rate of collector based on exergy analysis for no load in storage tank

Radiation intensity bandwidth (W/m^2)	Increasing radiation intensity From 400 to 900	decreasing radiation intensity from 600 to 900
Optimum flow rate(L/h)	80	120
Optimum flow rate with Rota meter correction factor (L/h)	67.37	101.06

Table 3. Average daily energy and exergy efficiency of SWH system for various collector flow rate and optimum flow rate							
Collector flow rate (L/h)	80	120	160	200	240	280	320
Daily energy eff. with fix flow rate (%)	51.9	53.7	49.5	49.9	46.9	48.6	48.8
Daily energy eff. with optimum flow rate (%)	53.9						
Daily exergy eff. with fix flow rate (%)	3.7	3.5	3.3	3.4	2.99	2.78	3.0
Daily exergy eff. with optimum flow rate (%)	3.9						

4.2. Thermal load 36 L/h

4.2.1. Energy analysis

The experimental data for low inlet and outlet temperature to collector with increasing solar thermal intensity and high inlet and outlet temperature with decreasing solar radiation intensity is presented in Figure 6. Results indicate that in the case of increasing and decreasing solar radiation intensity, energy efficiency with increasing temperature difference between inlet and outlet temperature increases.

In addition, it can be conclude that in the case of low initial tank temperature and increasing solar radiation intensity, for solar radiation intensity between 850 and 950 the collector flow rate of 280 L/h has the optimum energy performance. In the case of decreasing solar intensity and high initial temperature of tank result is shown in Table 4.

4.2.2. Exergy analysis

Exergy analysis gives similar results. Exergy analysis results show that increasing solar radiation intensity lead to increasing efficiency for increasing solar intensity.

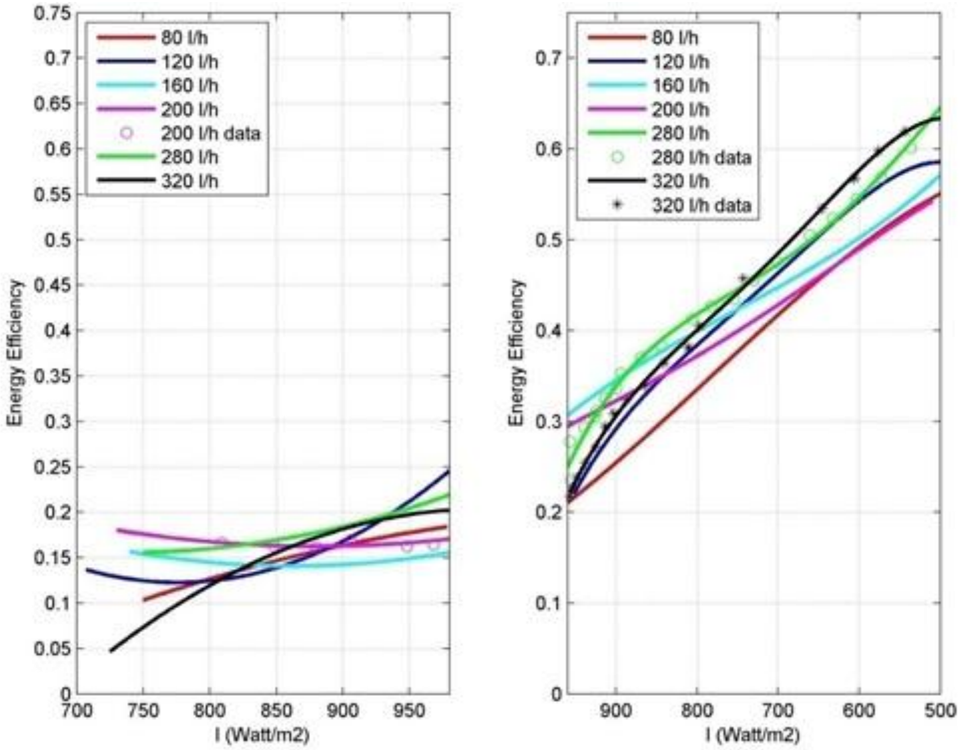

Figure 6. Exergy efficiency for various collector flow rate in variation solar intensity radiation with 36 L/h thermal load in storage tank

This trend continues for high temperature of storage tank and decreasing solar intensity with a trivial difference which exergy efficiency go down for some collector flow rate. (Figure 7)

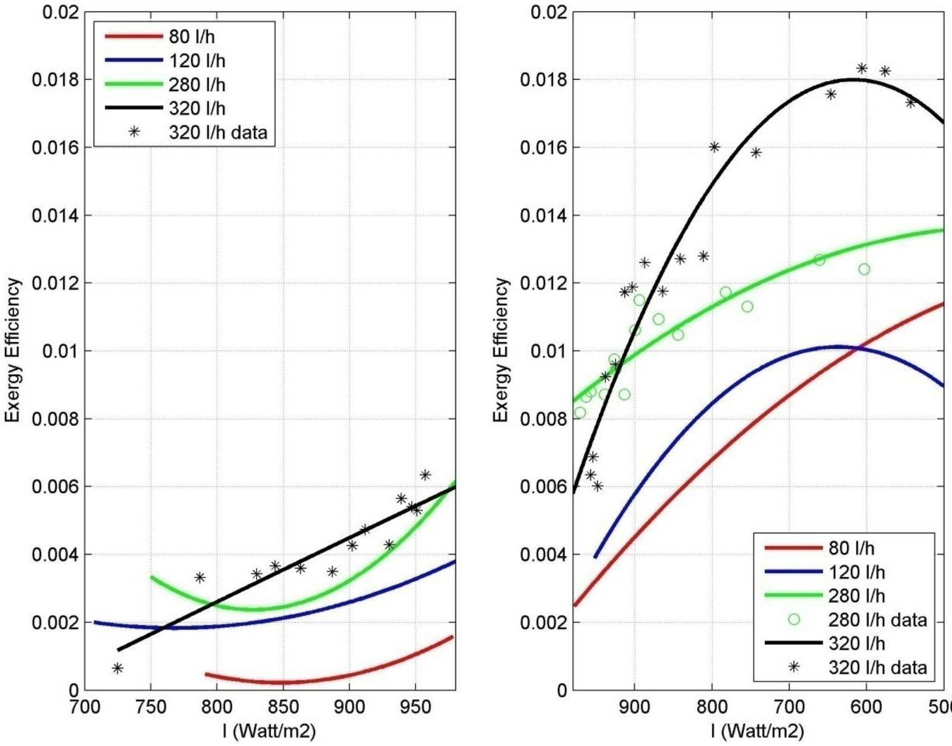

Figure 7. Exergy efficiency for various collector flow rate in variation solar intensity radiation with 36 L/h thermal load in storage tank

Based on exergy analysis, optimum flow rate can be divided into several range of solar intensity. Table 5 shows optimum flow rate for each solar radiation intensity span.

Average daily energy and exergy efficiency for optimum and other collector flow rates is calculated. Results indicate that energy efficiency of SWH system can be enhanced between 4.54% and 10.86% with using optimum flow rate of collector (Table 4).

4.3. Thermal load of 54 L/h and 72 L/h

The effect of storage tank thermal load on optimum flow rate of collector is investigated.

show the range of radiation intensity that the collector flow rates have the highest efficiency for 54 L/h and 72 L/h thermal load on storage tank.

Table 4. The optimum flow rate of flat collector based on energy analysis for 36 L/h thermal load on storage tank

Radiation intensity bandwidth (W/m^2)	Increasing radiation intensity From 850 to 950	Decreasing radiation intensity from 1000 to 900	Decreasing radiation intensity from 900 to 750	Decreasing radiation intensity from 750 to 550
Optimum flow rate (L/h)	280	160	280	320
Optimum flow rate with Rotameter correction factor (L/h)	235.81	134.75	235.81	269.504

Table 5. The optimum flow rate of flat plate collector based on energy analysis for 36 L/h thermal load on storage tank

Radiation intensity bandwidth (W/m^2)	Increasing radiation intensity From 770 to 950	Decreasing radiation intensity from 950 to 900	Decreasing radiation intensity from 900 to 5
Optimum flow rate (L/h)	320	280	320
Optimum flow rate with Rota meter correction factor (L/h)	269.5	235.81	269.5

Table 6. Average daily energy and exergy efficiency of solar water heating system for various collector flow rate and optimum flow rate							
Collector flow rate (L/h)	80	120	160	200	240	280	320
Daily energy eff. with fix flow rate (%)	49	52	44.7	46	49.6	50.2	49.1
Daily energy eff. with optimum flow rate (%)	53.07						
Daily exergy eff. with fix flow rate (%)	3	3.3	2.58	2.53	2.63	2.95	2.88
Daily exergy eff. with optimum flow rate (%)	3.39						

Table 8 gives the potential of increasing efficiency with optimum flow rate of collector. Results indicate that optimum flow rate can improve energy efficiency between 8.38 % and 15.08 % in the case of thermal load of 54 L/h on storage tank. The exergy efficiency has an increment between 0.11 % and 0.77% also. In the case of 72 L/h thermal load on storage tank energy and exergy analysis of collected data from experimental show that the energy and exergy efficiency can improve to 59.46 % and 1.26%, respectively.

Table 7. The optimum flow rate for various radiation intensity in 54 L/h and 72 L/h thermal load on storage tank				
	Storage tank flow rate		Increasing radiation intensity	Decreasing radiation intensity
Energy analysis	54 L/h		From 850 to 1000	From 1000 to 550
		Optimum flow rate	320 (L/h)	160 (L/h)
		Optimum flow rate with Rotameter correction factor	269.50 (L/h)	134.75 (L/h)
Exergy analysis			From 850 to 1000	From 1000 to 500
		Optimum flow rate	320 (L/h)	160 (L/h)
		Optimum flow rate with Rotameter correction factor	269.5 (L/h)	134.75 (L/h)
Energy analysis	72 L/h		From 950 to 1050	From 1000 to 600
		Optimum flow rate	240 (L/h)	240 (L/h)
		Optimum flow rate with Rotameter correction factor	202.13 (L/h)	202.13 (L/h)
Exergy analysis			From 900 to 1020	From 1000 to 600
		Optimum flow rate	240 (L/h)	320 (L/h)
		Optimum flow rate with Rotameter correction factor	202.13 (L/h)	269.5 (L/h)

Table 8. Average daily energy and exergy efficiency of solar water heating system for various collector flow rate and optimum flow rate in thermal load of 54 Lh and 72 L/h								
54 L/h	Collector flow rate (L/h)	80	120	160	200	240	280	320
	Daily energy eff. With fix flow rate (%)	38.6	38.1	46.7	43.6	40.5	43.6	44.8
	Daily energy eff. With optimum flow rate (%)	53.18						
	Daily exergy eff. With fix flow rate (%)	0.56	0.5	1.02	0.36	0.55	0.67	0.8
	Daily exergy eff. With optimum flow rate (%)	1.13						
72 L/h	Collector flow rate (L/h)	80	120	160	200	240	280	320
	Daily energy eff. With fix flow rate (%)	48.9	46.4	51.8	51.8	59.46	53.8	48.6
	Daily energy eff. With optimum flow rate (%)	59.46						
	Daily exergy eff. With fix flow rate (%)	0.67	0.43	0.56	0.86	0.76	0.78	1.26
	Daily exergy eff. With optimum flow rate (%)	1.26						

5. Conclusion

In this paper, an experimental study is carried out to find the optimum flow rate of collector for variation solar radiation intensity during daytime. In addition, the effect of storage tank thermal load on optimum flow rate is considered. The experimental results show that energy and exergy efficiency with using optimum flow rate of collector can be improved. With operating SWH with collector flow rate and no thermal load on storage tank, the overall energy and exergy efficiency can reach to 53.9% and 9.3%, respectively. Since for a SWH during normal operation thermal load varies, for different thermal loads optimum flow rate is carried out. It has been found that in the case of 36L/h, 54 L/h, and 72L/h storage tank thermal load, overall energy efficiency in the best-case show 10.86%, 15.08% and 13.06% improvement and the overall exergy show 0.86%, 0.77% and 0.83% improvement. Consequently, it can be found that collector flow rate as a critical parameter play an important role in SWH performance. The results of present study can assist to design a SWH with variable collector flow rate to gain a more efficient renewable energy device.

References

[1] T. G., W.M. California, Thermo-economic analysis of power plants, Electric power Research Institute (EPRI), report, 1984. (1984).

[2] D.J. Kim, H.S. Lee, K.H.Y.a.H. J.H., Thermo-economic Analysis of Power Plants with integrated exergy stream, in: ASME, Proceedings of the ASME, 2000.

[3] A. Bejan, G. Tsatsaronis, M.J. Moran, Thermal design and optimization, Wiley-Interscience, 1996.

[4] M.A. Rosen, R. Tang, Effect of altering combustion air flow on a steam power plant: energy and exergy analysis, International journal of energy research, 31 (2007) 219-231.

[5] T.J. Kotas, The exergy method of thermal plant analysis, 1985.

[6] M.J. Moran, Availability analysis: a guide to efficient energy use, (1982).

[7] A. Traverso, A.F. Massardo, Thermoeconomic analysis of mixed gas–steam cycles, Applied thermal engineering, 22 (2002) 1-21.

[8] S.J.S. Borelli, S. de Oliveira Junior, Exergy-based method for analyzing the composition of the electricity cost generated in gas-fired combined cycle plants, Energy, 33 (2008) 153-162.

[9] M.A. Rosen, I. Dincer, Exergoeconomic analysis of power plants operating on various fuels, Applied thermal engineering, 23 (2003) 643-658.

[10] M. Scialò, Thermoeconomic analysis of gas turbine based cycles, Journal of engineering for gas turbines and power, 122 (2000) 664.

[11] T. Yousefia, F. Veysia, E. Shojaeizadeha, S. Zinadinib, An experimental investigation on the effect of Al2O3eH2O nanofluid on the efficiency of flat-plate solar collectors, Renewable Energy 39 (2012) 293-298.

[12] T. Yousefi, F. Veisy, E. Shojaeizadeh, S. Zinadini, An experimental investigation on the effect of MWCNT-H2O nanofluid on the efficiency of flat-plate solar collectors, Experimental Thermal and Fluid Science, in press (2012).

[13] I. Dincer, H. Al-Muslim, Thermodynamic analysis of reheat cycle steam power plants, International journal of energy research, 25 (2001) 727-739.

[14] J.A. Duffie, W.A. Beckman, Solar Engineering of Thermal Processes, Wiley, New York, 2006.

[15] I.H. Aljundi, Energy and exergy analysis of a steam power plant in Jordan, Applied thermal engineering, 29 (2009) 324-328.

[16] M.A. Rosen, I. Dincer, A study of industrial steam process heating through exergy analysis, International journal of energy research, 28 (2004) 917-930.

[17] M. Ameri, P. Ahmadi, S. Khanmohammadi, Exergy analysis of a 420 MW combined cycle power plant, International journal of energy research, 32 (2008) 175-183.

[18] A. Valero, M.A. Lozano, L. Serra, G. Tsatsaronis, J. Pisa, C. Frangopoulos, M. Von Spakovsky, CGAM problem: definition and conventional solution, Energy, 19 (1994) 279-286.

[19] G. Tsatsaronis, Thermoeconomic analysis and optimization of energy systems, Progress in energy and combustion science, 19 (1993) 227-257.