Advances in Engineering Research, volume 208
Proceedings of the International Conference on Innovation in Science and Technology (ICIST 2020)

Preliminary Studies on Thermal Performance of Thermosyphon Solar Water Heating System

Putu Wijaya Sunu*, I Putu Gede Sopan Rahtika, I Dewa Gede Agus Tri Putra, A. A. Ngurah Bagus Mulawarman, I Made Suarta
Mechanical Engineering Department
Bali State Polytechnic
Badung-Bali, Indonesia
*wijayasunu@pnb.ac.id

I Wayan Edi Arsawan
Business Department
Bali State Polytechnic
Badung-Bali, Indonesia
wayanediarsawan@pnb.ac.id

I Nyoman Edi Indrayana
Electrical Engineering Department,
Bali State Polytechnic
Badung-Bali, Indonesia
eddyindrayana@pnb.ac.id

Ni Made Dwidiani
Mechanical Engineering Department
Udayana University
Badung-Bali, Indonesia
dwidiani@gmail.com

I Gede Santosa
Mechanical Engineering Department
Bali State Polytechnic
Badung-Bali, Indonesia

***Abstract*—Experimental investigation for determining the optimal tilt angle of flat-plate solar heater installation in Denpasar city to optimize the thermal energy performance. This preliminary research focused on the performance of a flat-plate-thermosyphon solar water heater system based on temperature difference and total heat absorbed by the water in June until July. The tilt angles were between 15 to 45-degrees with north-facing orientation. The energy-saving in the water provided by solar collectors depends on thermal stratification with in pipe collector. This condition was evaluated by measuring the temperature difference of the header pipe. The results display that the temperature difference inside the collector's 40-degree tilt angle has the best performance. The total heat absorbed between 6 am – 6 pm by the collector at 40-degree higher than the other collector's tilt angle**

Keywords—solar water heater, thermosyphon, thermal performance

I. INTRODUCTION

In recent decades, energy conservation and sustainability play an important issue in the engineering field. The quantity of energy needed to heat the water for domestic and industrial needs is enormous. The ease of operation and simplicity of solar water heaters to produce hot water in all sectors has proven to be economically viable, so its use is increasingly widespread [1-11]. A solar water heater offers a solution to energy sustainability problems by prioritizing the sustainable use of energy. Solar radiation converts into thermal energy through a working fluid inside the heater unit. The availability of solar energy, especially in a tropical country is very beneficial for Indonesia.

The passive solar water heater system operates on the principle of the thermosyphon with a natural flow. The thermosyphon solar heater has been applied in the domestic sector widely, and the thermal performance has been carried out [12-13]. In this passive system, there is no need for a pump to flow the working fluid into the loop. Cold fluid in the collector becomes hot due to solar radiation, then increases to the top due to differences in density. This process continues as a cycle. The thermal behaviour in a thermosyphon system involves many constraints, such as the intensity of solar radiation conditions, clearness of the sky condition, water volume flow rate through the system, collector orientation, heat exchanger effectiveness, and thermal load.

Yuechao et al. [14] examined solar heaters embedded with heat pipes, obtained efficiency reaching 50%. Other researchers investigate solar heaters which include the form of solar collector, the addition of twist tape, the performance of the integrated solar heater with heat pump, and variations in the collector's position were conducted by Li et al [15], Yao et al. [16], Lakshmi et al. [17], Pandya and Behura [18], and Sun et al. [19]. Dehghan and Barzegar [20], Barzegar and Dehghan [21] examined the vertical storage tank in the domestic application during the consumption period. Hamdan [22] conducted the measurement of air of the inlet and outlet temperatures of the collector, the surrounding temperature, and the pipe circuits insulation. The performance parameters were completed to find the optimum storage efficiency and the bed tilted angle. Most previous studies on thermosyphons solar water heater were majorly on the performance for domestic application systems. However, a more thermosyphons solar water heater may appear when the system loaded or sufficient hot water consumption is needed. Furthermore, the consequence of dirt accumulation on the glass cover of the collector has been conducted with various slope by Hegazy [23]. The influence of geographic environments, collector positioning, tilt angle, fabrication, and manufacturing material and configuration of the solar collector system has been investigated by many researchers.

In this present experiment, the passive solar water heater configuration and flat-plate thermal collector are used to absorb environmental solar radiation. The thermal performance of the solar water heater was investigated by varying the collector's tilt angle from the horizontal axis. The observation location in the city of Denpasar, Bali-Indonesia.

II. Description and Modelling of Solar Water Heater

For this experimental investigation, a typical laboratory-scale of flat plate solar water heater manufactured in Denpasar as shown in Fig. 1. The location of Denpasar city is 8°39'50" south latitude dan 115°11'40" east longitude. The principles of the solar water heater in general, solar radiation traverse's energy to working fluid inside the tube collector. A density stratification is formed by the temperature difference between the copper tube and makes a natural flow of water called the effect of thermosyphon. In this condition the warm water flowing up and the cold water flowing down.

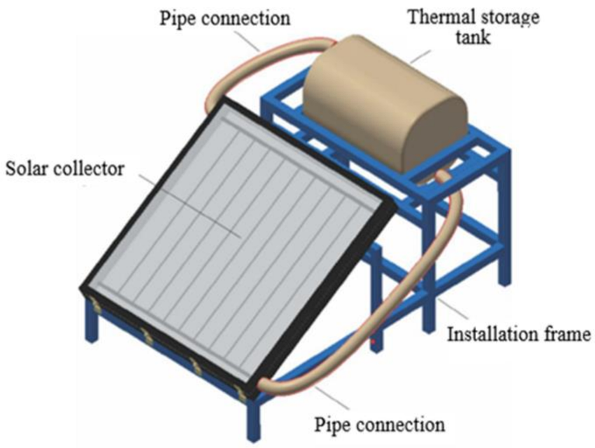

Fig. 1. Schematic installation.

The major physical specification for the flat-plate solar water heater is shown in Table 1. It involves an effective area of 1.0 m^2 of a flat-plate collector, orientating north, tilted angles ranged from 15°- 45° from horizontal level, and an insulated 60 L thermal storage tank. The water enters at the top section and exits at the bottom section of the tank. All pipe circuits are insulated well to prevent heat loss. A single solar water heater was tested at an outdoor test at 3 m elevation.

TABLE I. Component Description

No	Component	Specification
1	Collector aperture area	1.0 m2
2	Collector protection material	Single glass, 5 mm thickness
3	Collector channel	Copper tube, 0.25 inch
4	Collector slope	15° – 45°
5	Thermal storage tank	Horizontal orientation, 60L

A. Instrumentation

The test conditions at daily solar radiation and environment temperatures were measured digitally. The solar radiation was measured by solar power meter with sampling time 10 seconds, solar power accuracy 5%, and angular accuracy with a cosine corrected <5%. The water initial temperature, ambient air temperature, and the water temperature at each collector point were measured by K-type thermocouples. Data temperature from all sensing temperature were collected every 10 seconds for 12 hours in a day by acquisition equipment with the accuracy data 0.1°C.

B. Data Processing

This research aim is to calculate the total heat absorbed by the collector. The temperature observed from the solar heater model. The measured the temperature in the collector system was used to indicate the system performance.

The stratification of the temperature of the collector tube affects the thermal performance of a solar water heater. The temperature distributions inside the collector during the day indicate the heat distribution to the thermal storage tank through the working fluid.

The mean initial temperature of water (T_1) in °C, the end of the heating temperature (T_2) in °C, heat capacity on constant pressure (Cp) in kJ/kg°C were used to calculate the heat (Q) collected by the thermal storage tank at the end of the experimental period. The total heat absorbed by the working fluid determined below,

$$Q = m.Cp.(T_1 - T_2) \quad (1)$$

III. Results and Discussion

The solar water heater was connected with thermal storage tanks on a horizontal frame (about 3 m above the ground), and it oriented north at the Denpasar city in Bali. All of the data were collected from June to July 2020 on a sunny day. They were connected with the solar collector with insulated flexible pipes.

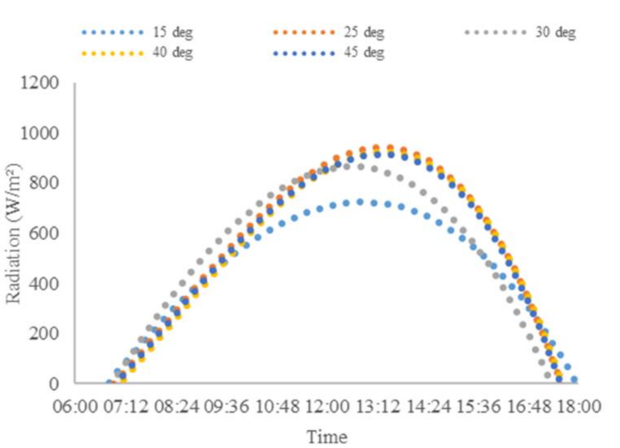

Fig. 2. Time series of the average solar radiation.

Fig. 2 shows the average variation of solar radiation measured by a solar power meter on typical days. Generally, the maximum solar radiation was recorded around 13:00 to 14:00 h on bright days. It is seen that the solar radiation of a 25-degree solar collector reached the maximum value compared to others.

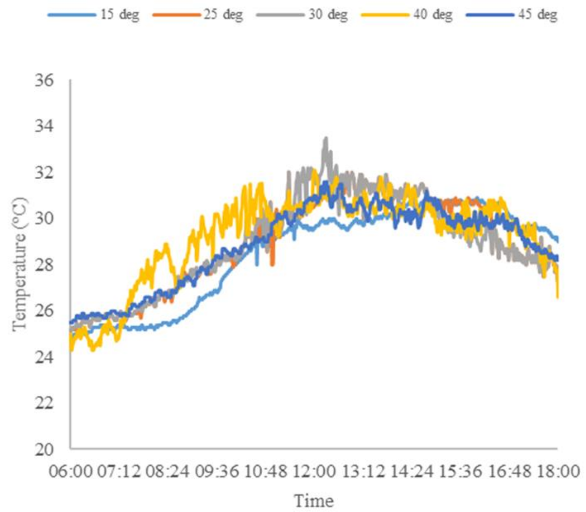

Fig. 3. Average ambient temperature.

The ambient temperature Fig. 3 observed similar trends with solar radiation. This ambient temperature has a strong correlation with meteorological circumstances. The data was taking from June to July 2020. The climate in Denpasar city is tropical, dry season. The clearness of the sky is high. The temperature ambient in this experiment periods was the lowest throughout the year.

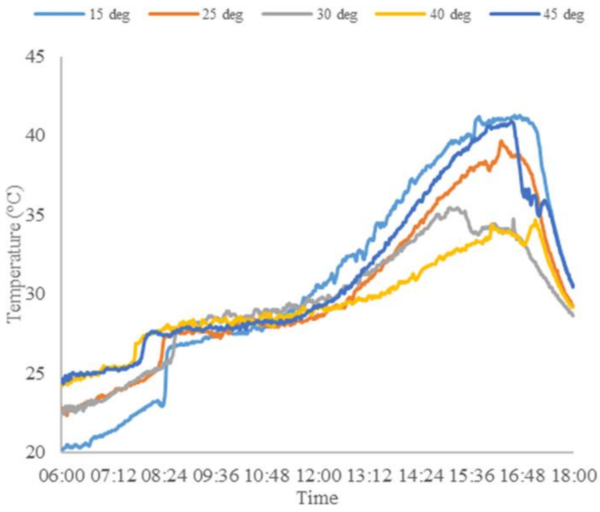

Fig. 4. Average inlet collector temperature.

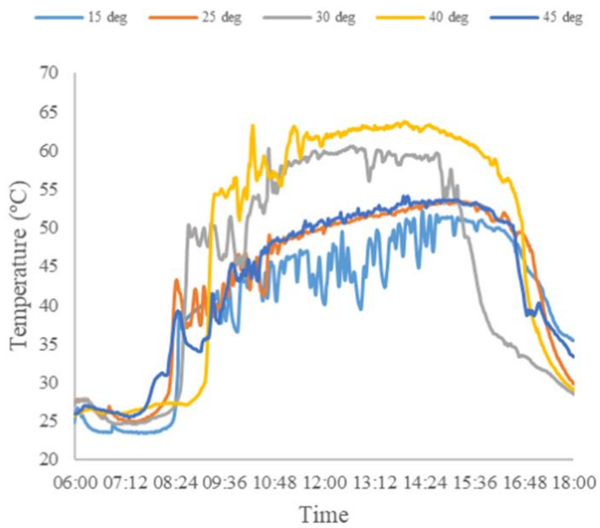

Fig. 5. Average outlet collector temperature.

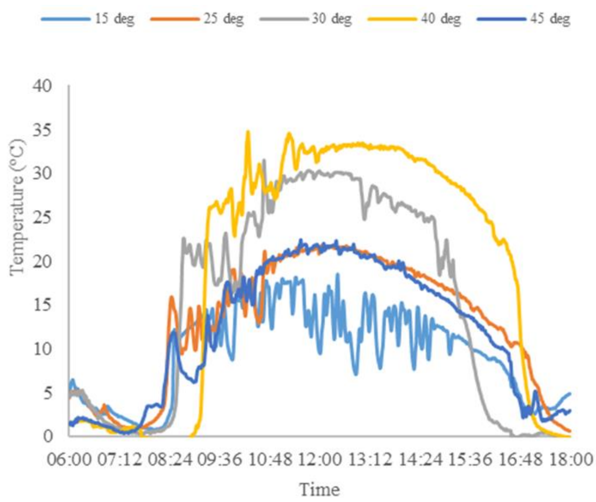

Fig. 6. Average delta t solar collector.

Fig. 4 to 6 shows the water temperature on inlet, outlet, and it's different measured by thermocouples. The inlet water temperature started slowly until 13.00 h and reached a maximum of around 16.00 h. It is shown that the water temperature inlet reached the maximum value at around 16.00 h. From Fig. 5 see the maximum outlet temperature reached by 40^0 solar collectors. The same trend is seen in Fig. 6. For a flat-plate-thermosyphon solar heater, the value of temperature and its difference inside a collector, glass cover temperature, thermal storage tank, and solar radiation intensity has a correlation on the thermal performance. The 40° tilted solar collectors have the lowest inlet water temperature as shown in Fig. 5. In the other hand, it has the highest outlet water temperature as proved in Fig. 6. So that the temperature difference between outlet and inlet collector for 40° tilted have the highest value.

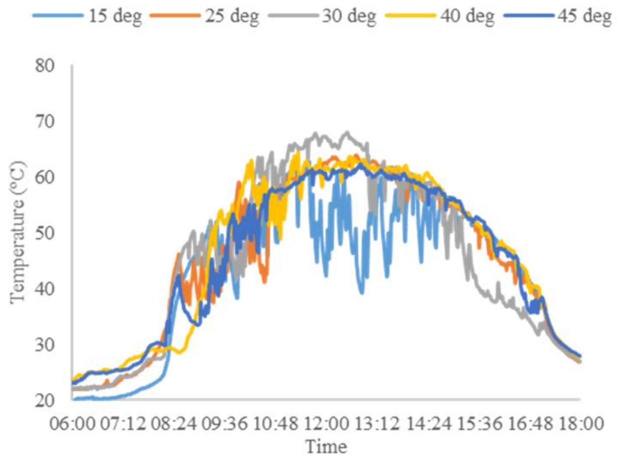

Fig. 7. Average glass cover temperature.

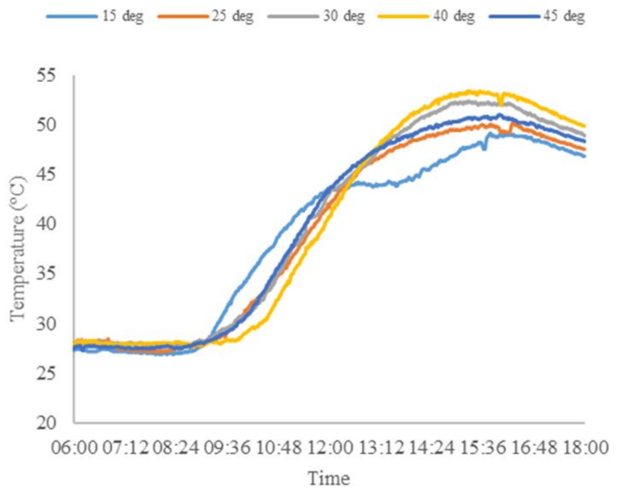

Fig. 8. Average thermal storage temperature.

For glass cover temperature, the 40° tilted solar collectors have modest value as shown in Fig. 7. The thermal performance of thermosyphon solar heater may indicated by outlet and inlet water temperature difference. This phenomenon proved in Fig. 8, as shown the maximum thermal storage tank temperature reached by 40° tilted solar collectors.

IV. Conclusion

A flat-plate-thermosyphon solar water heater equipped with a horizontal storage tank has been investigated in five different tilted angles. Water temperature was digitalized during solar collection on the day period. For the optimum tilted angle 40°, gave the best result (22°C) in temperature difference between outlet and inlet solar collector in this experiment. The total heat absorbed by the 40° solar collectors was about 5520 kJ.

Acknowledgment

The authors are very thankful to the Indonesian Ministry of Education and Culture, and Bali State Polytechnic for financial and administrative support.

References

[1] T. Roulleau, and C.R. Lloyd, “International policy issues regarding solar water heating, with a focus on New Zealand,” Energy Policy, vol. 36, pp. 1843–1857, 2008.

[2] M. Karagiorgas, A. Botzios, and T. Tsoutso, “Industrial solar thermal applications in Greece economic evaluation, quality requirements and case studies,” Renew. Sustain. Energy Rev. vol. 5, pp. 157–173, 2001.

[3] K.C. Chang, T.S. Lee, and K.M. Chung, ”Solar water heaters in Taiwan,” Renew. Energy, vol. 31, pp. 1299–1308, 2006.

[4] Z.S. Li, G.Q. Zhang, D.M. Li, J. Zhou, L.J. Li, and L.X. Li, “Application and development of solar energy in building industry and its prospects in China,” Energy Policy, vol. 35, pp. 4121–4127, 2007.

[5] K.C. Chang, T.S. Lee, W.M. Lin, and K.M. Chung, “Outlook for solar water heaters in Taiwan,” Energy Policy, vol. 36, pp. 66–72, 2008.

[6] K.C. Chang, W.M. Lin, G. Ross, and K.M. Chung, “Dissemination of solar water heaters in South Africa, “J. Energy South. Afr., vol. 22, pp. 2–7, 2011.

[7] M. Zago, A. Casalegno, R. Marchesi, and F. Rinaldi, “Efficiency analysis of independent and centralized heating systems for residential buildings in Northern Italy, “Energies, vol 4, pp. 2115–2131, 2011.

[8] C. Aigbavboa, “Low-income housing residents’ challenges with their government install solar water heaters: A case of South Africa,” Energy Procedia, vol 75, pp. 495 – 501, 2015.

[9] K.C. Chang, W.M. Lin, T.S. Lee, and K.M. Chung, “Solar heating in Taiwan,” Energy Procedia, vol. 57, pp. 834 – 839, 2014.

[10] A. Moreau, and F. Laurencelle, “Field study of solar domestic water heaters in Quebec,” Energy Procedia, vol. 30, pp. 1331 – 1338, 2012.

[11] S.J. Promparn, T. Krittayanawach, P. Deedom, and B Limmeechokchai, “An Experimental Study of Thermo-Syphon Solar Water Heater in Thailand,” Energy Procedia, vol. 79, pp. 442 – 447, 2015.

[12] A.A. Karaghouli and W.E. Alnaser, “Experimental study on thermosyphon solar water heater in Bahrain,” Renew. Energy, vol. 24,pp. 389–396, 2001.

[13] V. Belessiotis and E. Mathioulakis, “Analytical approach of thermosyphon solar domestic hot water system performance,” Sol. Energy, vol. 72, pp. 307–315, 2002.

[14] D. Yuechao, Y. Zhao, Z. Quan, and T. Zhu, “Experimental study of the thermal performance for the novel flat plate solar water heater with micro heat pipe array absorber,” Energy Procedia, vol. 70, pp. 41 – 48, 2015.

[15] K. Li, T. Li, H. Tao, Y. Pan, and J. Zhang, "Numerical investigation of flow and heat transfer performance of solar water heater with elliptical collector tube," Energy Procedia, vol. 70, pp. 285 – 292, 2015.

[16] K. Yao, T. Li, H. Tao, J. Wei, and K Feng, "Performance evaluation of all-glass evacuated tube solar water heater with twist tape inserts using CFD," Energy Procedia, vol. 70, pp. 332 – 339, 2015.

[17] D.V.N. Lakshmi, A. Layek, and P. M. Kumar, "Performance analysis of trapezoidal corrugated solar air heater with sensible heat storage material," Energy Procedia, vol. 109, pp. 463 – 470, 2017.

[18] H. Pandya, and A.K. Behura, "Experimental Study of V-Through Solar Water Heater for Tilt Angle and Glass Transmissivity," Energy Procedia, Vol. 109, pp. 377 – 384, 2017.

[19] X. Sun, Y. Dai, V. Novakovic, J. Wu, and R. Wang, "Performance comparison of direct expansion solar-assisted heat pump and conventional air source heat pump for domestic hot water," Energy Procedia, vol.70, pp. 394 – 401, 2015.

[20] A.A. Dehghan and A. Barzegar, "Thermal performance behavior of a domestic hot water solar storage tank during consumption operation," Energy Conversion and Management, vol. 52, pp. 468–476, 2011.

[21] A. Barzegar and A.A. Dehghan, "Transient thermal behavior of a vertical solar storage tank with a mantle heat exchanger during no-flow operation," J Appl Fluid Mech, vol. 2(1), pp. 55–69, 2009.

[22] M.A. Hamdan, "Investigation of an inexpensive solar collector storage system," Energy Convers. Mgmt., Vol. 39 (5/6), pp. 415-420, 1998.

[23] A. Hegazy, "Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors," Renewable Energy, vol. 22(4), pp. 525–40, 2001.