15 (2022) 100189

Contents lists available at ScienceDirect

International Journal of Thermofluids

journal homepage: www.sciencedirect.com/journal/international-journal-of-thermofluids

Experimental and numerical study to develop TRANSYS model for an active flat plate solar collector with an internally serpentine tube receiver

Ahmed Al-Manea [a,*], Raed Al-Rbaihat [b], Hakim.T. Kadhim [a], Ali Alahmer [b,c], Talal Yusaf [d], Karim Egab [e]

[a] Department of Mechanical Engineering, Al-Furat Al-Awsat Technical University, Kufa, Iraq
[b] Department of Mechanical Engineering, Faculty of Engineering, Tafila Technical University, P. O. Box 179, 66110 Tafila, Jordan
[c] Department of Industrial and Systems Engineering, Auburn University, Auburn, AL 36849, United States
[d] School of Engineering and Technology, Central Queensland University, Australia
[e] Electromechanical Systems Engineering Department, Thiqar Technical College, Southern Technical University, Iraq

ARTICLE INFO

Keywords:
Flat plate solar collector
TRANSYS simulations model
Collector efficiency
Serpentine tube receiver
Proposed solar collector

ABSTRACT

Flat solar collectors are extensively utilized in various domestic and industrial applications to reduce energy consumption. In this study, an-active flat plate solar collector (FPSC) with an internal absorber tube receiver was fabricated and tested in Al-Samawa city, Iraq (latitude 31.19°N and longitude 45.17°E). The ambient temperature and incident solar radiation at the experimental location were reached 39 °C and 840 W/m^2, respectively. In this study, the number of riser tubes connected to headers that are covered with a glass sheet in a conventional FPSC were replaced with a single serpentine-shaped collector tube covered with a plastic sheet. The proposed solar collector used a smooth copper tube with internal and exterior diameters of 9.5 and 12 mm, respectively, and a total length of 1000 mm. A TRNSYS model of a flat plate collector integrated with an absorber tube was developed, simulated, and validated using the experimental data. Temperature and flow rate data were obtained concurrently throughout the experiments to evaluate the performance of the fabricated solar collector. The temperature at the solar collector input stayed relatively constant at 37.7 °C, and the water flow rate remained constant at 0.75 L/min. The results indicated that the temperature at the solar collector output ranged from 52 to 61 °C, with an average of 58 °C. The efficiency of the proposed solar collector ranges from approximately 45% to 67%, with an average of 58%. Overall, the simulation results of the TRNSYS model are in excellent agreement with experimental data. The average discrepancy between the tests and simulations for temperature differential and collector efficiency is approximately 1%.

1. Introduction

Because of the oncoming energy crisis and escalating environmental degradation, the use of renewable energy has received a lot of attention [1–3]. Solar water heating systems are the most cost-effective, consuming only approximately 20% of the total energy consumption of an individual [4]. Solar water heating systems are a highly attractive and promising sustainable option owing to the near coincidence of lowering the high dependency on conventional energy [5,6]. Solar collector sustainability is being continuously promoted owing to its importance in energy generation, water harvesting, drying, preheating, and engineering applications [7–9]. Various approaches have been proposed for improving the efficiency of solar collectors [10–14]. Experimental and numerical techniques were used to improve the performance of a flat collector [15–18]. Experimental investigations were primarily focused on: (i) optimizing the shape and design parameters of the collector, (ii) improving the heat transfer between the heat transfer fluid (HTF) and the absorber tube [19,20], and (iii) integrating the solar collector with a phase change material (PCM) beneath the absorber plate [20–25].

The design and composition of the absorber plate have a considerably influence the efficiency of the solar collector [10]. The thermal conductivity of the absorber plate material also affects its performance [20]. Compared with a flat solar heater, a cylindrical solar water heater was designed to maximize the efficiency by Al-Madani [26]. The comparative results reveal that the performance of a cylindrical solar

* Corresponding author at: Department of Mechanical Engineering, Al-Furat Al-Awsat Technical University, Kufa, Iraq.
E-mail address: Dr.ahmed.Almanea@atu.edu.iq (A. Al-Manea).

https://doi.org/10.1016/j.ijft.2022.100189
Received 25 April 2022; Received in revised form 1 August 2022; Accepted 2 August 2022
Available online 3 August 2022

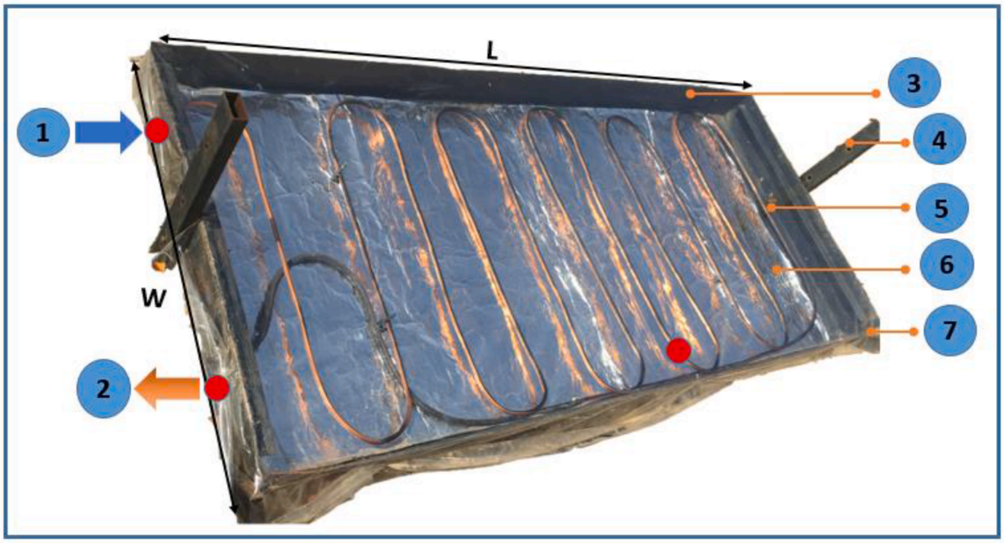

Fig. 1. A flat plate solar collector experimental design: (1) inlet from tank 1; (2) outlet to tank 2; (3) collector enclosure; (4) angle guide rod; (5) serpentine absorber tube; (6) fiberglass insulation; (7) plastic sheet cover.

heater outperforms flat solar heat without the need for direct exposure to the sun. The thermal efficiency of solar water heaters can be increased by modifying the collector and absorber materials and increasing the solar radiation [27]. Patil et al. [14] improved flat plate solar water collectors by altering the glass shape and increasing heat transfer through radiation. The innovative design yields high temperatures even under cloudy weather conditions. By enhancing water circulation, Vasanthaseelan et al. [28] improved the performance of a solar water heater coupled with a coil tabulator. Using a tabulator boosted the temperature of the solar water, which improved the heat transfer performance. Bhargava et al. [29] designed a hybrid system that combined a solar air heater with an electrical heater to power an electrical pump. Compared with a conventional electric heater, the hybrid system produces clean energy at a lower cost. Potgieter et al. [30] improved the effectiveness of hybrid solar air heat by creating turbulence and vortices in the airflow. The air recirculation and flow separation improved the average collector efficiency by 44%. Aoul et al. [31] elucidated the effect of azimuth and tilt angles on the energy production and efficiency of solar collector systems regarding to wind speed, solar radiation, and ambient temperature. An increase in the inclination angle improves energy efficiency during various seasons.

However, the heat transfer fluid has a significant impact on the efficiency of flat solar collectors [32–34]. Using a nanofluid as an HTF, such as Fe_3O_4, enhanced collector efficiency to approximately 83.97% [35]. In addition, utilizing a SiO_2/de-ionized water nanofluid improved heat transfer from 6% to 8% [36]. Fazilati and Alemrajabi [37] designed solar water heat using a PCM to store energy at various solar radiation levels. The amount of energy stored with PCM was 39% higher than the amount of energy stored without PCM. In addition, the usage of PCM reduced the time it takes to provide hot water by 25%. Dos Santos Bernardes [38] optimized the thermal and hydrodynamic properties of a radial solar-air heater for laminar convection heat transfer [35]. The radial design causes minor fluid disturbances, which influence thermal performance.

Numerical simulations were also performed to build an accurate model of the flat solar collector for further investigations. Many studies in the literature have employed computational fluid dynamics (CFD) software to develop a model and compare the findings with experimental cases [39,40]. Some researchers [41,15] have used TRANSYS (transient simulation software) to develop a model for a flat solar collector.

FPSCs are crucial apparatus that allow for the direct use of solar energy for heating water in residential and industrial applications. The efficiency of the existing FPSC is generally stagnant and relatively poor. More research is required to improve the efficiency of flat plate solar collectors by using a novel design. To address the gap, the current study is an experimental and simulation examination of a novel design and manufacturing strategy involving FPSC efficiency analysis. FPSC design improvements are always an essential option for achieving a considerable influence on thermal efficiency. Despite all attempts in the literature to establish a numerical model to forecast actual work outcomes related to improving the efficiency of solar collectors, further research is needed to produce an accurate model based on the TRANSYS software.

This study proposes an innovative technique that includes adding a single serpentine-shaped collector tube covered with a plastic sheet. This method was used to replace the existing number of riser tubes connected to the headers covered with a glass sheet in a conventional FPSC. The main concern is obtaining highly efficient solar collectors for domestic and remote areas utilities. Another aspect is to minimize the net weight of the system. This study investigates the thermal performance of an-active FPSC integrated with an internal serpentine tube receiver covered with plastic sheet.

2. Experimental design, setup, and procedure

2.1. Collector apparatus set-up

A flat plate solar collector with an internal serpentine absorber tube is designed and manufactured to examine its performance with the conventional one. Fig. 1 depicts a picture of the proposed a flat solar collector. The system consists primarily of (i) a flat steel frame, which is used to enclose the twisted copper tube, and its dimensions (1800 mm length (L) x 1500 mm width (W)). The inside of the frame was insulated with fiberglass insulation to preserve heat and avoid conduction losses; (ii) the U-shaped copper tube, which is the primary component, was coated in black to achieve optimum heat collection. The proposed solar collector had a 1000 mm long copper tube with internal and external diameters of 9.5 mm and 12 mm, respectively. A plastic sheet with a thickness of 1 mm was used to cover the collector and replace the typical glass cover, as indicated in Fig. 1. Two 40-liter-capacity tanks were used to maintain the inlet and outlet water. Two angle guide rods were installed on each side to alter the collector's titled angle. The collector title angle was set at 32° and faced south.

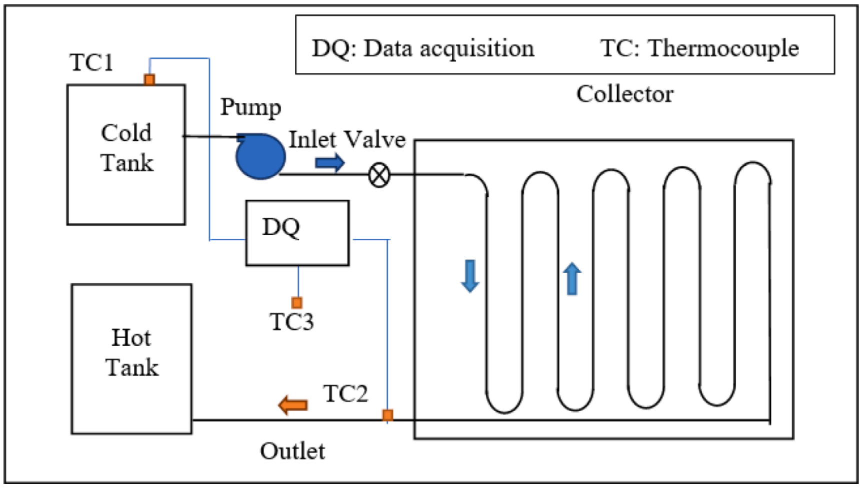

Fig. 2. Schematic configuration of the test rig for the proposed solar collector system.

Table 1
Errors calculated for various measurement devices.

Equipment	Accuracy	Range	Minimum value measured	Error %
k-type thermocouple	± 0.5 °C	−50–300 °C	35 °C	1.4%
Digital thermometer	± 1 °C	−50–1350 °C	35 °C	2.9%
Flowmeter YF-S401	± 0.1 L/min	0.3–6 L/min	1.8 L/min	5.5%

2.2. Experimental layout

Fig. 2 depicts a schematic of the experimental layout of the designed apparatus. The test conditions were verified to be stabilized before the data collection began. The tests were carried out by opening the main valve at the entrance. Water was then passed through the absorber tube. The outflow water was collected in a heated tank. Temperature data were collected using three k-type thermocouples.

2.3. Error analysis

To assess the errors in the experimental parameter, various devices were used in our experiments to develop an active flat plate solar collector with an internally serpentine tube receiver. These quantities include the temperatures in different locations as ambient temperature, inlet solar collector, and outlet solar collator) were measured by *k*-type thermocouples or digital thermometer. The volume flowrate was using water Flowmeter YF-S401. Table 1 displays the errors calculated for various measurement devices. The percentage error was computed using the equation below [10]

$$\text{Error } \% = \frac{\text{Equipment accuracy}}{\text{Minimum value of equipment measured}} \times 100\% \tag{1}$$

3. Simulation model

A TRNSYS (Transient System Simulation Software) simulation studio project (version 16) was used to construct a numerical model and validate the thermal performance of a proposed active FPSC with an internally serpentine tube receiver. The climatic conditions adopted in this study were based on the location of Al-Samawa (latitude 31.19°N, longitude 45.17°E, and elevation 15 m) in Iraq. TRNSYS is an energy system modeling program with a modular framework. This allows for the calculation and integration of dynamic output data (power, efficiency, mass flow rates, temperature, etc.) for any system component at any period of time [42,43]. The incident solar radiation data from a

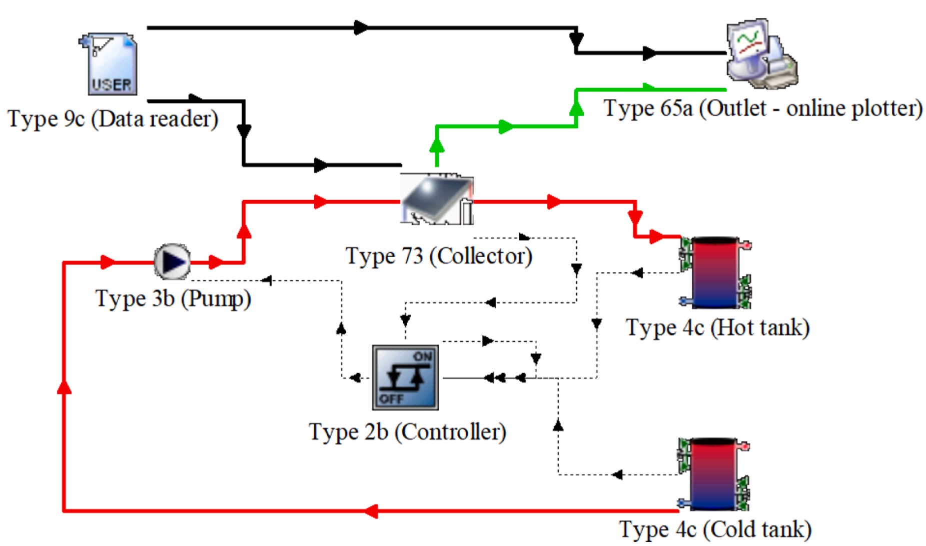

Fig. 3. TRNSYS scheme of the proposed solar collector system.

Table 2
TRNSYS type and key input of the main components of the TRNSYS model.

TRNSYS type	Key input
Type 9c – data reader	● Type 9c was used to calculate the incident solar radiation for the location of Al-Samawa (latitude is 31.19°N, longitude is 45.17°E, and elevation is 15 m) in Iraq ● The TRNSYS model was run with the available experimental data as input using Type 9c
Type 3b – single speed pump	● Type 3b was used as a main pump ● Maximum flow: 0.75 L/min ● Maximum power: 60 W ● Fluid specific heat: 4180 J/kg.K
Type 73 – flat plate solar collector	● Type 73 was used as a FPSC ● Collector area: 2.7 m^2 ● Number in series: 1.0 ● Fluid specific heat: 4180 J/kg.K ● Collector inclination angle: 32° ● Intercept efficiency: 0.6 ● Efficiency slope: 8.333 W/m^2.K
Type 4c – hot and cold thermal storage tanks	● Type 4c was used as hot and cold-water storage tanks ● Thermal storage tank loss coefficient: 0.694 W/m^2. K ● Thermal storage tank volume: 0.136 m^3
Type 2b – temperature control strategy	● Type 4c was used as a temperature control strategy ● The number of control oscillations: 4
Type 65a – output online plotter (TRNSYS-supplied units)	● Type 65a was used as an output online plotter (TRNSYS-supplied units)

typical meteorological year (TMY) file for Al-Samawa were used to model and simulate the system using the TRNSYS software. The experimental data for the FPSC with an internally serpentine tube receiver system is validated using a TRNSYS, which employs a set of components referred to as “Types", as illustrated in Fig. 3.

Fig. 3 displays the proposed solar collector system simulated using TRNSYS. The operating pump was responsible for transporting domestic hot water from the cold storage tank to the proposed solar collector. The next step was to use a heated storage tank. The controller regulates the operation of the pump to minimize the heat loss in the proposed solar collector.

Several components of the TRNSYS simulation model were utilized to predict the thermal performance of the proposed solar collector system at a given time of day [28 September]. The following are the primary components that are included in the TRNSYS modeling system:

Type 65a is an online output plotter (TRNSYS-supplied units), Type 9c is a data reader, Type 2b is a temperature control strategy, Type 4c is hot and cold-water storage tanks, Type 3b is a single-speed pump, and Type 73 is a theoretical flat plate collector.

A single-speed pump with a flow rate of 0.75 L/min is represented by the Type 3b model. The FPSC was modelled as a single number in series by the Type 73 design, and it had a collector area of 2.7 m^2. The cold and hot thermal storage tanks are both modelled using Kind 4c, which refers to stratified storage tanks with uniform losses and a constant heat loss coefficient of 0.694 W/m^2 K. Cold and hot storage tanks have the same capacity of 0.136 m^3. The rate of fluid flow between the stratified storage tanks and FPSC was regulated by a controller of type 2b. This controller activates only the pump when the outlet temperature of the collector is higher than its inlet temperature. Table 2 summarizes the parameters and key inputs of the TRNSYS model. The following are the results of the TRNSYS simulation for the city of Al-Samawa on a typical day [28 September] using a 10 s simulation time step. The TRNSYS model was run with the available experimental data as the main inputs, except for the incident solar radiation values generated from a typical meteorological year (TMY) file for Al-Samawa, because there were no incident solar radiation measurement data in this study.

4. Results and discussion

4.1. Ambient temperature and incident solar radiation

The accuracy of a weather database is extremely important for the performance analysis of solar collector systems. Weather data for Al-Samawa, Iraq (latitude 31.19°N, longitude 45.17°E, and elevation 15 m), were obtained using a typical meteorological year (TMY) file. Fig. 4 depicts the ambient temperature and incident solar radiation profiles for Al-Samawa city throughout a typical day in September. During the day, the radiation level increased from 270 W/m^2 at 8:00 am to 850 W/m^2 at 13:00 am and then slowly decreased to 400 W/m^2 at 17:00 am, which matches the ambient temperature. The ambient temperature and incident solar radiation peaks throughout the day were 39 °C and 850 W/m^2, respectively. This demonstrates that Al-Samawa city has a significant solar energy potential owing to the abundance of solar radiation.

4.2. Temperature profiles

Fig. 5 displays the temperature profiles for the solar collector system that were concurrently recorded at three locations: the solar collector

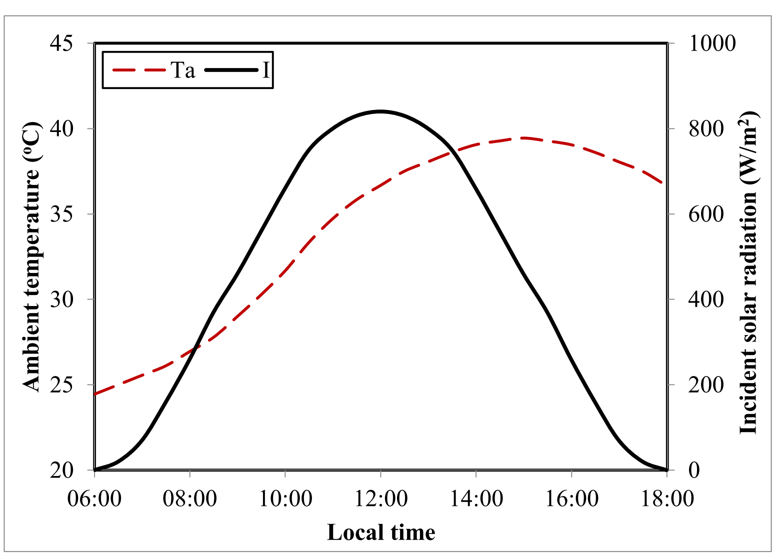

Fig. 4. Ambient temperature and incident solar radiation profiles for Al-Samawa city on a typical day [28-September] during daytime.

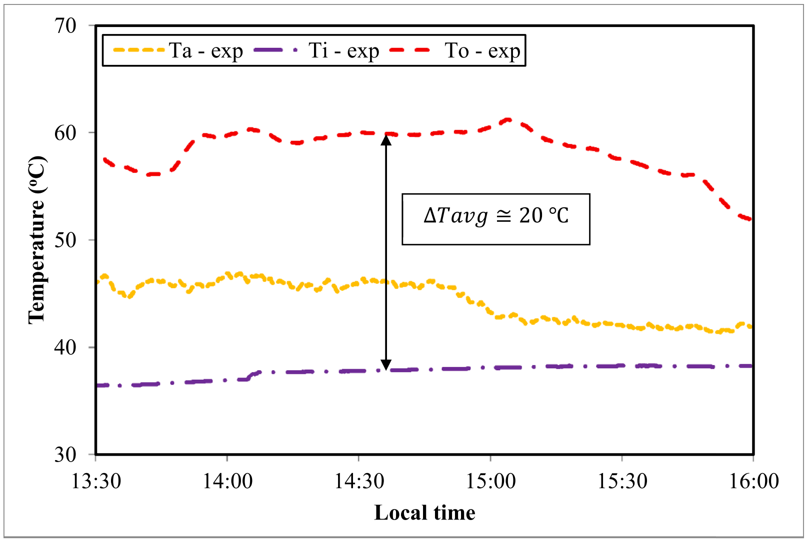

Fig. 5. Typical temperature readings based on experiments.

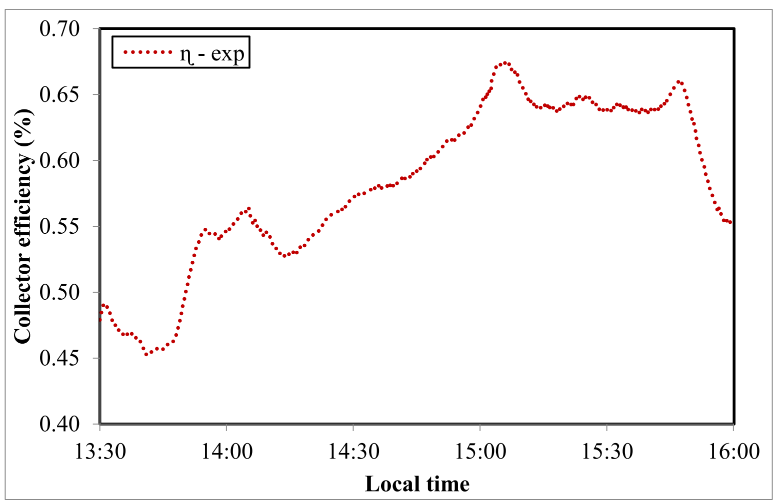

Fig. 6. The efficiency of the proposed solar collector.

inlet and outlet temperatures, and the ambient air temperature. The flow rate in the proposed solar collector system was maintained constant throughout the experiments at 0.75 L/min. The temperature at the solar collector input was kept at 37.7 °C. However, the temperature at the solar collector input gradually increased because of direct solar exposure. The temperature at the output of the solar collector ranged from 52 to 61 °C, with an average temperature of 58 °C. The designed solar collector had an average temperature difference of approximately 20 °C between its input and output temperatures. The ambient temperature was recorded as 44 °C on average, with minor changes, followed by a slight decrease over time. According to the data, the overall uncertainty in the recorded temperatures was predicted to be 2.1%. Fig. 4 shows that the theoretical ambient temperature was slightly lower than the measured ambient temperature, as illustrated in Fig. 5.

4.3. Collector efficiency

In our experiments, we analyzed the performance of a FPSC based on the ASHRAE standard. The standard assesses the performance by obtaining instantaneous efficiency values for different combinations of solar radiation, ambient temperature, and inlet fluid temperature. This requires experimental measurement of both the rate of incident solar radiation and the rate of energy absorption by the working fluid. The experiments were conducted at a flow rate of 0.75 L/min throughout the daylight hours from13:30 to 16:00. The useful energy gain of the working fluid is computed using Eq. (2) [28].

$$\dot{Q}_u = \dot{m}\ C_p\ (T_o - T_i) \tag{2}$$

The efficiency of the collector is defined as the ratio of useful heat gain of the working fluid to the energy impinging on the collector surface, which can be calculated using Eq. (3).

$$\eta = \frac{\dot{Q}_u}{A\ I} = \frac{\dot{m}\ C_p\ (T_o - T_i)}{A\ I} \tag{3}$$

Where; $\dot{Q}_u$ is the useful heat gain of water, W; $\dot{m}$ is the mass flow rate, kg/s; *Cp* is the heat capacity of water, J/kg.K; *To* is the outlet temperature of the solar collector, °C; *Ti* is the inlet temperature of the solar collector, °C; *Ta* is the ambient air temperature, °C; *A* is the surface area of the solar collector, m^2; and *I* is the incident solar radiation, W/m^2.

The efficiency of the proposed solar collector system was calculated based on Eq. (2). Fig. 6 depicts the efficiency of the proposed solar collector. Because the flow rate and fluid velocity were low throughout

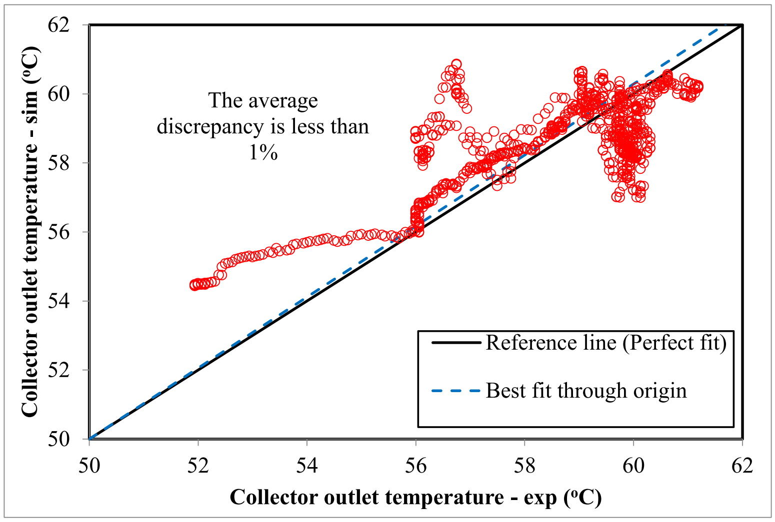

Fig. 7. A comparison of the experimental and simulated collector outlet temperatures.

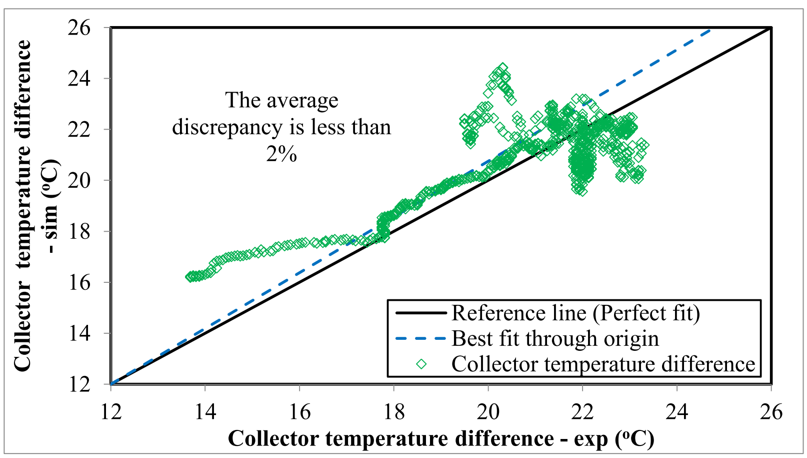

Fig. 8. A comparison of the experimental and simulated collector temperature difference.

the tests, more solar energy was absorbed, resulting in a higher temperature differential between the inlet and output fluids. Consequently, the overall collector efficiency increased over time. The efficiency of the proposed solar collector ranges from approximately 45% to 67%, with an average of 58%. According to the results, the total uncertainty in estimating efficiency is 2.3%.

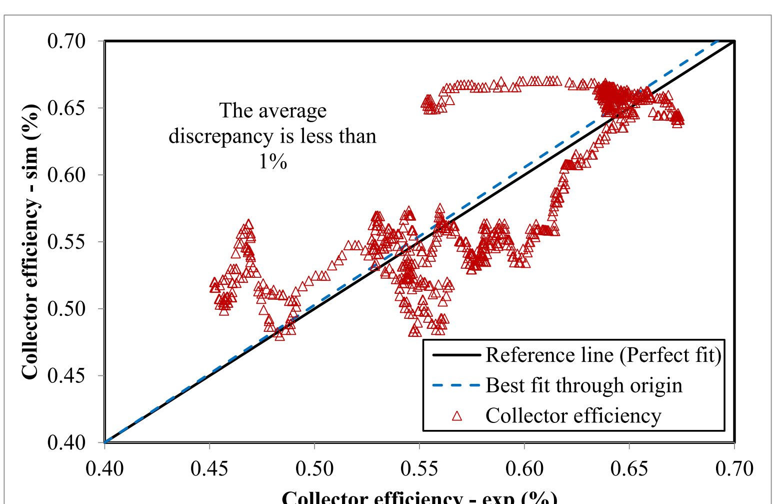

Fig. 9. A comparison of the experimental and simulated collector efficiency.

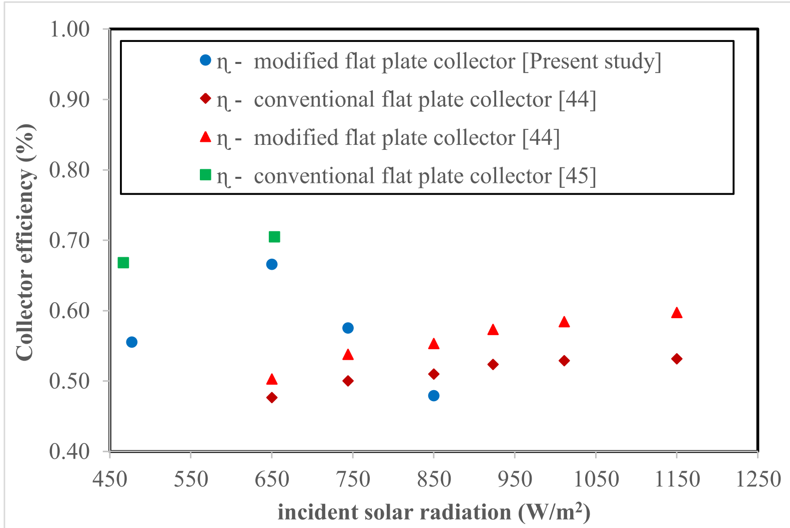

Fig. 10. The variation of collector efficiency with incident solar radiation.

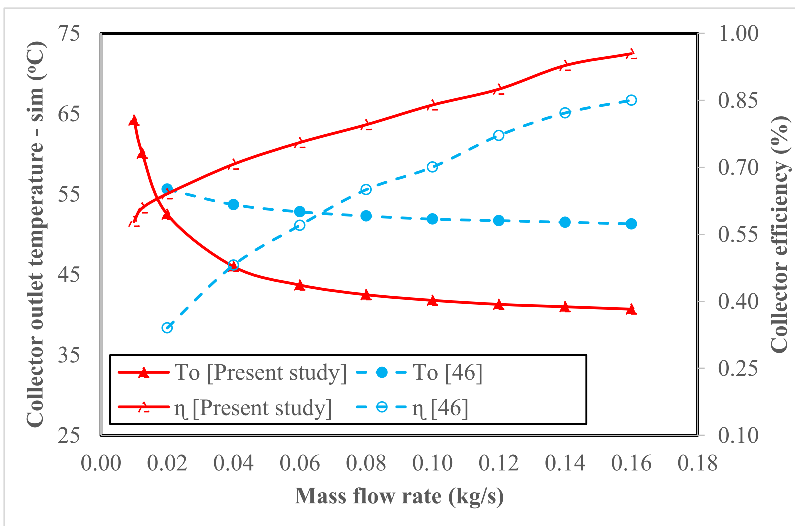

Fig. 11. Influence of water mass flow rate on collector outlet temperature and collector efficiency.

4.4. Validation model

To highlight the variance between the simulated and experimental results, a reference line with a unity slope was provided. Fig. 7 shows a comparison between the measured and simulated outlet temperatures. The simulation results for the TRNSYS simulation model were surprisingly compatible with the experimental data. The average difference in the output temperatures between the experimental and simulated conditions is less than 1%. The temperature at the solar collector output ranged from approximately 52 to 61 °C for both the tests and simulations, with an average of 58 °C.

Fig. 8 compares the experimental and simulated variations in collector temperature. The TRNSYS simulation results were found to be remarkably consistent with the experimental data. The average gradient in the output temperatures between the experimental and simulated conditions was also less than 2%. For all the experiments and simulation tests, the collector temperature difference ranged from approximately 14 to 24 °C, with an average of 14 °C.

Fig. 9 compares the experimental and simulated collector efficiencies. The TRNSYS simulation results were found to be interestingly matched with experimental data. The average temperature difference between the experimental and simulated conditions was again less than 1%. The efficiency of the proposed solar collector ranged from approximately 45% to 67%, with an average of 58%.

In order to compare the outcomes of the current of the modified solar collector with the conventional flat solar collector, the experimental data [44–46] for collector efficiency is displayed against mass flowrate and incident radiation. Fig. 10 depicts the fluctuation of collector efficiency with incident solar radiation. This is because the amount of solar radiation varies throughout time. The overall trend of the results is consistent with literature data. Fig. 11 shows the effect of water mass flow rate on the collector output temperature and efficiency. The results in Figs. 9 and 10 show that weather affected the outflow water temperature and collector efficiency (e.g., solar radiation intensity, ambient temperature, wind speed, and convection heat transfer coefficient). The outcome variations could also be attributed to differences in collector design characteristics. Such a comparison of multiple studies on FPSC may not be sufficient since these studies were conducted under varying parameters such as working fluid, operating conditions, ambient conditions, and collector geometry characterizations.

5. Conclusion

A novel approach was used in this study to improve the efficiency of FPSC. It incorporates a single serpentine-shaped collector tube covered with a plastic sheet to replace the current number of riser tubes linked to headers coated with a glass sheet. Experimental and simulation investigations were performed to evaluate the thermal performance of an active FPSC with an inner absorber tube in Al-Samawa, Iraq. A TRNSYS model for the proposed FPSC was developed and validated using the experimental data. The ambient temperature and incident solar radiation at the experiment site were 39 °C and 840 W/m^2, respectively. The findings indicate that the TRNSYS model strongly agrees with the experimental data. The average difference between the tests and simulations was approximately 1% in terms of temperature differential and collector efficiency. On a clear day, the average difference between the input and output temperatures of the proposed solar collector was approximately 20 °C. The average efficiency of the collector is approximately 58%. The developed model could be key to future improvements in FPSC. The proposed modification in this study is to provide highly efficient solar collectors for home and remote areas utilities. Another consideration is minimizing the net weight of the system. These findings encourage the development and implementation of the proposed solar collector system as an integrated system for various thermal engineering applications, including solar cooling systems, and solar distillation systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] A. Alahmer, X. Wang, K.C. Alam, Dynamic and economic investigation of a solar thermal-driven two-bed adsorption chiller under Perth climatic conditions, Energies. 13 (2020) 1005.

[2] R. Al-Rbaihat, A. Sakhrieh, J. Al-Asfar, A. Alahmer, O. Ayadi, A. Al-Salaymeh, Z. Al_hamamre, A. Al-bawwab, M. Hamdan, Performance assessment and theoretical simulation of adsorption refrigeration system driven by flat plate solar collector, Jordan J. Mech. Ind. Eng. 11 (2017) 1–11.

[3] M. Mahmoud, M. Ramadan, K. Pullen, M.A. Abdelkareem, T. Wilberforce, A. G. Olabi, S. Naher, A review of grout materials in geothermal energy applications, Int. J. Thermofluids 10 (2021), 100070, https://doi.org/10.1016/j.ijft.2021.100070.

[4] S. Ajib, A. Alahmer, Solar cooling technologies. Energy Conversion-Current Technol and Future Trends, IntechOpen, 2018.

[5] A. Karthick, M.M. Athikesavan, M.K. Pasupathi, N.M. Kumar, S.S. Chopra, A. Ghosh, Investigation of inorganic phase change material for a semi-transparent photovoltaic (STPV) module, Energies. 13 (2020) 1–12, https://doi.org/10.3390/en13143582.

[6] F. Hengel, C. Heschl, F. Inschlag, P. Klanatsky, System efficiency of pvt collector-driven heat pumps, Int. J. Thermofluids 5–6 (2020), 100034, https://doi.org/10.1016/j.ijft.2020.100034.

[7] K. Balaji, P. Ganesh Kumar, D. Sakthivadivel, V.S. Vigneswaran, S. Iniyan, Experimental investigation on flat plate solar collector using frictionally engaged thermal performance enhancer in the absorber tube, Renew. Energy 142 (2019) 62–72, https://doi.org/10.1016/j.renene.2019.04.078.

[8] M.R. Gomaa, M. Al-Dhaifallah, A. Alahmer, H. Rezk, Design, modeling, and experimental investigation of active water cooling concentrating photovoltaic system, Sustainability 12 (2020) 5392.

[9] A. Alahmer, M. Al-Dabbas, Design and construction of a passive solar power clothing dryer, Res. J. Appl. Sci. Eng. Technol. 7 (2014) 2785–2792.

[10] M. Al-Dabbas, A. Alahmer, A. Mamkagh, M.R. Gomaa, Productivity enhancement of the solar still by using water cooled finned condensing pipe, Desalin. Water Treat. 213 (2021) 35–43.

[11] P. Manoj Kumar, D. Sudarvizhi, K.B. Prakash, A.M. Anupradeepa, S. Boomiha Raj, S. Shanmathi, K. Sumithra, S. Surya, Investigating a single slope solar still with a nano-phase change material, Mater. Today Proc. 45 (2021) 7922–7925, https://doi.org/10.1016/j.matpr.2020.12.804.

[12] M.I. Al-Amayreh, A. Alahmer, A. Manasrah, A novel parabolic solar dish design for a hybrid solar lighting-thermal applications, Energy Rep. 6 (2020) 1136–1143.

[13] A. Padovan, D. Del Col, Measurement and modeling of solar irradiance components on horizontal and tilted planes, Sol. Energy 84 (2010) 2068–2084, https://doi.org/10.1016/j.solener.2010.09.009.

[14] P.P. Patil, D.S. Deshmukh, A.M. Vaidya, I.D. Paul, Experimental investigation of new innovative flat plate collector for solar water heater, Int. J. Recent Technol. Eng. 8 (2019) 282–287.

[15] A.K. Tiwari, S. Gupta, A.K. Joshi, F. Raval, M. Sojitra, TRNSYS simulation of flat plate solar collector based water heating system in Indian climatic condition, Mater. Today Proc. 46 (2020) 5360–5365, https://doi.org/10.1016/j.matpr.2020.08.794.

[16] S. Chantasiriwan, Comparison between two solar feed water heating systems in thermal power plant, Int. J. Thermofluids 15 (2022), 100167, https://doi.org/10.1016/j.ijft.2022.100167.

[17] M. Selmi, M.J. Al-Khawaja, A. Marafia, Validation of CFD simulation for flat plate solar energy collector, Renew. Energy 33 (2008) 383–387, https://doi.org/10.1016/j.renene.2007.02.003.

[18] H. Jouhara, N. Serey, N. Khordehgah, R. Bennett, S. Almahmoud, S.P. Lester, Investigation, development and experimental analyses of a heat pipe based battery thermal management system, Int. J. Thermofluids 1 (2020), 100004.

[19] E. Vengadesan, R. Senthil, A review on recent development of thermal performance enhancement methods of flat plate solar water heater, Sol. Energy 206 (2020) 935–961, https://doi.org/10.1016/j.solener.2020.06.059.

[20] E. Douvi, C. Pagkalos, G. Dogkas, M.K. Koukou, V.N. Stathopoulos, Y. Caouris, M. G. Vrachopoulos, Phase change materials in solar domestic hot water systems: a review, Int. J. Thermofluids 10 (2021), 100075, https://doi.org/10.1016/j.ijft.2021.100075.

[21] S. Pintaldi, C. Perfumo, S. Sethuvenkatraman, S. White, G. Rosengarten, A review of thermal energy storage technologies and control approaches for solar cooling, Renew. Sustain. Energy Rev. 41 (2015) 975–995, https://doi.org/10.1016/j.rser.2014.08.062.

[22] H. Jouhara, A. Żabnieńska-Góra, N. Khordehgah, D. Ahmad, T. Lipinski, Latent thermal energy storage technologies and applications: a review, Int. J. Thermofluids 5 (2020), 100039.

[23] M.K. Koukou, G. Dogkas, M.G. Vrachopoulos, J. Konstantaras, C. Pagkalos, V. N. Stathopoulos, P.K. Pandis, K. Lymperis, L. Coelho, A. Rebola, Experimental assessment of a full scale prototype thermal energy storage tank using paraffin for space heating application, Int. J. Thermofluids 1–2 (2020), 100003, https://doi.org/10.1016/j.ijft.2019.100003.

[24] G. Dogkas, M.K. Koukou, J. Konstantaras, C. Pagkalos, K. Lymperis, V. Stathopoulos, L. Coelho, A. Rebola, M.G. Vrachopoulos, Investigating the performance of a thermal energy storage unit with paraffin as phase change material, targeting buildings' cooling needs: an experimental approach, Int. J. Thermofluids 3–4 (2020), https://doi.org/10.1016/j.ijft.2020.100027.

[25] C. Pagkalos, G. Dogkas, M.K. Koukou, J. Konstantaras, K. Lymperis, M. G. Vrachopoulos, Int. J. Thermofluids 1–2 (2020), 100006, https://doi.org/10.1016/j.ijft.2019.100006.

[26] H. Al-Madani, The performance of a cylindrical solar water heater, Renew. Energy 31 (2006) 1751–1763, https://doi.org/10.1016/j.renene.2005.09.010.

[27] E. Nshimyumuremyi, W. Junqi, Thermal efficiency and cost analysis of solar water heater made in Rwanda, Energy Explor. Exploit. 37 (2019) 1147–1161, https://doi.org/10.1177/0144598718815240.

[28] S. Vasanthaseelan, P.M. Kumar, R. Anandkumar, K.H. Ram, R. Subbiah, V. Suresh, A.S. Abishek, R. Anith, P. Aravinth, S.V. Balaji, Investigation on solar water heater with different types of turbulators, Mater. Today Proc. 47 (2021) 5203–5208, https://doi.org/10.1016/j.matpr.2021.05.530.

[29] A.K. Bhargava, H.P. Garg, R.K. Agarwal, Study of a hybrid solar system-solar air heater combined with solar cells, Energy Convers. Manag. 31 (5) (1991) 471–479.

[30] M.S.W. Potgieter, C.R. Bester, M. Bhamjee, Experimental and CFD investigation of a hybrid solar air heater, Sol. Energy. 195 (2020) 413–428, https://doi.org/10.1016/j.solener.2019.11.058.

[31] K.T. Aoul, A. Hasan, H. Riaz, Solar water heating systems for different buildings under a hot climate; parametric optimization and economic analysis, Sustain. Build. 3 (2018) 3, https://doi.org/10.1051/sbuild/2018002.

[32] R. Loni, G. Najafi, E.A. Asli-Ardeh, B. Ghobadian, W.G. Le Roux, T. Yusaf, Performance investigation of solar ORC using different nanofluids, Appl. Sci. 9 (2019), https://doi.org/10.3390/app9153048.

[33] A.S.F. Mahamude, W.S.W. Harun, K. Kadirgama, D. Ramasamy, K. Farhana, K. Salih, T. Yusaf, Experimental study on the efficiency improvement of flat plate solar collectors using hybrid nanofluids graphene/waste cotton, Energies 15 (2022) 2309, https://doi.org/10.3390/en15072309.

[34] A.S.F. Mahamude, M.K. Kamarulzaman, W.S.W. Harun, K. Kadirgama, D. Ramasamy, K. Farhana, R.A. Bakar, T. Yusaf, S. Subramanion, B. Yousif, A Comprehensive Review on efficiency enhancement of solar collectors using hybrid nanofluids, Energies 15 (2022), https://doi.org/10.3390/en15041391.

[35] R. Dobriyal, P. Negi, N. Sengar, D.B. Singh, A brief review on solar flat plate collector by incorporating the effect of nanofluid, Mater, Today Proc. 21 (2020) 1653–1658, https://doi.org/10.1016/j.matpr.2019.11.294.

[36] S.K. Verma, A.K. Tiwari, D.S. Chauhan, Experimental evaluation of flat plate solar collector using nanofluids, Energy Convers. Manag. 134 (2017) 103–115, https://doi.org/10.1016/J.ENCONMAN.2016.12.037.

[37] M.A. Fazilati, A.A. Alemrajabi, Phase change material for enhancing solar water heater, an experimental approach, Energy Convers. Manag. 71 (2013) 138–145, https://doi.org/10.1016/j.enconman.2013.03.034.

[38] M.A. Dos Santos Bernardes, R.M. Valle, M.F.B. Cortez, Numerical analysis of natural laminar convection in a radial solar heater, Int. J. Therm. Sci. 38 (1999) 42–50, https://doi.org/10.1016/S0035-3159(99)80015-4.

[39] A. Al-Manea, T. Al-Jadir, Effect of ejector design parameters on flow structure inside the mixing chamber, IOP Conf. Ser. Earth Environ. Sci. 779 (2021), https://doi.org/10.1088/1755-1315/779/1/012033.

[40] Ahmed Al-Manea, Saleh Khalid, Supersonic Steam Ejectors: Comparison of Dry and Wet-steam CFD Simulation Models, Journal of Engineering Science and Technology 17 (2) (2022) 1200–1212.
[41] L.M. Ayompe, A. Duffy, S.J. McCormack, M. Conlon, Validated TRNSYS model for forced circulation solar water heating systems with flat plate and heat pipe evacuated tube collectors, Appl. Therm. Eng. 31 (2011) 1536–1542, https://doi.org/10.1016/j.applthermaleng.2011.01.046.
[42] A. Alahmer, X. Wang, R. Al-Rbaihat, K.C. Amanul Alam, B.B. Saha, Performance evaluation of a solar adsorption chiller under different climatic conditions, Appl. Energy 175 (2016) 293–304, https://doi.org/10.1016/j.apenergy.2016.05.041.
[43] D. Brough, J. Ramos, B. Delpech, H. Jouhara, Development and validation of a TRNSYS type to simulate heat pipe heat exchangers in transient applications of waste heat recovery, Int. J. Thermofluids 9 (2021), https://doi.org/10.1016/j.ijft.2020.100056.
[44] S.K. Verma, K. Sharma, N.K. Gupta, P. Soni, N. Upadhyay, Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector", Energy 194 (2020) https://doi.org/10.1016/j.energy.2019.116853.
[45] G. Buhari Abubakar, G. Egbo, Performance evaluation of flat plate solar collector (model Te39) in Bauchi, Am. J. Eng. Res. 3 (2014) 34–40. http://www.ajer.org.
[46] D. Zhang, J. Li, Z. Gao, L. Wang, J. Nan, Thermal performance investigation of modified flat plate solar collector with dual-function, Appl. Therm. Eng. 108 (2016) 1126–1135, https://doi.org/10.1016/j.applthermaleng.2016.07.200.