Kingdom of Saudi Arabia

Prince Sattam bin Abdulaziz University

College of Engineering

Mechanical Engineering Department

DESIGN AND ANALYSIS OF SOLAR WATER HEATER

Students :
Abdulrahman Al Ruwaita, Meshal Tareq Al Harbi, Moath Mohammed Al Sulaiman, Thamer Naif Al Enazi

Supervised by :
Dr. Ibrahim B. Mansir, Dr. AbdelKader Saad

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جامعة الأمير سطام بن عبد العزيز
Prince Sattam Bin Abdulaziz University

ABSTRACT

Flat plate solar water heating systems working based on Thermosyphon are renewable energy systems that make use of freely available solar energy to heat water. Many factors are involved in a detailed design and analysis of a flat plate solar water heater. The most important subsystems are the solar collector, transport fluid and distribution system, hot-water storage container, and control system. A flat plate solar water heater has been designed in this project based on Alkharj solar energy with capability of heating 200 liters of water by about 13 - 26ºC daily for four days in November 2020. The design was assembled, and experiments were conducted to obtain heating profiles. The same system was simulated using systems advisor model (SAM) software and the results were also compared to the heating profiles obtained experimentally.

OBJECTIVES

- Design of the solar water heater.
- Experimental analysis of the solar water heating system.
- Simulation of the solar water heater system using SAM software.
- Compare between experimental and simulation results.

CONSTRAINTS

Our study takes in consideration the following constraints:

- Economy
- Ethical
- Safety
- Sustainability
- Environment
- Political
- Social
- Technical

DESCRIPTION

The flat plate solar water heating system consists of four main parts (Figure 1): ***Solar collector:*** This device consist of Glazing cover, Absorber, Tubes, Insulation material and Support structure. It absorbs large portion solar energy and transfer it to the transport medium in the pipes for storage or use. ***Storage tank:*** It stores the hot water and retains its temperature. ***Pipes:*** For connecting the collector to the tank and transporting fluid. ***Supporting structure:*** For holding the system together.

Thermosyphon: As the water in the collector heats up, it rises into the top of the tank, causing cold water from the bottom of the tank to flow down into the collector. This natural circulation continues due to the water density gradient caused by the temperature difference.

DESIGN

The design of flat plate thermosyphon solar water heater involve several considerations:
- Desired hot water temperature.
- Solar energy availability at the location.
- Required volume of water.
- Material selection.
- Heat transfer characteristics.
- Cost. Etc.

Figure 1: Solar water heater diagram.

Figure 2: Solar water heater system assembly.

MATHEMATICAL MODELING

The collector energy balance is given by:

$$\dot{Q}_u = A_c F'[I_T(\tau\alpha) - U_L(T_{fm} - T_a)]$$

The collector efficiency factor F' is given by:

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[D+(W-D)F]}+\frac{1}{C_b}+\frac{1}{\pi D_i h_{f,i}}\right]} \qquad F = \frac{\tanh[m(W-D)/2]}{m(W-D)/2}$$

The overall loss coefficient U_L is given by:

$$U_L = U_b + U_e + U_t$$

$$U_e = (UA)_{edg}/A_c = (k/L)_{edg} * Pt/A_c$$

$$U_b = k/L$$

$$U_t = \left(\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_a}{N+f}\right]^e} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma(T_{pm}+T_a)(T_{pm}^2+T_a^2)}{\frac{1}{\varepsilon_p + 0.00591\,Nh_w} + \frac{2N+f-1+0.133\,\varepsilon_p}{\varepsilon_g} - N}$$

Heat absorbed by the water: $\dot{Q}_u = \dot{m}C_p(T_{out} - T_{in})$

Collector thermal efficiency: $\eta_c = \dot{Q}_u / I_T A_c$

EXPERIMENTS

The experiments were conducted using the system shown in Figure 2 in November 2020. The parameters of interest were Solar irradiance and water temperatures on hourly basis.

The following procedure was adopted:
- Cleaning the collector from dust.
- Installing the measuring instruments.
- Switching on the measuring instruments and allowing them to reach steady state.
- Record the readings.
- Repeat the measurements hourly (8am to 4pm)

SAM SIMULATION

SAM is a free techno-economic software model for renewable energy analysis. We uses a Typical Meteorological Year of Alkharj, KSA, for the simulations. Figure 3 shows the simulation steps.

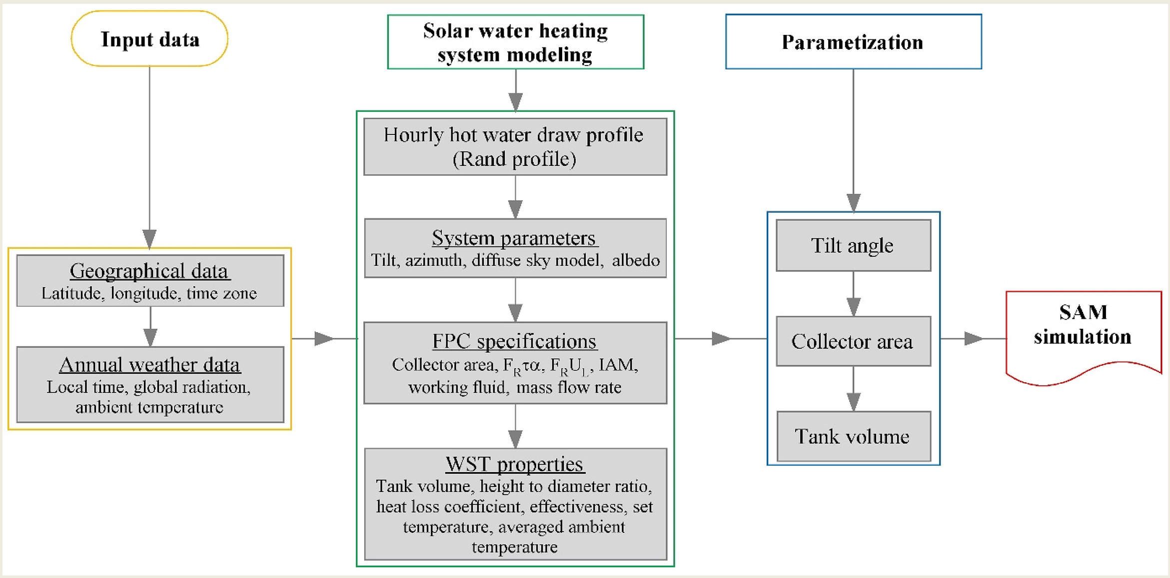

Figure 3: Simulation steps in SAM.

RESULTS

The following are experimental results on Nov. 9th

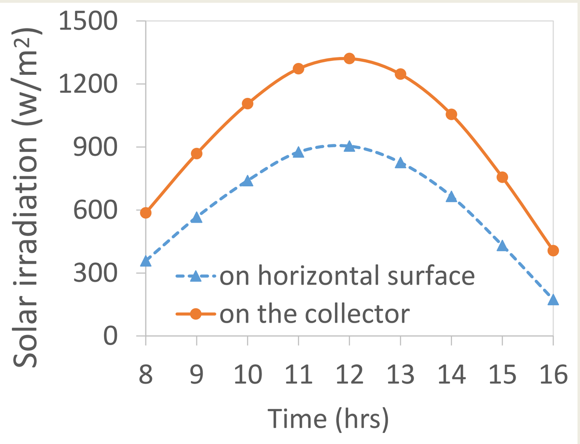

Figure 4: Measured solar irradiance.

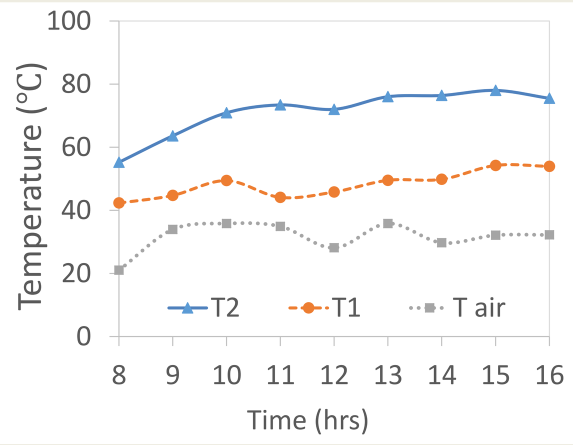

Figure 5: Measured temperatures.

COST ANALYSIS

The collector and storage tank represents about 80% of the total cost. The total cost of the solar water heater is around **2,300 SAR**.

CONCLUSION

- Thermal design of this SWH involved modeling of the thermal processes and solving the model to obtain the heat transfer characteristics, collector efficiency, as well as the required geometrical specifications.
- The SWH system components were acquired based on the modeling and the system was assembled. Experiments were conducted for four days and the water heating profiles were obtained.
- The SWH system was simulated using SAM.
- Safety was considered by isolating the SWH.