PROPOSED SOLAR POWERED WATER HEATING SYSTEM FOR BABYLON – IRAQ USING TRANSIENT SYSTEM SIMULATION (TRNSYS) TOOL

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Abstract

Based on the basic principles of thermodynamics, and heat transfer, this paper presented a model of a solar water heating system (SWHS) with the aim of improving on the performance of the system. The annual thermal performance of the SWHS was simulated on the TRNSYS platform. The typical Babylon weather situations, the fluctuations in water temperature within the storage tank, and the inlet and outlet temperature of the collector were investigated. Other parameters considered by the simulation include the sum of solar emission and the difference in heat collector efficiency. The development of a model simulating the SWHS is key to determining the parameters for operating the components. It makes room for selection of necessary parameters required in improving the overall performance of the SWHS. This study provides theoretical guidance for operating the solar hot water system.

Keywords: Solar water heater, TRNSYS, Solar fraction, Storage, Efficiency.

I. Introduction

Actually, energy demand and conversion are part of the basic human requirement to meet daily needs. Energy efficiency and affordability are strongly linked to the socio-economic well-being of a society. To this end, there are economic and health benefits attached to innovative ways of converting and managing energy. The Sustainable development goal 7 (SDG-7) advocated that energy should be affordable and clean. The implications were that renewable energy should be promoted over the non-renewable type of energy [VII].

The issues with non-renewable energies are the long period it takes before regaining it once they are exhausted. The fact is that the non-renewables also less environmental friendly. On the other hand, the rate at which renewable sources of energy are replenished is faster. These types of energies are not exhausted over a very long period, if only they are exhaustible within a timeframe, because they are self-rechargeable in nature [IV]. Solar energy is one of the most abundant sources of...
renewable energy derived from the sun rays. The sun is located at the center of the solar system, and has a surface temperature of about 5762°C. The power from this radiation was estimated at about 1.353 kW/m³ delivered to the exterior part of the earth in the atmosphere [VI].

When put to use, the solar energy has the ability to drastically reduce the carbon dioxide emission from fossil fuels, by curtailing its use. The continuous exploration of the potentials in solar energy may substitute for the dependence on the fossil fuels in the nearest future.

Solar water heater designers and manufacturers are preoccupied with the challenges of the feasibility and viability of SWHS. Such challenges are better confronted at the pre-design stage by developing computational studies that would allow stakeholders to predict the thermal performance of SWHS. Through this kind of simulations, the parameters such as the payback period may be projected. The relevance of such predictions when done effectively is in the rise in the level of acceptance and penetration of the SWHS.

The capacity and credibility of the TRNSYS in simulating and designing systems related to the solar system had been justified by scholars such as Shrivastava, Kumar [X]. The basis for ranking this tool high in terms of accuracy and dependability was the rigorous validations, innovations and assessments it had passed through. Additionally, it is affordable, user friendly, systematically comprehensive and require extensive meteorological data for optimum functionalities Tsilingiris [XI].

The potentials of this simulation tool was demonstrated in the studies conducted by Shariah, Rousan [IX]. The authors applied the TRNSYS in predicting the performance of SHW using the absorber plate thermal conductivity as a parameter. The potentials of this tool was equally demonstrated five years later in the findings of [II] using 30 years weather historical data extracted from the USA database on TRNSYS. The aim of the study was to mimic the SDWH system using the pipe-freeze model.

In a study targeted at determining the most appropriate design parameters for the adoption of thermo-siphon SWH system in Jordan, El-Sebaii and Al-Snani [III] sampled Amman and Aqaba conditions. The tool used in the simulation was TRNSYS. It turned out that the efficiency of the sunlight based division of the proposed system required improvement of 10±25%, giving due attention to each parameter. Additionally, the submissions were that the sun powered portion of the Aqaba (sweltering atmosphere) was less sensitive below the required standard, in comparative to the Amman (gentle atmosphere) scenario. The interpretation here is that an improvement was required for optimum benefications of the design.

The basis for the transient mathematical model advanced by [I, XII] was the energy balance equations. The study applied the analytical solution option in predicting the functionality of a single pass flat plate solar air heater. The accuracy of the model was adjoined to be good in measuring the projected parameters. The performance assessment of different coating materials on the thermal efficiency of the heater was investigated using computer simulation. The Ni-Sn selective coating material was
reported to outperform other black painted and selectively coated materials Shariah and Shalabi [VII]. This means Ni-Sn are suitable for coating plates.

The direction of research as far as SHWS is concerned is towards the integration of these systems with high-rise buildings and the monitoring of solar hot water projects for optimization. The justification for these integrated system was to promote the feasibility of adopting these technologies for application in urban buildings. The noble idea presented by Habeeb et al. [V] failed due to poor performance analysis. The study targeted the possibilities of delivering hot water throughout the year. However, issues of obstructions, placement of collectors, performance of different collectors and other influencing factors hindered a suitable assessment of the link between the parameters.

The integration of thermal storage system proposed in the findings was done to harness the huge energy resources from the solar for water heater. The centralization method targeted the high-rise and residential facilities for thermal storage. An assessment of the architecture of the proposed design showed that the system required significant improvement in the collector design. The study considered the design of collectors, mainly to improve on the heat collection capability, the structure and architectural appearance of the SWHS.

The gap here are in two folds. These studies were silent on the possibilities of exploring the solar energy for obtaining hot water in a cold winter day in a geographical location like Baghdad. Secondly, the aforementioned studies failed to consider contemporary technological and economic realities in Iraq, and bulk of the studies concentrated on numerical analysis without experimental validation of proposed models.

The objectives of the current study are to deliver a feasible and viable system of providing hot water in the cold winter days to the Baghdad province, using energy from solar through simulation on TRNSYS platform. The validation of the simulation model using experimental data to measure the field performance of the model forms the second objective of this paper. The analyses covered the changing direction of system parameters under normal operating conditions and system efficiency. This was done with the aim of solving the challenges caused by time and space constraints. The values added are improvement in the efficiency of the solar hot water system and reduction in energy waste. The benefits derivable from this study transient the technical and economic advantage, to promoting the cleaner and sustainable source of energy within the SDG-7 in Iraq.

II. TRNSYS Components Selection

The library of TRNSYS application is well equipped with various components required in performing the simulation of numerous energy systems. Relevant components required in the numerical analysis of SWHS were carefully chosen and coupled on the TRNSYS 16 simulation studio as shown in Fig.1. The design was done to replicate the conventional hot water demand used in houses to be powered by solar heating system.
III. Solar Water Configuration System

The system was made of various flat plate collectors (FPC) with total area of 5 m², and mass flow rate of 40*A coll. These were used in testing the conventional FPC for solar water heater.

Iraq has abundant sunshine, with completely clear skies during the day. Outside the highland areas, temperatures generally range from 27 °C to 45 °C in day time. This temperature rarely, if ever, drops below 8 °C at night. The average temperature is 30 ±5 °C. In this design, the optimum slope angle of the FPC was taken as 15 °C, since this was sufficient in tracking the energy from the sun. Other parameters used in the experiment are as listed below;

Fig.1: SWHS component coupled for modelling

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A cylindrical storage tank with height: diameter ratio of 3.

The system was installed with an auxiliary heater to augment as a boiler for low temperature of the outgoing water from the storage tank to the user. This heater supports the heating process to deliver the expected hot water to the consumer as may be demanded.

The direct-system was equipped with a circulator pump to support the delivery of the water between the plate collectors and the storage tank.

The Time Dependent Forcing Function was used in controlling the pump. A load profile of the estimate for daily consumption in the month of July is presented in Fig.2.

**Fig.2:** An illustration of the load profile for daily consumption in July, 2019

**IV. Mathematical Model**

In order to develop a mathematical model for predicting the transient performance of the SWHS, parameters such as solar radiation, heat dissipation factors and delivery rate of the external auxiliary heater were selected on the computer program. The simulation result is usually a result of the parameters selected, therefore this was done in accordance with the National Solar Radiation Data Base (USA).

**A. Analysis of Solar Radiation**

The basis for the analysis of solar thermal water heating system was done using the monthly average hourly global irradiation. This was used in determining the angle of inclination of the collector surface when estimated with the aid of the Type
109 weather data file. This weather data file was in the TMY2 format. This same format was used in the USA National Solar Radiation Data Base. The database has the advantage of being generated using other compactible programs. In this study, the three components of radiation considered in determining the total radiation on the tilted surface were the beam, diffuse radiation and the ground reflection components of radiations.

B. **The Flat Plate Collectors (FPC)**

The efficiency of the SWHS is affected by the quantum of solar energy trapped from the radiant of the sun by the collectors. The FPC function was to serve as a medium to collect and transmit the energy from the sun for the water (the flowing fluid). The useful energy gained is directly proportional to the rise in temperature of the flowing fluid. This affect the design and operational parameters used in this design as represented in equation (1).

\[ Q_u = A_c F_R (G(\tau\alpha) - U_L (T_{it} - T_a)) \]  

Here, FR = collector heat removal parameter, \((\tau\alpha)\) was defined as the transmittance-absorbance product, UL was total loss factor, Ac = Area of the collector, G was defined as the incident radiation. Other parameters were the Tin (K) and Ta (K) correspond to the water inlet and ambient temperatures. Theoretically, FPC model type 1 may comprise of array of series or parallel connected solar collector plates.

C. **Thermal Sectioned Storage Reservoir**

In order to develop a model for the tanks that were placed in sections, the energy differences between the tanks were considered. The assumption made in this study was that the tanks were thermally stratified. The tank was presumed to consist of N fully-mixed equal volume sections (where \(N \leq 100\)). N served as a factor used in determining the degree of segmentation of the tanks. For clarification, when \(N=1\), it means the storage tank could be designed as a fully-mixed reservoir, by extension, no stratification effects considered. The choice of the Type 4 models was more appropriate as it was assumed that there are variable inlet positions. This was more practical because the water going into the tank may have different temperature with the content of the tank. The assumption was that such temperature was to be as close as possible to the temperature of the tank, which was more rationale.

D. **External Supplementary Heater**

The function of the external heater was to provide supporting heat to the flowing water when modelled. The assumption was to control the heater using an internal, external or an amalgamation of the two types of controls. In the design, the quantum of heat added to the flow stream was assumed to be determined by the user and was tagged as maximum \((Q_{max})\) when the external control input is equal to one (1). In this same condition, heater output temperature is less than a user-specified maximum \((T_{set})\).

To achieve this aim, a value constant (K) was given as a control function of one. \(Q_{max}\) was also given as a large rate. These parameters would enable the system to function like a domestic hot water auxiliary having an internal control required in
maintaining the outlet temperature of Tset. When a control function with f (0 ≤ f ≤ 1) was applied, using a thermostat or controller, the flow would mimic a furnace which will be required to add heat at a rate of \( Q_{\text{max}} \) but not greater than the outlet temperature of Tset. For the purpose of this study, constant outlet temperature is not sought and Tset may be thought of as an arbitrary safety limit.

V. Energy Performance analysis

The parameters covered in measuring the performance indicator of this study include the collected and delivered energies, losses in the supply pipe, solar fraction, efficiencies of the collector and system respectively.

- Quantum of valuable energy collected by the solar energy plate is expressed as

\[
Q_c = mC_p(T_{c,o} - T_{c,i})
\]

(2)

- Losses in pipe and deliverable energy was

\[
Q_d = mC_p(T_{sc,i} - T_{sc,o})
\]

(3)

Losses in the supply pipe occurred as a result of the drop in temperature when the fluid flow between the inlet and the outlet points of the solar coil and collector respectively. This means that the temperature of the water at inlet and outlet differs and these losses were estimated as in equation (4) before delivery to the outlet tank.

\[
Q_L = mC_p(T_{c,o} - T_{sc,i})
\]

(4)

- Solar fraction

The solar fraction (SF) is the ratio of solar heat obtained to the sum of energy demanded in heating the water represented by equation (5).

\[
SF = \frac{q_s}{q_{aux} + q_s}
\]

(5)

VI. Results and Discussions

The pump was programmed to switch to run from 7 am till 8 pm daily local Iraq time. An analogue thermostat of External auxiliary heater was deployed to maintain the temperature of the water at 45 ±2 °C. The three daily load consumptions were set at 20 l/hr, scheduled to operate from 6 am noon to 8 am, 40 l/hr scheduled to operate from 11 pm to 13 pm and 17 till 22 pm respectively.

I. Daily Performance

The variation of the solar radiation and the ambient air temperature during the month of July are shown in Fig.3. The sum of daily solar radiant was 135.3 W/m² and 1930 W/m² on heavily overcast and clear sky days respectively. The ambient air temperature during the test periods ranged from 26 °C to 32 °C during the day time.
2. **System Temperatures**

Fig.4 shows plots of daily variation in solar fluid temperature at the collector’s outlet ($T_{o,\text{coll}}$), the outlet temperature of the hot water tank ($T_{o,\text{tank}}$ or $T_{i,\text{coll}}$) and the temperature of the fluid at outlet from the External auxiliary ($T_{o,\text{aux}}$). Fig.5 shows monthly average daily delivery to the hot water tank, external auxiliary energy and the useful energy of the solar collector.

Fig.4: Daily variation of $T_{o,\text{coll}}$, $T_{i,\text{coll}}$ and $T_{o,\text{aux}}$
Fig.5: Energy delivered by the auxiliary energy and average daily energy extracted from the tank

3. The Optimum Solar Panel Size

The collector is the main component of solar water heating system therefore evaluating their thermal performance and the size was vital to determine the efficiency of the system. It was found that the optimum solar panel size and optimum size of storage tank that resulted in the high solar fraction were ($A_{\text{cell}} = 3.5 \, \text{m}^2$ and $V_{\text{storage}} = 0.25 \, \text{m}^3$). Table 1 shows the effect of component size and the flow rate on the thermal performance of the system and the power required for the external auxiliary heater.

| $A_{\text{coll}}$ | DHW Daily Load | $V_{\text{Storage}}$ | FaColl | EPS | IColl | QColl | $Q_{\text{HIO}}$ | Quax |
|-------------------|----------------|----------------------|--------|------|-------|-------|----------------|------|
| 5                 | 1              | 500                  | 0.3    | 0.388| 0.688 | 290000| 563000        | 474000| 148000 |
| 5                 | 1              | 400                  | 0.3    | 0.388| 0.686 | 290000| 562000        | 474000| 149000 |
| 5                 | 1              | 300                  | 0.3    | 0.386| 0.682 | 290000| 560000        | 472000| 150000 |
| 5                 | 1              | 200                  | 0.3    | 0.383| 0.674 | 290000| 555000        | 468000| 153000 |
| 5                 | 1              | 200                  | 3      | 0.481| 0.183 | 290000| 698000        | 344000| 281000 |
| 8                 | 1              | 320                  | 0.48   | 0.497| 0.0023| 290000| 721000        | 314000| 314000 |
| 8                 | 1              | 320                  | 0.64   | 0.536| 0.89  | 290000| 770000        | 575000| 632000 |
| 8                 | 1              | 320                  | 0.72   | 0.546| 0.888 | 290000| 791000        | 570000| 640000 |
VII. Conclusion

TRNSYS simulation within the weather data for Babylon City, Iraq was used to analyze the space heating system from 1st August to 29th April. The main objectives were demonstrated by estimating the temperature of the solar system, breaking the solar system in the solar cycle, and gaining heat in the radiation cycle with full efficiency.

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