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Enhancing Thermal Efficiency in Solar Water Heaters: The Role of Reflective Walls

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ABSTRACT

With tremendous promise for environmentally friendly and economically viable solutions, solar water heaters have emerged as a prospective replacement for traditional energy-intensive water heating techniques. Integrated pressure solar water heaters have become more popular among different solar water heater designs because of their capacity to function under high-pressure settings, making them appropriate for both domestic and commercial applications. The best way to gather and use energy from such systems is to increase their thermal efficiency, which will also aid in overall energy conservation efforts. Reflective mirrors are used to reflect solar radiation from different dimensions, and a material absorbs incoming radiation at the same distance. Coordinates and time are determined for precision. The thermal reflection attributes of the solar heater material and layers are established, with projection altitude angle variations set from 0 to 40 degrees. The results show the temperature gradient favors reflectors at a distance of 5 cm, reaching 312 K at 1:00 pm. The temperature on the solar collector and reflector increases at a distance of 5 cm, reaching 318 K. The opacity wall absorbs solar radiation better than the obstruction wall, converting it into heat at 315 K. The altitude angle of 0 is better than 40 degrees, as the reflector reflects the radiation through tubes, resulting in higher solar radiation. The presence of the reflector improves the angle to 0 compared to 40 degrees. This knowledge represents the ease of choosing the angle of incident solar radiation in terms of installing solar collectors.

1. INTRODUCTION

Solar water heaters are a significant part of sustainable energy systems, harnessing the sun's abundant energy to meet hot water needs. Their history dates back to ancient civilizations, and technological advancements have led to their widespread adoption worldwide. In the face of climate change and finite fossil fuel resources depletion, solar energy holds immense potential to mitigate greenhouse gas emissions and reduce reliance on non-renewable energy sources. Solar water heaters can be regarded as a smart devise that allow us to save on water heating energy costs and carbon footprint. Energy-efficient solar water heater is critical for getting the most out of a solar installation, minimizing environmental effects, and improving the commercial viability of solar thermal power plant. On the one hand, reaching high thermal efficiency is a great matter because of the unpredictability of sunlight, variable ambient temperatures as well as designing cost-effective solutions. An innovative idea is applying the solar reflector walls in solar water heating systems. Reflective walls which are put on the solar collectors in a manner that converts the incident sunlight into more heat at the absorber surface and heats the water by increasing the heat transfer efficiency. The choosing of operative modes of reflective wall and the best materials allows to reach higher efficiency, particularly in those countries with the poor weather and where there is little sun. This research will be focused on the contribution of facing walls in bettering the thermal performance of a solar water heating system through the testing of prototypes and computational modeling. By relying on the solar energy abundant resource and through pioneering design strategies this research is going to raise the popularity of the solar heaters, which are not only clean and economical but also environment friendly as a replacement of the conventional water heating systems.

Solar energy is a clean, abundant, and environmentally friendly alternative to traditional energy sources, particularly in the production of hot water for domestic and commercial use. Integrated pressure solar water heaters, which can operate in high-pressure situations, are particularly popular for urban areas with higher water pressure requirements. However, the thermal efficiency of these systems depends on the solar collector's ability to absorb solar energy. To improve the absorber's thermal performance, strategies like selective coatings and larger surface areas have been researched. The wall, located in a place where it can redirect solar rays at their best, is capable to boost energy collection as well as thermal efficiency level. This research focuses on the intimate connection as well as an influence of a reflecting wall on the thermal performance of an integrated pressure solar water heater looking at an opportunity to improve the effectiveness of integrated pressure solar water heaters and advance renewable energy sources.

2. LITERATURE REVIEW

The solar thermal generator, consists of a dish collector setup in a grid manner for focusing solar electricity, is part of a residential space for students at the University of Calabria in Italy. The researchers may do an assessment of the plant's activity and propose updates in the design through the creation of a thermal model. The optical model of the solar energy collector was tested and the absorber emissive properties were established employing a thermal imaging camera. In order to determine the specific features affecting system operation and thermal equilibrium, respectively, a thermo-fluid dynamic analysis is conducted. The results also obviously are the evidence in supporting all elements in the energy balance and give stress on the most important lose-causing components [1]. A developing trend in the use of evacuated tubular solar collectors (ETC) in solar water heaters has seen solar energy being used as a sustainable source. Nevertheless, ETCs may be inefficient because of the varying sun intensity, but this will not be the case. Computation fluids dynamics (CFD) was used to simulate heat pipe ETC with and without phase change material (PCM), referred below as HPETC+PCM and HPETC, respectively. The research by applying tritriacontane paraffin (C33H68, melting temp. of 72°C) as PCM and 3D PCM HPETC model construction and simulate the commercially available HPETC model using it. The simulation data is simply applicable for future HPETC optimization in connection with thermal energy storage systems as it shows good accord with the experimental data [2]. The efficiency of a solar cabinet drying system that combines a thermal storage system, an evacuated tube solar collector, and a heat pipe is examined in this research. It examines the solar collector, the efficiency of drying, CFD modeling, and the evaluation of dried apple slice quality. Experimental information was used to evaluate the dryer's performance. Results indicated that, at airflow rates of 0.025 kg/s and 0.05 kg/s, respectively, employing PCM increases input thermal energy by 1.72% and 5.12%. Extreme increases, however, use less thermal energy. Using a high degree of concordance between simulated and real data, the system using PCM had the best overall drying efficiency at 0.025 kg/s. The quality of the dried product is unaffected by PCM [3].

Using computational fluid dynamics, the reflector is a compound parabolic concentrator with 25 mirrors facing a receiving tube. Utilizing user-defined functions, the entropy generation rate is calculated while taking viscous dissipation, heat transfer, and radiation into account. The receiver tube has the greatest values for radiation temperature, incoming radiation, and absorbed radiation (7800 W/m^2), according to the results. The secondary receiver's top half and bottom half experience the greatest temperature variation (39,000 K/m^2). Thermal exchange is the leading contributor of the entropy generation, and being 2.59% and the viscous dissipation with the negligible amount [4]. One of the research issues focused on is the enhanced use of solar energy through analysing the thermal performance of solar evacuated tubes in tie with mini-compound parabolic concentrators (mini-CPCs). According to the conservation principle, the mathematical model of heat transmission for a mini-CPC vacuum tube was computed. The main factor which impairs the heat loss is thermal convection resistance. This is why the low conductive vacuum interlayer is very significant by ameliorating the heat transfer rate. The small area-CPC and standard evacuated tubes experienced a 63.4 K and 49.8 K temperature rise, respectively. By including varying climate conditions in the calculations, the value of the thermal efficiency jumps from 24.3% to 29.2%. This experimental gadget functions efficaciously and can be considered a paradigm for the technical applications in the field of engineering [5]. That study suggests a new dynamic modeling methods which is aimed at improving the efficiency of solar collectors, which have been shown to have a high efficiency. The research is aimed at retooling air-cooled vacuum tubes for increasing the packing density and efficiency. The redesigned tubes ensure thermal process of cooling and heating in case of harsh solar heating, so the system does not overheat. The research offers the proof of the changes' efficacy and will provide a better understanding of the processes involved in heat exchange between the tubes, solar radiation and the environmental conditions. The approach is aimed at a sustainable and productive solar power use, by setting up the world towards renewable energy sources. For the purpose of preventing solar collector overheating and as a result of two designs of vacuum tubes are studied. The efficiency function is approximated by a fourth-order function in the study's numerical solar-thermal simulation. The effects of two modified vacuum tubes—increasing heat convection coefficient and infrared emissivity—are explored. The mechanisms of simulated heat losses are simulated. When these collectors' performance at low temperatures was investigated, the first changed design resulted in a reduction of up to 26% in performance. Despite increasing infrared heat losses, the second design had little impact. The scientists discovered that utilizing additional vacuum tubes on cloudy days might improve performance. Even on cloudy days, a solar collector based on a 200-l water tank could produce 200 kg of hot water at 45°C [6].

A two-step SiO_2/water nanofluid was produced using a micro fluidizer processor. The experiment tested the nanofluid's thermal conductivity and transmissivity at mass fractions of 1%, 3%, and 5%. Numerical simulations ascertained the working fluid's properties with regard to heat transmission. The results demonstrated that the SiO_2/water nanofluid's heat-transfer capabilities were better than those of water and improved with mass fraction. The study also discussed the effects of polarization nanofluid residence time on heat transfer characteristics. The research showed that longer exposure time and less clustering resulted in poorer heat transfer [7]. The research highlights the façade integration and the environmental impact such as the Building-Integrated Solar Thermal collectors (BIST) tube-based systems. Environmental concern on vacuum-tube collectors and their usage with regard to their life span is raised in the literature review. Two-thirds of the session are a case study that analyze the environment effect of two kinds of systems, one is vacuum tube/BIST and the other is flat plate/BIST setup. Corsica in France was the scene of the systems' research and development and life cycle was analyzed. The study reported that the shortest energy payback times of flat-plate/BIST and vacuum-tube/BIST thermal systems correspond to one year and one month, respectively. Those of the research are compared with those of previous researches and the authors find that deploying vacuum tube/BIST system rather than flat plate/BIST system may cause less serious impacts [8]. In Mehsana, Gujarat, the research project examined for a whole year a double basin solar still fed by vacuum tube. The design of vacuum tubes in the past was such that they were all attached to the lower basin which in turn led to the heating of the water and the production of distillate. Condensation heat was trapped in the upper bay which had the effect of raising the quality of the distillate. To generate more water at that depth, the system put out an average distillate of 8 and a water value of Rs/kg [9]. A solar power plant based on the Fresnel linear reflector with a molten salt HTF and evacuated tube as a primary reflector and CPC as secondary reflector is built. The method of MCRT's radiation transmission was implemented with the help of the Monte Carlo Ray Tracing (MCRT) technique. The 3D optical model of parabolic and cylindrical mirrors as well as the effects of time, location, orientation angle and other variables were built, used and explored to verify this model was done. In order to analyze the temperature transmission efficiency, MCRT and FVM were made part of each other. With a 65.0% optical efficiency at normal incidence and a range of 55.2% to 34.8% for the annual mean optical efficiency, the improved cylindrical mirrors attained performance levels comparable to parabolic mirrors. The temperature profiles on the absorber followed the uneven solar radiation, and the tested conditions resulted in collector efficiencies of over 46.0%. Molten salt may be used successfully in a Fresnel system as the HTF, according to the suggested approach [10]. The goal of this study is to build a dual basin solar still with inner basins that are 1006 mm, 325 mm, and 380 mm in size and outside basins that are 1006 mm, 536 mm, and 100 mm. The production of distillate is increased when black granite gravel is used because it reduces brackish or salty water. To evaluate the effectiveness of the double basin solar still at Mehsana, Gujarat, three circumstances were studied. According to experimental results, connecting vacuum tubes with black granite gravel enhances daily distillate output by 56% and 65%, respectively [11].

A single-pass evacuated tubular collector (SPETC) has been developed for solar heat generation, consisting of six expansion joints and a double-glass evacuated tube with a selective absorbing coating. A symmetrical compound parabolic concentrator (CPC) is built using high-reflectivity 3 m mirror sheets. Experimental data is used to construct and validate numerical models using a three-dimensional CFD technique. The SPETC can achieve a daily thermal efficiency of 48% with a temperature difference of 59.6 K and a volume flow rate of 0.0077 m^3s^{-1}. The SPETC is used to cool industrial process heat in combination with an adsorption chiller or desiccant wheel. A low-cost linear Fresnel reflector solar thermal micro-concentrating collector (MCT) was also developed for high temperatures up to 220°C. The MCT enhances thermal efficiency by minimizing convective losses and leveraging natural convection and radiation heat transfer. A 3D computational fluid dynamics model was built using ANSYS-CFX, and the MCT's annual performance was evaluated using TRNSYS in Australia [12-14].

Two apparently unconnected problems in electrostatics and optics may be analytically resolved by using a physically appealing approach. The issue is the electrostatic field coupled to a parallel array of stripes and the diffraction of a plane wave at a thin, perfectly conducting half-plane. For calculating the electron optical phase shift during electron microscopy operations, the solution is essential and largely directed towards undergraduate students; however, general physicists could also find it interesting [15].

The development of solar energy collection machinery has 3 resulted in a solar vacuum tube system, which is one of the oldest and less efficient devices that were ever created. Increasing the resultant rate, the side refractors were installed, this being a good means of reflecting the solar radiation and increasing the temperature. The best thermosyphon angle for heat transfer was determined by changing the heights of the sides of the wall, varying the width of the wall, and comparing angles at different wall heights. One of the first improvements was rotating mirrors from 30 degrees to almost 90 degrees, and size from 250 mm to 500 mm. The temperature difference on collectors increased with time and the angle of mirrors, the maximum was obtained at noon and 30 degrees. The size of the mirror-wall width made difference in radiation reflection and distribution, 500mm size being more effective. Thermal efficiency reached 84% with the angle of 30 degrees, whereas the width has the smallest effect at a difference of 500 mm and obtained 86% [16]. An outdoor experimental site that contains a solar latent heat storage unit with an underlying thermal energy store was studied. The model has a porous media part full of packed glass beds with a fluid moving through the air voids. To reach that temperature, two tanks were filled with porous materials that form heights of 10 centimeters and 20 centimeters. The experiment's data show that the highest thermal storage for 110 minutes is at the hot flow rates 4 liters per minute (LPM), 5 LPM, and 20 cm, while it reaches 90 minutes at the same flow rates without por When food is heated, both of these components change [17]. The article focused on how MFs (magnetic fields) could be used in water heating improvement, highlighting advantages in these conditions. It applies magnetic induction of the solar electric to demonstrate the variety of flow patterns in different locations of water warming. Numerical simulations were performed to elucidate the viability of the heaters in regards to their ability to meet heat load requirements, temperature distribution at different points, and flow rate during both induction heating and magnetic field heating. Electrical resistance heating with magnetic field cooling was gauged along the hottest surface of the heater, while induction heating was evaluated by electromagnetic field simulations. Experiments showed there were differences in convective flow [18]. When heating was just begun. A material (CFD) simulation of a 2 m × 1.5 m PTC which used a coaxial membrane to seal the reflector's optical properties and its glass enclosure against the environmental hardness was presented in a study. The qualification of this model is established by the analysis of the simulation and computational results. The investigation was involved into the effects of PTC duration, water mass flow, and the solar angular tracking pattern on the water exit temperature, which led to optimization of the PTC dimension, mass flow rate and thermal performance to tap potential PTC applications in industry and residential areas. The objective of the study was to develop an improved heat insulation and thermal efficiency especially in the thermoelectric power plants [19]. Energy storage is, in fact, a kind of storage when the energy is conserved at one time and used in the coming period. This study is directed at adding more storing time in a water tank in hot water by choosing the most suitable porous media and the most beneficial packing material. The topic is thermal energy storage methods and their applications by using solar water heating and solar air heating systems. The experiment came with a family of 5 people with the use of a solar heater with a 120-liter tank, 20 vacuum tubes and a porous media tank of 50 liters. During the experiments which were done without using the porous media and with different levels of porous media (150, 300, 450 mm), they were performed. The observed results revealed that the height of porous media that was added has a direct correlation with the time of availability of hot water above 20℃ in a day. With the first experiment consuming 256 liters of hot water, the second experiment followed with the highest consumption of 273 liters, the third experiment consumed 273 liters, the fourth experiment used 261 liters, while the highest savings was registered in the fifth experiment of 207 liters. The study highlights the importance of proper porous media and packed bed materials in enhancing the storage time of hot water. Energy storage is essential for the optimization of energy consumption in renewable systems such as solar water heating and solar air heating [20].

3. METHODOLOGY

Research on solar radiation dynamics is carried out to better understand renewable energy sources. A surface-to-surface solar radiation model is used to investigate the variations in solar radiation receipt caused by the solar collector angle. To create a 3D account, this model employs mathematical and Cartesian (x, y, and z). The framework mathematics are then connected by using COMSOL 5.6.

3.1 Governing equations

Continuity equation:

$$\nabla \cdot \vec{V} = 0 \cdot V = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \nabla \vec{V} = \frac{1}{\rho}\left(-\nabla P + \mu \nabla^2 \vec{V} + \rho \vec{g} \beta \left(T - T_{ref}\right)\right) + S_m \tag{2}$$

Energy equation:

$$\frac{\partial h_{sens}}{\partial t} + \frac{\partial h_{lat}}{\partial t} + \nabla \cdot \left(\vec{V} h_{sens}\right) = \nabla \cdot \left(\frac{k}{\rho c_p} \nabla h_{sens}\right) \tag{3}$$

The view factor (F_{ij}) is the equivalent as the fraction of radiation emitted by surface (i) that is intersected by others of surface (j). The geometry of the surfaces and orientations affect F_{ij}. The factor view equations, which depend on geometry and are derived from the given surface configuration, are taken into consideration when the calculations are executed. A Stefan-Boltzmann law governs the radiation of a point due to its temperature. It is given by the equation:

$$Q = \varepsilon \times \sigma \times A \times T^4 \tag{4}$$

where, Q is the radiation heat transfer rate, ε is the emissivity of the surface, σ is the Stefan-Boltzmann constant, A is the surface area, and T is the absolute temperature of the surface.

The net radiation heat transfer between two surfaces is calculated using the view factors and the Stefan-Boltzmann law. It can be expressed as:

$$Q_{net} = F_{ij}\left(\varepsilon_i \times \sigma \times Ai \times T_i{}^4 - \varepsilon_i \times \sigma \times A_i \times T_j^4\right) \tag{5}$$

Ai and A_i are the surfaces' surface areas, Q_{net} is the rate of net heat transfer, F_{ij} is the view factor from surface i to surface j, i and j are the surfaces' emissivities, and T_i and T_j are the respective surfaces' absolute temperatures.

To build up these equations and provide the essential parameters for surface-to-surface radiation simulations, COMSOL offers a user-friendly interface. In accordance with the aforementioned governing equations, COMSOL will automatically solve the radiation heat transfer issue after you have specified the geometry, material attributes, and boundary conditions for the surfaces.

3.2 Mesh generation

The data presented in Table 1 illustrates the exact size of the business that was utilized in the process of developing the solar heater. The need for these three-deck unstructured grids is caused by their capability for accuracy when modeling complex geometries. COMSOL mesh and model were built using solid geometry and with minimal help from single stage users at user interface level as in Figure 1. Therefore, in line with the ethics in research, the research used a total of 1542100 cells as observed in Figure 2.

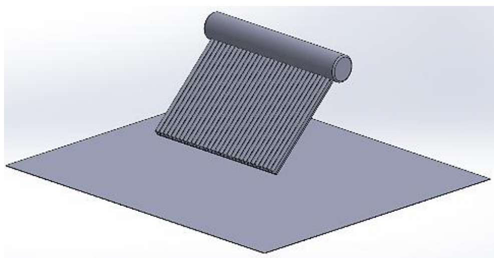


Figure 1. System geometry

Table 1. Specifications of vacuum tube [21]

Inner Tank	Imported food-grade stainless steel SUS304-2B, thickness: 0.5 mm^2				
Outer Tank	Coated steel of high grade, thickness:0.4 mm^3				
Vacuum Tube	Solar vacuum tube D58-L1800 mm with three targets				
Frame	Fine design, coated steel, thickness:1.2-1.5 mm				
Workmanship	Use an automated argon arc welding technology with high pressure capacity, super antisepsis capability in the welding junction, and no seeping indefinitely. Superinsulation capability is achieved with the use of an automated equipment foaming approach.				
Water Tank	Quantity	Tube Diameter	Length	Tank's capacity	Net weight
460 mm	30	58 mm	1.8 m	300 L	123.2 kg.s

So that the results are more reliable, the mesh size should be modified such that the details can be fully covered as more elements are added. Where the Table 2 has demonstrated the achieved stability of the output with the mesh size of 0.001 m, the procedure comes to an end as in Table 1.

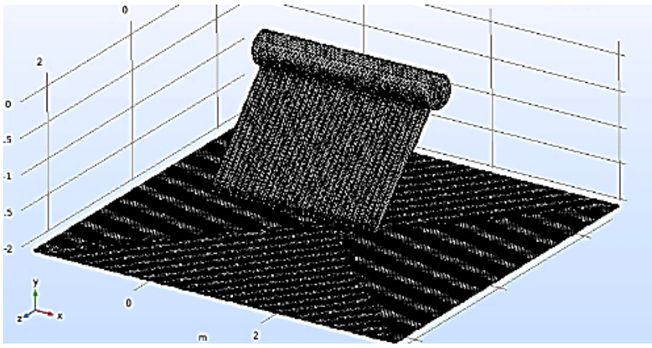


Figure 2. Mesh generated

Table 2. Mesh independency

Case	Element	Max. Temperature (°C)
1	735440	321.4
2	1094655	319.3
3	1367979	318.7
4	1542100	318.5

4. BOUNDARY CONDITIONS

Reflective mirrors were used behind the solar system to reflect a larger amount of the falling solar radiation with different dimensions from the solar collector tubes, where 5, 10 and 15 cm were taken. A material that absorbs incoming radiation was also used at the same distance from the solar collector. In order to estimate the quantity of solar radiation falling with great precision, the coordinates of the target location (Baghdad) as well as the year, month, day, and hour are determined. The solar heater material's and its layers' necessary attributes for thermal reflection are then established, and the projection altitude angle variation is set from 0 to 40 degrees by rotate the whole geometry for comparison between angles and from 5 in the morning to 5 in the evening, with a one-hour difference for each reading. The difference in the distance between the tube and the reflective surface helps in the different reflection angles for the solar radiation beams to be distributed over the tubes.

5. RESULTS AND DISCUSSION

In this section, the results will be reviewed and discussed regarding the placement of mirrors and reflectors behind the solar collector and the effect of their distance.

5.1 Effect of mirror distance on temperature and solar radiation

The distance between the mirrors in a solar vacuum water heater system may significantly affect the temperature and solar energy the device receives. The distance between the mirrors and the thermal energy receiver or solar water heater is termed as the diameter of the mirror. The action of reflecting sunlight through the close receiver from mirrors with the exact distance to it depends largely on the precision of its adjustment. The more concentrated solar beam could come about when the distance between reflectors becomes shorter, consequently intensifying the radiation at the receiving end. A decreased distance between the mirrors will help focus more sun light on the solar panel where it will be converted into electricity. Temperature of the water or heat transfer fluid inside the solar water heater may get hotter as a result of this improved concentration providing an additional heat effect. The light falling on the receiver comes from the change of distance between the mirror and the receiving surface. The solar heater of the water will be a more concentrated solar radiation when the mirrors are closer together and they are able to focus more light onto a small area. The phenomenon of higher water temperatures is attributed to the system's enhanced collection and conversion of solar radiation into heat because the length of the mirror distance has been reduced, the radiation being short and sharp. In order to control the reflecting surface, the outing of the focus distance will be an important factor as an over-focusing might result in overheating of the receiver and solar water heater components, eventually leading to burns. On the other hand, a number of components, including the mirror design, solar intensity, the type of receiver and the overall efficiency, will be determining factors of how much the solar radiation and the temperature will impact the system. A solar vacuum water heater also works in a close-cycle loop, where the heat carrying fluid moves back and forth between the receiver and a heat exchanger for transferring the solar warmth to water supply. The efficiency of the whole system, heat losses, and thermal management should be taken into account while designing and optimizing the mirror distance. Varied mirror lengths will have varied impacts on the concentration of solar radiation and the increase in temperature that results in the solar vacuum water heater. Computer simulations using software like COMSOL Multiphysics or other computational tools may assist examine these effects. These simulations may help determine the ideal mirror distance, which increases energy collection and efficiency while preserving the system's security and dependability.

Figure 3 shows the temperature gradient with time, as it noted that the temperature rises using reflectors at 1:00 pm at a distance of 5 cm, reaching 312 K, while at 10 and 15 cm it decreased by two degrees Celsius, and this gives an impression of the preference of the case in which the distance is 5 cm.

Figure 4 shows the temperatures on the solar collector and the reflector, it is noted that they increased at a distance of 5 cm compared to the remaining cases, as they reached 318 K.

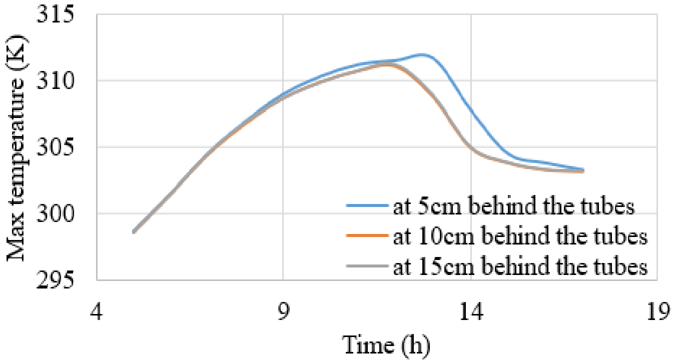
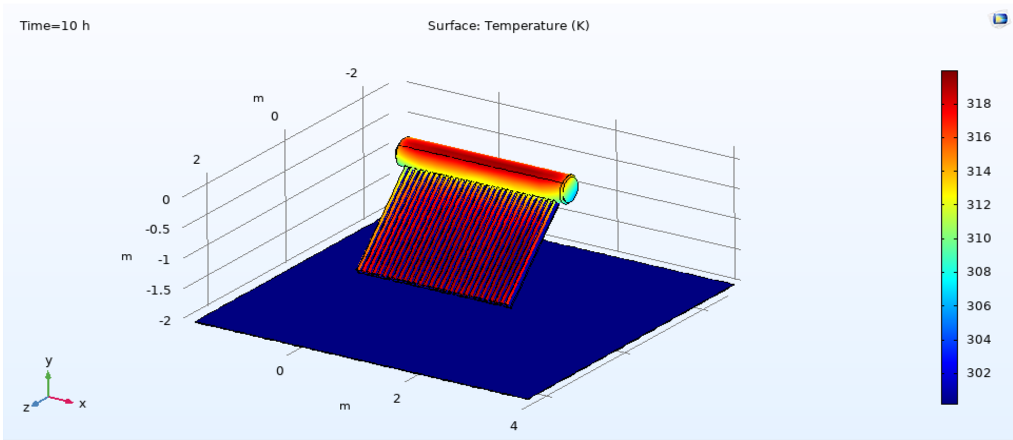


Figure 3. Temperature gradient by using reflector at different space



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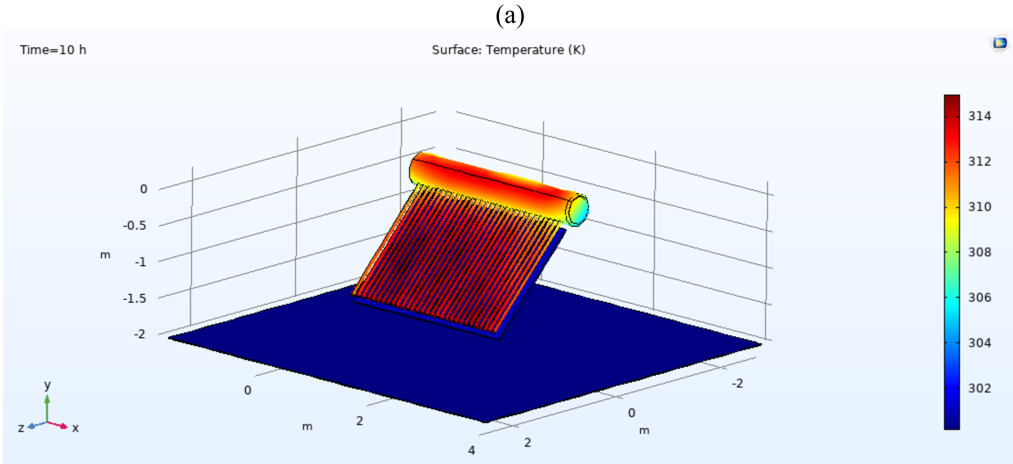

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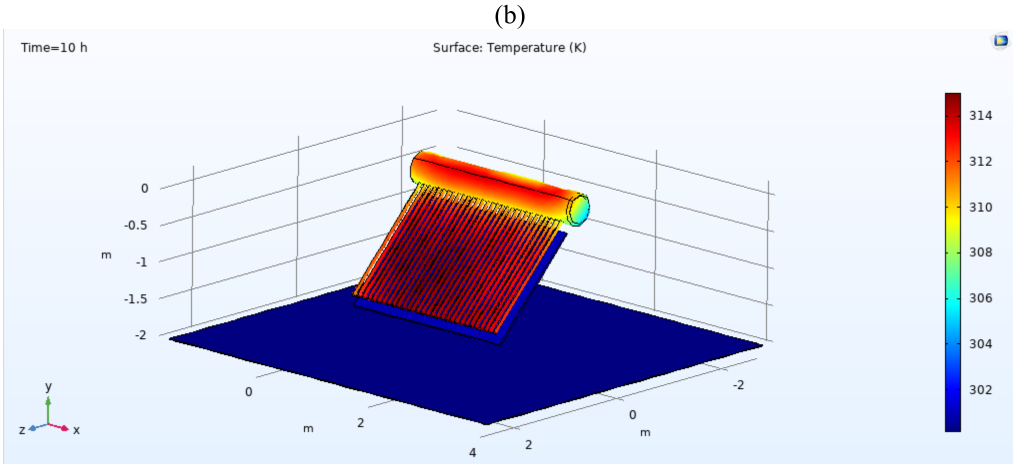


(c)

Figure 4. Temperature contour by using reflector at different space

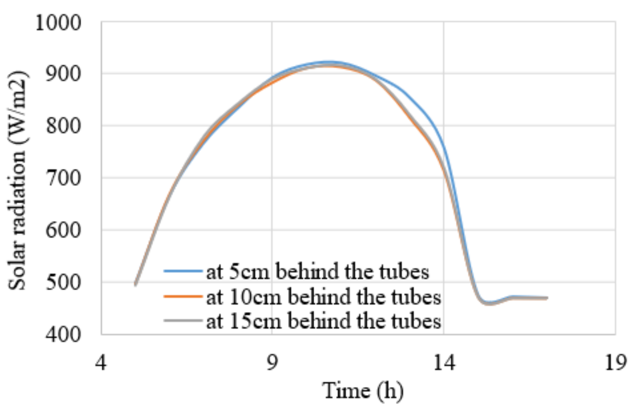


Figure 5. Solar radiation gradient by using reflector at different space

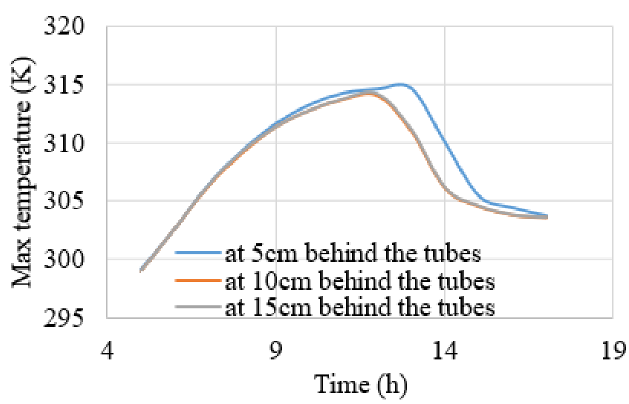


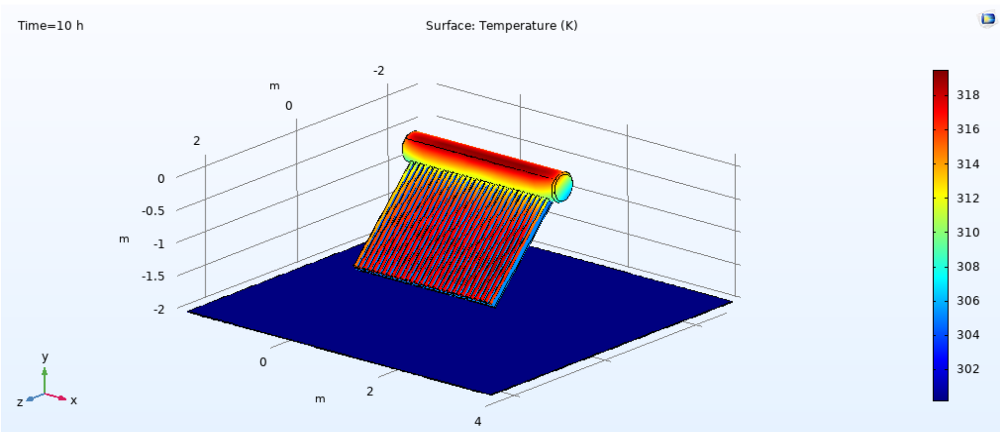
Figure 6. Temperature gradient by using opacity wall at different space

The reason for the high temperatures in the solar collector as a result of placing a reflector behind the tubes is the reflection of the incident solar radiation, as Figure 5 shows the high solar radiation at a distance of 5 cm compared to the remaining cases.

5.2 Effect of opacity wall distance on temperature and solar radiation

The opacity wall distance is not a typical concept or word in solar water heating systems. A specific kind of solar water heating system called a solar vacuum water heater effectively warms water by absorbing solar energy via vacuum tubes. Due to the vacuum created within the tubes, which minimizes heat loss, the system may function well even in frigid climates. The primary elements influencing the temperature of the water in a solar vacuum water heater are the amount of solar radiation absorbed by the system and the efficiency of energy transfer to the water. The opacity wall distance refers to the distance between the vacuum tubes and the plate, which is where solar energy is absorbed. If this distance is too large, heat transfer to the water may be less effective. A smaller opacity wall distance may improve the performance of the solar vacuum water heater by reducing heat loss and optimizing heat transfer from the absorber surface to the water.

Figure 6 depicts the temperature gradient over time. It can be seen that at 1:00 pm, the temperature rises using the dimming wall at a distance of 5 cm, reaching 315 K, whereas at distances of 10 and 15 cm, it decreases by 2 degrees Celsius, giving the impression that the case at 5 cm is preferred.
Regarding Figure 7, which depicts the temperatures on the blackout wall and the solar collector, it should be observed that these temperatures rose over a distance of 5 cm in comparison to the other examples, reaching 317 K.



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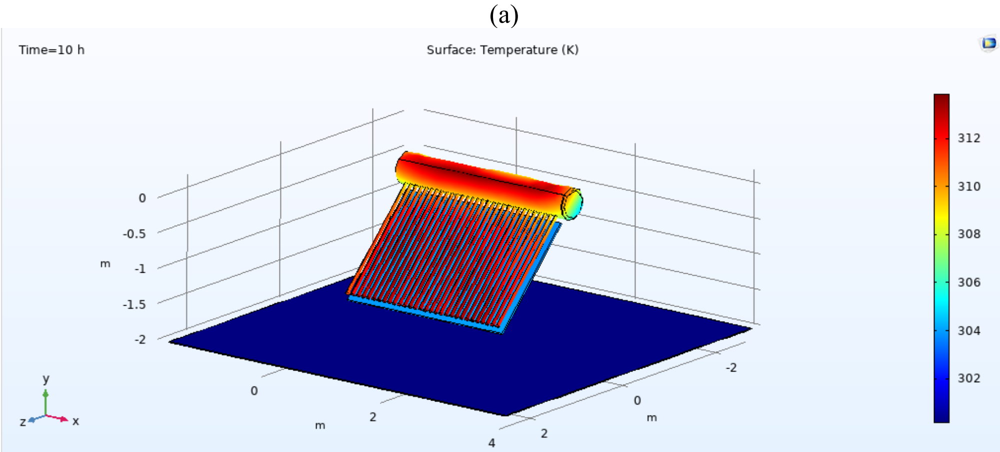

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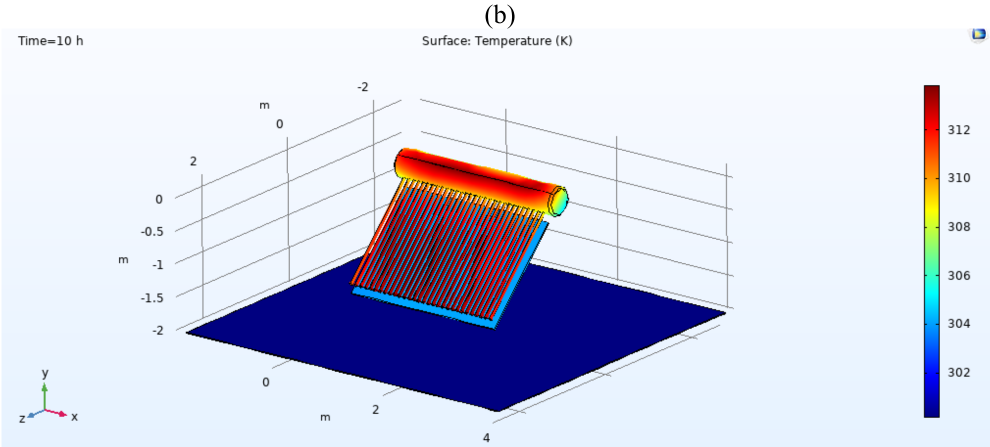

(c)

Figure 7. Temperature contour by using opacity wall at different space

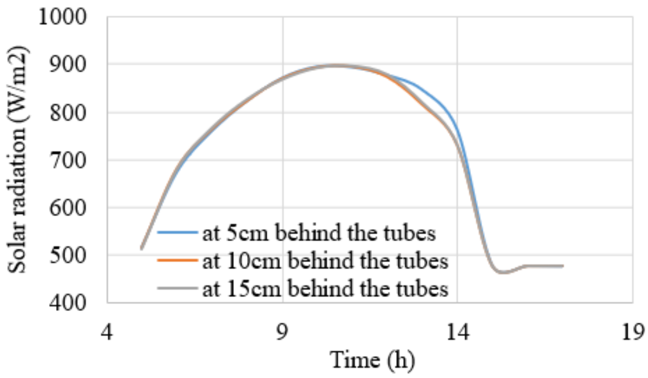

Figure 8. Solar radiation gradient by using opacity wall at different space

As shown in Figure 8, where the solar radiation rises at a distance of 5 cm in comparison to the other situations, the blackout wall absorbs the incoming solar radiation, which leads to the high temperatures in the solar collector as a consequence of positioning it behind the tubes.

5.3 Effect of altitude angles on temperature and solar radiation

The angle between the horizon and the sun in the sky is referred to as the altitude angle, also known as the solar elevation angle or solar altitude. It is a crucial factor that impacts how much solar radiation a solar vacuum water heating system receives, which in turn affects the temperature and efficiency of the system. The amount of solar energy a solar vacuum water heater receives is influenced by the angle at which the sun's rays hit the surface of the collector. Solar radiation is strongest and gives the system the most energy when the sun is directly above (at an altitude angle of 90 degrees). Less direct solar radiation results in less energy being absorbed by the solar collector when the altitude angle lowers (the sun advances towards the horizon). Localities close to the equator see more constant and plentiful solar radiation since the height angle there is relatively high throughout the whole year. The altitude angle changes with the seasons in areas further from the equator. Since the sun's rays are at a lower altitude in the winter, there will be less solar radiation and maybe less efficiency from the solar vacuum water heater. The quantity of solar radiation absorbed by the system and the effectiveness of energy transmission to the water both have an impact on the temperature of the solar vacuum water heater. As was already noted, the relationship between solar radiation intensity and sun angle at altitude is straightforward. More direct and concentrated solar radiation is produced at higher altitude angles (nearer to 90 degrees), which causes the water in the solar vacuum system to heat up more quickly. As a consequence of less direct solar radiation and lower temperatures, lower altitude angles (closer to the horizon) result in lower altitudes and lower altitude angles. The ultimate temperature of the water in the solar vacuum water heater is also influenced by other elements, including ambient temperature, wind speed, and system efficiency. Overall, the quantity of solar energy received and, subsequently, the temperature of the water in a solar vacuum water heating system are significantly influenced by altitude angles. A more effective and efficient solar water heating solution may be achieved by being aware of these impacts and taking them into consideration during system design and installation.

It can be seen from Figure 9 that the blackout wall is better compared to the obstruction wall, due to its absorption of the incident solar radiation and converting it into heat, where the temperature reached 315 K. As for the angle of altitude, the angle of 0 was better compared to the angle of 40 degrees.

As for Figure 10, it is known that the reflector works to reflect the solar radiation through the tubes, and thus we notice the higher solar radiation when the reflector is present compared to the presence of the blackout wall. In addition, the angle of 0 is better compared to the angle of 40 degrees.

5.4 Validation with previous research

The use of gene expression programming to replicate the evacuated tube solar collector (ETSC) (GEP) is discussed by Sadeghi et al. [22]. Computing fluid dynamics (CFD) was used to estimate the ETSC for different thermal storage tank contents (10–50 Lit) under a variety of solar radiation intensities. To choose the mathematical model (expression) that was the most precise and to more accurately predict how well the system would function, a trial-and-error approach was adopted. The GEP model was trained and tested using the numerical data. Whereas the simulation utilized to compare the two works was carried out using the same constraints as the research and engineering programs, the findings showed that the percentage of convergence of the outcomes did not surpass 1% as shown in Figures 11 and 12.

One potential limitation of our study is not adding details of the flow related to the laws of momentum because it requires complex solvers and large computers. Future research could explore adding details to the flow rates, quantities, and momentum equations.

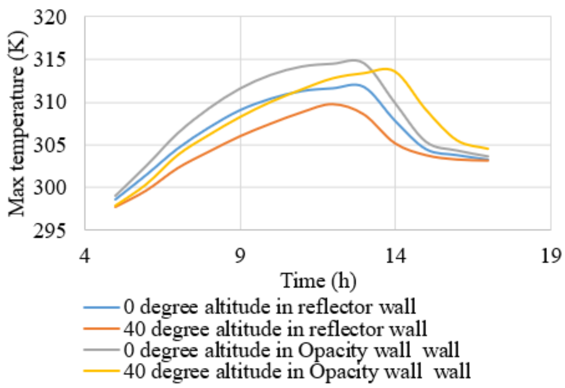

Figure 9. Temperature gradient by using opacity wall and reflector wall at different altitude angles

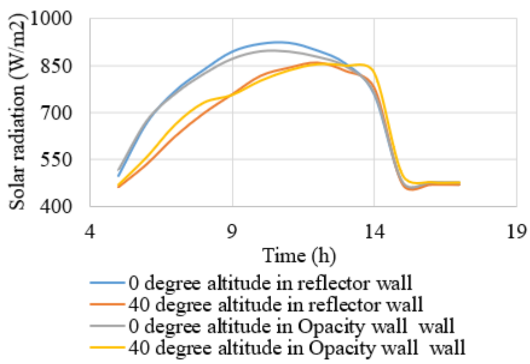

Figure 10. Solar radiation gradient by using opacity wall and reflector wall at different altitude angles

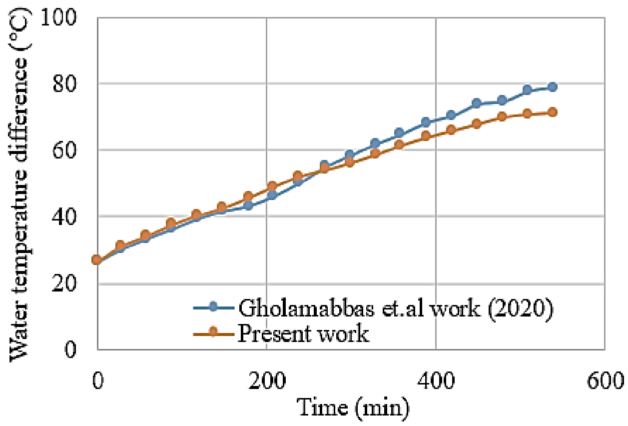

Figure 11. The water temperature difference comparison of the numerical and the previous studies

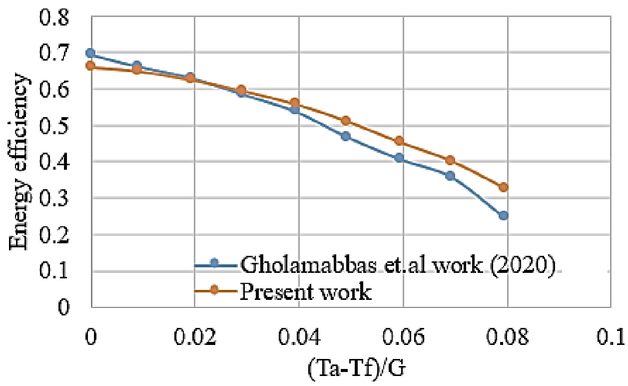

Figure 12. The comparison of the energy efficiencies of the numerical and the previous studies

6. CONCLUSIONS

The results are summarized as follows:

(1) The temperature gradient shows a preference for reflectors at a distance of 5 cm, reaching 312 K at 1:00 pm. The temperature on the solar collector and reflector increased at a distance of 5 cm, reaching 318 K. This is due to the reflection of incident solar radiation, which is higher at a distance of 5 cm compared to the remaining cases. This may be because the smaller the distance between the reflector and the tube, the greater the effect of reflecting solar rays.

(2) The temperature gradient shows a preference for the 5 cm distance between the opacity wall and the solar collector at 1:00 pm. The temperature rises at 1:00 pm, reaching 315 K, while at distances 10 and 15 cm, it decreases by 2 degrees Celsius. The opacity wall absorbs incoming solar radiation, resulting in high temperatures in the solar collector due to positioning behind tubes.

(3) The opacity wall absorbs solar radiation better than the obstruction wall, converting it into heat at a temperature of 315 K. The altitude angle of 0 is better than 40 degrees, as the reflector reflects the radiation through tubes, resulting in higher solar radiation. The reflector's presence also improves the angle of 0 compared to 40 degrees.

Most solar collectors have a low efficiency value that does not reach the required level. The originality of the research paper lies in solving this problem, obtaining the greatest amount of benefit from the solar collectors, and increasing their efficiency.

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