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# ANALYSIS OF A SIMULATED FLAT PLATE SOLAR COLLECTOR SYSTEM USING SOLIDWORKS FLOW SIMULATOR INTERFACE

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**ABSTRACT:** One of the promising source of renewable energy is solar energy. Water heating by solar energy for domestic use is one of the most successful and feasible applications of solar energy. Other areas of application of solar energy include solar drying, electricity generation using photovoltaic cells, solar cooling and refrigeration, solar still (or solar distillation) and solar cooking. In this study flat plate solar collector was simulated, a temperature of $58^{o}C$ and an efficiency of 51% was achieved respectively. Solar radiation being abundantly present in Nigeria is one area of focus among the renewable energy resources and this can be harnessed for heating water for both domestic and industrial purposes.

**Keywords:** Simulation, Solid works, Solar Collector, Flow Simulator, Ambient Condition.

## 1. INTRODUCTION

Solar flat plate collector is a type of solar thermal systems, it provides environmental friendly heat for industrial water heating, commercial building, space heating, hospital water, household water and the heating of swimming pools. Such systems collect the suns energy to heat a fluid. The heated water is then stored in a tank similar to a convectional gas or electric water tank and some systems use an electric pump to circulate the fluid through the collectors [1].

The analysis of thermal collectors is able to be done experimentally and by simulating the heat transfer phenomena within the system. Sopian et al. [2] conducted an experimental study on the thermal performance of a solar flat plate collector having a wooden case, no glass cover (unglazed) and a solar water heater integrated with a storage system.

Several studies which compare experimentally results with Computational Fluid Dynamics (CFDs) results are shown by [3, 4].

Farahat et al [5] and Chamoli [6] used MATLAB to optimize a flat plate collector considering its exergy analysis in order to improve the efficiency of the collectors by decreasing the losses. Garg and Rani [7] calculated the overall heat loss coefficient and the collector efficiency under different conditions such as the absence of cover, with single and double glazing under different ambient conditions, tilt angles, wind speeds, emissivity of both glass cover and absorber plate.

Pillai and Agarwal [8] discussed the influence of various parameters on the efficiency of solar collectors and concluded that at low solar insolation in the range of 200-600 W/m$^2$ with double glazed collectors are superior to single glazed collectors. Anderson et al [9] examined the performance by changing the colors of solar collector. Based on the transmittance-absorptance result of various colored collectors the hypothetical performances of these collectors were calculated using the Hottel-Whillier-Bliss 1-D steady-state model given by Duffie and Beckmann [10].

This research helps to analyze and simulate the flat plate solar collector, in this study the computational tool is SolidWorks which gives many design opportunities. The design of the collector and the thermal simulation were made in the same environment by adding flow simulation tab.

## 2. MATERIALS AND METHOD

This simulation was done using Solidworks as a simulation tool. The initial conditions, boundary conditions and the control condition are shown in Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and were selected based on the thermodynamic analysis done.

Flow Simulator software was the subprogram attached to Solidworks for the simulation of the flat plate solar collector. The initial/ambient conditions were selected based on the design consideration and parameters gotten from the thermodynamic analysis of the collector system.

Table 2, 3 and 4 are the ambient condition selected on the Flow Simulator bearing in mind the design and thermodynamic parameters gotten. Table 5, 6, 7, 8, 9, 10 are the control platforms on the Flow Simulator after the ambient conditions have been meet.

**Table 1.** Initial conditions selected for the ambient state.

| Ambient conditions generated from Solidworks | |
|---|---|
| Thermodynamic parameters | Static Pressure: 101325.00 Pa<br>Temperature: 299.1 K |
| Velocity parameters | Velocity vector<br>Velocity in X direction: 0.500 m/s<br>Velocity in Y direction: 0.020 m/s<br>Velocity in Z direction: 0.020 m/s |
| Solid parameters | Default material: Copper<br>Initial solid temperature: 303.00 K<br>Radiation Transparency: Opaque |
| Turbulence parameters | Turbulence intensity and length<br>Intensity: 2.00 %<br>Length: 0.007 m |

**Table 2** Initial conditions selected for inlet mass flow rate**.**

| Inlet Mass Flow 1 | |
|---|---|
| Type | Inlet Mass Flow |
| Faces | Face<2> at Plate and tubes-1 |
| Coordinate system | Face Coordinate System |
| Reference axis | X |
| Flow parameters | Flow vectors direction: Normal to face<br>Mass flow rate: 0.014 kg/s<br>Fully developed flow: No<br>Inlet profile: 0 |
| Thermodynamic parameters | Temperature: 299.1K |
| Turbulence parameters | Turbulence intensity and length<br>Intensity: 2.00 %<br>Length: 0.007 m |
| Boundary layer parameters | Boundary layer type: Turbulent |

**Table 3.** Initial conditions selected for static pressure conditions.
Static Pressure 1

| | |
|---|---|
| Type | Static Pressure |
| Faces | Face<6> at Plate and tubes-1 |
| Coordinate system | Face Coordinate System |
| Reference axis | X |
| Thermodynamic parameters | Static pressure: 101325.00 Pa<br>Temperature: 299.1 K |
| Turbulence parameters | Turbulence intensity and length<br>Intensity: 2.00 %<br>Length: 0.007 m |
| Boundary layer parameters | Boundary layer type: Turbulent |

**Table 4.** Control conditions for temperature (1).
GG Av Temperature (Fluid) 1

| | |
|---|---|
| Type | Global Goal |
| Goal type | Temperature (Fluid) |
| Calculate | Average value |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

**Table 5.** Control conditions for temperature (2).
GG Av Temperature (Fluid) 2

| | |
|---|---|
| Type | Global Goal |
| Goal type | Temperature (Fluid) |
| Calculate | Average value |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

**Table 6.** Control conditions for temperature (3).
GG Av Temperature (Fluid) 3

| | |
|---|---|
| Type | Global Goal |
| Goal type | Temperature (Fluid) |
| Calculate | Average value |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

**Table 7.** Control conditions for mass flow rate.
GG Mass Flow Rate 1

| | |
|---|---|
| Type | Global Goal |
| Goal type | Mass Flow Rate |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

**Table 8.** Control conditions for net radiant flux (solar).
GG Av Net Radiant Flux (solar) 1

| | |
|---|---|
| Type | Global Goal |
| Goal type | Net Radiant Flux (solar) |
| Calculate | Average value |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

**Table 9.** Control conditions for the temperature (solid).

| GG Av Temperature (Solid) 1 | |
|---|---|
| Type | Global Goal |
| Goal type | Temperature (Solid) |
| Calculate | Average value |
| Coordinate system | Global coordinate system |
| Use in convergence | On |

Table 9 presents the selected flat plate solar collector size on the design interface on Solidworks using the Flow Simulator program.

**Table 10.** Size of computational domain.

| | |
|---|---|
| X min | -0.483 m |
| X max | 1.265 m |
| Y min | -0.275 m |
| Y max | 1.082 m |
| Z min | -1.282 m |
| Z max | 0.398 m |

The basic mesh dimensions applicable to the X, Y and Z coordinates of the flat plate solar collector was presented in Table 10. This was necessary in the simulation of the collector system, coarse mesh with large elements require less computation time which may result to inaccurate results. Mesh convergence obtained on X, Y and Z coordinates were 17, 12 and 17. The process was followed by mesh refinement which resolved the model with finer mesh sizes for accurate results.

**Table 11.** Basic Mesh Dimensions.

| | |
|---|---|
| Number of cells in X | 17 |
| Number of cells in Y | 12 |
| Number of cells in Z | 17 |

The mesh properties employed in modelling of the flat plate solar collector are presented in Table 11. This shows the values of the total cell count, fluid cells, solids cells, etc as shown in Table 12. This mesh analysis was gotten after using the mesh dimensions and the sizes of the computational domain.

**Table 12.** Analysis of Mesh.

| | |
|---|---|
| Total cell count | 79740 |
| Fluid cells | 20139 |
| Solid cells | 13480 |
| Partial cells | 46121 |
| Trimmed cells | 0 |
| Heat transfer analysis | Heat conduction in solids |
| Flow type | Laminar and turbulent |
| Time- dependent analysis | Off |
| Gravity | On |
| Radiation | On |
| Humidity | 50.0% |
| Default Wall Roughness | 1.0 micrometer |

## 3. RESULTS AND DISCUSSION

The collector system where simulated using Flow Simulator on Solidworks interface, the input parameters were estimated from system design and thermodynamic analysis and some of the input parameters are designed conditions set by the Flow Simulator considering ambient and boundary conditions.

**Table 13.** Input/output parameters.

| Name | Input | Output |
|---|---|---|
| Pressure [Pa] | 101291.63 | 107615.07 |
| Temperature [K] | 299.08 | 331 |
| Density (Fluid) [kg/m^3] | 1.15 | 995.74 |
| Velocity [m/s] | 0 | 6.790 |
| Velocity (X) [m/s] | -4.487 | 5.470 |
| Velocity (Y) [m/s] | -5.760 | 2.214 |
| Velocity (Z) [m/s] | -4.716 | 3.292 |
| Mass Fraction of Steam [ ] | 0 | 0.0041 |
| Mass Fraction of Air [ ] | 0 | 0.9959 |
| Mass Fraction of Water [ ] | 0 | 1.0000 |
| Volume Fraction of Water [ ] | 0 | 1.0000 |
| Temperature (Fluid) [K] | 299.08 | 315.56 |
| Temperature (Solid) [K] | 299.13 | 327.88 |
| Mass Fraction of Condensate [ ] | 0 | 0 |
| Mass Fraction of Vapour [ ] | 0 | 0 |
| Volume Fraction of Vapour [ ] | 0 | 0 |
| Density (Solid) [kg/m^3] | 2600.00 | 8960.00 |
| Mach Number [ ] | 0 | 0.02 |
| Vorticity [1/s] | 0.031 | 1037.197 |
| Shear Stress [Pa] | 0 | 1.80 |
| Relative Pressure [Pa] | -33.37 | 6290.07 |
| Prandtl Number [ ] | 0.6956699 | 5.8635293 |
| Efficiency [%] | 0 | 0.51 |
| Relative Humidity [%] | 0 | 20.02 |
| Heat Transfer Coefficient [W/m^2/K] | 0.001 | 6620.796 |
| Surface Heat Flux [W/m^2] | -520.709 | 18453.624 |
| Heat Flux [W/m^2] | 0.032 | 1450886.891 |
| Overheat above Melting Temperature [K] | -1053.927 | -765.702 |

Table 13 shows the input parameters and the output parameters used during the simulation of the flat plate solar collector on the Solidworks interface. The output parameters are then compared with results gotten from the collector thermodynamic analysis results, which is then validated using the developed model with the experimental results.

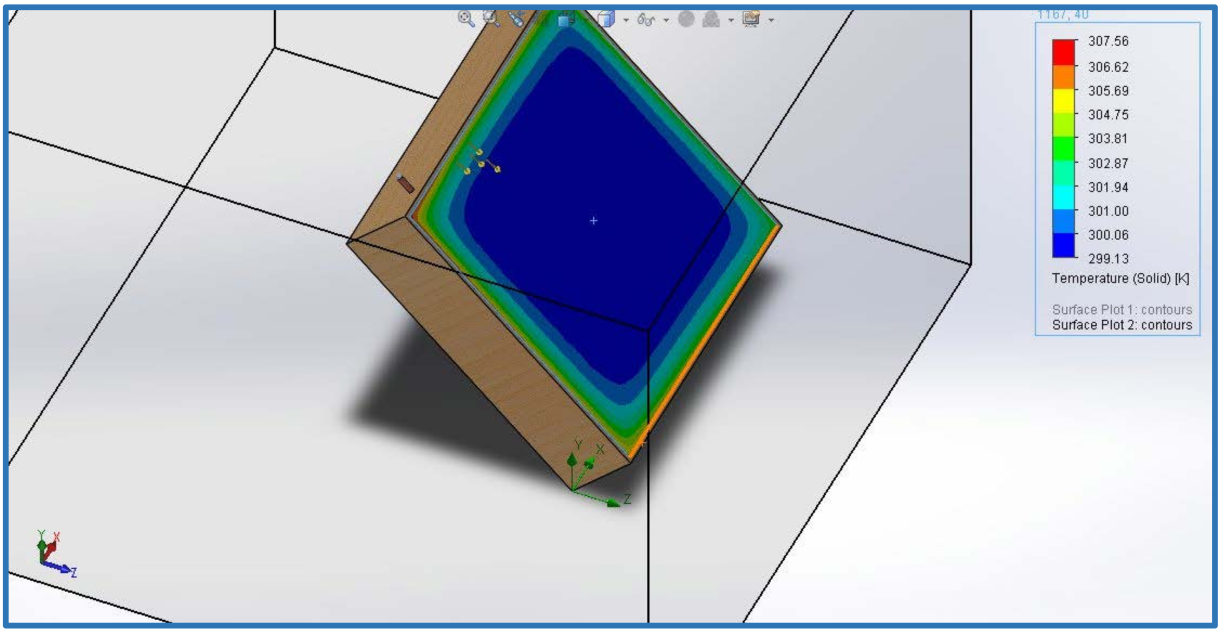


**Figure 1.** Glass Temperature after Simulation.

Figure 1 indicates that the glass did not lose much heat to the atmosphere, it acts as a thermal cover to protect the flat plate solar collector against heat loss. The blue colour around the mid area indicates that there was no heat loss around that region, as it moves towards the edge of the collector it shows a mixture of colour showing little heat loss at the edge.

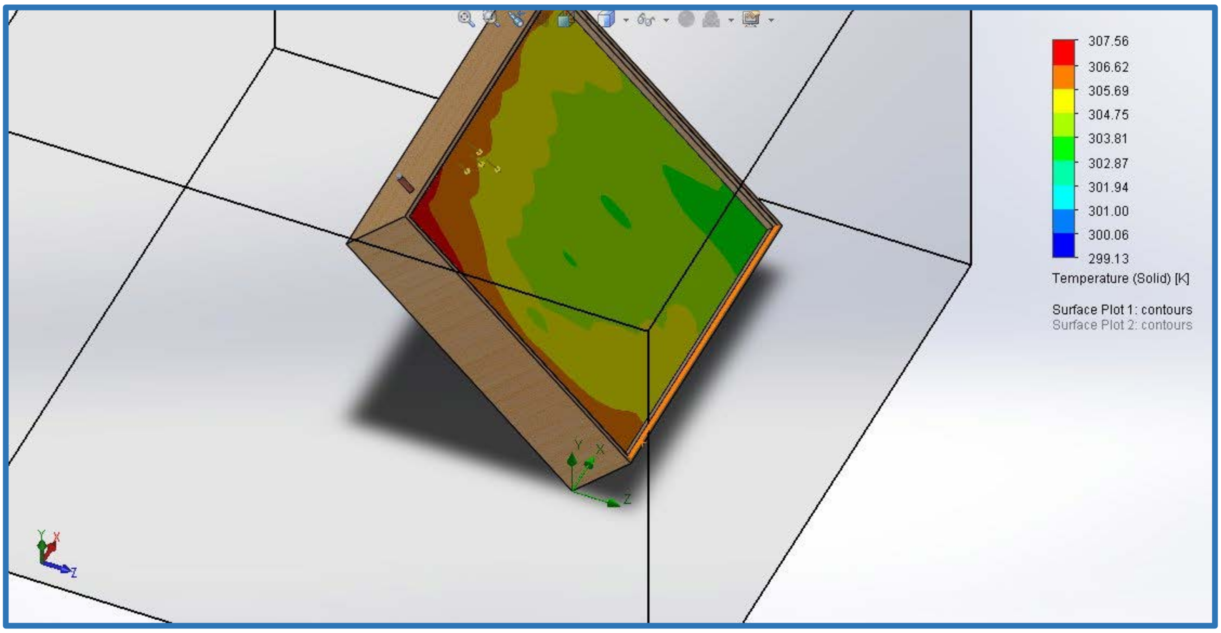


**Figure 2.** Plate Temperature after Simulation.

Figure 2 indicates that the plate temperature after simulation shows a mixture of colours and also show red which is the colour code form the maximum temperature achieved at the inlet temperature of $299.13^{O}C$, it acts as a thermal cover to protect the flat plate solar collector against heat loss. This means the absorber plate efficiently passed the heat to the heat pipe.

**Table 14.** Temperatures gotten from simulation without preheat.

| Day | Inlet temp (K) | 10am Outlet Temp (K) | 11am Outlet Temp (k) | 12:00NOON outlet temp (K) | 1:00PM outlet temp (K) | 2:00PM outlet temp (K) | 3:00PM outlet temp (K) |
|---|---|---|---|---|---|---|---|
| 17th Jan | 295 | 305 | 313 | 321 | 324 | 326 | 328 |
| 16th Feb | 295 | 303 | 310 | 318 | 320 | 322 | 325 |
| 16th Mar | 295 | 303 | 310 | 316 | 319 | 322 | 324 |
| 15th Apr | 295 | 300 | 304 | 310 | 305 | 304 | 304 |
| 15th May | 295 | 300 | 303 | 302 | 305 | 302 | 302 |
| 11th Jun | 295 | 297 | 302 | 299 | 297 | 300 | 299 |
| 17th Jul | 295 | 297 | 301 | 300 | 299 | 297 | 301 |
| 16th Aug | 295 | 299 | 302 | 306 | 308 | 310 | 310 |
| 15th Sep | 295 | 302 | 302 | 305 | 310 | 312 | 315 |
| 15th Oct | 295 | 304 | 308 | 318 | 320 | 322 | 322 |
| 14th Nov | 295 | 304 | 310 | 318 | 318 | 324 | 326 |
| 10th Dec | 295 | 305 | 310 | 319 | 322 | 325 | 330 |

Table 14 shows the temperature that was gotten from the simulation, the inlet water was allowed to flow into the system from 10am to 3pm. At an interval of one hour, it was also observed that the temperature was highest for January, December and lowest for June, July respectively.

**Table 15.** Temperatures gotten from simulation with preheat**.**

| Day | Inlet temp (K) | 12:00NOON outlet temp (K) | 1:00PM outlet temp (K) | 2:00PM outlet temp (K) | 3:00PM outlet temp (K) |
|---|---|---|---|---|---|
| 17th Jan | 295 | 343 | 343 | 344 | 348 |
| 16th Feb | 295 | 338 | 338 | 339 | 341 |
| 16th Mar | 295 | 333 | 332 | 333 | 333 |
| 15th Apr | 295 | 327 | 325 | 326 | 323 |
| 15th May | 295 | 322 | 322 | 320 | 318 |
| 11th Jun | 295 | 320 | 319 | 317 | 314 |
| 17th Jul | 295 | 321 | 320 | 319 | 316 |
| 16th Aug | 295 | 325 | 324 | 324 | 322 |
| 15th Sep | 295 | 330 | 330 | 330 | 330 |
| 15th Oct | 295 | 336 | 336 | 337 | 338 |
| 14th Nov | 295 | 341 | 342 | 343 | 346 |
| 10th Dec | 295 | 344 | 344 | 346 | 350 |

Table 15 shows the temperature that was gotten after preheating the flat plate solar collector from 9am to 12noon. It shows an increase in temperature when compared to the temperatures gotten without preheating.

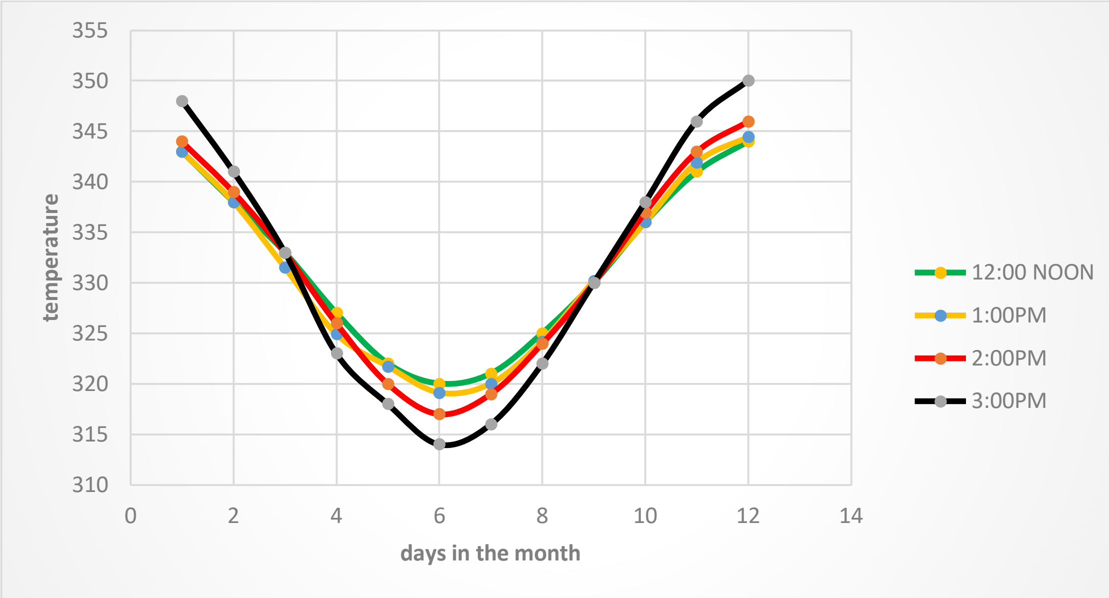


**Figure 3.** A graph of temperature against days in the month.

The graph shown in figure 3 indicates that the outlet temperatures increases in the beginning of the year with the first few months (dry season) and it goes down towards the middle of the year (raining season) and rises again towards the last few months of the year (dry season).

## 4. CONCLUSION

The flat plate solar collector was simulated using SolidWorks, an output temperature of $58^oC$ and an efficiency of 51% was achieved respectively. The obtained temperature can be used for domestic and some industrial applications. The analysis was done for both preheat and without preheat, preheat occurs when the flat plate collector system is place outside under open sky for direct contact with the sun for some hours before passing water through the system. The condition for without preheat involves passing water from the supply tank into the collector without allowing the flat plate solar collected to be heated before opening the water supply tank.

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