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# Experimental Analysis of Inclined Solar Water Heater with Baffles

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This work presents the experimental analysis of solar water heater using baffles and flat absorber. Experiments are conducted with different water flow rates of water inside the baffled basin with the flat absorber. A flow rate of water was increased by 2, 4, and 8 times that an initial mass flow rate of water. Experimental results show that the water temperature is higher in the case of a water heater with baffles as compared to flat plate absorber. The maximum water temperature with minimum and maximum flow rates were found to be 65 $^{C}$ and 53 $^{C}$, respectively with baffles held as path deviator. Also, the exit temperature of water depends on the solar intensity, absorber temperature and ambient condition.

## 1. Introduction

Due to rapid population growth and industrial developments, fossil fuels are depleting which results in the need, research and development of renewable energy sources. For industrial and domestic applications, the solar water heater has become one of heating application to harness solar energy as well as for increased comfort for humans. Several geometries are used in solar water heating which includes a spiral tube, helical tube and serpentine tubes. To increase the efficiency of solar water heating system several methods are employed which includes nanofluids, evacuated tubes, collectors connected in series and parallel. Concentrating collectors are expensive and only used for applications operating at a higher temperature. For moderate temperatures flat plate collectors connected in parallel and series (Devanarayanan et al., 2014; Hossain et al., 2011; Jaisankar et al., 2011; Jamar et al., 2016; Kee et al., 2017; Lin et al., 2015; Mostafaeipour et al., 2017; Shukla et al., 2009; Singh et al., 2016; Smyth et al., 2006; Deng et al., 2015) discovered the performance for the new Flat Plate Collector (FPC) with mica heat pipe absorber Solar Water Heater (SWH). The test outcomes demonstrated that the daily thermal energy gains on the three days in various seasons are 13.43 MJ/m$^2$, 11.05 MJ/m$^2$, and 7.42 MJ/m$^2$ separately, compared to the sun-powered illumination of 18.9 MJ/m$^2$, 17.2 MJ/m$^2$, and 14.7 MJ/m$^2$. Next, the daily average thermal efficiencies are 71.05%, 64.25%, and 50.49%, individually. Xue (2016) designed an ETC with Phase Change Material (PCM) and it was reported that this novel system produced the maximum efficiency of 45%. (Hadjiat et al., 2018) integrating the Compound Parabolic Concentrator (CPC) with SWH. This set-up reached the maximum water temperature of 74° C. (Taheri et al., 2013) researched the compact solar water heater and it was submitted that this compact system reached the efficiency up to 70%. (Pandya et al., 2017) designed a new V-through SWH and they studied the effect of dust particles on collector surface and collector cover surface. It was reported that the optimum collector cover surface is 25°. Dust particles reduced the SWH performance by limiting the solar intensity input to the SWH. (Al-Kayiem et al., 2014) incorporated the PCM nanocomposite with the SWH. It was reported that SWH with and without PCM produced the maximum efficiency of 47.6 and 51%, respectively. The PCM enhances the SWH efficiency up to 5 to 8.5% higher than the normal SWH. (Al-Madani 2006) experimentally investigated the performance of the SWH and he reported that this SWH has the

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maximum efficiency of 41.8% and maximum temperature of 66 ° C. (Badran et al., 2010) designed a novel portable SWH and solar cooker. They conducted experiments and submitted that this portable SWH reached the maximum efficiency of 77%. (Ziapour et al., 2016) researched the PVT type SWH and based on the experimental results, it was reported that PVT type SWH produced the maximum water temperature of 72 ° C with an efficiency of 70%. The concentrating collectors such as PDR and PTC are employed for higher temperature applications (Kalogirou 2004; Balaji et al., 2017) investigated a flat plate collector with heat transfer enhancer absorber tube. (Shojaeizadeh et al., 2016) investigated a flat plate collector with $Al_2O_3$ nanofluid. (Verma et al., 2016; Verma et al., 2017) experimentally analyzed the use of different nanofluids in flat plate collector. (Noghrehabadi et al., 2016) used $SiO_2$ nanofluid in a flat plate collector for enhancing the heat transfer. Using computational technique (Kajla et al., 2016) analyzed the effect of the concentration of CuO nanofluids on the performance of flat plate collector. (Maheshwaran et al., 2013) experimentally investigated a spiral tube solar water heater. Results concluded that the system efficiency is higher in the case of least water flow rate. (Sathyamurthy et al., 2015) experimentally investigated the effect of baffles in a semicircular trough solar water heater. Results showed that the effect of baffles in a semi-circular trough deviated the flow of water inside the absorber with absorbing the heat from the circumferential surface and increased the temperature of water which results in an increase in temperature of water. From the detailed literatures survey, it was found that very less experimental works has been reported on SWH with baffles. Hence in this experimental study, a solar water heater with a square cross-section with baffles is analyzed for its performance. Similarly, the temperature of water from flat plate absorber is compared for its performance. Experiments were carried out with different flow rates of water with baffles inside the collector and flat absorber.

## 2. Experimental methodology

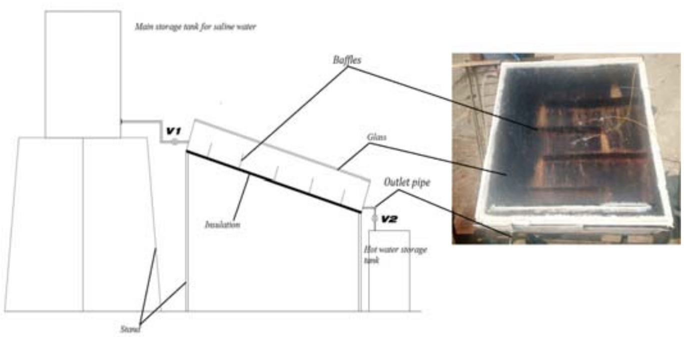


*Figure 1: Schematic diagram and experimental photograph of inclined solar water heater*

Figure. 1 shows the schematic diagram and photograph of the experimental setup of flat plate solar collector with baffles. It consists of a square basin with an area of $0.42m^2$. At consecutive distance baffles plates are held in the flat absorber. The cavity is in the form of rectangular cross-section with a distance of 0.15 m between the water surface and glass surface. A total of four baffles with distance of 0.1 m are held in the flat absorber. For comparative analysis a similar solar water heating system is made for the same area with a flat absorber. Water is fed through the inlet by gravity fed method. At particular points PT100 RTD sensors are fixed to find the inlet water, exit water, glass and absorber temperature. A mass flow rate of water is measured through stopwatch collection method and the flow rate is controlled through a control valve fixed in between inlet and storage tank. In order to avoid heat loss to the surrounding the entire absorber and hose pipes are insulated. Experiments were carried out in the open terrace of Hindustan Institute of Technology and Science, Chennai. The average temperatures of glass and absorber plate are averaged by fixing five thermocouples each at a different position. The solar collector is fixed with an inclination of $13^o$ North with the glass facing south.

*Table 1: Uncertainty, standard uncertainty, error and measuring range of instruments*

| Instrument | Accuracy | Range | Error (%) | Observed error (%) | Standard Uncertainty |
|---|---|---|---|---|---|
| Thermocouple | ±1$^o$C | 0-100$^o$C | 0.25 | 1.2 | ±0.57 $^o$C |
| Solar power meter | ±1W/m$^2$ | 0-2500 W/m$^2$ | 2.5 | 3.1 | ±0.57 W/m$^2$ |
| Anemometer | ±0.1m/s | 0-45 m/s | 10 | 6.8 | ±0.05 m/s |
| Beaker | ±10mL | 0-1000mL | 10 | 8.3 | ±5.77 mL |

## 3. Results and discussion

Figure. 2 shows the hourly variation of solar intensity and ambient temperature for different experimental days. And all experiments were carried out when there is clear sky condition. It is observed that the maximum average solar intensity measured during the month of February 2016 as 1012 W/m$^2$ and maximum average ambient temperature as 34.2$^o$C. The solar intensity and wind velocity are measured using TES 1333R solar power meter and AM4836 3 cup anemometer respectively. Similarly, the accuracy of the instruments used is given in Table. 1. Figure. 3 shows the hourly variation of wind velocity during the experiments. It is observed that there is an abnormal variation in wind velocity during different experimental conditions.

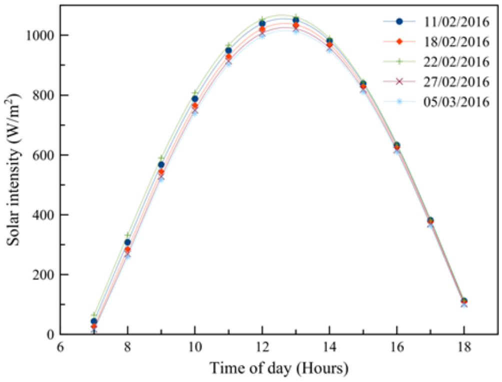


*Figure 2: Variation of solar intensity during the experimental days*

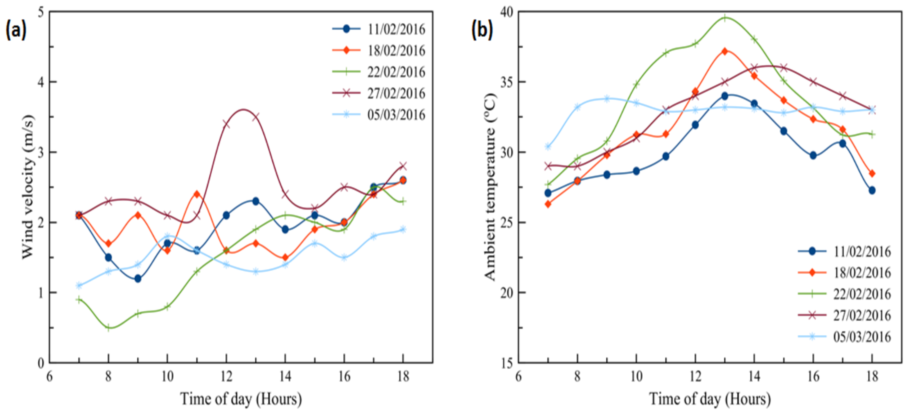


*Figure 3: Hourly variation of wind velocity and ambient temperature during the experiment*

Figure. 4 (a-c) shows the hourly variation of the temperature of different elements of a solar water heater with baffles. It can be observed that the average water temperature inside the baffled absorber is higher with a decreased flow rate of water. The maximum temperature of the water with minimum and maximum water flow rate of water inside the baffled system is found to be 73 and 37.4$^o$C respectively during the peak intensity. This is due to the maximum absorption of solar radiation by the flowing water and maximum utilization of heat by the flowing water inside the basin. Similarly, the maximum glass and absorber temperature of the water heater with baffles is found to be 70 and 75$^o$C respectively at a lower flow rate. Due to the reduced flow rate absorber plate receives the maximum heat energy by the solar intensity and stored in the form of sensible heat energy.

Figure 5 shows the hourly variation of percentage increase in water temperature as a function of inlet water temperature. It can be observed that the water temperature increases with decreasing the flow rate of water inside the absorber. The maximum increase in water temperature with respect to inlet water temperature is found as 71.3% during the maximum (peak) intensity. While increasing the flow rate to 0.166, 0.322 and 0.644 kg/min the maximum increase is found as 48.2, 32.3 and 27.5%, respectively. The trend of increase in water temperature is more similar to the solar intensity curve, and this increase completely depends on the dependent parameter of solar intensity.

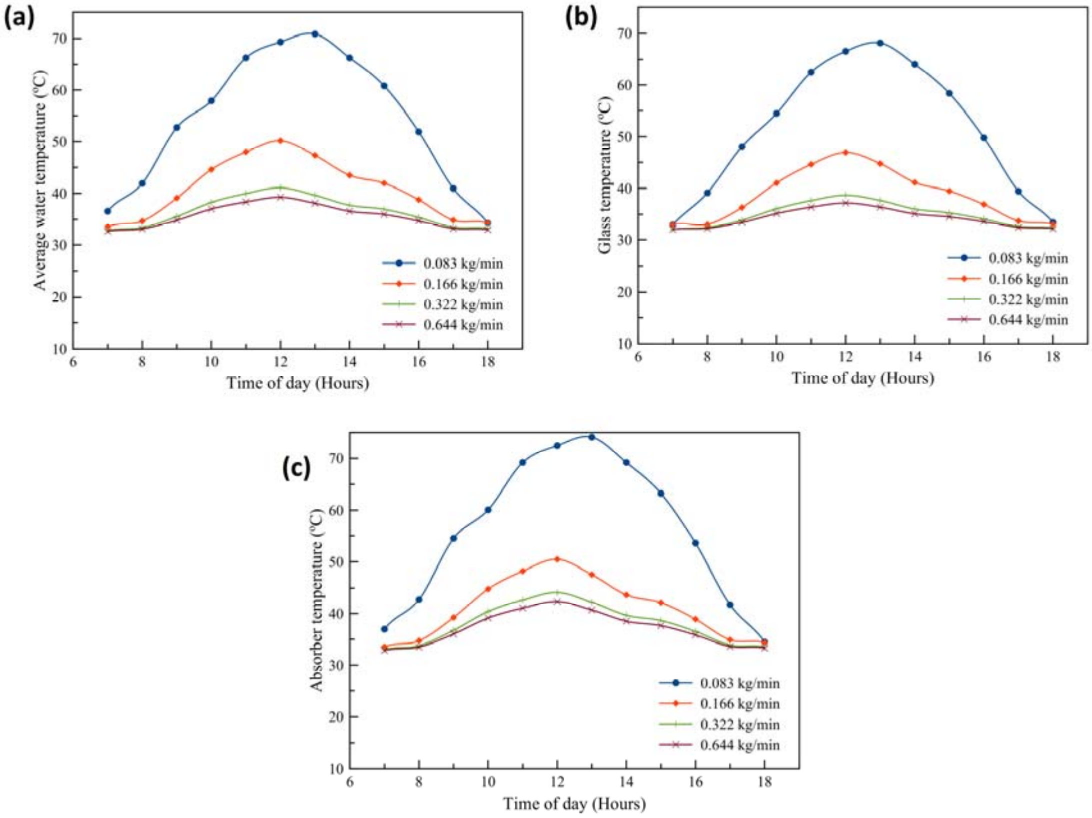


*Figure 4: Hourly variation of (a) average water (b) glass and (c) absorber temperature*

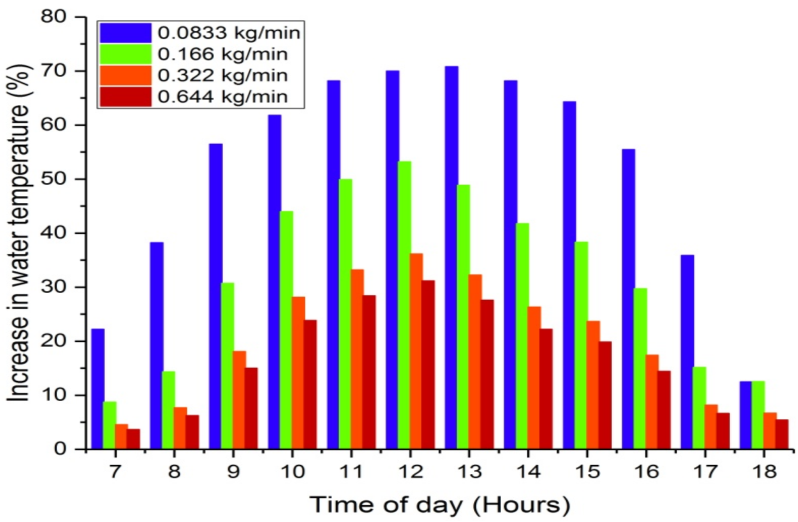


*Figure 5: Hourly variation of increase in water temperature from the inlet boundary condition*

Table 2 summarizes the different SWH system has been researched by different researchers. From the table, it is found that the maximum water temperature of 90 $^{o}$C was obtained by compact SWH and minimum water temperature of 66 $^{o}$C was obtained by conventional SWH. In this present study the maximum water temperature of 73 $^{o}$C was obtained which is 7 $^{o}$C higher than the Al-Madani work and 17 $^{o}$C lower than the Taheri et al. work.

*Table 2: Different types of SWH with their maximum water temperature and efficiency*

| S.no | Authors | Type of SWH | Maximum water temperature (°C) | Efficiency (%) |
|---|---|---|---|---|
| 1 | Deng et al., (2015) | FPC with mica heat pipe absorber SWH. | - | 71.05 |
| 2 | Xue (2016) | ETC with PCM | 82 | 45 |
| 3 | Hadjiat et al., (2018) | CPC with SWH | 74 | - |
| 4 | Taheri et al., (2013) | Compact SWH | 90 | 70 |
| 5 | Pandya & Behura (2017) | V-through SWH | 69 | - |
| 6 | Al-Kayiem et al., (2014) | PCM nanocomposite with the SWH | 67 | 51 |
| 7 | Al-Madani (2006) | SWH | 66 | 41.8 |
| 8 | Badran et al., (2010) | Novel portable SWH and solar cooker | - | 77 |
| 9 | Ziapour & Khalili (2016) | PVT type SWH | 72 | 70 |
| 10 | Present study | Inclined SWH with baffles | 73 | - |

## 4. Conclusions

From the above experimental study, the following conclusions have arrived: -

The residence time of flowing water inside the baffled system is reduced for increased water temperature inside the absorber.

The temperature of the water is higher with a minimum water flow rate inside the absorber with baffles.

The average water temperature is higher in the case of the absorber with baffles inside the system and found as 70°C.

The increase in temperature of the water with baffles is found as 70 % as compared to a collector with a flat absorber.

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