International Journal of Energy Production and Management
Vol. 9, No. 1, March, 2024, pp. 57-64
Journal homepage: http://iieta.org/journals/ijepm

Optimizing Tilt Angle for Thermal Efficiency of Vacuum Tube Solar Collectors

Safaa Mohemmed Ali Mohemmed Reda[1], Mohammed A. Mahmood Hussein[2*], Jinan Mahdi Hadi[3], Hasan A Al-Asadi[4], Karrar A. Hammoodi[4], Sadoon K. Ayed[3], Hasan Shakir Majdi[5]

[1] Department of Mechanical Engineering, College of Engineering, University of Kerbala, Karbala 56001, Iraq
[2] Department of Refrigeration and Air Conditioning Engineering, Al-Rafidain University Collage, Baghdad 10066, Iraq
[3] Mechanical Engineering Department, University of Technology-Iraq, Baghdad 10066, Iraq
[4] Department of Air Conditioning and Refrigeration, Faculty of Engineering, University of Warith Al-Anbiyaa, Karbala 56001, Iraq
[5] Department of Chemical Engineering and Petroleum Industries, Al-Mustaqbal University College, 51001 Hillah, Iraq

Corresponding Author Email: Mohamed.ali71@ruc.edu.iq

https://doi.org/10.18280/ijepm.090107

Received: 20 December 2023
Revised: 2 March 2024
Accepted: 20 March 2024
Available online: 31 March 2024

Keywords:
vacuum tube solar collectors (VTSCs), altitude angle, optimal tilt angle, solar radiation, system performance, energy efficiency

ABSTRACT

The ideal altitude angle for evacuated tube solar collectors, taking into account factors such as solar radiation availability, geographical location, seasonal variations, and collector tilt, is taken into account in this comparative analysis. This study focuses on obtaining the best thermal energy that can be obtained from the falling sunlight to increase the thermal efficiency of the solar collector. This model uses a Cartesian direction model (x, y, and z) and mathematical ordering methods to generate a 3D model. COMSOL 5.6 is then utilized to link the framework with mathematics and simulate the case. Solar radiation increases from March to June, peaking from 5-6 a.m. to 18-19 p.m. during the summer. The highest solar evaluation and azimuth occurred at 12 hV in the south direction. Temperature has a major impact on the performance of water heaters and vacuum tube solar collectors. The specific tilt angle analyzed is 40 degrees. The location where the analysis was done is Baghdad. The optimal tilt angle was found at 25° at the start of the day and reached 40° at 12 p.m. The best case was reached when the angle was 40 degrees. The magnitude of efficiency improvements was seen; the value of efficiency reached 78% compared to other cases. Where the difference is between it and the angle of 0 degrees altitude, at which the efficiency rate reached 64%, the amount of improvement is 14%.

1. INTRODUCTION

Experimental and theoretical research are conducted to determine the total heat loss coefficient (U-value) of a vacuum tube solar collector in relation to the pressure of the residual gas within the evacuated glass envelope. The majority of the analyzed collector tubes had greater total heat loss coefficients than anticipated, consistent with the presence of a significant quantity of gas [1]. The review article discusses experiments using computational fluid dynamics (CFD) to demonstrate the effectiveness of evacuated thermal solar collectors (ETSCs), nanofluids as heat transfer fluids, reflectors, and methods for decreasing heat losses on ETSC performance [2]. This work proposes a crossover computational method to foresee the warm behavior of intensity pipe-emptied tube sun-oriented gatherers over the course of constant activity [3]. Using phase change material (PCM) increases input nuclear power by 1.72 percent and 5.12 percent, respectively, for wind current paces of 0.025 and 0.05 kg/s, with the highest complete drying proficiency [4]. Sun-oriented energy should be used as a sustainable power source due to rising ozone-harming substances. HPETC was demonstrated using CFD and field-testing information [5]. CFD research assessed five design iterations of a novel manifold header to verify its viability and choose the best design components [6]. Nano-liquids improved heat transmission in ETSCs, with Cu-Water nano-liquid having the best warm recuperation. To improve energy change, ETSC's warm exhibition must be improved [7]. Gene expression programming was used to model the ETSC for various thermal storage tank volumes under a range of solar radiation intensities, resulting in a maximum energy efficiency of 72% [8]. At low volumetric flow rates, the emptied tube gatherer beats the flat plate solar collector (FPC) regarding warm execution, while at high volumetric flow rates, the FPC produces more absolute entropy [9]. This work proposes a new plan for an even tank used to store boiling water. CFD reproductions showed that when the quantity of intensity pipes increased, the level tank's normal temperature increased. The flat stockpiling tank's releasing viability was affected by the water's temperature [10]. This paper presents the enhancement of an emptied tube solar-powered gatherer with low-temperature water in glass using a computational liquid elements model and a re-enacted toughening method. Results showed that the mass flow rate, safeguard region, and cylinder width significantly affected warm execution [11]. This study recreated the development of intensity in two parts of sun-powered water warming frameworks, including the flat warm stockpiling tank and the flow pipe. Parametric examinations of the intensity lines' shape were completed, and rectangular intensity pipes were the most efficient. Water information and exit should be arranged at the base and top of the course pipe [12]. The sun-powered gatherer's effectiveness increases when the liquid flow rate is raised, and the filled-type emptied tube with graphite delivers the best outcomes [13]. CFD was used to estimate the water temperature at the sun-oriented gatherer complex's outlet, with the Boussinesq Approximation (BA) model being more accurate than the variation of the properties with temperature (VPT) model [14]. Powerful cycles have been created to secure the behavior of a warm sunlight-based gatherer without expensive exploratory examinations, and CFD has been used to focus on heat transport issues [15]. A CFD-based strategy can be used to assess strain misfortunes for parting and joining liquid flow across tee intersections [16]. Research is being conducted to assess solar water heating using evacuated tube solar collectors using CFD software [17]. Small adjustments can improve evacuated-tube solar collectors, but may not be worthwhile from an economic perspective [18]. Study found correlation between natural circulation flow rate, solar input, tank temperature, collector tilt, tube aspect ratio [19]. Computational liquid elements showed that the gatherer with the briefest cylinder length had the greatest efficiency, and the stream structures were unaffected by the delta stream rate [20]. Computational fluid dynamics investigation of heat transfer and flow structures in glass evacuated tubular collectors under various operating conditions found that the collector with the shortest tube length achieved highest efficiency [21].

This study explores the relationship between the angle of the solar collector and the thermal efficiency of integrated-pressure solar water heaters. Researchers aim to identify the optimum angle for optimal solar radiation absorption, considering installation site latitude and seasonal sun path variations. This understanding can help optimize solar energy system design, increase energy savings, and reduce greenhouse gas emissions. This study addresses the limitations of knowing the optimal use to increase the efficiency of the solar heater using different angles. The main originality lies in the possibility of simulating the model completely, because most research takes a specific part of the solar collector and simulates it, not all of it.

2. METHODOLOGY

Solar radiation dynamics research is conducted to expand knowledge of renewable energies. To explore the differences in solar radiation reception from the angles of solar collectors, a surface-to-surface solar radiation model is used. This model uses a Cartesian direction model (x, y, and z) and mathematical ordering methods to generate a 3D model. COMSOL 5.6 is then utilized to link the framework mathematics and replicate a single case. The creation and improvement of vacuum tube solar collectors (VTSCs) rely heavily on the potent and adaptable simulation software program COMSOL Multiphysics. Innovative solar thermal technologies known as VTSCs are created to effectively capture and harness solar energy for a variety of uses, such as space heating, water heating, and electricity generation. For engineers, researchers, and designers working in the fields of renewable energy and sustainable technologies, COMSOL is an essential tool.

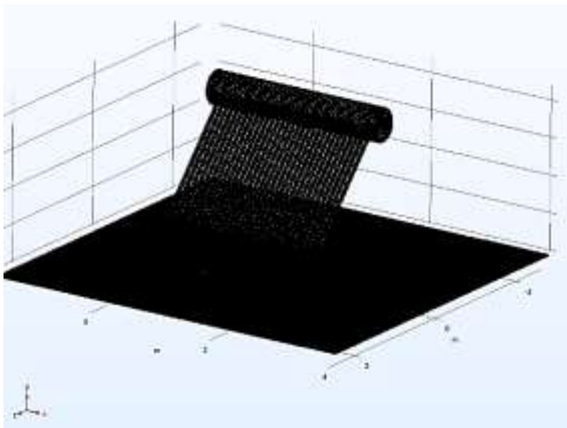
2.1 Mesh generation

The solar heater was designed according to the actual dimensions of the company, as these details can be seen in Table 1. The unstructured three-deck grids were chosen because they work well with complex geometries. COMSOL was used to generate a solid geometry mesh and 3D model with minimal input from a single user stage. A total of 863925 cells were used in this study (see Figures 1 and 2).

Figure 1. System geometry

Table 1. Specifications of vacuum tube [22]

Inner Tank	Imported SUS304-2B food-level stainless-steel, thickness: 0.5 mm^2				
Outer Tank	High quality coated steel, thickness:0.4 mm^3				
Vacuum Tube	Three targets solar vacuum tube D58-L1800 mm				
Frame	Coated steel, fine designing, thickness: 1.2-1.5 mm				
Workmanship	Use automatic argon arc welding technique; good pressure capability; super antisepsis capability in welding joint; no seeping forever. Using automatic machinery foaming technique, superinsulation capability.				
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



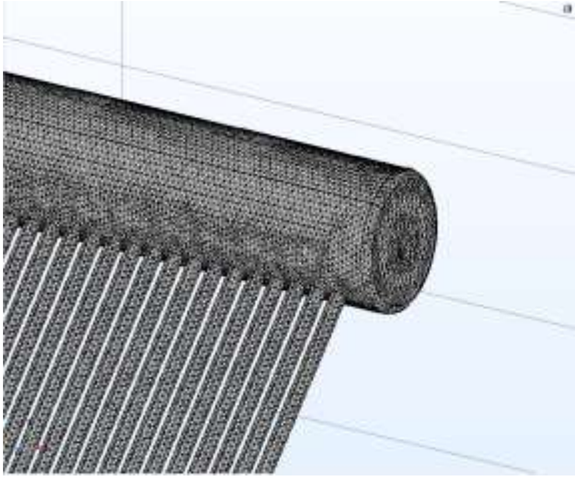


Figure 2. Mesh generated

For reliable results, the mesh size should be adjusted to observe the change in output when increasing the number of elements. The process stops when the output result is stable at a constant number with a mesh size of 0.005 m (see Table 2 and Figure 3) and an error of 2.56%. The element type was a tetrahedron extreme fineness.

Table 2. Mesh independency

Case	Element	Max. Temperature(ºC)	Error(%)
1	513219	44.6	-
2	613440	41.5	6.95
3	724579	39.0	6.02
4	863925	38.9	2.56

COMSOL Multiphysics 5.6 was the powerful software utilized to simulate and find the solutions to the complicated governing equations dealing with the heat transfer processes and fluid dynamics that occurred within the vacuum tube solar collector system. Unlike the theoretical equations, this research discusses the practical use of COMSOL as a tool for optimization of rotation angles, which leads to better thermal performance. Vacuum tube solar collector design could be assessed and optimized through a systematic exploration of design parameters, a process that helped in obtaining a better understanding of the operation of vacuum tubes. COMSOL Multiphysics 5.6 is a tool effective when optimizing the tilt angle for vacuum tube solar collectors to provide the highest thermal efficiency. Through the employing of the computational simulations, it achieved the tilt angle that yielded the greatest energy capture and an improvement in the system performance. This research fits into the ongoing avenue for solar thermal energy, helping the development of environmentally sound solutions.

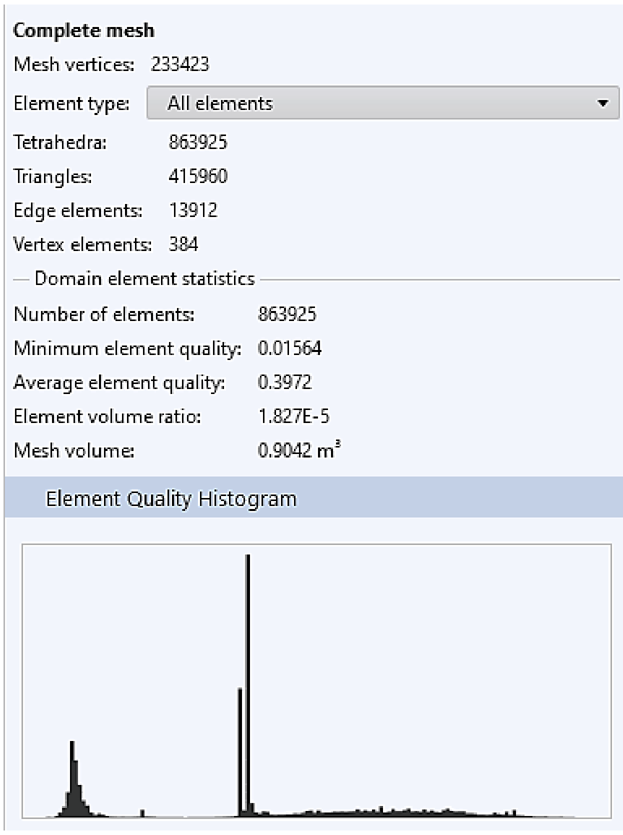


Figure 3. Mesh quality

2.2 Boundary conditions

Here, the coordinates of the target region (e.g., Baghdad), year, month, day, and hour are determined to obtain the amount of solar radiation falling with high accuracy. From figures 4 and 5, the solar location is defined by coordinates at latitude (+ to N) 33.333º and longitude (+ to E) 44.433º. The solar radiation was 1000 W/m^2 at 8:00 a.m. on July 15, 2021. The heat transfer coefficient was (h = 20) W/m^2, and the outside temperature was 20ºC. The spectral band for solar was [0, 0.25] µm and for ambient was (2.5 µm, +∞). The fractional emissive power was blackbody/graybody.

Vacuum-tubed solar collector limits are extremely important to their thermal efficacy. Conditions include the solar intensity, its direction, and the surrounding ambient temperature. The proximity of the solar panels to lines and elevation factors leads to changes in the intensity and angle of solar radiation. The ambient temperature surrounding the environment is another concept that could increase the heat losses. As the temperature rises, the heat losses also increase. This characteristic determines the ability of the collector tubes to achieve heat exchange and transfer to the working fluid. The physical specifications of the collector tube and its effect on thermal operation are linked. Knowledge of these factors gives way to the renovation of more sustainable and efficient methods that lead to enhanced performance.

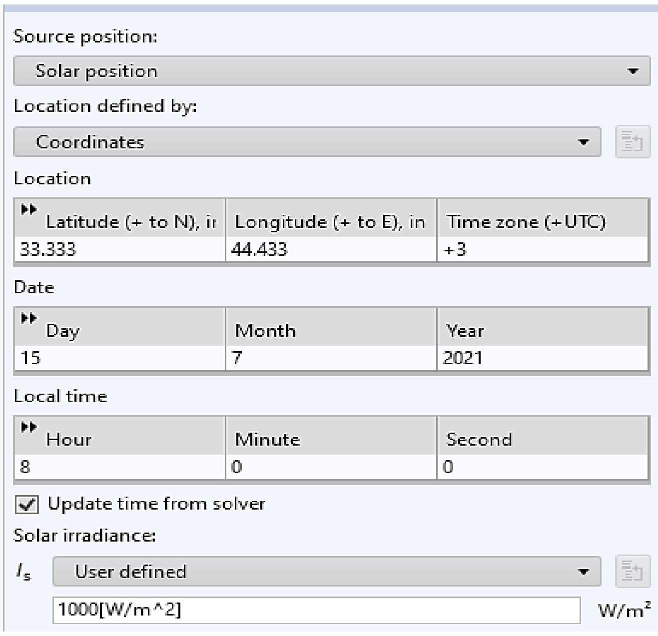
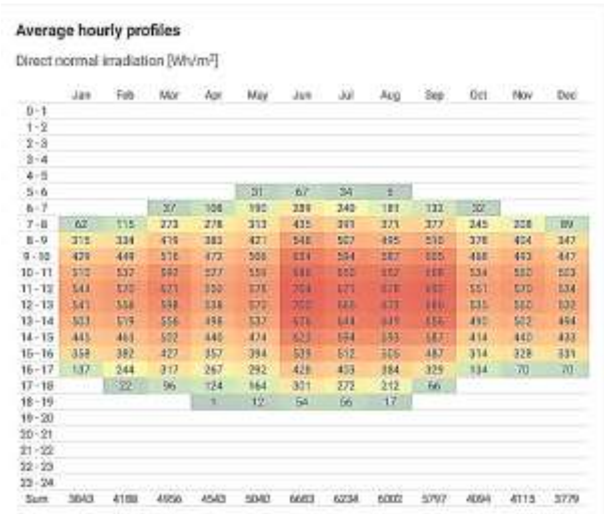


Figure 4. Location

Then the required properties for thermal reflection of the solar heater material and its layers are determined, and the projection altitude angle variation is set from 0 to 90 degrees and from 5 in the morning until 5 in the evening, with an hour difference for each reading. The exact conditions were imposed on different surfaces/domains in the surface-to-surface S2S model.

2.3 Average hourly solar radiations and sun path

Figure 6 shows the average solar radiation and its effect on the radiation rate throughout the day for the three cities. In general, solar radiation increases from March to June, peaking from 5–6 a.m. to 18–19 p.m. during the summer. The highest solar evaluation and azimuth occurred at 12 H in the south direction.



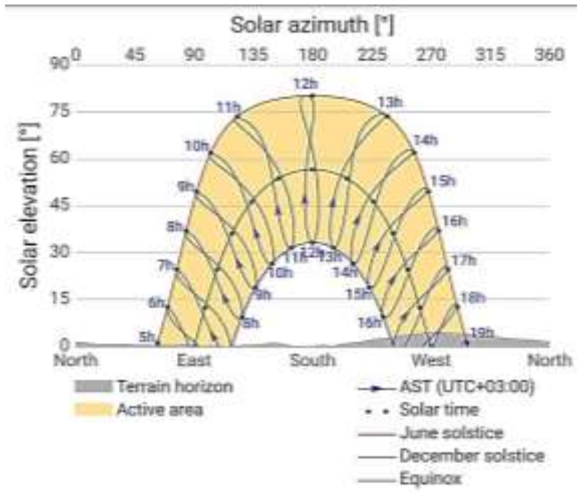


Figure 5. Total sun radiation chart and sun path for Baghdad city

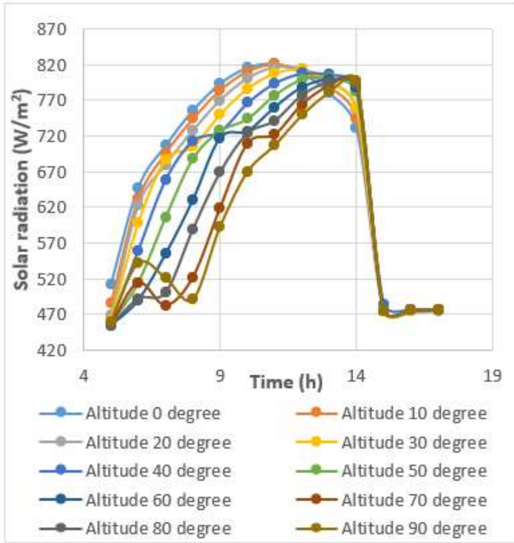


Figure 6. Solar radiation chart with time at different altitude angles for Baghdad city

3. RESULTS AND DISCUSSION

The test involved numerical work with angles of 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, and 90° from 5 a.m. to 6 p.m. The sun uses altitudes X and Z to measure solar radiation and temperature.

3.1 Solar radiation

Iraq's high solar radiation throughout the year makes it suitable for solar heater operation. Results indicate that solar radiation is directly proportional, with higher radiation leading to an increase in temperature. This increased, so the cell should be cooled to maintain optimal efficiency.

The altitude angle of a vacuum tube solar collector is the tilt angle at which the collector is installed relative to the horizontal plane. It affects how solar radiation interacts with the collector's surface, affecting its performance. When tilted at an optimal altitude angle, the collector maximizes direct sunlight absorption, enhancing energy absorption and system efficiency. The incidence angle of solar radiation is also affected, with a steep angle reducing energy absorption and lowering efficiency. The collector's performance can be optimized throughout the year by adjusting the tilt angle to match seasonal variations in the sun's position. Other factors like geographical location, local climate, tracking mechanisms, and collector design also play a role in determining the system's effectiveness and energy output.

In Baghdad (Figure 6), solar radiation starts at 444.49 W/m^2 at 5 a.m. and gradually increases until its highest value of 820 W/m^2 at 12 p.m. This is because the sun is perpendicular to the solar plane, which subsequently raises the temperature. Comparing the data, it is evident that the higher curve in the vertical direction is at 40 degrees and the higher curve in the horizontal direction is at 90 degrees, corresponding to the sun and solar directions.

3.2 Temperature effect

Water heater performance, with higher temperatures resulting in better performance ratios. Vacuum tube solar collectors also experience temperature effects, with different altitude angles affecting their performance. Higher temperatures increase heat loss from the collector, while steeper angles expose the collector to direct sunlight, resulting in increased heat loss. Higher temperatures generally lead to higher thermal efficiencies, but excessively high temperatures can result in thermal losses and reduced efficiency. Steeper altitude angles can also improve fluid drainage and maximize solar exposure, but they can also induce thermal stress on collector materials, necessitating appropriate design and material selection.

In Baghdad (Figure 7), temperatures were 25° at the start of the day and reached 40° at 12 p.m. The best case was reached when the angle was 40 degrees, and therefore to increase the concentration of incident radiation and increase the impact time compared to the remaining cases.

Figure 8 shows the axial movement of the sun and its effect on the opposite heat and radiation phenomena in the different regions of the water heater.

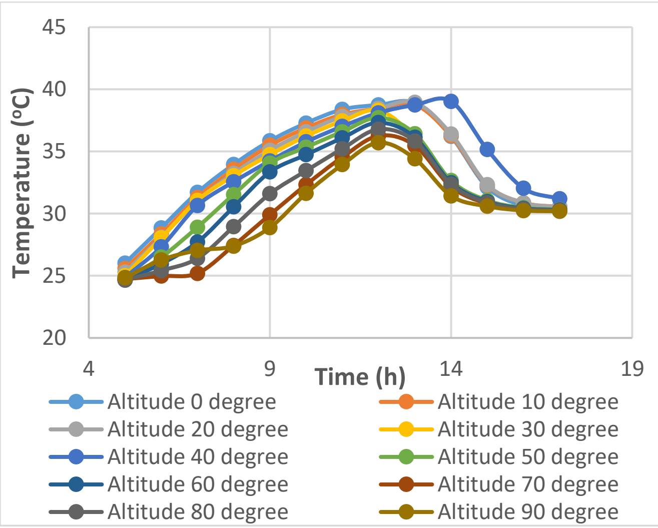
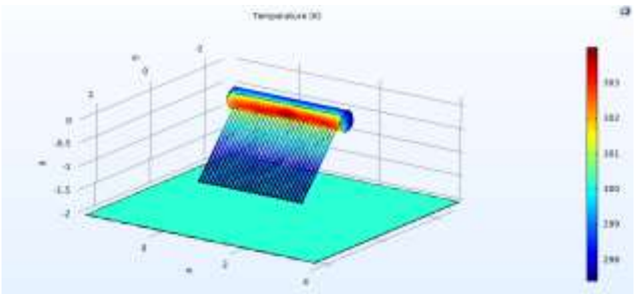
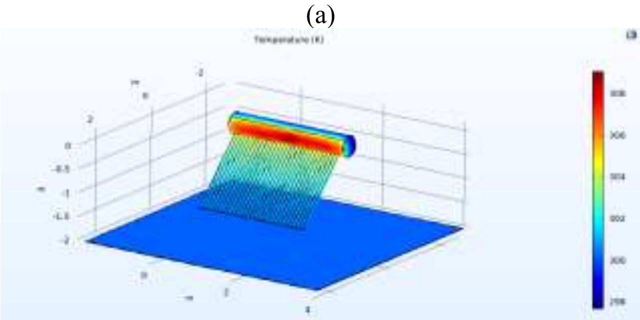


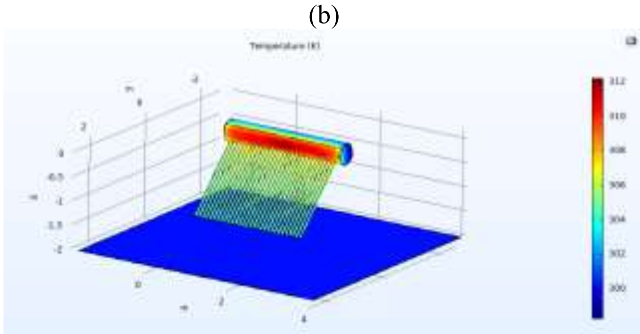
Figure 7. Temperature chart with time at different altitude angles for Baghdad city



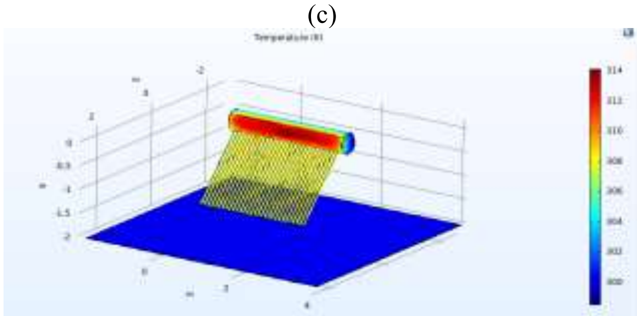
(a)



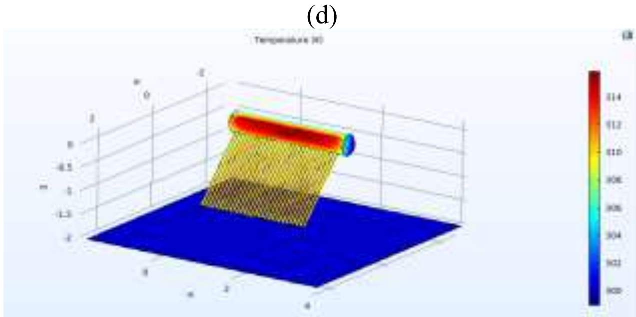
(b)



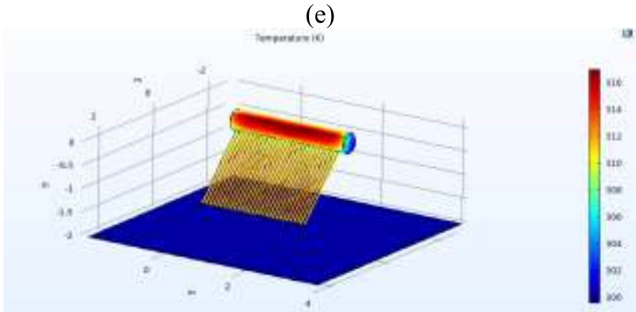
(c)



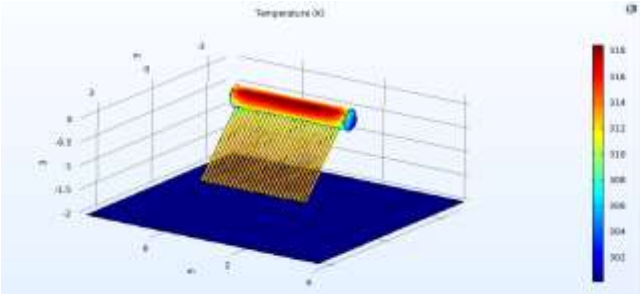
(d)



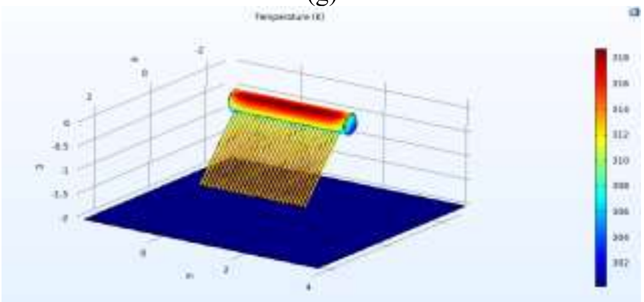
(e)



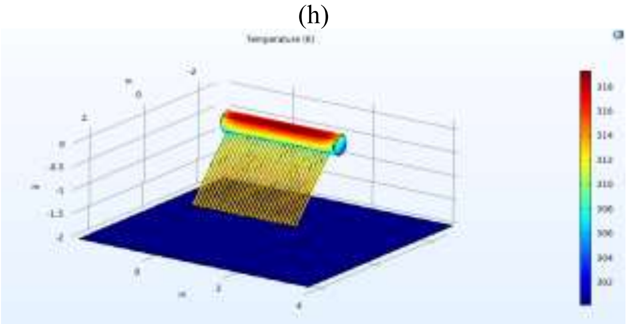
(f)



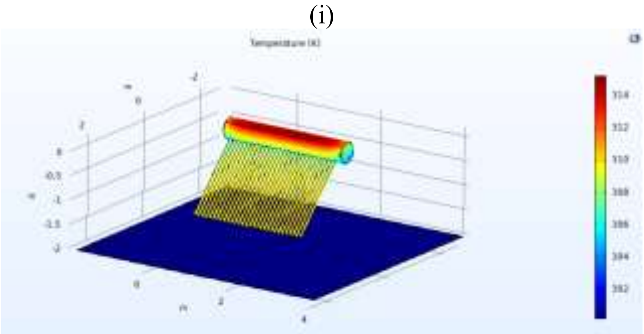
(g)



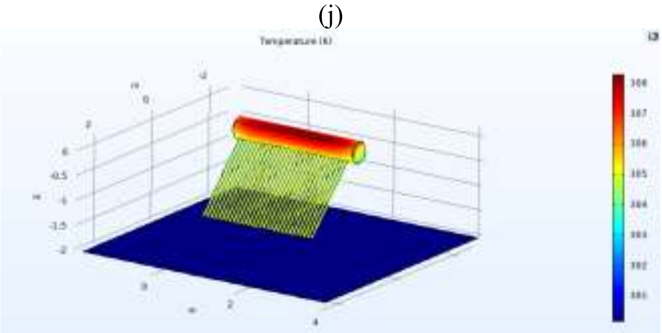
(h)



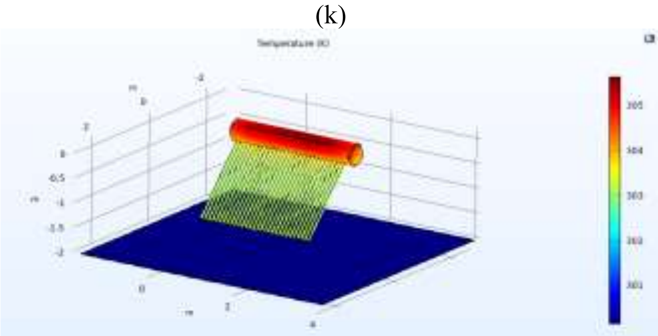
(i)



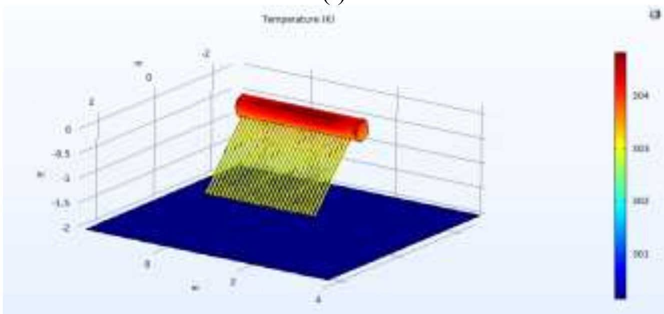
(j)



(k)



(l)



(m)

Figure 8. Temperature contours with time at 40 altitude angles for Baghdad city. (a) at 5 a.m., (b) at 6 a.m., (c) at 7 a.m., (d) at 8 a.m., (e) at 9 a.m., (f) at 10 a.m., (g) at 11 a.m., (h) at 12 a.m., (i) at 1 p.m., (j) at 2 p.m., (k) at 3 p.m., (l) at 4 p.m., (m) at 5 p.m

3.3 Thermal efficiency

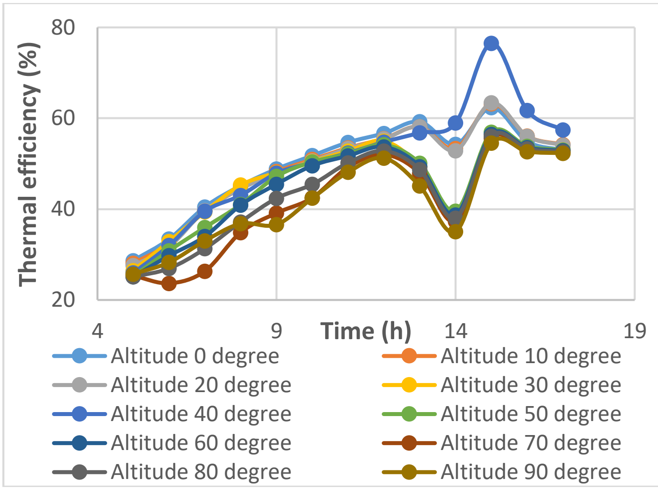


Figure 9. Thermal efficiency chart with time at different altitude angles for Baghdad city

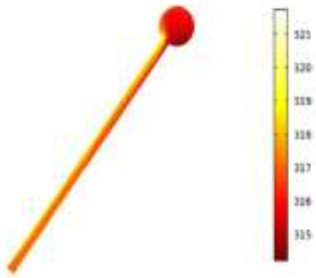
The altitude angle, also known as the tilt angle or inclination angle, is crucial for the thermal efficiency of a vacuum solar tube. It affects the angle at which solar radiation strikes the tube's surface, enhancing heat absorption and maximizing solar radiation capture. Adjusting the altitude angle based on latitude and the sun's position throughout the year can improve thermal efficiency. However, it is essential to avoid shading or obstructions that may reduce solar radiation capture. Other factors, like solar irradiance, collector design, insulation, fluid flow rate, and temperature differentials, affect the system's overall efficiency.

The results confirm through Figure 9 that the best case reached was at angle 40, where the value of efficiency reached 78% compared to the rest of the cases. The quantitative relationship seen between tilt angle and efficiency is direct to angle 40 and then inverse.

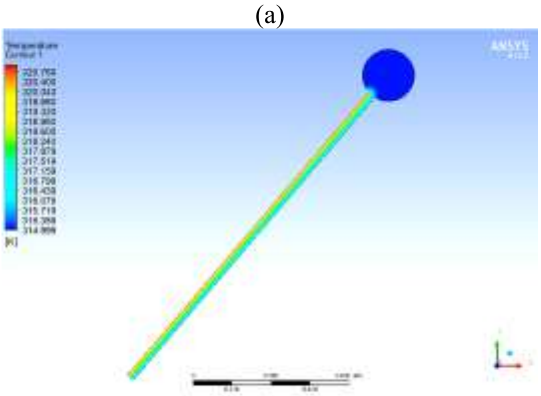
3.4 Validation with previous research

This Gholamabbas et al. (2020) [8] paper is a report on the use of gene expression programming to mimic the evacuated tube solar collector (ETSC) (GEP). The information was obtained by modeling the ETSC for various thermal storage tank volumes (10–50 liters) under a range of solar radiation intensities using computational fluid dynamics (CFD). A trial-and-error method was used to find the mathematical model (expression) that was the most accurate and to better forecast how well the system would work. The numerical data was used to test and train the GEP model. The process of comparison between the two works was done through simulation with engineering programs provided and with the same limits used in the research, and the results found that the percentage of convergence of the results did not exceed 1%.

It is evident from Figure 10 that the temperature value in the previous work reached 321 K as the maximum temperature, while in the current research it is 320.76 K, which is a small difference that can be relied upon. As for Figure 11, which represents the pressure values, the maximum pressure in the previous research reached 11600 Pa, while in the current work it reached 11520 Pa.

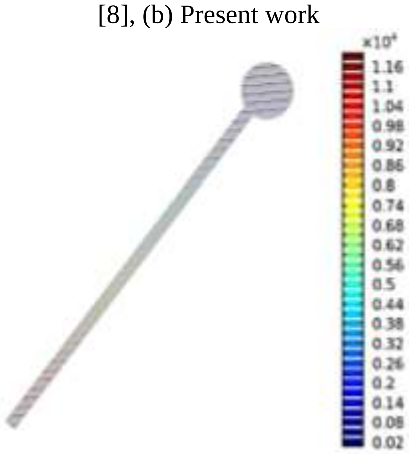


(a)

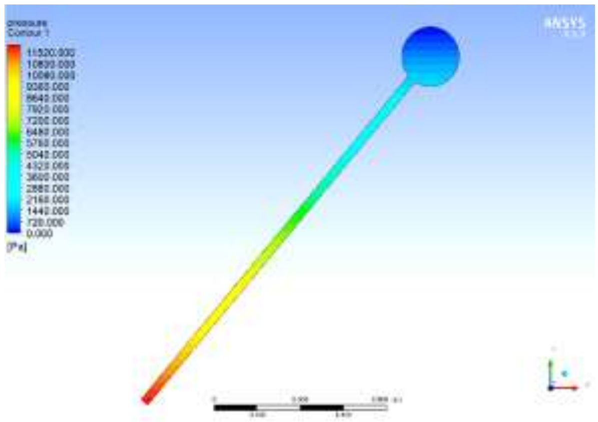


(b)

Figure 10. Temperature profile of the ETSC water heater with 26 Lit tank capacity. (a) Gholamabbas et.al work (2020) [8], (b) Present work



(a)



(b)

Figure 11. Pressure distribution of the working fluid (Pa) inside the ETSC. (a) Gholamabbas et.al work (2020) [8], (b) Present work

4. CONCLUSIONS

Iraq's high solar radiation throughout the year makes it suitable for solar heater operation. The altitude angle of a vacuum tube solar collector affects how solar radiation interacts with the collector's surface, which influences its performance. It affects the amount of direct sunlight absorbed by the collector, the incidence angle of solar radiation, and the potential for shadows and shading on the collector's surface. Adjusting the tilt angle to match the seasonal variation of the sun's position can optimize energy absorption. The optimal altitude angle for a vacuum tube solar collector is based on the latitude of the installation location. Other factors, such as geographical location, local climate, tracking mechanisms, and collector design, also play a role. The results obtained through the simulation process will be summarized as follows:

1. Solar radiation increases from March to June, peaking from 5–6 a.m. to 18–19 p.m. during the summer. The highest solar evaluation and azimuth occurred at 12 H in the south direction. Temperature has a major impact on the performance of water heaters and vacuum tube solar collectors. Solar radiation starts at 444.49 W/m^2 at 5 a.m. and gradually increases until its highest value of 820 W/m^2 at 12 p.m.
2. Higher temperatures can increase heat loss from the collector, while higher temperatures can lead to higher thermal efficiencies. Different altitude angles can affect the operating temperature range of the collector, particularly in regions with cold climates. Temperature changes can induce thermal stress on the materials used in the collector, such as glass and metals. The efficiency improvements reached 78%.
3. The best case was reached when the angle was 40 degrees, which increased the concentration of incident radiation and increased the impact time.

REFERENCES

[1] Badar, A.W., Buchholz, R., Ziegler, F. (2011). Experimental and theoretical evaluation of the overall heat loss coefficient of vacuum tubes of a solar collector. Solar Energy, 85(7): 1447-1456, https://doi.org/10.1016/j.solener.2011.04.001

[2] Du, B., Lund, P.D., Wang, J. (2021). Combining CFD

and artificial neural network techniques to predict the thermal performance of all-glass straight evacuated tube solar collector. Energy, 220: 119713. https://doi.org/10.1016/j.energy.2020.119713
[3] Aggarwal, S., Kumar, R., Kumar, S., Bhatnagar, M., Kumar, P. (2021). Computational fluid dynamics based analysis for optimization of various thermal enhancement techniques used in evacuated tubes solar collectors: A review. Materials today: Proceedings, 46: 8700-8707. https://doi.org/10.1016/j.matpr.2021.04.021
[4] A. Nokhosteen, S. Sobhansarbandi, Numerical modeling and experimental cross-validation of a solar thermal collector through an innovative hybrid CFD model. Renewable Energy, 172: 918-928. https://doi.org/10.1016/j.renene.2021.03.070
[5] Iranmanesh, M., Akhijahani, H.S., Jahromi, M.S.B. (2020). CFD modeling and evaluation the performance of a solar cabinet dryer equipped with evacuated tube solar collector and thermal storage system. Renewable Energy, 145: 1192-1213. https://doi.org/10.1016/j.renene.2019.06.038
[6] Pawar, V.R., Sobhansarbandi, S. (2020). CFD modeling of a thermal energy storage based heat pipe evacuated tube solar collector. Journal of Energy Storage, 30: 101528. https://doi.org/10.1016/j.est.2020.101528
[7] Beer, M., Rybár, R., Cehlár, M., Zhironkin, S., Sivák, P. (2020). Design and numerical study of the novel manifold header for the evacuated tube solar collector. Energies, 13(10): 2450. https://doi.org/10.3390/en13102450
[8] Yurddaş, A. (2020). Optimization and thermal performance of evacuated tube solar collector with various nanofluids. International Journal of Heat and Mass Transfer, 152: 119496. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119496
[9] Sadeghi, G., Najafzadeh, M., Safarzadeh, H. (2020). Utilizing gene-expression programming in modelling the thermal performance of evacuated tube solar collectors. Journal of Energy Storage, 30: 101546. https://doi.org/10.1016/j.est.2020.101546
[10] Ramírez-Minguela, J.J., Alfaro-Ayala, J.A., Rangel-Hernández, V.H., Uribe-Ramírez, A.R., Mendoza-Miranda, J.M., Pérez-García, V., Belman-Flores, J.M. (2018). Comparison of the thermo-hydraulic performance and the entropy generation rate for two types of low temperature solar collectors using CFD. Solar Energy, 166: 123-137. https://doi.org/10.1016/j.solener.2018.03.050
[11] Bouhal, T., Kousksou, T., Jamil, A., Benbassou, A. (2018). Experimental study and CFD thermal assessment of horizontal hot water storage tank integrating evacuated tube collectors with heat pipes. Solar Energy, 170: 234-251. https://doi.org/10.1016/j.solener.2018.05.062
[12] Alfaro-Ayala, J.A., López-Núñez, O.A., Gómez-Castro, F.I., Ramírez-Minguela, J.J., Uribe-Ramírez, A.R., Belman-Flores, J.M., Cano-Andrade, S. (2018). Optimization of a solar collector with evacuated tubes using the simulated annealing and computational fluid dynamics. Energy conversion and management, 166: 343-355. https://doi.org/10.1016/j.enconman.2018.04.039
[13] Bouhal, T., Agrouaz, Y., El Rhafiki, T., Zeraouli, Y., Jamil, A. (2018). Towards an energy efficiency optimization of solar horizontal storage tanks and circulation pipes integrating evacuated tube collectors through CFD parametric studies. Sustainable Energy Technologies and Assessments, 26: 93-104. https://doi.org/10.1016/j.seta.2017.10.004
[14] Farjallah, R., Chaabane, M., Mhiri, H., Bournot, P., Dhaouadi, H. (2016). Thermal performance of the U-tube solar collector using computational fluid dynamics simulation. Journal of Solar Energy Engineering, 138(6): 061008. https://doi.org/10.1115/1.4034517
[15] Alfaro-Ayala, J.A., Martínez-Rodríguez, G., Picón-Núñez, M., Uribe-Ramírez, A.R., Gallegos-Muñoz, A. (2015). Numerical study of a low temperature water-in-glass evacuated tube solar collector. Energy Conversion and Management, 94: 472-481. https://doi.org/10.1016/j.enconman.2015.01.091
[16] Tagliafico, L.A., Scarpa, F., De Rosa, M. (2014). Dynamic thermal models and CFD analysis for flat-plate thermal solar collectors–A review. Renewable and Sustainable Energy Reviews, 30: 526-537. https://doi.org/10.1016/j.rser.2013.10.023
[17] Badar, A.W., Buchholz, R., Lou, Y., Ziegler, F. (2012). CFD based analysis of flow distribution in a coaxial vacuum tube solar collector with laminar flow conditions. International Journal of Energy and Environmental Engineering, 3: 1-15. https://doi.org/10.1186/2251-6832-3-24
[18] Sato, A.I., Scalon, V.L., Padilha, A. (2012). Numerical analysis of a modified evacuated tubes solar collector. In International Conference on Renewable Energies and Power Quality, pp. 384-389. https://doi.org/10.24084/repqj10.322
[19] Hayek, M. (2009). Investigation of evacuated-tube solar collectors performance using computational fluid dynamics. In 2009 International Conference on Advances in Computational Tools for Engineering Applications, pp. 240-244.
[20] Budihardjo, I., Morrison, G.L., Behnia, M. (2007). Natural circulation flow through water-in-glass evacuated tube solar collectors. Solar Energy, 81(12): 1460-1472. https://doi.org/10.1016/j.solener.2007.03.002
[21] Shah, L.J., Furbo, S. (2007). Theoretical flow investigations of an all glass evacuated tubular collector. Solar Energy, 81(6): 822-828. https://doi.org/10.1016/j.solener.2006.09.007
[22] "Products." GetX, www.getx.ca/products/, accessed on 25 May 2023.