Exergy analysis of a developed flat-plate wickless-heat-pipes solar-collector with series condensers

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Abstract: A flat-plate wickless-heat-pipes solar-thermal collector with series condenser-coolers (FHSC-S) is developed. Indoor solar experiments are conducted to investigate the thermal behaviour of the FHSC-S collector. The collector is tested under different experimental parameters (collector tilt angles, water flow-rates, solar irradiance levels, and inlet-water temperatures). This part presents the collector design and details, besides an exergy analysis. The experimental results showed that the collector performed well. The inlet fluid exergy, outflow exergy, and gained exergy are increased with the increment in the inlet temperature. The maximum and average values of the collector's exergy efficiency are 0.20 and 0.08, respectively.

Keywords: solar thermal-collector, heat pipes, exergy analysis.

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1 Introduction

Flat plate collector (FPC) and evacuated collector (ETC) are typically, used in the low temperate applications. They can be used for water heating, space heating, and crop drying (Asif and Muneer, 2007). However, each of them has its own disadvantages. These disadvantages are related to the collector's ability to function in specific environment, to the individual parts, and to the costs (production, installation, and maintenance). For example, the FPC has low efficiency at higher temperature (low rate of heat-transport), high stagnation temperature, high heat-capacity, high heat-emissivity, slow heat-generation, and has at cloudy-times and night time a cooling effect (or reverse-cycle), besides freezing (antifreeze is required) and corrosion problems. In addition, the panels are heavy, it consumes considerable amount of energy to circulate the fluid through the collector, frequent maintenance, and whole-panel replacement (in event they are broken or damaged).

Evacuated tube collectors, need advanced technologies to make the tubes; high vacuum is recommended (to have a low heat-loss), special processes like sputtering, selective coating, are required, which all increase the production cost compared to that of the FPC. In addition, in cold weather, they melt the heavy frost and snow very slowly, as compared to FPC; as the vacuum hinders the absorber-plate from heating the outer-glass surface. They are also having possibility of losing the vacuum (with time), snow build-up (accumulation below the tubes). The later reduces the functional time of the ETC, as melting-off the snow take prolonged period. Arés-Muzio et al. (2014) designed and characterized a prototype evacuated-tube collector. They found that their collector has 50% efficiency at 150°C. Ayompe et al. (2011) conducted a field study to compare the performance of FTC and ETC for domestic-water-heating system. With similar environmental conditions, the collector efficiencies were found to be 46.1% and 60.7%

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for FPC and ETC, respectively. Hayek et al. (2011) studied experimentally the overall performance of solar collectors, under local weather. The water-in-glass tubes collector and the ETC are tested. They observed that ETC collectors are performed better; having efficiency 15%-20% higher than other one. Pluta (2011) carried a comparison between the evacuated tubular and the classical FTC. They concluded that for solar-domestic hot-water-systems there is no clear superiority of vacuum-solar-collector over the much cheaper FTCs. Hoffmann et al. (2014) presented an economic-environmental comparison between FTC and ETC collectors.

Their study showed that the production of FTC has higher environmental-impact. Miloştean and Flori (2017) gave an outlines on the technical-solutions developed by different researchers, in order to increase the thermal-efficiency of the flat-plate solar collectors. Sabiha et al. (2015) provided many progresses and developments of ETC collectors.

The exergy is a combination of the principles of energy conservation and entropy non-conservation. The latter, which states that entropy, is created during a process due to irreversibility. Exergy is consumed due to irreversibility, and this consumption is proportional to entropy creation (Rosen, 2007). Exergy is defined by Petela (2010) as the maximum useful work obtainable from the considered matter (substance or field matter) in known environmental conditions. The exergy of any matter expresses the maximum ability of this matter for carrying out work, in reference to a specific environment (Hepbasli, 2008; Sato, 2004; Petela, 2003).

Moreover, exergy is a measure of the quality or the usefulness of the energy (Chamoli, 2013), and due to the irreversibility, it is consumed in actual processes, while in ideal processes it be conserved. The use of energy formulae only in the analysis of the performance of solar thermal collectors is not a sufficient criterion to describe the collector's efficiency, as it does not account for internal losses (Farahat et al., 2009; Ajam et al., 2005; Ge et al., 2014). Exergy analysis is carried out, generally, to complement, but not to replace the energy analysis (Chamoli, 2013). This analysis can be an effective way to find the optimal relation of the fluid flow-rate and the area of the collector (Kalogirou, 2012). Moreover, irreversibility is the destruction of exergy, which is differ from losses. The later usually are energy, in the form of low temperature heat, which is not useful in a specific conversion process.

These losses simply involve a conversion to another non-useful energy form, and not certainly a destruction of energy (Filho et al., 2006). Generally, the destruction of exergy indicates a permanent reduction in the quantity of work available during energy conversion process. Pandey et al. (2015) evaluated the thermal-performance of a solar water-heater with ETC of direct-flow type. The evaluation included the energy, exergy analyses and some other thermodynamic parameters (e.g., fuel depletion ratio, relative irreversibility). They found that the energy-efficiency was found higher than exergy-efficiency, as energy denotes the quantity, while exergy characterised the quality of energy). Singh et al. (2012) conducted an exergy-based analysis of solar air-heater SAH having discrete V-down rib roughness on absorber plate. They showed that it performed thermally better than the conventional SAH under same operating conditions. Farahat et al. (2009) carried out a detailed energy and exergy analysis for evaluating the thermal and optical performance, exergy flows and losses as well as exergetic efficiency for a typical FTC collector under given operating conditions. They included the absorber plate area, dimensions of solar collector, pipes' diameter, mass flow rate, fluid inlet, and outlet temperature, the overall loss coefficient.

A simulation program is developed for the thermal and exergetic calculations. There is a good agreement between the computational program results and the experimental measurements from the cited works. They also found that the overall-loss coefficient is not constant, and the optical efficiency has a great effect on the exergy efficiency. Besides, the FTC with optical-concentrators is found to have better the optical efficiency. Jafarkazemi and Ahmadifard (2013) presented a theoretical model for energy and exergy analysis of FTC. According to the studies it is obvious that energy and exergy efficiencies have conflicting behaviours in many cases. While an increase in fluid inlet temperature leads to a decrease in energy efficiency of collector, it leads to an overall increase in exergy efficiency even to its maximum. Similarly, while an increase in mass flow rate leads to an increase in energy efficiency, it has an inverse effect on exergy efficiency. Most of exergy destructions occur during the absorbing process in the absorber plate.

Based on the theoretical results, the maximum energy and exergy efficiency of FTC is close to 80% and 8%, respectively. The design and development of novel flat-plate wickless heat-pipes solar collectors, that can use some advantages of the heat pipes technology and incorporated it into FTC, to produce a solar collector that can minimize or eliminate several drawbacks of both ETC and FPC, is mandatory, highly essential, and of great concern. Moreover, the evaluation of the performance of these novel solar collectors is also important and crucial. However, works on hybrid solar collector that uses the benefits or the advantages of both FPC and ECT collectors, while reduces or eradicates their disadvantages were not found in the cited literature. Hence, the aims of this study are to develop a hybrid solar collector, i.e., a flat-plate wickless-heat-pipes solar-collector with series cooler (FHSC-S), and to test and evaluate the performance of this collector. This part presents the design details of the FHSC-S collector, as well as an exergy analysis.

2 Materials and methods

Different indoor solar experiments are conducted to find out the thermal behaviours of the flat-plate wickless heat-pipes solar collectors. The experiments are carried out using a Laboratory Solar Simulator (at the Centre for Integrated Design for Advanced Mechanical Systems, Faculty of Engineering and Built Environment, National University of Malaysia; Bangi, 43600, S.D.E., Malaysia). In conducting solar-energy research, solar simulators play an important role (Codd et al., 2010). Solar simulator is typically used to simulate the Sun radiation or light, with approximately same spectrum and intensity (EMSS, 2022). Several experimental parameters are tested, which include, the inlet temperatures, solar irradiance levels, collectors tilt angles, and water flow-rates. A summary of the parameters, variables, and characteristics used in the solar collector's experiments are given in Table 1.

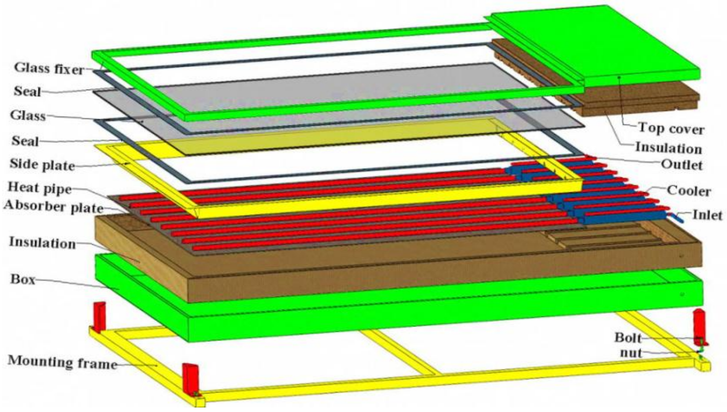
Table 1 Experimental parameters for flat-plate heat-pipes solar-collectors tests

Parameters	Specifications, replicates				
Controlled parameters:					
Type of working fluid	Pure water				
Filling-ratio (%)*	30				
Total heat pipe length (mm)	1500				
Evaporator section length (mm)	1220				
Condenser section length (mm)	250				
Adiabatic section length (mm)	30				
Heat pipe Outer diameter (mm)	22				
Heat pipe Thickness (mm)	0.9				
Variable parameters:					
Cooling water flow rates (kg s^{-1})	0.0235	0.0387			
Collector's inlet-water temperature (^oC)	30	35	40	45	
Solar irradiance (W m^{-2})	475	625	850	1050	
Solar collectors tilt angles (^{o})	5	10	20	30	40

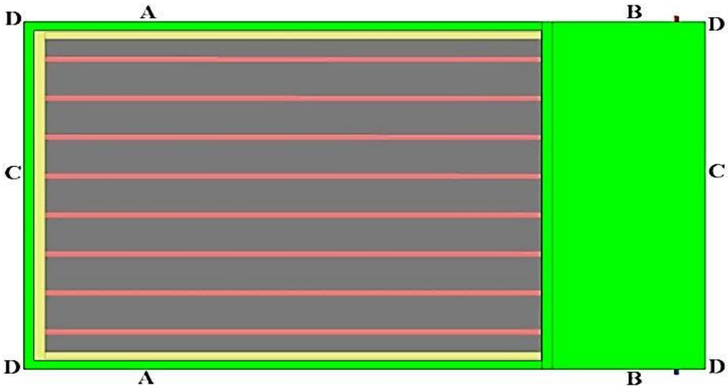
Note: *30% of the total heat pipe's volume = 37% of evaporator volume.

2.1 Solar thermal-collector

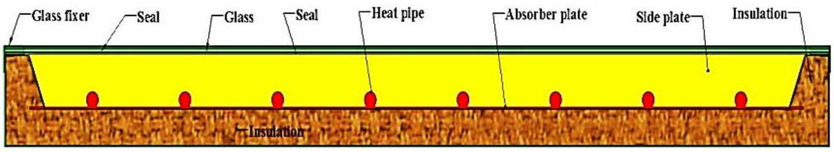
A flat-plate heat-pipes solar collector with series condensers (FHSC-S) is developed and evaluated. Figure 1 shows detailed 3D drawings of the FHSC-S collector. Moreover, the specifications of the FHSC-S collector are given in Table 2. In this solar collector the cooling water inters the cooler at the first heat-pipe condenser, where the outlet of this heat-pipe cooler is connected to the inlet of the second heat-pipe cooler, and so on, until the last heat pipe.



FHSC-S collector: exploded view



FHSC-S collector: top view



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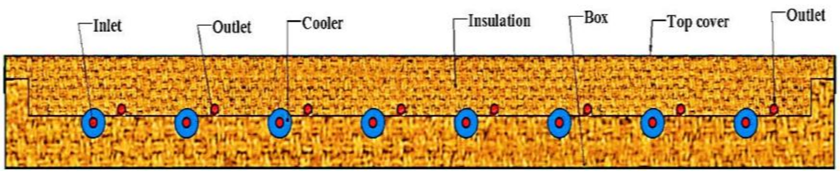

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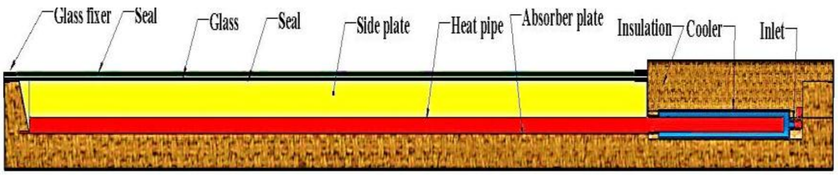

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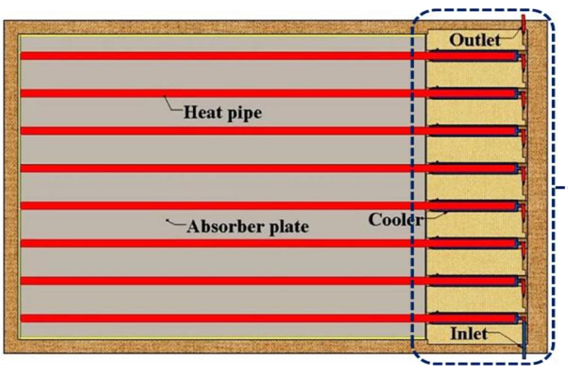

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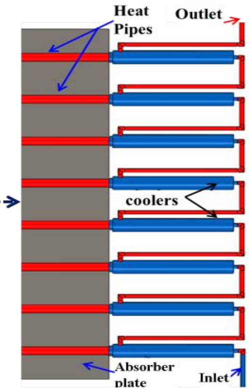


Condensers-Coolers

Figure 1 FHSC-S collector: detailed 3D drawings

Table 2 Specifications of the FHSC-S collector

Parts/Items	Descriptions/Units	Parts/Items	Descriptions/Units
Absorber plate		Thermal conductivity	0.603-0.680 W (m °C)$^{-1}$
Type	Flat plate	Filling ratio	37%
Material	Aluminium	4. Glass cover	
Construction	Fin and tube	Type	Windows glass
Thickness	2 mm	Number of layers	1
Thermal conductivity	205 W (m °C)$^{-1}$	Area	1.3 m^2
Absorptance	0.90	Thickness	5 mm
Emittance	0.10	Transmittance (τ)	0.80
Surface	Flat Black Paint	Refractive index	1.526
Area:	Gross: 1.2 m^2	Absorption coefficient	4 m^{-1}
	Exposed: 1.1 m^2	Emittance	0.88
Wickless heat pipes		Thermal conductivity	0.75 W (m °C)$^{-1}$
Number	8	5. Insulation	
Outside diameter	22mm	Type	Fibreglass
Inside diameter	20.2mm	Thickness: Back	35mm
Tube distance	114mm	Sides	35mm
Thermal conductivity	394 W (m °C)$^{-1}$	Thermal conductivity	0.04 W (m °C)$^{-1}$
Working fluid (water)		6. Casing (box)	
Specific heat	4.185 kJ kg^{-1} K^{-1}	Material	Aluminium
Mass density	1000 kg m^{-3}	Size	0.142 m^3

2.2 Mathematical modelling

Solar-radiation exergy from the Sun on the solar collector's surface (exergy inflow of solar-energy on the surface) (E_{i-s}), is given by (Baghernejad and Yaghoubi, 2010; Torres-Reyes et al., 2001; Zhai et al., 2013):

$$E_{i-s} = I_T\, A_c \left(1 - \frac{T_a}{T_s}\right) \quad (1)$$

The absorbed solar-radiation exergy by the solar collector's plate ($E_{,abs}$), (Farahat et al., 2009):

$$E_{,abs} = Q_s \left(1 - \frac{T_a}{T_s}\right) = I_T(\tau\alpha)A_c \left(1 - \frac{T_a}{T_s}\right) \quad (2)$$

The rate of the inlet exergy carried by the fluid flow (E_{i-f}), (Kotas, 1995; Badescu, 2007; Ge et al., 2014):

$$E_{i-f} = \dot{m}C_p \left((T_i - T_a) - T_a Ln\left(\frac{T_i}{T_a}\right)\right) \quad (3)$$

The rate of outlet exergy carried by the fluid flow (E_o), (Kalogirou, 2009; Kalogirou, 2012; Badescu, 2007):

$$E_o = \dot{m}\, C_p \left((T_0 - T_a) - T_a Ln\left(\frac{T_o}{T_a}\right)\right) \quad (4)$$

The useful-exergy rate (E_u) is expressed as (Chamoli, 2013; Bejan, 1988; Kotas, 2012; Ge et al., 2014):

$$E_u = E_o - E_{i-f} \quad (5)$$

The leakage exergy (E_l), i.e., the heat leakage from the absorber plate to the environment, is given by (Farahat et al., 2009; Dutta Gupta and Saha, 1990):

$$E_l = U_L A_c(\bar{T}_p - T_a)\left(1 - \frac{T_a}{\bar{T}_p}\right) \quad (6)$$

Solar-radiation exergy losses from the collector surface to the absorber plate $E_{s,p}$ is given by (Ge et al., 2014):

$$E_{s,p} = I_T\,[A_c - (\tau\alpha)_e A_c]\left(1 - \frac{T_a}{T_s}\right) \quad (7)$$

Exergy losses due to the temperature difference between the surface of absorber-plate and the Sun ($E_{p,s}$) is given by (Dutta Gupta and Saha, 1990; Zhai et al., 2013; Ge et al., 2014):

$$E_{p,s} = (\tau\alpha)_e I_T A_c T_a \left(\frac{1}{\bar{T}_p} - \frac{1}{T_s}\right) \quad (8)$$

Exergy losses due to temperature difference between the absorber plate and the fluid ($E_{\Delta T}$), is expressed as (Suzuki, 1988a, 1988b; Ge et al., 2014):

$$E_{\Delta T} = \dot{m}\, C_p T_a \left[Ln\left(\frac{T_o}{T_i}\right) - \frac{(T_o - T_i)}{\bar{T}_p}\right] \quad (9)$$

Exergy efficiency can be given as the ratio of the useful-exergy (E_u) to the solar radiation exergy ($E_{in,s}$), (Chamoli, 2013; Ge et al., 2014):

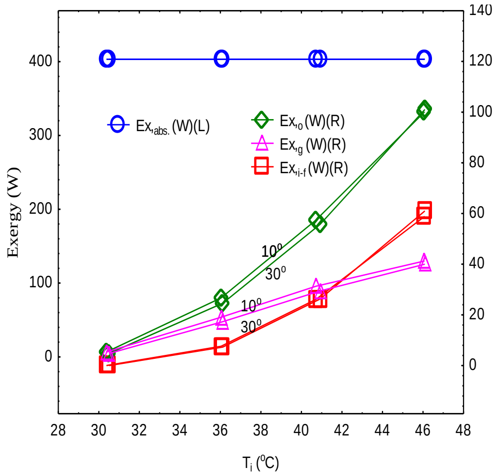
$$\eta_x = \frac{\dot{m}\, C_p\left[(T_o - T_i) - T_a\left(Ln\,\frac{T_o}{T_i}\right)\right]}{I_T A_c\left(1 - \frac{T_a}{T_s}\right)} \quad (10)$$

3 Results and discussions

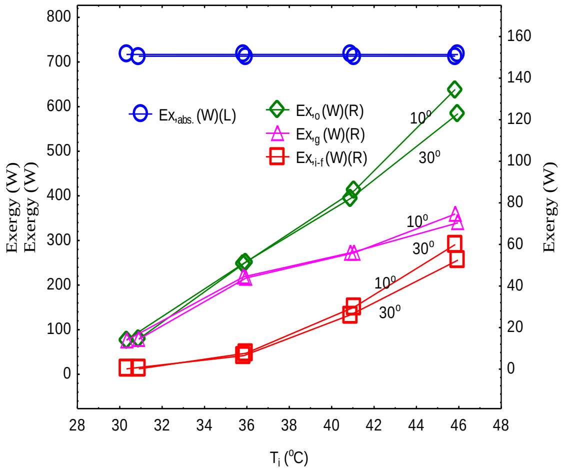
3.1 Absorbed exergy ($Ex_{,abs.}$), outflow exergy ($Ex_{,o}$), and gained exergy ($Ex_{,g}$)

3.1.1 Effects of collector's tilt angles on the $Ex_{,abs.}$, $Ex_{,o}$, and $Ex_{,g}$

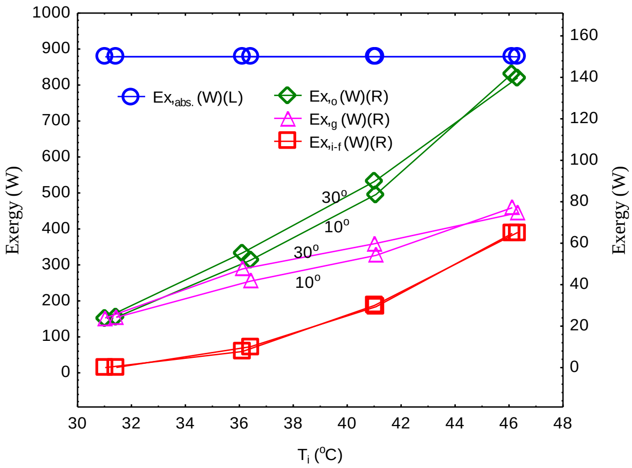
The effects of the tilt angles (10^o - 30^o) on the absorbed exergy ($Ex_{,abs.}$), outflow exergy ($Ex_{,o}$), and gained exergy ($Ex,_g$) are shown in Figure 2, at different solar irradiance levels. The values $Ex,_{abs.}$, $Ex,_o$, and $Ex,_g$, are very similar, showing that the tilt angles have non-significant effect on these exergy values. However, slightly higher values are shown at angle 10^o compared to that at angle 30^o.



475 W m^{-2}



850 W m^{-2}



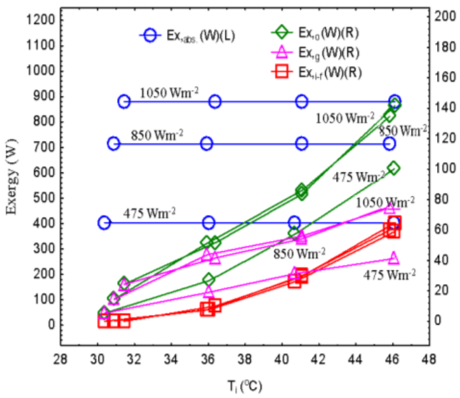
1050 W m^{-2}

Figure 2 FHSC-S exergy ($Ex,_{abs.}$, $Ex,_o$, $Ex,_g$): 10 - 30^o

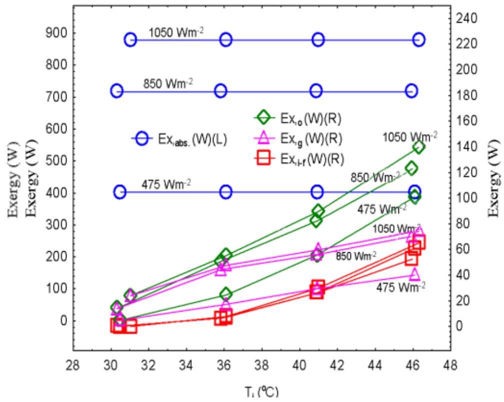
3.1.2 Effects of irradiance levels on the $Ex,_{abs.}$, $Ex,_o$, and $Ex,_g$

Figure 3 show the effects of solar irradiance on the absorbed exergy ($Ex,_{abs.}$), outflow exergy ($Ex,_o$), and gained exergy ($Ex,_g$). Generally, as the solar irradiance level is increased, the gained or useful exergy rate to be increased (Ge et al., 2014). As it observed from Figure 3a (0.0235 kg s^{-1}) and Figure 3b (0.0387 kg s^{-1}), the $Ex,_{abs}$ is increased with the solar insolation from ≈ 400W at 745w m^{-2}, 700 W at 850 W m^{-2}, to 900 W at 1050 W m^{-2}. Moreover, the inlet-fluid exergy ($Ex,_{i-f}$), outflow exergy $Ex,_o$, and gained exergy $Ex,_g$ are increased with the increment in the inlet temperature.

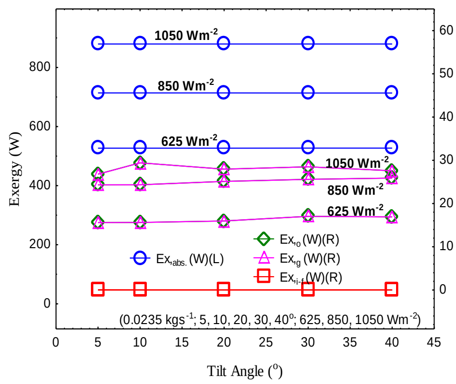
Furthermore, these exergy values ($Ex,_{abs.}$, $Ex,_o$, and $Ex,_g$) are also plotted versus the collector's tilt angles, at fixed inlet temperature, which is kept-near to the ambient temperature ($T_i \approx T_a \approx 30.5^oC$). Figures 3c - 3d show the effects of the experimental parameters on the absorbed exergy ($Ex,_{abs.}$), the inlet-fluid exergy ($Ex,_{i-f}$), outflow exergy ($Ex,_o$), and gained exergy ($Ex,_g$), at different water-flow rates. When the solar irradiance is increased from 625, 850, to 1050 W m^{-2}, the $Ex,_{abs.}$, $Ex,_o$, and $Ex,_g$ are considerably increased from ≈500, 700 to 900 W, respectively. While the $Ex,_{i-f}$ has the same value; as the inlet temperature is kept at a constant value. Step increase in the collector's tilt angles (5, 10, 20, 30, to 40^o), showed slight effects on the FHSC-S collector thermal behaviour, at this constant fluid-inlet temperature. It is also observed from Figures 3c - 3d that increasing the water flow rate from 0.0235 kg s^{-1} to 0.0378 kg s^{-1} decreased the outflow exergy ($Ex,_o$), as well, the gained exergy ($Ex,_g$).



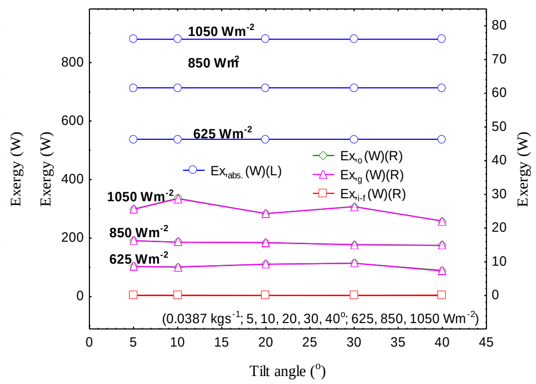
(a) 10°



(b) 30°

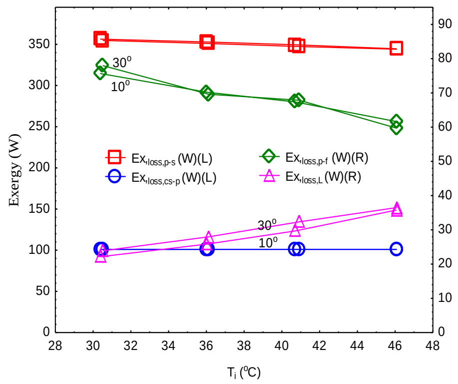


(c) 0.0235 kg s^{-1}

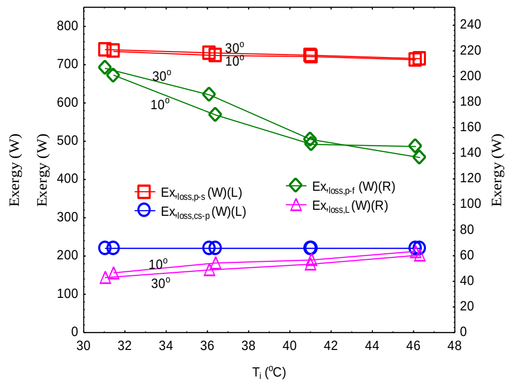


(d) 0.0387 kg s^{-1}

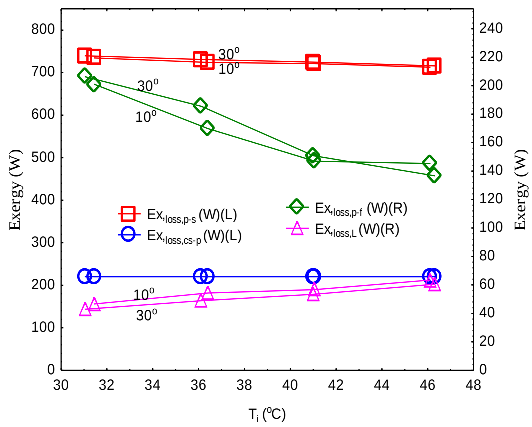
Figure 3 FHSC-S exergy ($Ex_{,abs.}$, $Ex_{,i\text{-}f}$, $Ex_{,o}$, $Ex_{,g}$): 625, 850, 1050 W m^{-2}



(a) 475 W m^{-2}

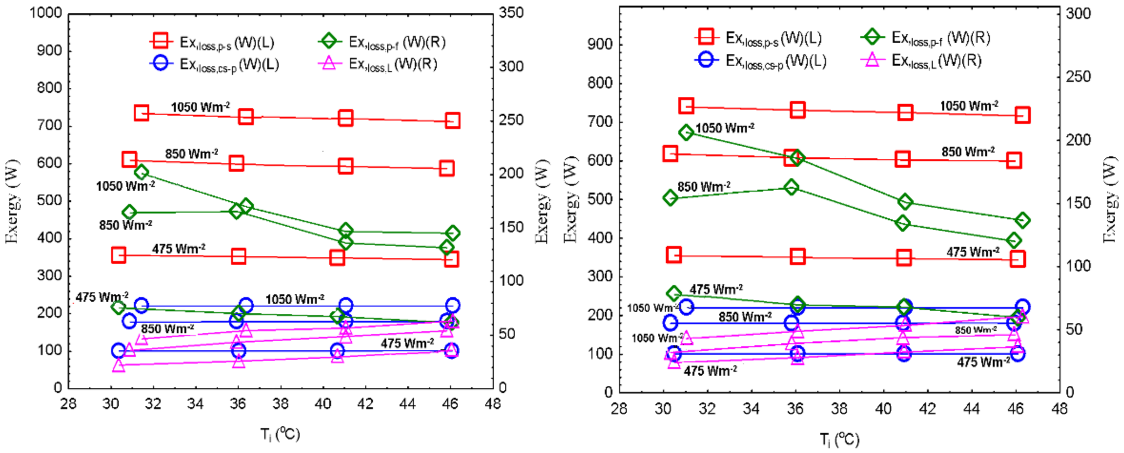


(b)1050 W m^{-2}



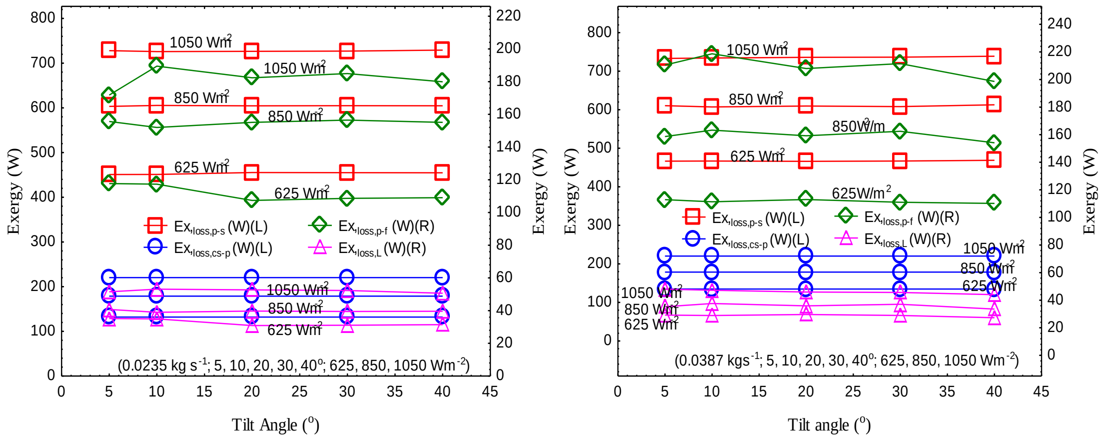
(c) 1050 W m^{-2}

Figure 4 FHSC-S exergy losses: 10 - 30°



(a) 10° (b) 30°

Figure 5 FHSC-S exergy losses: 475, 850, 1050 W m^{-2}



(a)0.0235 kg s^{-1} (b)0.0387 kg s^{-1}

Figure 6 FHSC-S exergy losses: 625, 850,1050 Wm^{-2} and 5° - 40°

3.2 Exergy losses

3.2.1 Effects of tilt angles on the exergy losses

The effects of the collector's tilt angle on the exergy losses are shown in Figure 4. Increasing the tilt angle from 10 to 30°, have a slight effects on the exergy loss between collector's plate and the sun ($Ex_{,loss,p-s}$), exergy loss between collector's surface and plate ($Ex_{,loss,cs-p}$), exergy loss between collector's plate and the fluid ($Ex_{,loss,p-f}$), and exergy leakage ($Ex_{,loss,L}$).

According to Ge et al. (2014), the major exergy-losses, are due to the temperature-differences between the surfaces of Sun and the solar collector's absorber-plate (account for approximately 72%). As the inlet temperature is increased the exergy-leakage is increased, while the exergy losses between collector's plate and the Sun and between collector's plate and the fluid are decreased. The exergy losses between collector's surface and plate ($Ex_{,loss,cs-p}$), have almost similar values for both angles; 10° and 30°.

3.2.2 Effects of solar irradiance on the exergy losses

The effects of the solar irradiance on the solar collector exergy losses are shown in Figure 5a and 5b, at angle 10° and 30°, respectively. When the solar irradiance is increased (475 - 1050 W m^{-2}), the exergy loss between collector's surface and plate ($Ex_{,loss,cs-p}$), exergy loss between collector's plate and the sun ($Ex_{,loss,p-s}$), exergy loss between collector's plate and the fluid ($Ex_{,loss,p-f}$), and exergy leakage ($Ex_{,loss,L}$) are increased. Although, when the inlet-fluid temperature is increased (from 30 to 45°C), it reduced the $Ex_{,loss,p-f}$ and $Ex_{,loss,p-s}$ (Ge et al., 2014), and increased the $Ex_{,loss,L}$.

Furthermore, the exergy losses between the collector's plate and the sun ($Ex_{,loss,p-s}$), exergy between collector's surface and plate ($Ex_{,loss,cs-p}$), between collector's plate and the fluid ($Ex_{,loss,p-f}$), and exergy leakage ($Ex_{,loss,L}$), are plotted against the tilt-angles, as shown in Figure 6. The Figure presents effects of the experiments-parameters on the collector exergy losses, at fixed inlet temperature (T_i), where the inlet temperature is controlled closely to the ambient temperature (≈ 30.5°C). As it clear from Figure 6, the tilt angle, as it increased from 5° to 40°, have little effects on the exergy losses. However, the $Ex_{,loss,p-f}$ and the $Ex_{,loss,L}$ are slightly decreased as the tilt angle is increased.

3.2.3 FHSC-S exergy efficiency

Table 3 shows the FHSC-S collector's exergy efficiency. This efficiency is found at different tilt angles, solar irradiance levels, inlet temperatures, and water flow-rate of 0.0387 kg s^{-1}. The maximum and the average experimental values of the FHSC-S collector's exergy efficiency are found equal to 0.20 and 0.08, respectively.

Table 3 FHSC-S collector exergy efficiency

Tilt Angle (°)	Water Flow rate (kg s^{-1})	Solar irradiance (W m^{-2})	Exergy efficiency (-)				
			T_i (°C)				Aver.
			30	35	40	45	(-)
10	0.0387	475	0.01	0.05	0.11	0.20	0.09
		850	0.02	0.06	0.10	0.15	0.08
		1050	0.02	0.05	0.08	0.13	0.07
30	0.0387	475	0.01	0.05	0.11	0.20	0.09
		850	0.02	0.06	0.09	0.14	0.08
		1050	0.02	0.05	0.08	0.13	0.07

The exergy efficiency be reduced as the solar irradiance level be increased. However, exergy efficiency be increased with the increment in the fluid-inlet temperature. Moreover, the experimental exergy efficiency values are agreed-well with the similar research findings in the cited literature, e.g., exergy efficiency of 0.0596 is found by Ge et al. (2014), and 0.08 exergy efficiency is reported by Jafarkazemi and Ahmadifard (2013).

4 Conclusions

The effect of the experimental parameters on the absorbed, outflow, gained exergy, and exergy losses, in addition to exergy efficiency are shown. The useful exergy rate be increased as the solar irradiance level be increased. The exergy losses between collector's plate and the sun and between collector's plate and the fluid be decreased as the inlet temperature be increased, but the exergy-leakage be increased. The maximum FHSC-S collector's exergy efficiency is 20%. As the inlet temperature is increased the exergy efficiency be increased, however the exergy efficiency is found to decrease with the increment in solar irradiance level. To improve the performance of this solar collector, some suggestions are presented for the future works. These include the use of different heat pipes (different evaporator and condenser lengths, fill-ratios, etc.), the use of more heat-pipes per unit area of the absorber plate, the use of heat pipes at the bottom of the absorber plate, and the use of optical concentrators with glass cover (e.g., small lens at the evaporator section).

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Nomenclature:

A_c	Collector area (m^2)	$Ex_{,loss,p-s}$	Exergy loss: collector's plate & Sun (W)
C_p	Specific heat (J kg^{-1} K^{-1})	$Ex_{,o}$	Outlet fluid exergy (W)
$E_{\Delta t}$	Rate of gain exergy (W)	$\dot{m}$	Mass flow rate (kg s^{-1})
E_{i-s}	Solar radiation exergy (W)	I_T	Incident solar radiation (W m^{-2})
$E_{p,s}$	Exergy: plate-sun (W)	Q_s	Energy absorbed by absorber plate (W)
E_s	Stored exergy rates (W)	T_a	Ambient temperature (K)
$E_{s,p}$	Exergy: sun-plate (W)	T_i	Fluid inlet temperature (K)
E_u	Gain exergy (W)	T_o	Fluid outlet temperature (K)
$Ex_{,abs.}$	Absorbed exergy (W)	T_p	Plate temperature (K)
$Ex_{,g}$	Gained exergy (W)	T_s	Apparent solar (sky) temperature (K)
$Ex_{,i-f}$	Inlet fluid exergy (W)	U_L	Heat loss coefficient (W m^{-2} K^{-1})
$Ex_{,loss,cs-p}$	Exergy loss: collector's surface & plate (W)	α	Absorptance the absorber plate (-)
$Ex_{,loss,L}$	Exergy leakage (W)	η_x	Solar collector exergy efficiency (-)
$Ex_{,loss,p-f}$	Exergy loss: collector's plate & fluid (W)	τ	Transmittance of the glass cover (-)