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TEMPERATURE DISTRIBUTION WITHIN THE RISING PIPE IN FLAT PLATE SOLAR COLLECTOR

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Abstract: In the present study, the effect of increasing absorption area by using two different cross-section shapes of rising pipe namely semi-circle cross-section (model -A-) and elliptic cross-section (model -B-) on the temperature distribution of operating liquid within rising pipe of the FPSC is studied numerically and experimentally. Experimental tests are conducted under weather Baghdad – Iraq, while the numerical results are obtained by using Ansys Fluent CFD. The difference between the experimental findings and numerical findings for the average temperature of the water in the tank and the temperature of the operating liquid at exit rising pipe is 8.12 % and 8.36 % respectively. The results have shown that the temperature distribution for all new models higher than the traditional model. Furthermore, model -B- has higher other models under study. Hence, the best model according to the current study is model -B- increase by (2.4%), (2.2%) and (2.5%) regarding the temperature of the operating liquid at the inlet, center, and outlet respectively compared to the traditional model.

Keywords: *Solar energy, Flat plate solar collector (FPSC), rising pipe, Computational fluid dynamics (CFD)*

1. Introduction

Renewable energy includes a variety of types, but solar energy is the most common because it is available almost everywhere in the world. Solar energy is received by the earth in the form on solar radiation. The radiation includes ultraviolet, visible and infrared radiation. A variety of solar energy technologies are used to converting the solar radiation into thermal and electrical energy. There are several devices used to converting the solar radiation into thermal energy that are used to heat water, heat space in buildings, cook food in solar cookers, etc., [1]. One of the most important of these devices is solar water heater system (SWHs). In order to enhance a thermal performance of this device, the effect of several parameters have been examined by many researchers such as Vishal and Chinmay [2] carryout numerical study to investigate thermal performance by comparing between two shapes of tubes in FPSC defined as circular and elliptical tube. They have been reported that the FPSC with elliptical tube shows increase average surface temperature about 4.17 ^{o}C compared to circular tube. Experimental study for investigation the effect of dimpled tube on thermal performance for FPSC has been conducted by Ajinkya [3]. Compared between dimpled tube and smooth tube has been done. The results have been shown that the average surface temperature increase about 2.5 ^{o}C with dimpled tube that mean the

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dimpled tube better than smooth tube. Freegah et. al. [4] have conducted a numerical study to comparation between the traditional and a helical model, as well as changeable turns number 10, 20, and 30. The results have been shown that use a helical model leads to an important enhancement of a thermosyphon performance compared to conventional model. Furthermore, the heat exchanger's temperature was raised as the number of turns on the helical pipes was increased. The efficiency improvement and heat transfer study of the solar collector was investigated by Yarshi and Paul [5]. Numerical analysis CFD simulation has been used to study the impact of differences in the shape of the rising pipes, mass flow rate and kind of absorber pipe material on performance of FPSC. The semicircular pipe has been documented to absorb more heat than the circular pipe because of increment surface absorption. Kamble and Badgujar [6] examined the effect of different geometries of the absorber tubes on solar collector thermal efficiency. They used different absorber tubes shapes namely rectangular, semi-circular, square, elliptical, triangular, and circular cross-section. They noticed that the semicircular rising pipe provides a greater heat rate of transfer than the circular rising pipe. While the triangle tube gives the best thermal efficiency compared to other cases under analysis. Thakare and Khot [7] conducted an experimental study to investigate the influence of variable rising pipe shapes on solar collector performance. Several rising pipe shapes have been studied are square, circular, elliptical, and triangular on FPSC performance. The findings have been shown that the triangular tube was found to gives maximum efficiencies comparing to other tubes. Bute and Kongre [8] performed an experimental study to enhance solar collector heat collection. The influence on the heat transfer mechanism and the thermal behavior of various rising pipe shapes namely zigzag and straight has been investigated. They have reported that heat transfer amount was greater for zigzag model comparing to straight model. Moreover, the zigzag rising pipe recorded increase the heat transfer coefficient by 19.6% compared to straight pipe. Narendran and Balachandar [9] analyzed experimentally the fluid flow and heat transfer of FPSC. The effect an inner groove of the rising pipe of FPSC on heat transfer characteristics has been examined. The results have been shown that FPSC performance enhanced by 5% for use proposal collector comparing to traditional collector. Varying cross section of rising pipe has been tested experimentally on the SWHs via Shrirao et. al. [10]. The influence of two shapes are airfoil and circular shape has been examined. They reported that the airfoil absorber tubes absorbed significantly more solar radiation than the other absorber tubes. Hence, the performance of the airfoil-shaped absorption tube enhanced by 10 to 12% as comparing to the circle cross section. Qasim et.al [11] performed numerical study to examine thermal performing of FPSC for two types of rising pipe are straight and helical pipes. The findings have shown that the helical pipe is more effective than the straight pipe. In addition, increasing the number of turns leads to the increase in temperature percentage minimal. Gorle et. al. [12] explored the influence of different shapes of rising pipe on the output performance of FPSC experimentally. Compared between conventional FPSC with circular pipe and trapezoidal FPSC with semi-circular pipes have been conducted. They reported that the increasing in heat gain is 39.34 % and maximum water temperature difference was 5.1℃ for proposed FPSC as compared to conventional model.

Although the huge number of studies investigating the influences of various shapes of rising pipe in FPSC, the results of studies were conducted under steady-state heat flux and with active systems to circulate the operating liquid inside the system. The current study is being carried out to investigate the impact of different shapes of rising pipe in FPSC under transient heat flux using passive systems. Furthermore, the operating liquid temperature behavior, as well as the thermal performance of FPSC have been studied. To achieve that, two proposed models namely model -A- and model -B- have been studied. Model- A-: The surface absorber exposed to heat flux in this model is increasing by growing the diameter of the rising pipe by transforming the shape of the cross-section to a semi-circle. Model -B-: The surface absorber exposed to heat flux is increasing in this model by transforming the shape of the cross-section into an elliptic.

2. Numerical Analysis

2.1. Geometric Models

In the current analysis, there are three shapes of rising pipe for the FPSC, are the conventional model (circle cross-section), the semi-circle cross-section of the rising pipe (model -A-) and the elliptical cross-section of the rising pipe (model -B-), as depict in Figure 1(a-c). With a width of 0.6m and an incline angle of 33 °, the height of the FPSC is 1200 mm, consisting of one rising pipe connected from the top to the upriser and from the bottom to the downcomer. In addition, the rising pipe length is 1m, and the return pipe is similar in thickness and diameter to that of the traditional model rising pipe. In the current analysis, all the dimension of the models remained unchanged, excluding the rising pipe's diameter and cross-section shape. The rising pipe specifications with all models with dimension are given below.

Conventional model: The outer and inner diameters are 15.88 mm and 14.26 mm respectively for the rising pipe. Model A: semi-circle cross section shape of rising pipe with inner and outer radius are (9.13 mm) and (9.94 mm), respectively. Model B: elliptic cross section shape of rising pipe with semi-manor axis and semi-major axis is 5.04 mm and 10.08 mm respectively.

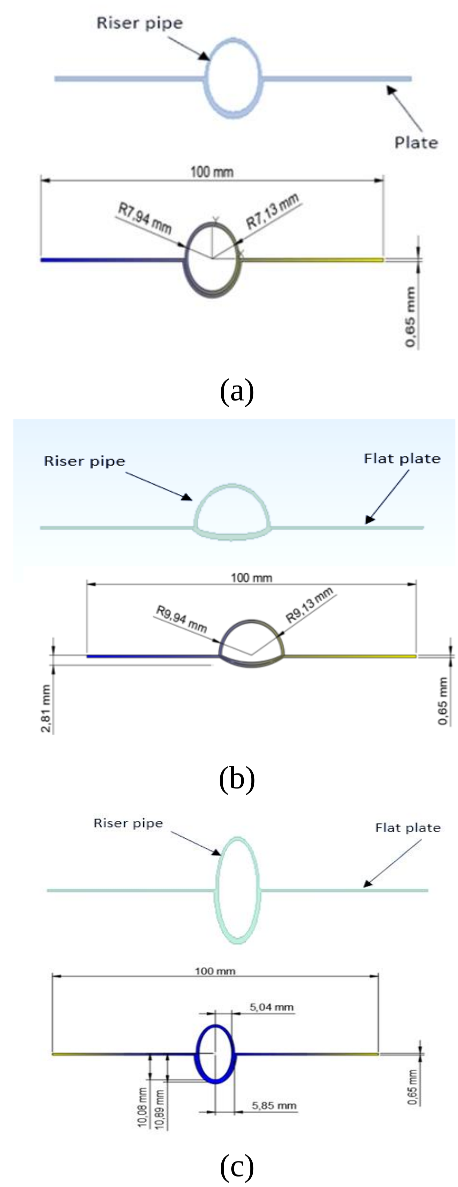


Figure 1. geometric model of FPSC for (a) traditional model, (b) model- A-, and (c) model -B-

2.2. Mesh Generation

One of the most critical techniques influencing the accuracy of the effects of numerical simulation is the geometry mesh. In this research, therefore, an unstructured hexahedral grid is used to mesh the domain of geometry models under consideration. In the mesh generation, this type of technique was used because it provides more exact results, less memory supplies and the ability of this type to connect composite geometric shapes, like the geometry model being studied [13]. the grid of domain via the present analysis for one model tested is shown in figure 2.

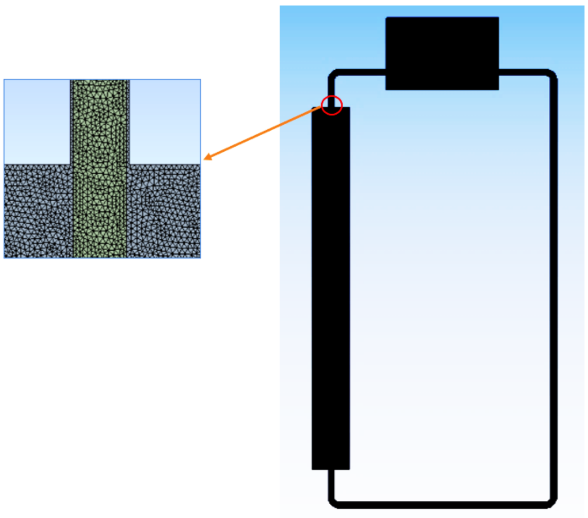


Figure 2. Geometry mesh domain

The accuracy of the findings is significantly influenced by the size and type of the mesh domain. The mesh independent tests are also performed in order to prove the choice of the sufficient number of meshes for the geometry model. All the results of this tests were clearly described in the table-1- which summarizes the numerical results of the tank temperature under different grid conformations of three cases. According to this table, that doubling of the number of grids does not significant influence the numerical findings. Therefore, in the simulation program, the minimum number of grids for each case was used to minimize the cost and time of the simulation run.

Table 1. Mesh Independence Tests Results

model	Number of element, (million)	Average temperature in the tank (°C)	Difference in temperature (%)
Traditional model	2.1	26.62	
	4.3	26.58	0.187
Model -A-	2.2	27.22	
	4.5	27.17	0.1836
Model -B-	2.25	28.14	
	4.6	28.1	0.142

2.3. Boundary Condition

For all the suitcases considered in numerical model, the boundary conditions used are the initial water temperature and the operating liquid is 21.6°C, the water volume within the storage tank is (9.4 Liter) and the volume inside the FPSC of the operating liquid is (0.59 L). In addition, transient heat flux was added to the rising pipe and plate for seven hours (see Figure 3), which was measured using Eq. (1) [14]. In addition, the user-defined function (UDF) was used in Ansys Fluent as the input of heat flux values (CFD). The water inside the FPSC was it used as operating liquid. The water value of the property used in the current study is specific heat, density, viscosity, thermal conductivity and rate of thermal expansion are 4.182 kJ/kg-K, 998.2 kg/m^3, 1003*10^{-6} (kg/m.s), 0.6 W/m-K and 149*10^{-6}K^{-1}.

$$q = I_T\, \varepsilon\, \tau [\sin\delta\, \sin(\theta-\propto) + \cos\delta \cos(\theta-\propto) \cos\omega] \quad (1)$$

Where δ, τ ,θ, I_T ,$\propto$ and ω the incline angle of FPSC system, the transmittance of atmospheric, local latitude, denote intensity of solar radiation and the sun hour angle respectively. while, ε represent the earth's orbit correction factor that can be estimated by using Eq. (2) [15].

$$\varepsilon = \left[1 + 0.033 \cos\left(\frac{360N_d}{365}\right)\right] \quad (2)$$

where N_d and represent the day number during the year

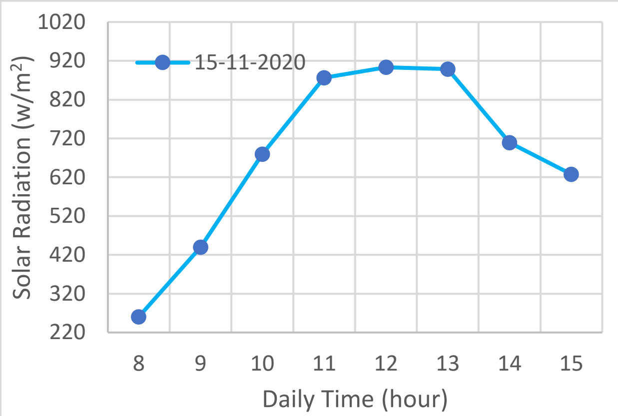


Figure 3. Heat flux variant for seven hours

In addition, Table 2. It shows all the amounts of the important parameters that used to input in the numerical simulation.

Table 2. Numerical simulation input parameters

Parameters	amount
Copper density	8978 kg/m3
Copper Specific Heat	0.381 kJ/kg-K
Copper Thermal Conductivity	0.386 kW/m-K
Water density	998.2 kg/m3
Water viscosity	$1003*10^{-6}$ kg/(m.s)
Water Specific Heat	4.182 kJ/kg-K
Water Thermal Conductivity	0.0006 kW/m-K
Water Thermal expansion	$149*10^{-6}K^{-1}$

2.3. Governing Equations

In this analysis, Simulation of transient flow and the average temperature of water in the tank and operating liquid at the outlet of the rising pipe for the FPSC for seven hours of operating time, energy equation, the three-dimensional Navier-Stokes equations and the continuity equations were numerically resolved. In the current analysis, Bellow takes into account certain presumptions. The operating liquid that circulating with in the FPSC is water. The flow is laminar, single phase, steady state and compressible. The properties of water are calculated based on film temperature.

For incompressible flow liquids the continuity equation can be defined as:

$$\nabla.\vec{U} = 0. \quad (3)$$

About the energy equation of heat conduction for the different materials, it can give by [16] as:

$$K_m.\nabla^2.\mathrm{T} = 0 \quad (4)$$

While, the energy equation can be symbolized as [17]:

$$\nabla.(\rho h\vec{U}) = -p\,\nabla\vec{U} + \nabla(k\,\nabla T) + \phi + s_h \quad (5)$$

Lastly, the three-dimensional Navier-Stokes equations can write as group of equations as illustrated in Eq. (6) [18]:

$$\nabla.(\rho\vec{U}\,u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}$$

$$\nabla.(\rho\vec{U}\,v) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}$$

$$\nabla.(\rho\vec{U}\,w) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \quad (6)$$

3. Experimental Work

The descriptions of the rig components and the specifications of the measurement devices used in the present paper are given in this section. All experimental tests were conducted under winter boundary conditions in Baghdad, Iraq (33.3°N and 44.3°E). The test equipment involves of a rising pipe, storage tank for water with capacity 9.6 L, the heat exchanger inside the tank, the wooden structure, a glass sheet, copper flat plate, downcomer that returns the operating liquid from the heat exchanger to the rising pipe. In addition, the measurement devices are seven thermocouples (type k) are utilized to measure the temperature. Three thermocouples are used to measure the plate temperature and, one thermocouple is used to measure the operating liquid temperature at the outlet of rising pipe, as well as three thermocouples used to measure the water temperature inside a tank, solar meter, and data logger system attached to a laptop as shown in figur4&5.

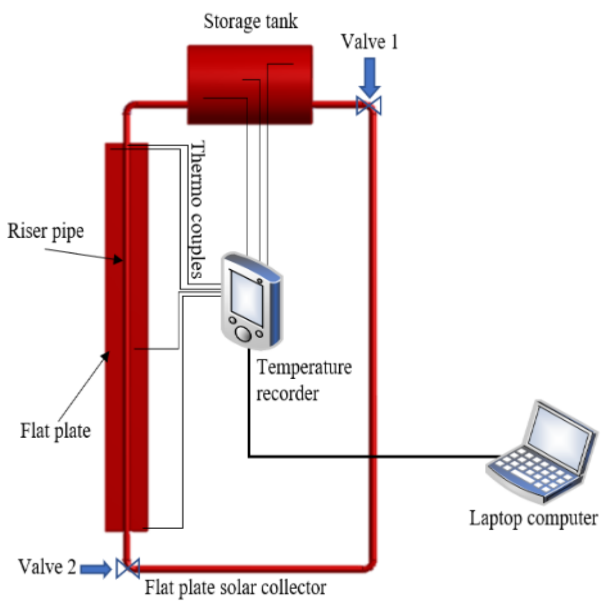


Figure 4. Schematic view of the FPSC under study.

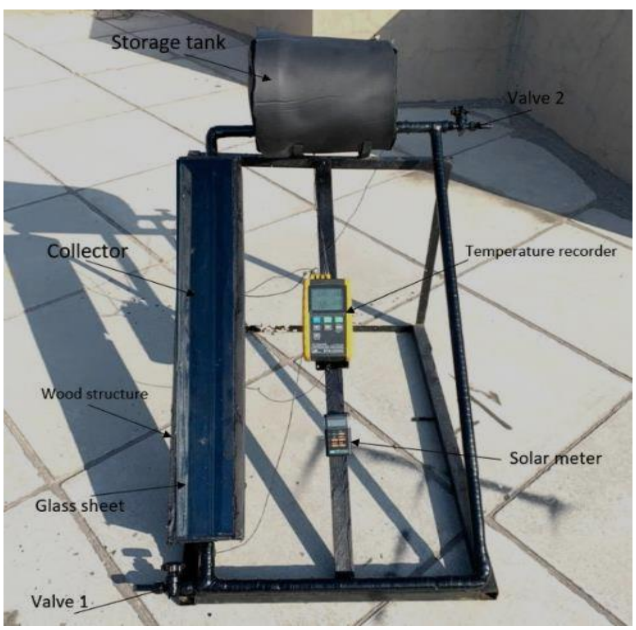


Figure 5. Plate of the FPSC under study

4. Result and Discussion

The numerical analysis was used in this study to clearly demonstrate the normal convection phenomenon and, thus, the temperature distribution of the operating liquid within the FPSC and the temperature distribution of water within the tank.

4.1. Validation of Numerical Calculations

To illustrate the numerical comes about accuracy, together of the geometry and boundary condition were used precisely comparative to the experimental test rig. Giving to this basis, the temperature of water in the tank and operating liquid at the outlet of the rising pipe along 7 an hour's process was compared as showed in Figures 6&7. Based on these estimates, it can be noticeably seen that the effects of the numerical result (CFD) and experimental findings converge satisfactorily. The maximum inconsistency among numerical and experimental findings is 8.12% and 8.36% for the average water temperature inside the tank and operating liquid at the exit of rising pipe respectively. The causes behind this modification between an experimental finding and present results probably is the thermal losses of system and, devices measurement errors that used in experimental. Moreover, these results are very similar to temperature behaver of researcher results by Jasim et al. [19][20].

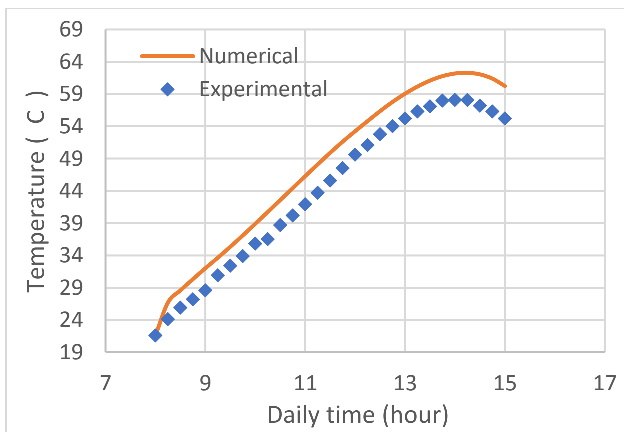


Figure 6. Comparison of temperature among the numerical and experimental model for the operating liquid at the outlet of the rising pipe.

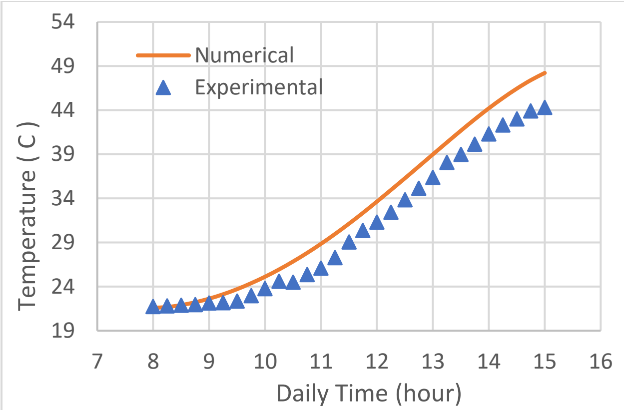
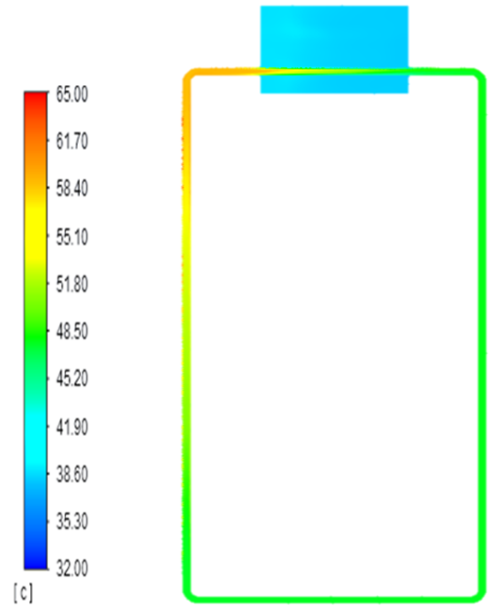


Figure 7. Comparison of temperature among the numerical and experimental model for the water within the tank

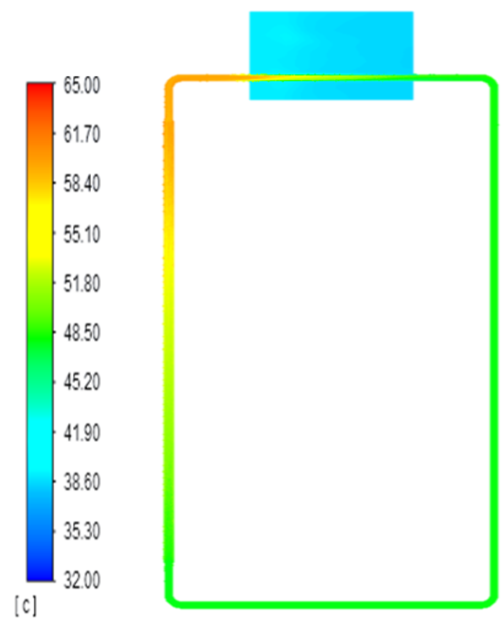
4.2. The Effect of Cross Section Shape of Rising pipe

In the current section, three sets of simulations are taken up in depth to examine the influence of cross section shape of rising pipe in FPSC system. Firstly, traditional model (circular cross section shape of rising pipe), second, semi-circle cross section of rising pipe (model -A-) was used. Third, use elliptic cross section of rising pipe (model-B-).

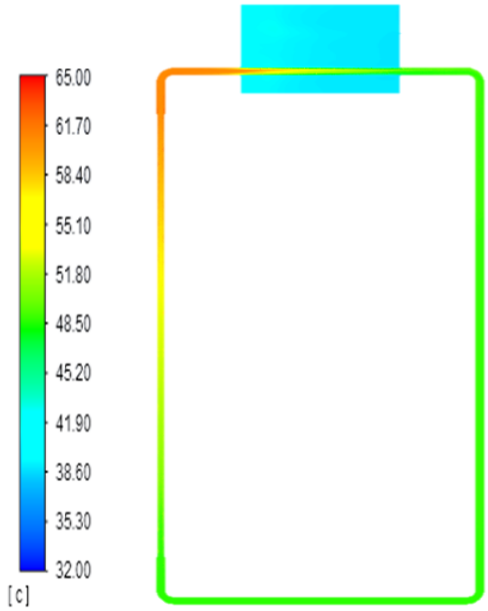
Figure 8 the temperature contour of the operating liquid inside pipes and the water in the storage tank for traditional model, model-A- and model-B- at 1:00 pm. From figure 8 (a-c) it has been observed the temperature of the operating liquid inside the rising pipe is higher than the down-comer temperature for all models. Additionally, the temperature for both water in the storge tank and operating liquid for models -B-is higher than traditional model and model -A-. Moreover, the temperature for operating liquid and water in the storage tank for models -A- is higher than traditional model. The reason behind increase of temperatures because of increase the absorption area that received solar radiation, and so the heat flux has been increased. The water temperature within the tank for traditional model, model-A-, and model-B- is 38.99 °C,39.39 °C and 40 °C respectively. While, the temperature of operating liquid at outlet of rising pipe for traditional model, model-A-, and model-B- is 59.05 °C, 60.16 °C and 61.07 °C respectively.



(a)



(b)

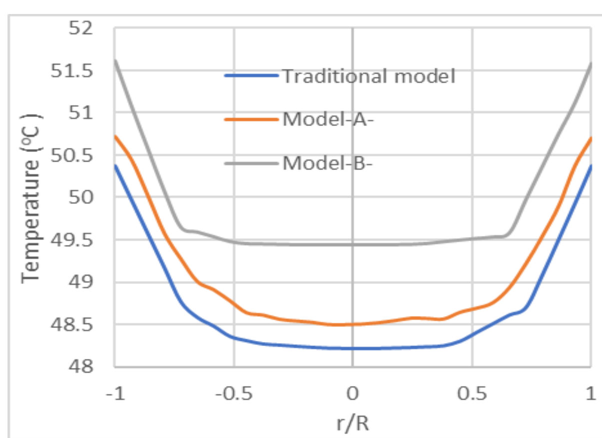


(c)

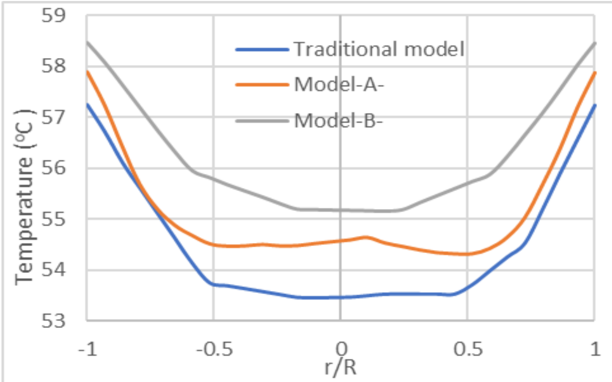
Figure 8. Show temperature contour of operating liquid and water in FPSC and the storage tank for (a) traditional model, (b) model-A-, and (c) model-B-.

Figure 9 depicts the relationship between the temperature distribution of the operating liquid within the rising pipe and radius ratio of cross-section rising pipe on the x-y plane for traditional model, model-A- and model-B- at 1:00 pm. It can note that a temperature of the operating liquid in the rising pipe near the wall greater than the temperature of operating liquid at the middle rising pipe, because the thermal resistance of operating liquid at the middle rising pipe is higher than the thermal resistance near the wall of rising pipe. Figure 9,a shows that the temperature distribution of operating liquid at the inlet of rising pipe. The temperature of operating liquid near the wall at inlet rising pipe for traditional model, model -A- and model -B-is 50.35°C,50.69°C and 51.58°C respectively, while at the middle rising pipe is 48.2°C,48.51°C and 49.43°C respectively. The temperature distribution of the operating liquid at the center of the rising pipe is shown in Figure 9,b. For the traditional model, model -A-, and model -B-, the temperature of the operating liquid near the wall at the center rising pipe is 57.22°C, 57.89°C and 58.45°C respectively, while at the middle rising pipe is 53.45°C, 54.55°C and 55.17°C respectively. Figure 9,c indicates that the temperature distribution of operating liquid at the outlet of rising pipe. The temperature of operating liquid near the wall at outlet rising pipe for traditional model, model - A- and model -B- is 61.63°C, 62.42°C and 63.22°C respectively, while at the middle rising pipe is 59.04°C, 60.1°C and 61.05°C respectively. From three figures it can be noticeably seen that the temperature distribution of the operating liquid within the rising pipe for model -B- is higher than the other models. Moreover, these results are very similar to temperature behaver of numerical simulation was studied by Freegah [21].

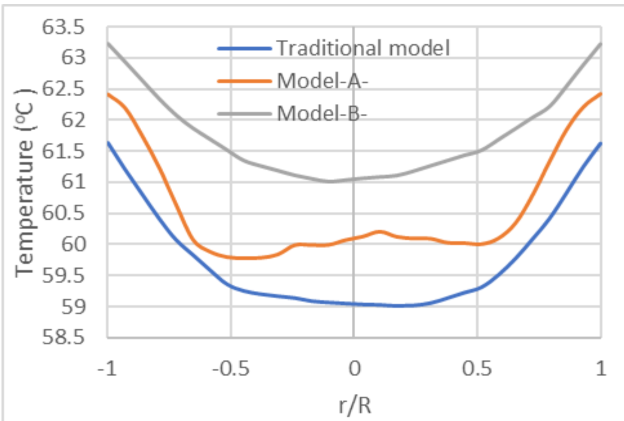
Figure 10 illustrates the relationship between the temperature distribution of the operating liquid within the rising pipe and radius ratio of cross-section rising pipe on the x-y plane for model-B- at 1:00 pm for the inlet, the center and the outlet of rising pipe. It can be seen that the temperature distribution of the operating liquid in the rising pipe at outlet is greater than the inlet and center of rising pipe. The temperature of operating liquid near the wall at inlet, center and outlet rising pipe is 51.58°C, 58.45°C and 63.22°C respectively, while at the middle rising pipe is 49.43°C, 55.17°C and 61.05°C respectively.



(a)



(b)



(c)

Figure 9 static temperature within rising pipe for a) the inlet of rising pipe, b) the center of rising pipe, and c) the outlet of rising pipe.

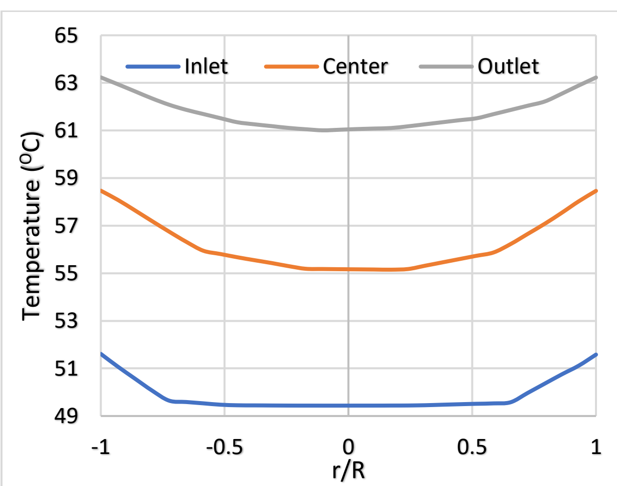


Figure 10. The temperature distribution of the operating liquid within the rising pipe for model-B-.

5. Conclusions

In the current study numerical and experimental study is perforated to investigate the thermal performance of FPSC system for traditional and two propose models namely model -A- and model -B-. the model -A- includes solar collector with semi-circle cross section shape of rising pipe, while model -B- involves solar collector with elliptic cross section shape of rising pipe. The findings in this work are the difference between numerical results and experimental outcomes are found (8.12 %) and (8.36 %) for the water temperature within the tank and operating liquid at the outlet rising pipe respectively. Furthermore, the temperature distribution of the operating liquid within the rising pipe for model -B- is higher than the other models during time. Moreover, the increase in temperature distribution for new models with change rising pipe cross section shape of the FPSC has negligibly small effect on the performance of a FPSC.

Acknowledgments

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Nomenclature

Prandtl number	Pr
Solar water heating system	SWHs
Flat plate solar collector	FPSC
temperature, C^o	T
Temperature in tank, C^o	$T_{w,t}$
The rising pipe outlet temperature, C^o	$T_{w,o}$
Heat flux w/m2	q

Greek symbols

Kinematic viscosity, m^2/s	v
Density, kg/m^3	ρ
Dynamic viscosity, N•s/m^2	μ
Intensity of solar radiation	I_T

Declaration angle	δ
Earth's orbit correction factor	ε
Incline angle of FPSC	θ
Atmospheric transmittance	τ
Sun hour angle	ω
local latitude	∝

Conflict of interest

The authors declare no conflict of interest in publication of this research.

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