Proceedings of the 11th World Congress on Mechanical, Chemical, and Material Engineering (MCM'25)
Paris, France - August, 2025
Paper No. HTFF 109
DOI: 10.11159/htff25.109

Design and Analysis of Moveable Solar Water Heater

Haifa El-Sadi and Sammy Riadi
Wentworth Institute of Technology
550 Huntington,
Boston, MA, USA 02115,
elsadih@wit.edu

Abstract **-** Solar water heating systems are a fantastic way to harness the sun's energy to heat water for domestic use. By converting solar energy into thermal energy, these systems can significantly reduce reliance on traditional energy sources and lower energy costs. Solar water heaters provide a wide range of benefits. Such as the reduction of energy cost consumption, and environmental sustainability. However, there are inconveniences with this type of technology. It will be influenced by location, weather, system designs, and quality of the components.

The aim of this project is to improve the design of solar water heater components such as solar collectors, water tank, piping system, and pump using SolidWorks. SolidWorks was used to simulate conditions akin to Boston, Massachusetts, in early July, around noon, which is considered optimal for real-life testing. Factors such as head loss in each connection and variations in water temperature within the piping and the pump have not been fully accounted for. The flow rate of water at the intake and outtake points may fluctuate based on the water's temperature, introducing uncertainties into the system's performance. Moreover, the outtake area can be influenced by the sizing of the pipes, thereby impacting the efficiency of the pump. Changes in pipe sizing could alter the flow dynamics, affecting the overall efficiency of the system. These complexities highlight the need for further analysis and refinement to ensure accurate modeling and interpretation of results.

On the other hand, the system was designed to optimize the energy capture by continuously adjusting the position of the solar panels to follow the sun's path. We faced some setbacks when assembling the motors to the base and collector frame, including alignment issues and motor synchronization challenges. These hurdles required careful calibration and iterative adjustments to ensure that the motors operated smoothly and accurately. Despite these initial difficulties, the solar tracking system ultimately met and even exceeded its objectives.

Keywords**:** solar water heater, pump, collector, pipe, design, SolidWorks

1. Introduction

Solar water heaters are designed to be powered by the sun, a process dating back to ancient Roman times. American Indians used solar energy to heat their homes. During the 1500s, the Dutch began to use glass walls to increase the exposure of the sun to grow their vegetables year-round. In the 1880s, solar water heaters began to circulate in Baltimore and made their way to California and Florida. Solar water heaters then began to fade slightly due to cheap natural gas and electric power. Solar energy then took another turn and began to rise in 1973 due to the oil embargo and rising oil/natural gas prices. Today, solar power is becoming more prevalent as time goes on to combat climate change and pollution and offers lower costs than oil or gas. The solar water heater is just one application of clean energy and one we would like to focus on. Extensive work on improving the thermal efficiency of solar water heaters resulted in techniques to improve the convective heat transfer. Passive technique has been used to augment convective heat transfer. These techniques, when adopted in solar water heaters proved that the overall thermal performance improved significantly [1]. Heat exchangers are indeed a critical component of solar water heating systems. They play a crucial role in transferring heat from the solar collector to the storage tank. El-Sadi et al.'s work on designing and analysing different heat exchangers is valuable for optimizing the performance of solar water heating systems [2, 3]. On the other hand, El-Sadi et al.'s research on different heat exchanger sizes such as micro and macro scales is valuable for optimizing the performance of solar water heating systems. Where the thermal efficiency of the heat exchanger can be influenced by factors like the surface area, flow rate, and temperature difference [4]. E. Natarajan et. al. research showed that the fluids with nanosized solid particles suspended in them are called "nanofluids." The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Nanofluids are expected to exhibit superior heat transfer properties compared with conventional heat transfer fluids [5]. Also previous studies revealed that a theoretical and experimental analysis of the thermal performance of a solar water heater prototype with an internal exchanger using a thermosiphon system [6]. Jamar et al. discussed the latest developments and advancements in solar water heaters, focusing on three key components that can significantly impact the system's thermal performance. Also it provides a comprehensive overview of solar water heater technology, including a detailed discussion of various solar collector types., including both the non-concentrating collectors (flat plate collector, evacuated tube collector) and the concentrating collectors (parabolic dish reflector, parabolic trough collector) [7].

2. Design and manufacturing process

2.1. Design and Analysis

SolidWorks has been used to design and analyze the solar water heater system. Different design iterations have been created and modified, allowing for rapid experimentation and optimization. As shown in Figure 1, the 3D models of design of Solar Collector Piping provide a clear visual representation of the system, aiding in understanding the system.

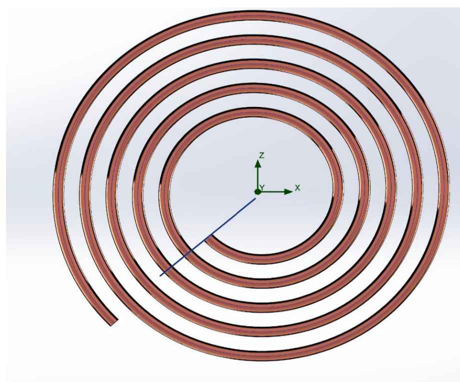

Fig. 1 SolidWorks Design of Solar Collector Piping

Engineering equation solver (EES) [8] has been used to simulate heat transfer within the system, helping to predict thermal performance under different conditions as shown in the code and the results for Heat Transfer on EES below:

```
"GIVEN"
Temp = 80 [F]
Density = 1000 [kg/m^3]
V =2.5 [m/s]
k= 0.98 [W/(m*C)]
Cp_w=4.18 [kJ/kg C]
D= 0.6096 [m]
A_c = (pi*(D)^2)/4 [m^2]
M_dot = density*V*A_c
D_i = 0.0127 [m]
D_o = 0.015875 [m]
L_pipe=0.6096 [m]
W = 0.0254 [m]
Dynamic viscosity = 3.178*10^ (-5) [kg/(m*s)]
Emissivity= 0.9
k_pipe= 398 [W/(m*C)]
Stefan_boltzman = 5.67037 *10^ (-8) [W/(m^2*k^4)]
temp_2= 100 [F]
L_glass = 0.0254 [m]
```

```
"ANALYSIS"
Pr = (Dynamic viscosity*Cp_w)/k
T_s = (temp_2-32) *5/9 +273 [K]
T_in=(temp-32) *5/9 +273 [K]
Re=(density*V*D)/Dynamic viscosity
Nu= 0.664*Re^0.5*(Pr^ (1/3))
h_o = k*Nu/ D_o
h_i = k*Nu/ D_i
T_out = T_s -(T_s-T_in)*exp(-h_o*A_o/(M_dot*Cp_w))
A_i=pi*D_i*L_pipe
A_o=pi*D_o*L_pipe
R=1/(h_i*A_i)+ln(D_o/D_i)/((2*pi*k_pipe*L_pipe)+1/(h_o*A_o))
U*A_i= 1/R
DELTAT_1=T_s-T_in
DELTAT_2=T_s-T_out
DELTAT_lm=(DELTAT_2-DELTAT_1)/ln (DELTAT_2/DELTAT_1)
Q_dot=U*A_i*DELTAT_lm
A_g= L_glass*W
Q_rad= A_g* Stefan_boltzman* Emissivity*(T_s^4 -T_out^4) [W]
Q= Q_dot+ Q_rad [W]
```

Unit Settings: SI C kPa kJ mass deg

A_c = 0.2919	A_g = 0.0006452	A_i = 0.02432	A_o = 0.0304	Cp_w = 4180
D = 0.6096 [m]	ΔT_1 = 85.76	ΔT_2 = 22.91	ΔT_{lm} = 47.62	Density = 1000 [kg/r
$Dynamic_{viscosity}$ = 0.00003178	D_i = 0.0127 [m]	D_o = 0.01588 [m]	Emissivity = 0.9	h_i = 3.310E+07
h_o = 2.648E+07	k_{pipe} = 398 [W/(m*C)]	k_{water} = 0.98	L_{glass} = 0.0254 [m]	L_{pipe} = 0.6096 [m]
$\dot{M}$ = 145.9	ν = 1056	Pr = 0.1356	Q = 322557	$\dot{Q}$ = 322557
Q_{rad} = 0.1582	R = 0.0001476	Re = 9.591E+06	$Stefan_{boltzman}$ = 5.670E-08	T_{in} = 299.8 [K]
T_{out} = 362.7	T_s = 385.6 [K]	U = 278520	V = 0.5 [m/s]	w = 0.0254 [m]

Using SolidWorks to design and analyze multiple pump models including the impeller design, as shown in figure 2, can help to identify the most efficient design, the most efficient pump design was 82.8%. Figure 3 shows the design for Dual Axis Collector Stand including the collector, pump and the stand.

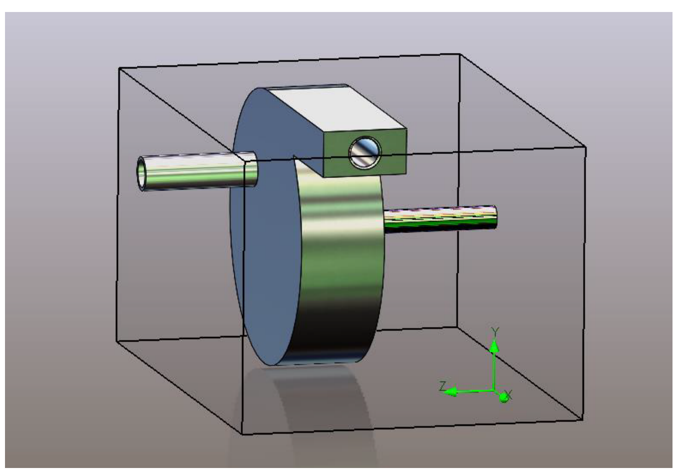

Fig. 2 *Complete Assembly View of Pump*

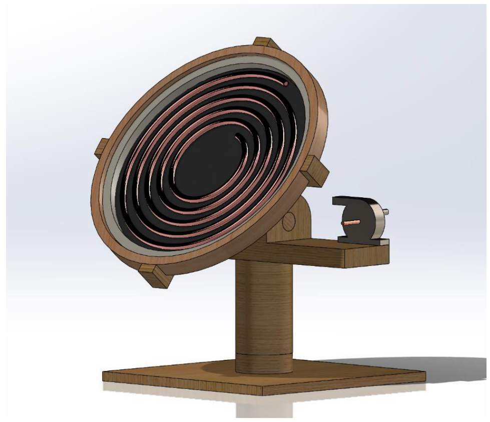

Fig. 3 Design for Dual Axis Collector Stand

2.2. Manufacturing process

1. Shaping the Pipe: a. Use pipe bender to carefully bend copper into a spiral shape b. Start with an initial diameter of 24 inches and gradually increase the angle until it is about 6 inches in diameter in the center.

2. Assembling the Collector: a. Start with screwing on the pieces of the 3D printed rim onto the wooden base b. Cut insulation into the correct shape and to the bottom and sides of the inside of the collector. c. Place aluminum backing on the bottom side of the inside of the collector and screw it into the wooden base on top of the insulation. d. Take copper piping and use pipe fasteners to secure it to the base. e. Bring the collector to the painting area and spray the paint on the internals of the collector black. f. Install tempered glass on the very top of the collector.

3. Assembling Pump a. Submit STL files for 3D printing. b. Assemble pump along with DC Motor. Connect pipes to the pump and water bucket.

4. Assembling and Testing Entire System a. Connect collector and pump. b. Record the environmental conditions of the day (temperature, atmospheric pressure, cloud cover). c. Place the solar collector in direct sunlight for 15 minutes. d. Record the temperature of water in the bucket. e. Turn on the pump. f. Record the temperature of the water coming out of the collector.

3. Results

Solar radiation settings were conducted to simulate conditions akin to Boston, Massachusetts, in early July, around noon, which was considered optimal for real-life testing. Through this experimental testing, the temperature of the continuous water flow was taken every 5 minutes. The solar water heater system was able to heat the continuous water flow to a maximum temperature of 89.4 degrees Fahrenheit as shown in Figure 4. This is a significant achievement, as it demonstrates the system's ability to effectively harness solar energy and convert it into usable heat.

The second test involved letting the water sit inside the collector for 15 minutes. This test got much higher temperatures and much better results. The water ended up at much higher temperatures when exiting the collector. Overall, it was a successful test and showed that the collector can heat water. Another successful part of our project was its solar tracking system. This system was designed to optimize the energy capture by continuously adjusting the position of the solar panels to follow the sun's path. We faced some setbacks when assembling the motors to the base and collector frame, including alignment issues and motor synchronization challenges. These hurdles required careful calibration and iterative adjustments to ensure that the motors operated smoothly and accurately. As shown in figure 5, the temperatures were taken every 15 minutes, as the solar collector absorbs more energy, the temperature of the stored fluid (and the collector itself) increases rapidly. This is especially noticeable in non-continuous flow systems where the heat is not continuously removed.

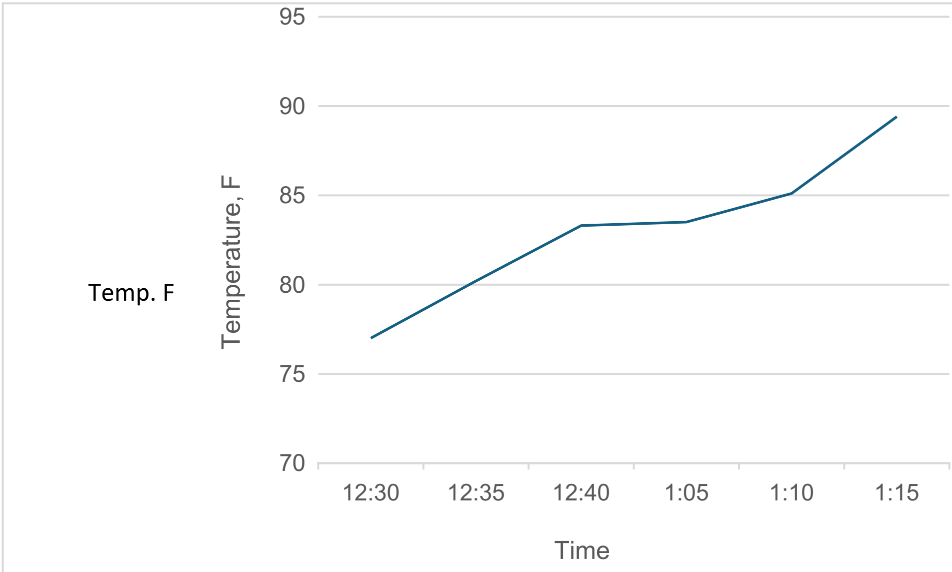

Fig. 4: Temperatures vs time for continuous water flow

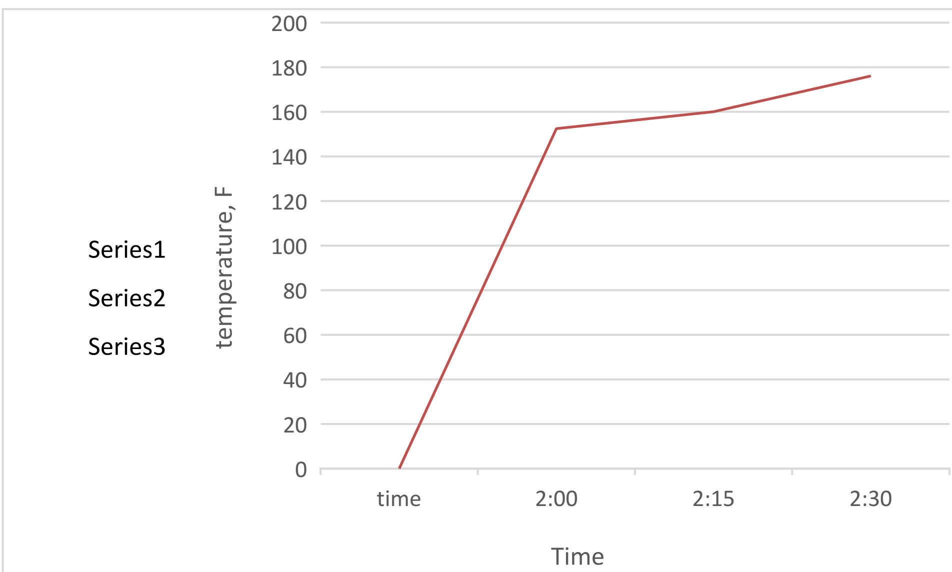

Fig. 5. Temperatures vs. time for noncontinuous flow of water

4. Conclusion

This research involves the integration of a comprehensive system comprising a water tank, pump, piping system, and solar collector. Within solar energy utilization, both passive and active systems offer the abilities for harnessing the sun's power. Passive systems involve strategic use of specific materials or architectural designs to optimize solar radiation for heating and lighting. A water pump is used to circulate water through the solar collector. The water is heated as it flows through the collector and is then stored in an insulated tank for household use. The core component, the solar collector, captures and absorbs solar radiation, converting it into heat. This heat is then transferred to the water circulating through the system. In a non-continuous flow system, the temperature can indeed rise more rapidly than in a continuous flow system. This system was designed to optimize the energy capture by continuously adjusting the position of the solar panels to follow the sun's path.

References

[1] S. Jaisankar, J. Ananth, S. Thulasi, S.T. Jayasuthakar, K.N. Sheeba, “A comprehensive review on solar water heaters”, Renewable and Sustainable Energy Reviews , Volume 15, Issue 6, August (2011), Pages 3045-3050, ELSEVIER.

[2] Haifa El-Sadi, Herb Connors, “Experimental studies of Heat Exchangers for Diesel Generator”, International Journal of Advanced Network, Monitoring and Controls. Volume 8, No.3, (2023).

[3] Haifa El-Sadi*, Joe Aitken, Jason Ganley, David Ruyffelaert, Cam Sweeney”, Design Heat Exchanger: optimization and efficient”, International Journal of Advanced Network, Monitoring and Controls, Volume 05 (2020), Issue 3, Page range: 30-35.

[4] Haifa El-Sadi, Nabil Esmail and Andreas K. Athienitis, “High Viscous Liquids as a Source in Micro- Screw Heat Exchanger: Fabrication, Simulation and Experiments”, 10.1007/s00542-006-0366-x, 0946-7076, Journal of Microsystem Technologies, (2007)

[5] E. Natarajan and R. Sathish, “Role of nanofluids in solar water heater”, special issue - original article, Published: 01 July The International Journal of Advanced Manufacturing Technology, (2009)

[6] P.M.E. Koffi, H.Y. Andoh, P. Gbaha, S. Touré, G. Ado, “Theoretical and experimental study of solar water heater with internal exchanger using thermosiphon system”, Energy Conversion and Management, Volume 49, Issue 8, August (2008), Pages 2279-2290

[7] A. Jamar, Z.A.A. Majid, W.H. Azmi, M. Norhafana, A.A. Razak, “A review of water heating system for solar energy applications”, International Communications in Heat and Mass Transfer Volume 76, August 2016, Pages 178-187

[8] Haifa El-Sadi, “Using Engineering Equation Solver (EES) to Solve Engineering Problems in Mechanical Engineering”, Paper No. IMECE2018-86078, pp. V005T07A040; 4 pages, doi:10.1115/IMECE2018-86078, 2018