International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 08 – Issue 02 || February 2023 || PP. 162-171

Modeling of the charging process of an evacuated tube using CFD in the climatic conditions of Iraq

Yahya F. Taha[1], Abdul Jabbar N. Khalifa[1]
[1]*Department of Mechanical Engineering, Al-Nahrain University, Iraq*

Abstract: The influence of geometrical variables on the temperature of the ETSWH has not been completely examined, despite the fact that performance enhancement of ETSWH has garnered attention from a significant number of investigators. In this study, 3D commercial CFD modeling was used to examine the impact of the SWH tube's length, diameter, and tilt angle on temperature variation within the water tank. The CFD model's predictions were checked against weather data from Iraqi experiments. It was discovered that the temperature in the water tank was significantly affected by the length of the SWH tubes. It was discovered that the water tank temperature distribution was significantly affected by the SWH tube length. While comparing SWH tubes of different lengths, the longest (2200 mm) produced the maximum temperature. The average water temperature in the tank was found to be higher when using SWH tubes with a 54 mm diameter as a comparison to 40 mm or 47 mm. Tilt angles of 10, 45, and 60 degrees were used to assess the effect of tilt on temperature variation. Tilt angle 45 was found to have the highest average water temperature compared to the other tilt angles.
Keywords: evacuated tube, solar water heater, CFD, performance

I. INTRODUCTION

As the world's population rises, so does the need for energy, making it more difficult to meet both of these needs. Over the past 4 decades, scientists have studied methods of energy conservation in an effort to find more efficient uses for energy and new, sustainable energy sources. The fundamental goal of all recent studies in this field [1] has been to devise methods for efficiently and at scale to capture solar energy and put this limitless natural energy source to use for mankind. The majority of the gathered energy may be used to heat air or water, dry materials, warm rooms, and generate electricity [2]. Solar water heating, in particular, has been widely accepted and has seen fast commercialization in recent years. Although there are a variety of solar water heaters available, the evacuated tube collector type solar water heater (ETSWH) has quickly established itself as the go-to for most people, whether they're using it for a home or an industrial building. The evacuated tube for energy harvesting, water storage tank, pipe, and insulation, are the primary components of an ETSW. The design and changes used on ETSWH are mostly focused on enhancing thermal efficiency [3].The thermal performance of a household water solar collector was studied by Abdelhak et al. [4] using a numerical (3-D analysis, Fluent v6.3) examination of its dynamical operation mode. Specifically, the paper analyzes tank orientation (horizontal or vertical), flow rate, and thermal stratification that affect the charging and discharging modes of operation. The influence of tilted locations of flat plates put within vertical storage tanks on the development of thermal stratification was investigated by Bouhal et al. [5], who provided a CFD study to this effect. Results confirmed that the position of the plate inside the tank has a significant impact on the onset of thermal stratification. An experimental and theoretical examination of the thermal characteristics of solar storage was reported by Shah and Furbo [6]. Moreover, CFD tool was used to do an extended simulation utilizing three intake types and with varying intake flow rates to study thermodynamic efficiency. Levers and Lin [7] used the Fluent program to examine how tank shape (variable heights and aspect ratio) and operational circumstances affected thermal stratification inside a water tank. The outcome indicated that the tank with the greater aspect ratio was the superior performer. The performance boost seen after 3.5 was, however, minimal at best. After observing the results of varying the mass flow rate and inlet/outlet location, it became clear that the thermally stratified layers were more easily destroyed at higher mass flow rates. Hazami et al. [8] reported the findings of a year-round energy performance monitoring of a novel type of household solar water heating system (DSWH) based on an evacuated tube collector (ETC). Using the TRNSYS simulation tool, a full model was first created, taking into consideration various mechanisms of heat transfer in the DSWH. Experimental testing under local weather conditions was conducted over 6 days over a two-month period to verify the TRNSYS model. The ETC generated around 9% more energy than the FPC, according to the results. Sokhansefat et al. [9] investigated the thermos economics of two separate solar hot water systems based on two types of flat plate collectors (FPC) and evacuated tube collectors (ETC) in Iran's chilly environment. The TRNSYS16 program was used to determine the yearly solar collector energy output and the collectors' output temperature. As a consequence, the input temperature and weather conditions are discovered to be the two key factors that influence collector performance. Finally, according to the thermal and economic study, ETC systems perform 41 percent better than

FPC systems, and ETC's yearly usable energy gain in a cold environment is 30 percent more than FPC's. As a result, using ETC in a cold environment is a good idea. Yaoa et al. [10] used CFD to analyze and compare the performance of the all-glass evacuated tube solar water heater with twist tape inserts to normal ones. Numerical modeling was used to analyze the flow and heat transfer performance of evacuated tube solar water heaters with twist tape inserts at various beginning temperatures ranging from 273K to 313K.The purpose of this study is to look at the possibilities of improving the performance of an evacuated tube solar collector for water heating by adopting three different inclination angles, especially 10, 30, and 45 during Static mode. The static mode of operation occurs during daylight hours when the system warms up and no inflow or outflow from the tank occurs. Solar radiation strikes the evacuated tubes' surface, causing the system to heat up.

II. COMPUTATIONAL FLUID DYNAMICS

For the numerical simulations of ETSWH, ANSYS-Fluent 21's commercial CFD program is used.

1.1 Mesh Generation

ANSYS® Mesh Tools modeled the computational domain. This work discretizes the computational field into a finite number of control volumes using the unstructured mesh. Structured mesh is suitable for basic cases but inaccurate and laborious in complex geometries Saito et.al.[11]. ANSYS FLUENT Meshing was used to create the grid triangular mesh depicted in Fig. 1. As illustrated in Fig. 1. the evacuated tubes were finely meshed, whereas the tank holding water was meshed with low density meshing. All of the computational domain was outfitted with hybrid hexagonal and triangular elements.

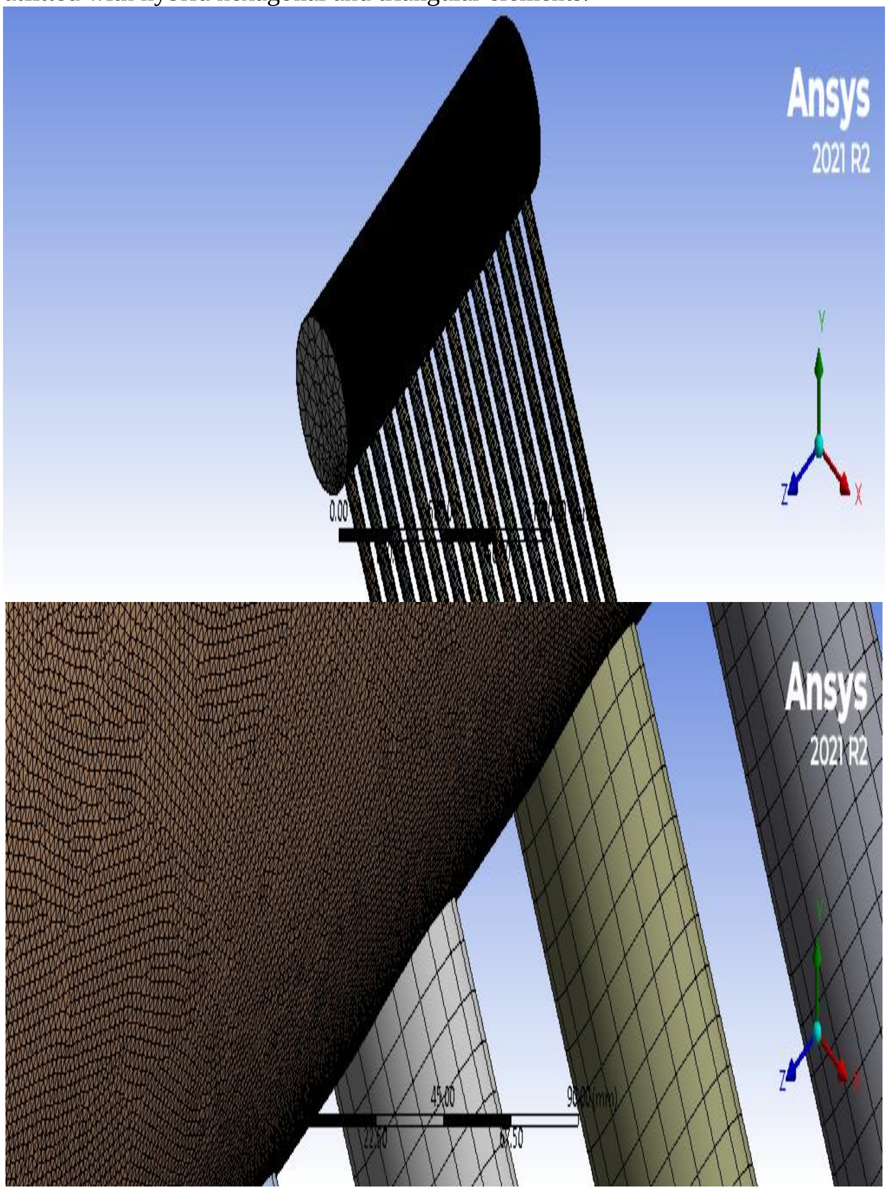


Fig.1 Evacuated tube solar collector mesh

1.2 Grid independence testing

The grid independence test was used to identify the best grid size for the computing domain. The computational domain was tested on three different grid volumes of 3578364, 4812875, and 555364 elements each. In terms of computation time, a grid of 4812875 elements with a skewness of 0.214 and orthogonal quality of 0.931 was determined to be the optimal mesh size. A convergence threshold of 10-3 was employed for the momentum and mass residuals, whereas a criterion of 10-6 was applied for the energy residual.

1.3 Boundary conditions

Accurate boundary conditions provide the best CFD results. This work exposed collector tubes to transient heat fluxes from the top and bottom of evacuated tubes. Sunlight heated the system. The water tank's circumference and evacuated tubes' bottoms were the adiabatic walls. The input and output ports were adiabatic walls because there was no net mass transfer when charging and discharging. Under these circumstances, charging was observed over 12 hours.

1.4 Governing equations

The entire computation time step is set to 43200 seconds, which corresponds to the period of 12 hours during which the system would be in operation. This was determined after the system and the boundary conditions were set up. Following is a list of equations that are solved for the system by ANSYS Fluent at each time step.

- **Continuity Equation**

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{U}) = 0 \tag{1}$$

- **Momentum equation**

$$\frac{\partial (\rho \vec{U})}{\partial t} + \nabla(\rho \vec{U}\vec{U}) = -\nabla p + \mu(\nabla^2 \vec{U}) + \rho \vec{g} \tag{2}$$

- **Conservation of Energy**

$$\frac{\partial (\rho H)}{\partial t} + \nabla(\rho \vec{U} H) = \nabla(k \nabla T) \tag{3}$$

III. RESULTS

Fig.1 shows a comparison between the numerical and experimental findings. Both computational and experimental studies show a consistent trend of rising water temperatures in tanks. Figures show that the numerical model is reliable for the experimental study of this kind of ETSWH, with just a 5% discrepancy between simulated and experimental results during the charging process.

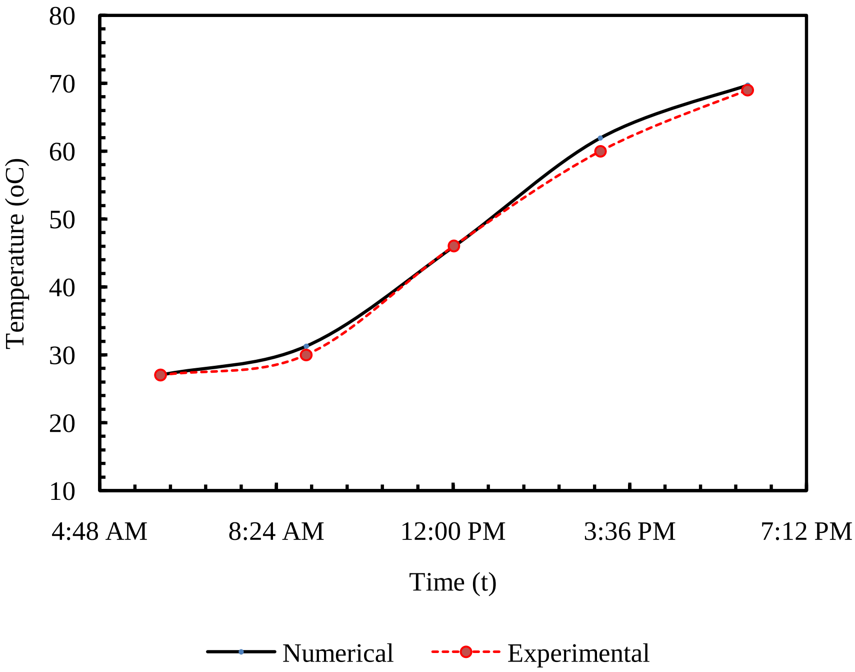
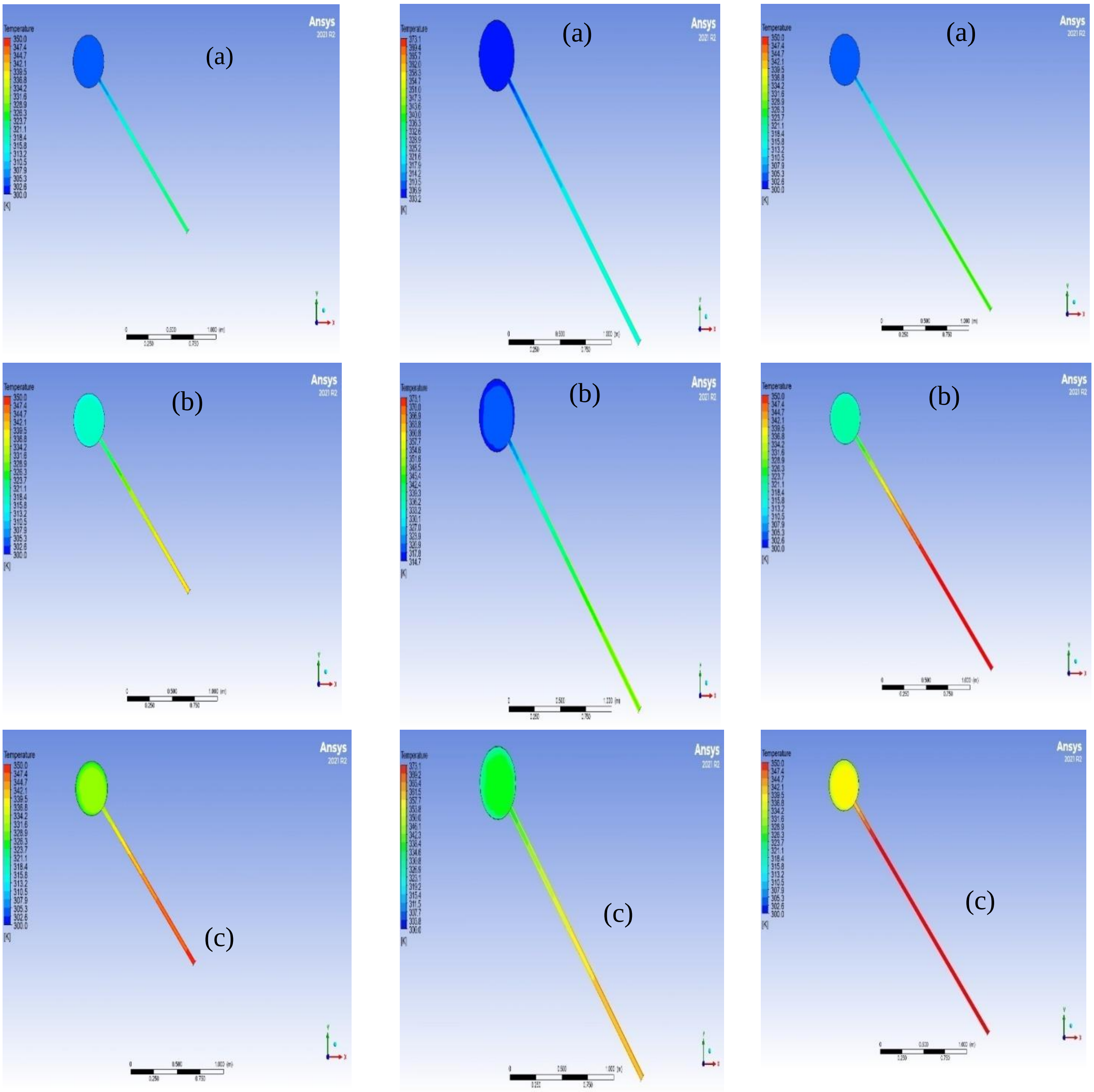
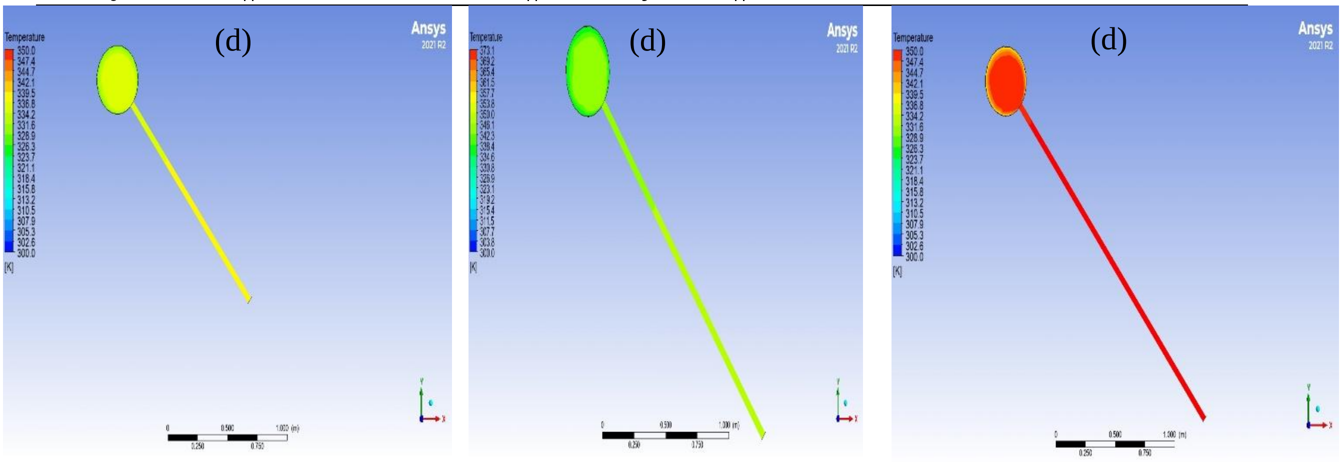


Fig. 2. Comparison between the numerical and experimental tank water temperature

The influence of evacuated tube length on the temperature of an evacuated tube solar water heating system was studied using tubes of varying lengths (1400 mm, 1800 mm, and 2200 mm). The length of the evacuated tube was varied while all other geometric parameters remained constant. As can be seen in Fig. 3 and Fig. 4, the findings showed that the evacuated tube length has a major impact on the temperature of the ETSWHS.

The mean temperature of the storage tank at the end of the day was greatest for the ETSWHS with the longest tube (2200 mm), and minimum for the ETSWHS with the shortest tube. This is because more solar energy is absorbed by the larger surface area provided by the longer evacuated tubes. Higher mean temperatures for longer horizontally installed evacuated tubes are consistent with the results of the research by Shah & Furbo [12]. The increase in evacuated tube length from 1400 mm to 2200 mm resulted in a temperature difference of roughly 13.215 °C. Thus, longer evacuated tubes are preferred when using an ETSWH to raise the water temperature. Nevertheless, setup space, cost, and portability must all be considered while settling on the best evacuated tube length.





Length 1400 mm | Length 1800 mm | Length 2200 mm

Fig. 3. Temperature contours of ETSWH different length during the charging period at (a) 6.00 a.m. (b) 9.00 a.m.(c) 12.00 p.m. (d) 3.00 p.m. (e) 6.00 p.m.

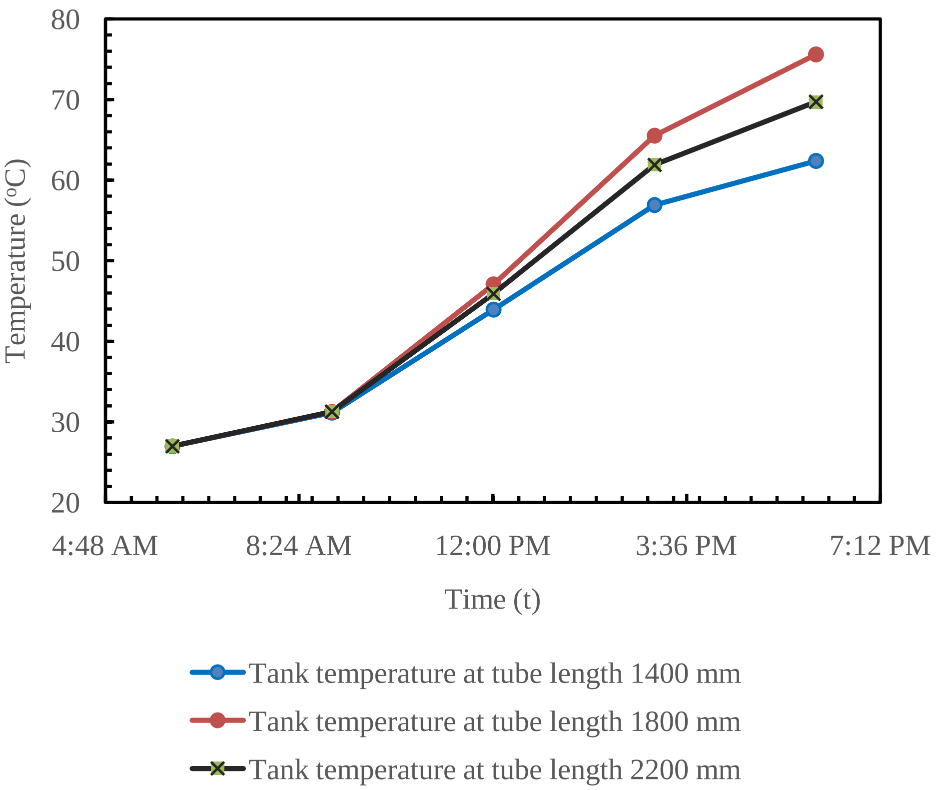
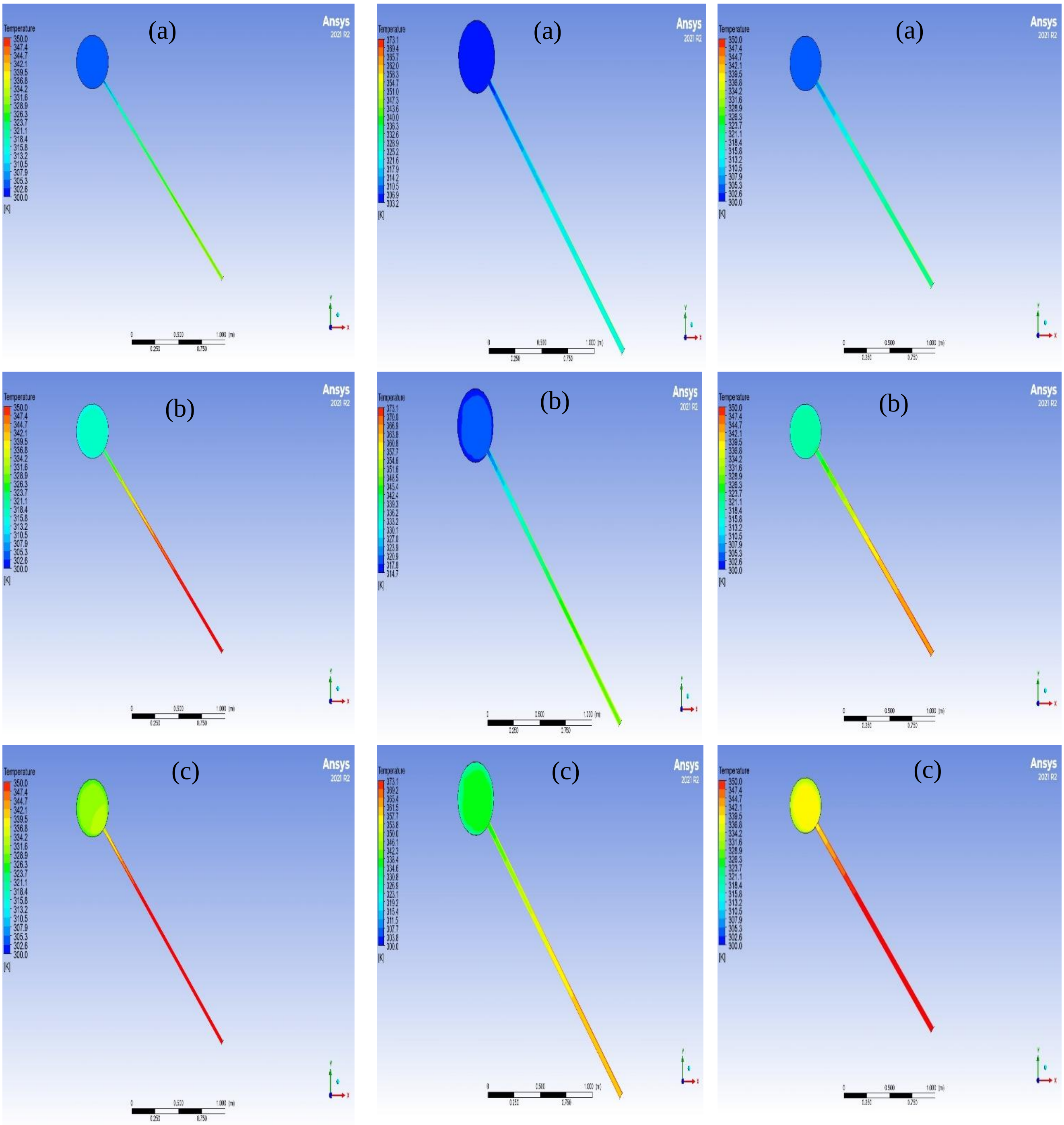


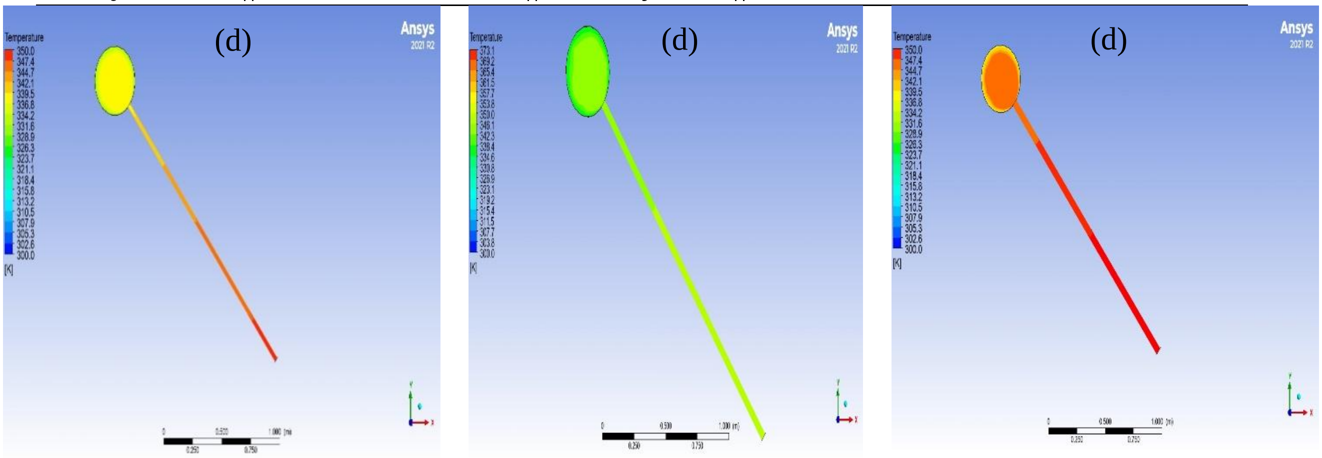
Fig.4The influence of evacuated tube length on the temperature of an ETSWHS

While keeping all other variables constant, the influence of evacuated tube diameter on the performance of an ETSWH was studied using tubes of 40 mm, 47 mm, and 54 mm diameters. The temperature gradient in the storage tank was determined to be influenced by the evacuated tube diameter (see Fig. 5, and Fig. 6).

As compared with the other two evacuated tubes, the one that had the maximum diameter (54 mm) fared the best. The mean temperature of the 54 mm evacuated tube was roughly 7.3 °C higher compared to the 40 mm evacuated tube. As the diameter of the evacuated tube is increased, the amount of solar insulation that may be absorbed is also increased. Also, it increases the amount of water in the evacuated tubes, which is necessary for the efficient removal of heat.

Nevertheless, numerous criteria, including the number of evacuated tubes, the length of the water tank, and the spacing between the centers of the neighboring evacuated tubes, must be considered in order to determine the optimal diameter of the evacuated tube.





Diameter 40 mm   Diameter 47 mm   Diameter 54 mm

Fig. 5. Temperature contours of ETSWH for different diameters during the charging period at (a) 6.00 a.m. (b) 9.00 a.m.(c) 12.00 p.m. (d) 3.00 p.m. (e) 6.00 p.m.

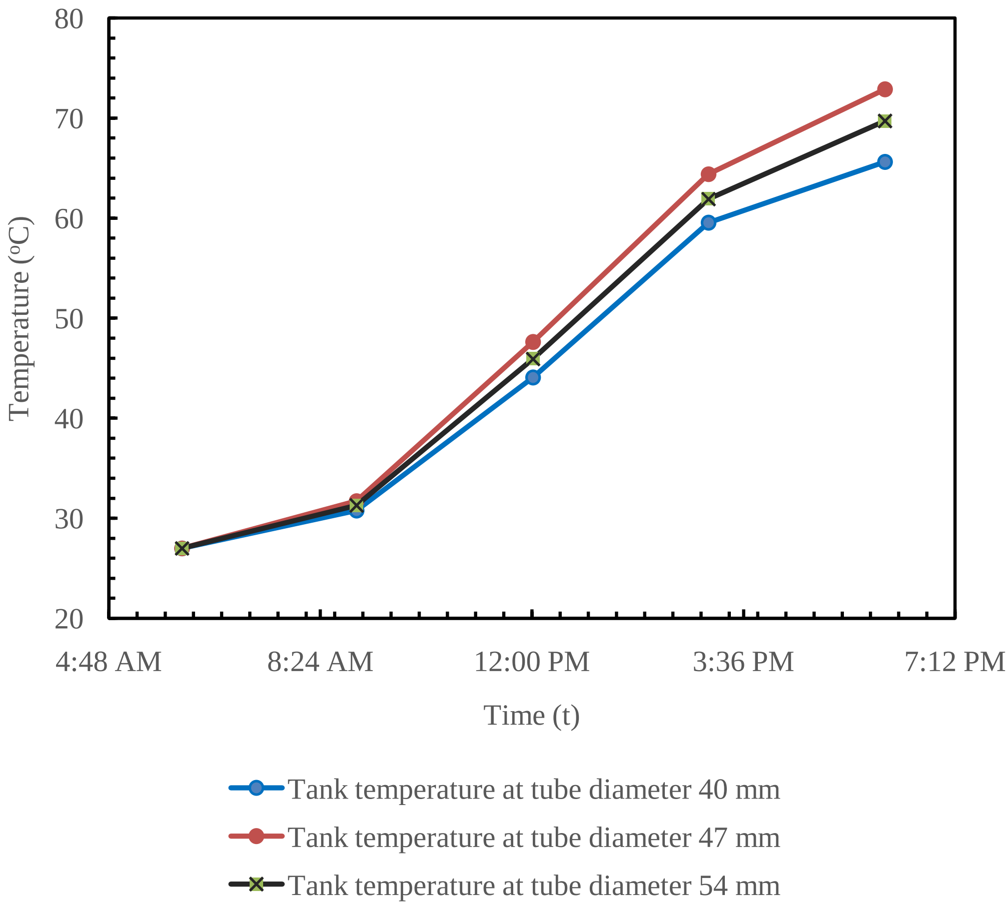
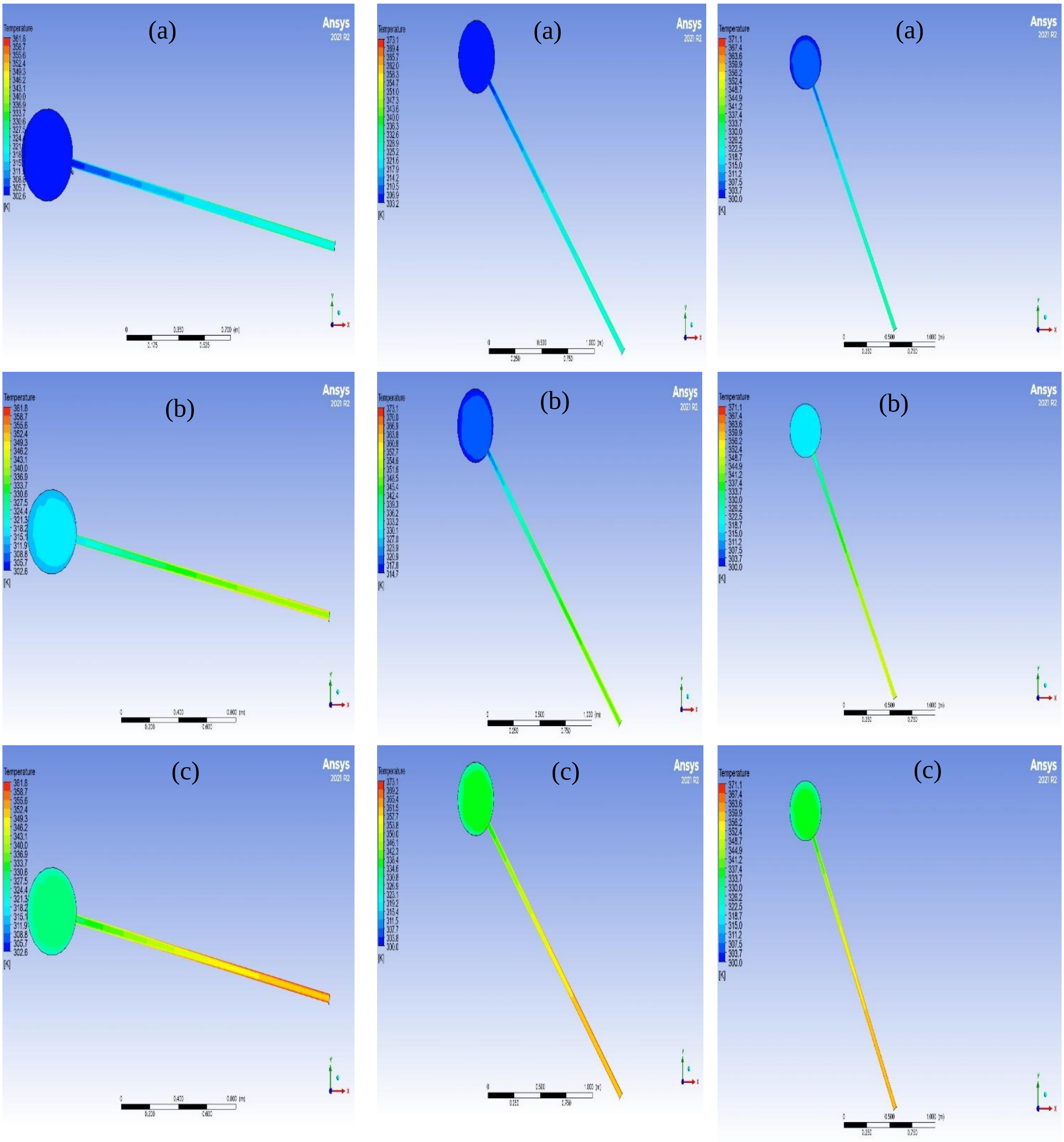
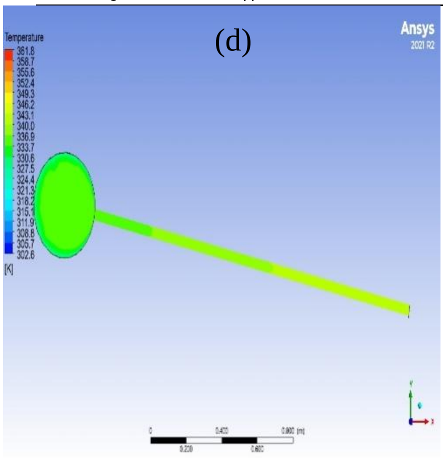


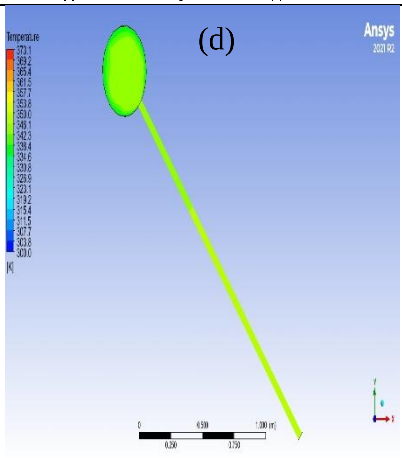
Fig.6 The influence of evacuated tube Diameter on the temperature of an ETSWHS

Fig. 7 and Fig. 8 shows how different tilt angles (10, 45, and 60 degrees) affected the ETSWH's temperature distribution. The study found that the stratification influence in the water tank is affected by the collector tilt angle because of the temperature variation in the evacuated tube. Tilt angle 45 was found to have a warmer average water temperature than the other tilt angles. Figure 8 demonstrates this. Figures 7 and 8 show that the best angle of the ETSWH under the weather conditions utilized in the experiment is 45 degrees. When the ETSWH's title is raised to 60, the temperature drops at the end of the day. The temperature was lowest when the ETSWH was tilted at an angle of 10 compared to 45 degrees.

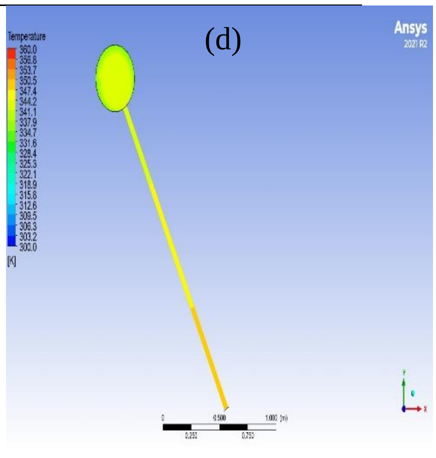




Tilt angles 10



Tilt angles 45



Tilt angles 60

Fig. 7. Temperature contours of ETSWH for tilt angles during the charging period at (a) 6.00 a.m. (b) 9.00 a.m.(c) 12.00 p.m. (d) 3.00 p.m. (e) 6.00 p.m.

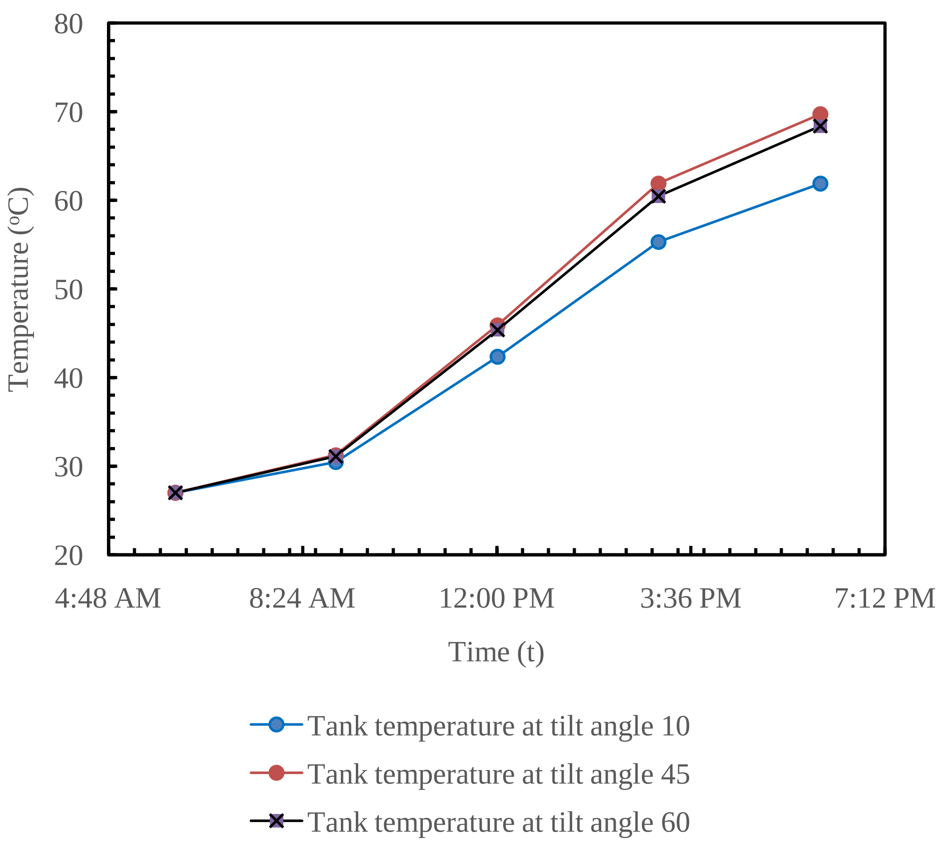


Fig.8 The influence of evacuated tilt angles on the temperature of an ETSWHS

IV. CONCLUSION

This study's numerical findings show that the length of the SWH tube of ETSWHS has a major impact on the system's performance. Findings also show that longer SWH tubes are better than shorter ones in terms of absorbing solar insulation, leading to warmer water at the storage tank's outlet.

Higher temperatures were reached in SWH tubes with larger diameters compared to SWH tubes with small diameters. Based on these results, determining the optimal SWH tube length and diameter after accounting for all important variables is crucial for increasing the water output temperature in an ETSWHS.

The stratification influence in the water tank is significantly affected by the temperature gradient in the

SWH tube, which is in turn affected by the ETSWH tilt angle. It was discovered that the mean temperature of the water at tilt angle 45 is greater than at any of the other tilt degrees.

REFERENCES

[1] Y. Tian, & C. Y. Zhao. A review of solar collectors and thermal energy storage in solar thermal applications. Applied Energy, 104, 2013, 538-553.
[2] K. R. Arun, M.Srinivas, , C. A.Saleel, , &S.Jayaraj. Active drying of unripened bananas (Musa Nendra) in a multi-tray mixed-mode solar cabinet dryer with backup energy storage. Solar Energy, 188, 2019, 1002-1012.
[3] I. Budihardjo, & G. L. Morrison. Performance of water-in-glass evacuated tube solar water heaters. Solar Energy, 83(1), 2009, 49-56.
[4] O. Abdelhak, H. Mhiri, & P. Bournot. CFD analysis of thermal stratification in domestic hot water storage tank during dynamic mode. In Building Simulation, Vol. 8, 2015, August, pp. 421-429.
[5] T.Bouhal, S. Fertahi, Y. Agrouaz, T. El Rhafiki, T. Kousksou, , & A. Jamil. Numerical modeling and optimization of thermal stratification in solar hot water storage tanks for domestic applications: CFD study. Solar Energy, 157, 2017, 441-455.
[6] L. J. Shah & S. Furbo. Entrance effects in solar storage tanks. Solar energy, 75(4), 2003, 337-348.
[7] S. Ievers & W. Lin. Numerical simulation of three-dimensional flow dynamics in a hot water storage tank. Applied Energy, 86(12), 2009, 2604-2614.
[8] M.Hazami, S.Kooli, N.Naili, & A.Farhat. Long-term performances prediction of an evacuated tube solar water heating system used for single-family households under typical Nord-African climate (Tunisia). Solar Energy, 94, 2013, 283-298.
[9] T.Sokhansefat, A.Kasaeian, K.Rahmani, A. H.Heidari, F.Aghakhani& O. Mahian. Thermoeconomic and environmental analysis of solar flat plate and evacuated tube collectors in cold climatic conditions. Renewable Energy, 115, 2018, 501-508.
[10] K.Yao, T.Li, H.Tao, J.Wei, & K.Feng. Performance evaluation of all-glass evacuated tube solar water heater with twist tape inserts using CFD. Energy Procedia, 70, 2015, 332-339.
[11] A.Saito, S.Okawa, T.Shintani, & R.Iwamoto. On the heat removal characteristics and the analytical model of a thermal energy storage capsule using gelled Glauber's salt as the PCM. International journal of heat and mass transfer, 44(24), 2001, 4693-4701.
[12] L. J.Shah, &S.Furbo. Theoretical flow investigations of an all glass evacuated tubular collector. Solar Energy, 81(6), 2007, 822-828.