Biomechanism and Bioenergy Research 1(2), 56-60

Simulating and Evaluating the Effects of Air Passing through a Linear Parabolic Solar Collector on Some Properties of Leaving Air

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INFO

ORIGINAL RESEARCH PAPER

KEYWORDS

Linear parabolic collector; Solar Energy; Computational fluid dynamics.

Received: ***08 November 2022***

Revised: ***28 November 2022***

Accepted: ***30 December 2022***

Available Online: ***31 December 2022***

ABSTRACT

In the current energy and environmental conditions, it is necessary to implement systems based on renewable energy sources in order to reduce energy consumption worldwide. Solar collectors have been studied for years, and many researchers have focused their attention on increasing their efficiency and cost-effectiveness. Solar collectors are implemented for heating domestic water, heating or industrial processes. A promising system that is not yet widely known is air heating by solar collectors, which can be an efficient way to use solar energy with lower investment costs, a system that can preheat the fresh air needed for heating, drying. In this research, the air was established between the absorbent space and its glass cover at speeds of 2, 4, and 6 m/s using a fan, and the effect of incoming air speed and weather conditions such as solar radiation intensity, wind speed, and ambient temperature on the outlet air temperature from the collector and the absorber rod temperature were checked. Based on the obtained results, the temperature of the air coming out of the collector and the temperature of the absorber decreases with the increase in the speed of the incoming air. The greatest impact of weather conditions on the temperature of the absorber rod is related to the intensity of the sun's radiation. The numerical analysis results were obtained with an error of 5% compared to the experimental results.

INTRODUCTION

Solar energy is one of the forms of renewable energy that is cheap, clean and available. Many technologies have been developed for the use of renewable energies in the world. One of the main challenges in this field is to maximize the utilization of thermal energy from solar radiation. A solar collector has the ability to absorb solar radiation, convert it into heat, and transfer it to the working fluid. This working fluid can be air, water or oil (Desisa and Shekata, 2020). This thermal energy is a form of energy in the working fluid of the solar collector that can be used directly for various applications. In the current conditions of energy and environment, it is necessary to implement systems based on renewable energy sources in order to reduce energy consumption all over the world. Solar collectors have been studied for years and many researchers have focused their attention to increase their efficiency and cost-effectiveness. Solar collectors for heating water are often implemented for domestic hot water, heating or industrial processes and currently have a place in the market. A promising system that is not yet widely known is the heating of air by solar collectors, which can be an efficient way to use solar energy with a lower investment cost, a system that can preheat the fresh air needed for heating, drying and so on be used.

Concentrated solar thermal systems (CST) or concentrated solar power systems (CSP) as energy conversion systems using a combination of reflective mirrors to focus direct sunlight to produce useful forms of energy such as heat, electricity or fuel by various technologies such as the Rankine steam cycle are known for generating electricity (Lovegrove and Stein, 2012). Currently, there are four main CST technologies, which are parabolic collector (PTC), linear Fresnel reflector (LFR), central receiver system (CRS) and parabolic dish (PD) (Bjerg *et al.*, 2002). Parabolic collector and linear Fresnel reflector are classified as linear concentrator technologies, while central receiver system and parabolic dish are classified as point concentrator technologies (Singh and Singh, 2018). Point concentrator technologies are relatively more expensive and basically limited in application due to higher operating temperature and as a result higher thermodynamic cycle efficiency. On the other hand, linear concentrator technologies are relatively economical and flexible; therefore, they have been widely used in various fields such as electricity generation, solar heating and cooling, desalination, industrial process heat, solar fuel production, etc. The linear parabolic collector is one of the most prominent and promising technologies used to convert solar radiation into useful heat (El Ghazzani *et al.*, 2017). Stefanovik conducted a study on the numerical and mathematical modeling of compound parabolic collectors at different exit temperatures at the radiation intensity of 950 W/m^2 and the mass flow rate of 0.00162 kg/s and concluded that by increasing the inlet air temperature the useful energy of the collector absorber was reduced and as a result, the thermal efficiency decreased (Stefanovic and Pavlovic, 2011). Kotschar et al. conducted an experiment on the

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DOI: 10.22103/BBR.2022.20511.1027

collector's efficiency and concluded that as the solar radiation increases, the amount of efficiency was increased (Kutscher *et al.*, 2012).Yaqoubi and mokhtari l. conducted numerical studies in 2007 to optimize the collectors. For one collector, several parameters are important, including round angle, collector length, focal length, concentration ratio, adsorbent pipe diameter, absorbent pipe thickness, glass thickness on the adsorbent, adsorption coefficient, adsorption coefficient, adsorption coefficient There are dubbing, radiation, fluid input temperature, light efficiency, heat efficiency, glass reflection. By solving a numerical by MATLAB software, they came to the conclusion that there are two ways to evaluate the optimal collector: change the adsorbent diameter or change the collector curve diameter (yaghoubi and mokhtari, 2007). Currently, more than 82 % of the world's total CSP capacity is taken by PTC and only 4 % by LFR. The temperature obtained by the linear collector in the focal point can be up to 400 ˚C and guarantees relatively higher performance (El Ghazzani *et al.*, 2017). It is also worth noting that there are challenges for the PTC system. For example, the support structure of the PTC system is complex and it is difficult to install and build. At the same time, due to the fragile reflection mirrors and the relatively large area facing to wind, the potential change of natural wind creates a major challenge for effective and safe PTC performance (Iranmanesh *et al.*, 2020). How to obtain a uniform thermal distribution around the absorbent is another major challenge (El Ghazzani *et al.*, 2017). All the problems that PTC encounters will eventually lead to a significant increase in investment and the cost of operation and maintenance. The main application of Computational fluid dynamics is to solve the equations governing fluid flow (Yadav and Bhagoria, 2013). These non-linear component differential equations are disintegrated by Ansys software and become one of the algebraic equations and solve using a limited volume method. The purpose of Computational fluid dynamics is to model fluid flow and heat transfer. The purpose of this study is to find optimal air speed to obtain the highest output air temperature from the collector and simulate the collector and its glass coating.

MATERIALS AND METHODS

In this study, a linear collector with a length of 2 m and a width of 1 m was used.

To create a model in CFD software three steps must be completed.

- The first step involves the definition of the geometry of the problem by the appropriate software. First, the geometry and computational range are defined and with meshing, the scope of the examination is divided into small cells, and the initial definition of boundary conditions for all levels was dealt with.
- In the next step, the solution of relevant equations such as conservation of mass, momentum, energy, radiation and turbulence in cells was discussed based on a method such as finite volume and determination of solution parameters and convergence range, and the physical characteristics and materials as well as the definition of boundary and initial conditions were discussed in this stage was completed.

And the last stage includes the interpretation of the results obtained from the solution, and in order to depict the features of the flow and have a better view of the problem, diagrams were drawn.

Definition of physical model

In this research, firstly, a three-dimensional model of the absorber and its glass cover was designed. Two concentric circles with diameters of 5 and 2.5 cm were drawn in Design Modeler software and given a volume of 2 m which can be seen in Fig. 1.

Fig 1. Geometry created in Design Modeler

Model geometry meshing

The generated geometry was meshed using Ansys Meshing software that are shown in Fig. 2. Edge Sizing was used for the meshing of the pipe in question so that a structured mesh could be produced.

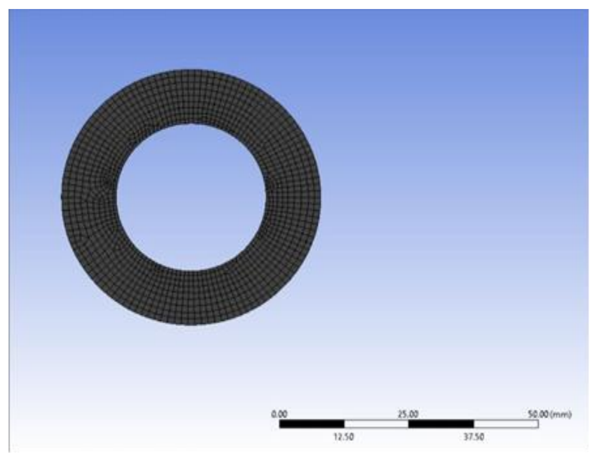

Fig 2. Geometry meshing

Different sizes were used for the inner and outer circles as a check for the independence of the mesh in the next step, which are shown in Fig. 3, the place of air entry, and exit of the inner and outer wall was named.

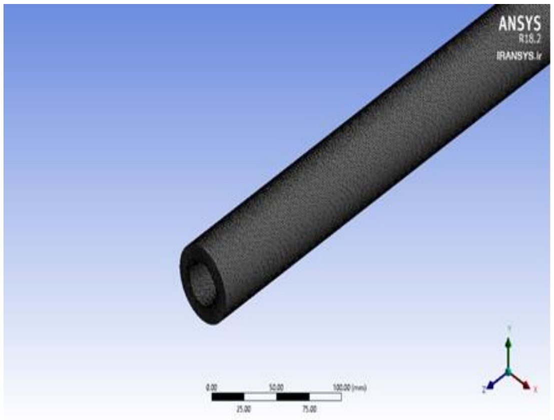

Fig 3. Networking of the created geometry

Boundary conditions of the model

To solve the physics of the problem, the type of solution was selected and after examining the Reynolds number, the k-ϵ model was used to continue the solution. In the input boundary conditions, speeds of 2, 4, and 6 were entered with an initial temperature of 8 ˚C, and in the output boundary conditions, ambient pressure was entered which shown in Fig. 4. Then, the surface of the internal wall of the fluid with a temperature of 85 ˚C and for the external wall the boundary conditions of heat transfer coefficient with a temperature of 27 ˚C and a heat transfer coefficient of 5.6 $W/m^2.k$ were used.

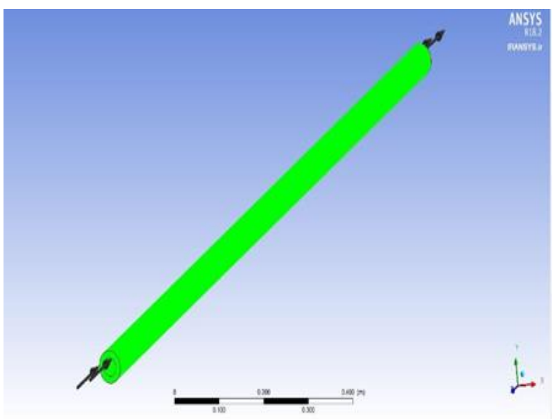

Fig 4. Boundary conditions of the problem

What I have written is simulation validation; an experimental set up was built. A fan with 12 volts and 3.3 amps specifications was used to establish the airflow between the absorber and the glass cover. To adjust the fan speed, PWM signal was sent to the fan with Arduino software. PWM is a method to control analog devices using digital values. For example, controlling the light intensity of an LED or controlling the speed of a DC fan. These devices work with analog signals, but PWM does not produce pure analog signals.

In fact, it produces pulses with a very small width that look like an analog signal. These short pulses are made based on "duty cycle". The meaning of duty cycle is the ratio of the time in which the signal is in the state of maximum voltage to the total time of a cycle. With this definition, it is clear that if a signal is always one, its duty cycle is 100% and if it is always zero, its duty cycle is zero percent. Therefore, by adjusting the duty cycle with the help of Arduino board, the speed of the fan was adjusted and its speed was measured using the turbine anemometer. To install the fan on the device, an intermediary was made using a 3D printer. The fan was installed on the absorber glass cover with the help of a mediator and a knee on the mediator to establish the airflow between the absorbent space and the glass cover. After connecting the fan, the remaining seams were sealed using foam. After setting up the airflow system, the collector was placed in the north-south direction and followed the path of the sun in the east-west direction. Air flowed inside the glass cover at velocities of 2, 4, and 6 m/s, and the outlet temperature was recorded every two minutes using the LM-335 temperature sensor installed in the outlet air path. The experiments were conducted on three different days, which included different sun intensity, ambient temperature, and wind speed.

TESS 1333R solar power meter was used to measure the radiation on the surface of the collector. One of the features of this solar power meter is that it is small and can be installed on different surfaces. Moreover, the wind speed was measured using a turbine anemometer. After simulating and conducting experiments, in order to validate the simulation, its results were compared with the results obtained through experimental tests.

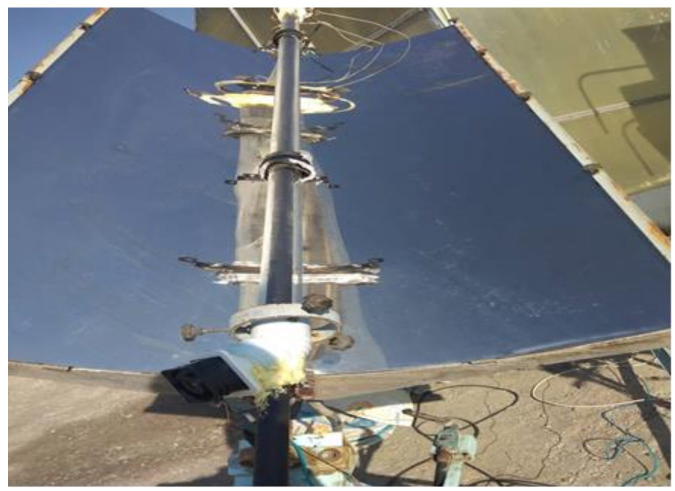

Fig 5. A view of the collector

RESULTS AND DISCUSSION

In this research, the effect of flow speed entering the collector and weather conditions (sun intensity, wind speed, and ambient temperature) with the passage of time on the outlet temperature of the collector and the absorber temperature were investigated. The experiments were conducted with different weather conditions in January 2021 and the data were analyzed using Mini tab software. According to the conducted experiments, it was found that for each air speed input, after a certain period of time, the air coming out of the collector reached a certain temperature. According to the obtained data and results, the best mode was at the input speed of 2 m/s, according to Fig. 6. At a speed of 2 m/s, the average outlet temperature obtained was 50 ˚C. A study was conducted on the flat plate collector, and in the radiation conditions of 425 to 790 W/m^2, the output temperature of the collector varied between 35 and 115 ˚C (Fudholi *et al.*, 2013). Also, Omojaru et al. passed the air with a flow rate of 0.012 kg/s from the collector and obtained a temperature between 36 and 42 ˚C at the outlet (Omojaro and Aldabbagh, 2010).

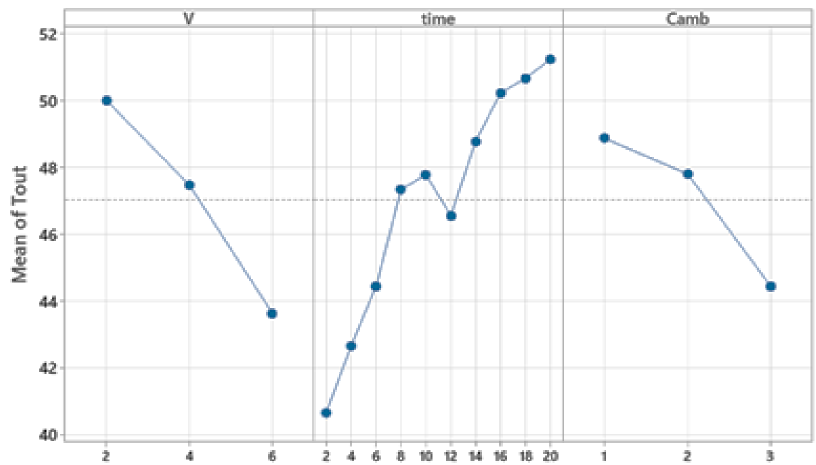

Fig 6. The relationship between the average temperature with different speeds and environmental conditions over time.

According to Fig. 7-b, c, on the first day (average ambient temperature of 11 ˚C, average solar radiation intensity of 1320 W/m^2 and average wind speed of 1.3 m/s), which has the highest radiation intensity among the environmental conditions, the best outlet temperature was obtained, which shows the effect The intensity of solar radiation is on the output temperature of the collector. The input temperature to the collector is another important parameter that affects the output temperature. By comparing conditions 2 (with an average radiation intensity of 940 W/m^2, an average ambient temperature of 14 ˚Cand an average wind speed of 0.4 m/s) and conditions 3 (with an average radiation intensity of 1125 W/m^2, an average ambient temperature of 8 ˚C and the average wind speed of 2 m/s) it can be concluded that in ambient conditions 2, although the intensity is lower than in ambient conditions 3, the temperature at the outlet has increased because in ambient conditions 3 the wind speed is higher and as a result the ambient temperature has decreased.

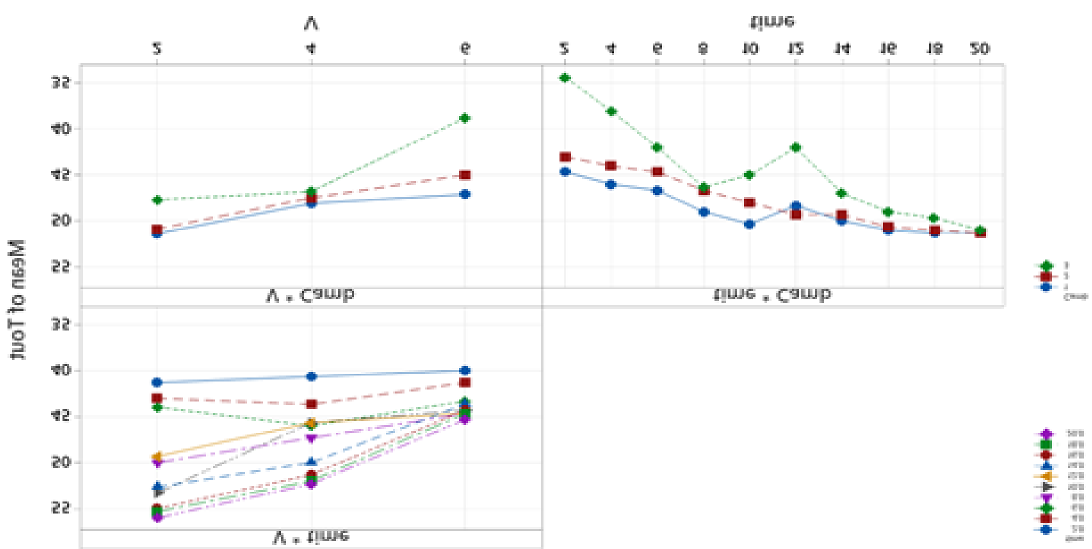

Fig 7. The relationship between outlet temperature and inlet speed and environmental conditions

Analysis of results with software:

In this simulation, because the Reynolds number is higher than the critical value, the airflow inside the collector tube is turbulent and the k-ϵ turbulence model is used. It can be seen that the convergence graph during solving by the repetition method, which is according to Fig. 8, shows that the convergence slope is high and that the mesh structure is suitable. Mesh optimization is very important. At this stage of the research, a method should be chosen so that the absorbent tube with its cover that was studied is correctly modeled and the results are reliable and the volume of calculations is at its lowest level. For this purpose, the temperature parameter was investigated at the outlet with different meshes and as shown in Fig. 8, by making the meshing finer, more accurate answers were obtained until the independence of the mesh was obtained.

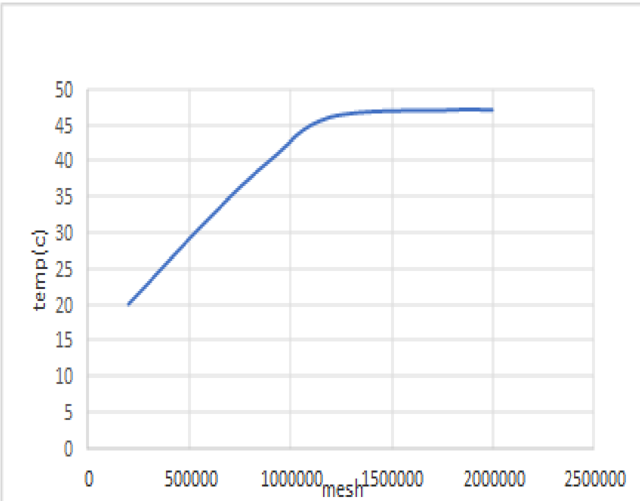

Fig 8. Mesh number independence diagram

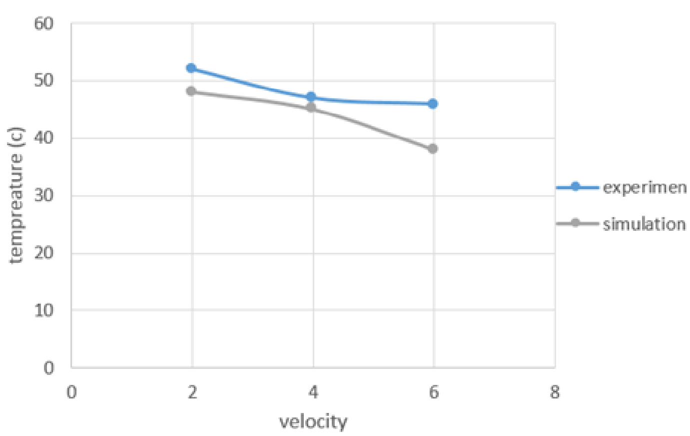

Fig 9. Comparison of the results obtained from the experiment and the software

CONCLUSIONS

The experiments were performed in three different environmental conditions with different intensity of sunlight, ambient temperature and wind speed. The best condition for the outlet temperature of the collector and the temperature of the absorber rod was at a speed of 2 m/s and in the first environmental conditions, when the outlet temperature of the collector reached 52 ˚C. By increasing the inlet air speed from 2 m/s to 4 m/s, the outlet temperature of the collector decreased to 47 ˚C, and at the speed of 6 m/s, the outlet temperature of the collector reached 46 ˚C. The results obtained from the software have an acceptable proximity to the results obtained from the experiment. Fig. 9 shows the comparison of the results obtained by the software and the experiments.

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