The 19th Annual Conference of Mechanical Engineering Network of Thailand
October 19-21, 2005, Songkla, Thailand

Investigation of Water Flow Rate in a Thermosyphon Solar Water Heater

Pisit Techarungpaisan*1 Bancha Buddadee2 Sivanappan Kumar3
1,2)Mechanical Engineering Department, Faculty of Engineering
Ubon Ratchathani University 85 Satollamat Rd, Warinchamrab, Ubon Ratchathani, 34190, Thailand
3)Energy Program, School of Environment, Resource and Development
Asian Institute of Technology, Klong Luang, Pathumtani, Thailand
Tel. 0-4535-3382 Fax 0-4535-3333
*E-mail: tec_pisit@yahoo.com1

Abstract

Domestic solar water heaters (DSWH) with horizontal tank are commonly used in Thailand. Only a few studies to improve performance of the thermosyphon DSWH for Thailand are available. This paper proposes the predicted and experimental results of water flow rate through the collector in a natural circulation solar water heater. The water flow rate through the collector is one parameter to indicate the system performance. The accurate model to predict the water flow rate can use to design and improve the DSWH. The model of Close was found to predict the flow rate within reasonable tolerant and easily to use for horizontal storage tanks as well. Three different DSWH systems were used in the study. There are different in the diameter of supplying and returning pipe of collector, diameter of riser, location of returning pipe and elevation of horizontal tank.

Keywords

Solar Water Heater; Thermosyphon Flow; Solar Collector

1. Introduction

The simplicity and low cost of natural circulation systems led them to be one of the preferred means of water heating for both amateur solar energy enthusiasts and an appropriate technology for use in developing countries. The hot water produced by thermosyphon systems has also been utilized for purposes other than washing and cleaning. The advantage of a natural circulation solar water heater are its low initial and maintenance cost and low operating cost, due to the absence of pump. The performance of DSHWs depends on the parameters influencing each component, such as, collector, storage tank and connecting pipe. The factors influencing solar collector performance can be divided into three main categories: construction, meteoclimatological, and operational factors. The first group is mainly related to the collector design and materials. The second group includes solar radiation, ambient temperature, and wind speed. The third group includes the orientation and tilt of the collectors, operation time, flow rate, etc.

The water flow rate is the one parameter affected to the water temperature distribution in the storage tank. For no water draw off condition, the thermosyphon flow rate indicate that how long to circulate the whole of water in tank. If the water flow rate is high, it can circulate all of the water in tank in the short period. In the small tank, the whole water can be circulated in many times for a day. The capacity of tank can be design for the suitable system by evaluation the possible water flow rate occurring.

2. Literature Review

The thermosyphon flow depends on the thermosyphonic driving head that is usually in the range of 1-30 mm of water. The thermosyphonic driving head will occur due to the buoyancy force, which is the result of change of density of water due to temperature rise of water in the solar collector. The first published analysis of a thermosyphon solar water heater circuit was by Close (1962) [1], who worked out an analysis of circulation rates in natural circulation systems and comparing the predicted and experimental inlet and outlet water temperatures. Close (1962) estimated the performance of solar water heaters connected to a storage tank by thermosyphon. Ideal conditions of no drawoff

* Corresponding author

during the day and clear sunshine is assumed. Close's model and his experimental observations are discussed below:

To determine the thermosyphon head which is generated by the differences in density of the fluid in the system, it is necessary to examine the temperature distribution in the circuit.

A diagram of water temperature at different positions in the circuit is shown in figure 1. The assumptions necessary to draw this diagram are:

(a) The temperature distribution inside the tank is linear.
(b) The water from the absorber rises to the top of the tank.
(c) There are no losses in the connecting tubes.

Since the temperature differences 1-2 and 4-5 are about 15°C, the relationship between specific gravity and temperature may be assumed to be linear. Thus, figure 1 also represents the specific gravity distribution in the circuit.

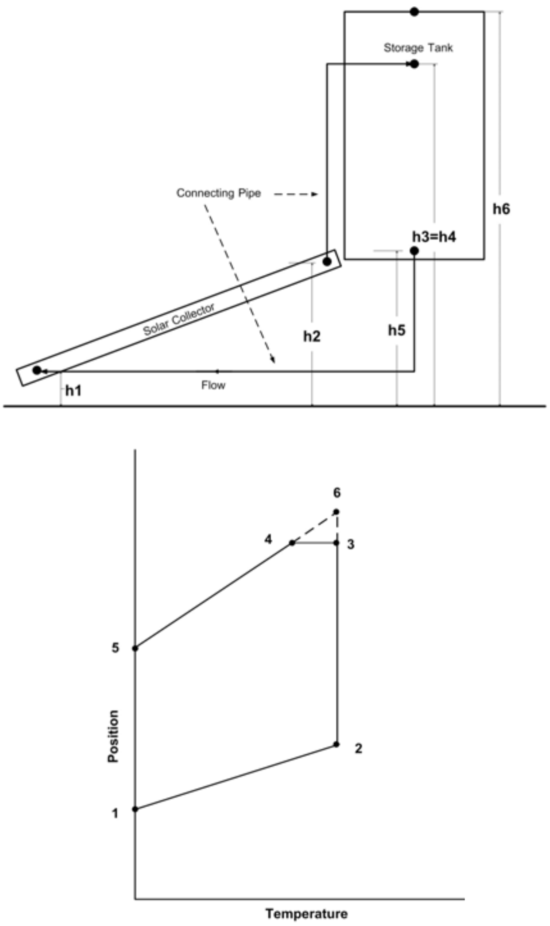

Figure 1 Diagram showing hypothetical temperature distribution of a thermosyphon system (Close, 1962) (1)

The thermosyphon driving head (H_T) can be estimated by considering the area 12345. Therefore,

$$H_T = ½.(S_1 - S_2).[2(h_3 - h_1) - (h_2 - h_1) - (h_3 - h_5)^2/(h_6 - h_5)] \quad (1)$$

$$f(h) = 2(h_3 - h_1) - (h_2 - h_1) - (h_3 - h_5)^2/(h_6 - h_5) \quad (2)$$

$$H_T = ½.(S_1 - S_2).f(h) \quad (3)$$

Then, the specific gravity is given by,

$$SG = At^2 + Bt + D \quad (4)$$

The approximation used is shown in figure 2

$$H_T = ½.[A(t_1^2 - t_2^2) + B(t_1 - t_2)].f(h) \quad (5)$$

$$t_m = (t_1 + t_2)/2 \quad (6)$$

$$H_T = (t_1 - t_2)/2.(2At_m - B).f(h) \quad (7)$$

where, $A = -2.5x10^{-6}$, $B = 5.83x10^{-5}$

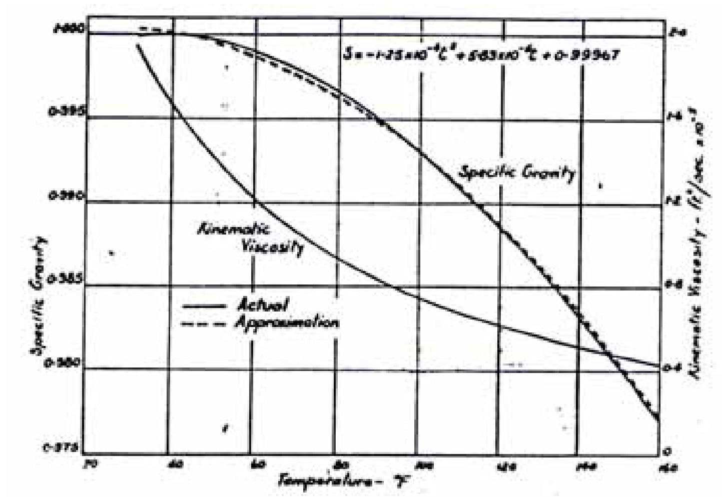

Figure 2 Curve of kinematic viscosity and specific gravity variation with temperature, and the approximate specific gravity-temperature relation (Close, 1962) (1)

The friction head losses (h_f) is obtained by using the Darcy Weisbach equation for the friction head loss in the flow circuit as:

$$h_f = flu^2/2gd + ku^2/2g \quad (8)$$

$$f = 64/Re = 64\nu/ud \quad (9)$$

$$u = (5.68 \times 10^{-6}m)/d^2 \quad (10)$$

$h_f = (5.65x10^{-6} l \nu_m m)/d^4 + (5.02x10^{-13} k m^2)/d^4$ (11)

If it is not known whether the flow is laminar, turbulent, or in the transition region, then assume, f = 0.035, k = 39.6 and ν_m is determined from figure 2

The thermosyphon flow (m) is therefore obtained as

$$H_T = h_f \quad (12)$$

Gupta and Garg (1968) [2] modified the basic model of Close so as to take into account the system capacity and heat exchanger efficiency of the absorber and heat losses in connecting pipes. Like Close, they also assumed that the mean absorber temperature is close to mean tank temperature and that the temperature distribution in the collector and tank are linear. These modifications make the model valid for cloudy weather also, as is verified by their experimental studies.

Ong (1974) [4] developed a mathematical model that follows closely the analysis of Close(1962) and Gupta and Garg(1968) in assuming that the mean temperatures of the absorber unit, the storage tank, the connecting piping and water contained in them are equal. He presented a finite-difference method of solution for predicting the thermal performance of a flat plate solar water heater operating under natural convection (thermosyphon) flow and compared the predicted results with experimental values obtained for a solar water heater operating under Malaysian weather conditions.

Zvirin et al.(1977) [5] presented the natural circulation solar heater-model with linear and nonlinear temperature distributions. The flow rate calculated by the model of Zvirin et al.,1977 are different about 33 per cent between the theoretical and the experimental values, the model results may be described as satisfactory.

Morrison and Ranatunga (1980) [3] developed a laser anemometer to eliminate the problem of flow restriction and to provide the comparatively fast response needed to measure transient flow rate in thermosyphon operation. They also presented the mathematical model to predict the thermosyphon flow and compared it with experimental data

Most of the flow rate models are validated with the experimental except the Close's flow rate model. He has not been validated his flow rate model to the experiment due to the difficulty of measuring low flow rate in connecting pipe. Since the Close's model is simply and easily to use compared to the others shown in table 1, the validation of Close's model is important to carry out. This paper is present how accuracy of the Close's model.

Table 1 Previous works to predict the flow rate in natural DSWH system. [6]

	Close (1962)	Ong (1974)	Shitzer (1979)	Morrison (1980)
1. Model characteristic	Thermosyphonic driving head equation	A finite-difference Method	Dimensionless Equation	An analytic model Base on Ong's model
2. Validation	Yes by calculation	Yes by experiment	Yes by experiment	Yes by experiment
3.Ease of equation	Simple	Difficult	Difficult	Difficult

3. Experimental Set-up

The experiments were conduct in three DSWH systems. These were fabricated by different manufacturers. There are the same tank capacities which are 200 liters.

3.1 Flow rate measurement

Thermosyphon flow in DSWH is very low of the order of 10 cm^3/sec. The flow rate is also difficult to measure. In order to be sure that the dye trace inject [4] is a reliable method for flow rate measurement, a preliminary test was done by comparing its result with those of actual measurement and also by the model of Close (1962). Dye trace inject was calibrated by experiments in the range 1-25 cm^3/sec. The dye trace inject was installed at the supply and return pipe (show in figure 3). The dye was injected by syringe and the time taken for it to move through 5 cm. was noted. This was repeated two or three times and the average time taken for the dye to move through 5 cm were calculated. This was then used to estimate the flow rate by considering the area of cross section of tube.

3.2 Water temperature measurement

Thermocouple type K was used in this study. All the thermocouples used in this experimental study were calibrated with a standard thermometer

3.3 Solar Radiation

A solarimeter was used to measure the solar radiation on a tilted surface (15°) which was connected to data logger. It measured the total radiation falling on the system every five minutes. The solarimeter used in this experiment was Epply

Radiometer, which has been compared with the Epply group of reference standards.

Figure 3 The dye trace inject installed at collector water inlet pipe

4. Experimental Results

The flow distribution of collector was measured at the inlet and outlet pipe of collector by using dye trace inject.

4.1 Flow distribution in inlet and outlet pipe of collector of DSWH no. 1

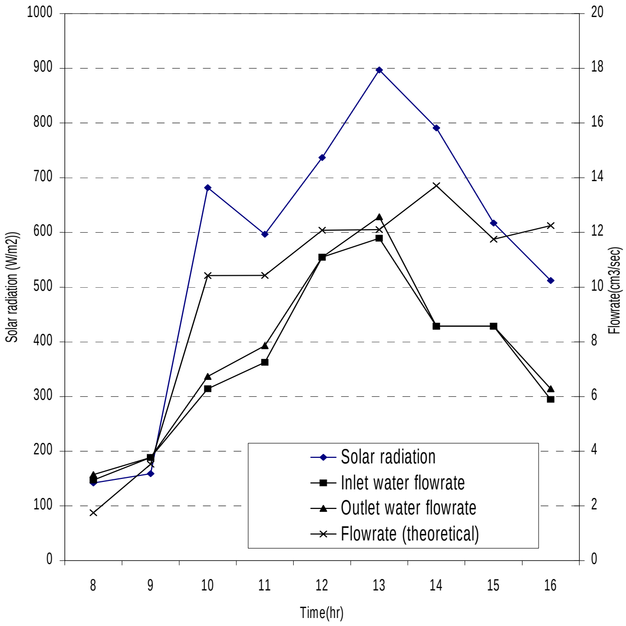

Figure 6 Solar radiation and flow rate versus time for DSWH no.1

Figure 6 shows the maximum flow rate was estimated to be 12.6 cm^3/sec at 1:00 pm and at this hour the solar radiation was maximum at about 897 W/m^2. The inlet and outlet flow rate changed according to solar radiation. Compared to the Close's model, the difference was in the range that is reasonable of about 39 %.

4.2 Flow distribution in inlet and outlet pipe of collector of DSWH no. 2

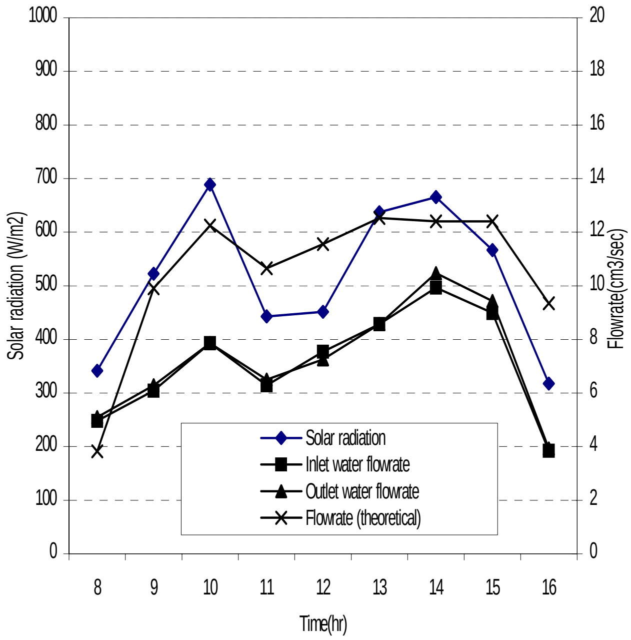

Figure 7 Solar radiation and flow rate versus time for DSWH no.2

Figure 7 is similar as figure 6. The maximum flow rate was about 10.5 cm^3/sec when the solar radiation was 666 W/m^2 at 1:00 pm. Compared to the theoretical, the measured flow rate was different by about 33%.

4.3 Flow distribution in inlet and outlet pipe of collector of DSWH no. 3

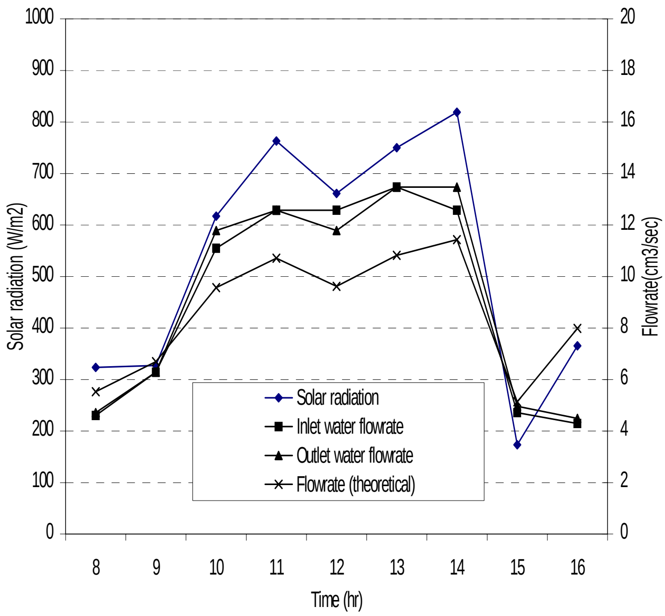

Figure 8 Solar radiation, flowrate versus time for DSWHs no.3

Figure 8 shows that the maximum outlet flow rate was 13.5 cm^3/sec when the solar radiation was maximum about 819 W/m^2. The inlet and outlet flow rate changed when the solar radiation changed. The flow rate measured compared to theoretical was different by about 30%, and the difference is within reasonable limits.

5. Discussion

The flow rate at inlet and outlet pipe of collector depends on the solar radiation, as the radiation causes to heat the absorber plate, which transfers heats to water. This causes the flow of water due to temperature difference. If the solar radiation is high the flow rate was found to be high. The solar radiation influences the flow rate in some ranges to a large extent. This can be observed for all the three systems

Close (1962) has already given the mathematical model to evaluate the flow rate in a natural circulation in solar water heater. His model was developed for the system with vertical tank, but in this study for DSWH with horizontal tank, the results of the experiment shows that Close's model can be used reasonably by only knowing the inlet and outlet temperature of collector and this can be used to predict the flow rate.

The Close's model is easily used. An sample estimation of the water flow rate can be evaluated as follow for evidence the easily used of the model. Figure 9 shows the DSWHs with horizontal tank for flow rate calculation.

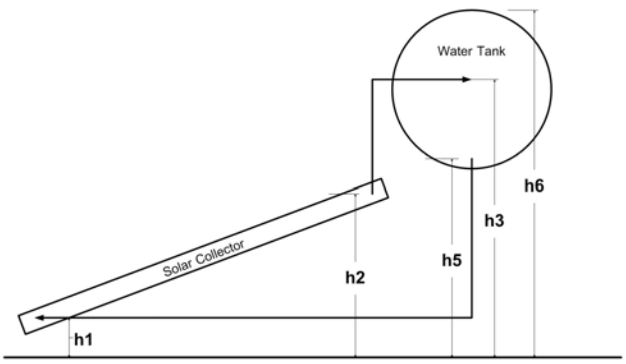

Figure 9 Schematic showing the various heights of the DSWHs for flow rate calculation.

h_1 = 0.175m. = 0.5741 ft.
h_2 = 0.70 m. = 2.2966 ft.
h_3 = 1.04 m. = 3.4120 ft.
h_5 = 0.84 m. = 2.7559 ft.
h_6 = 1.26 m. = 4.1338 ft.
l = 7.23 m. = 23.7202 ft.
d =0.016 m. = 0.05249 ft.
t_1 = 37.2°C. = 99.01 °F.
t_2 = 60.4°C = 140.72 °F.
$t_m = (t_1 + t_2)/2$ = 119.87 °F

$f(h) = 2(h_3 - h_1)-(h_2 - h_1)-((h_3 - h_5)^2 / (h_6 - h_5))$

$f(h) = 3.6409$

$H_T = (t_1 - t_2)/2 . (2At_m + B).f(h)$

$A = -2.50 \times 10^{-6}$; $B = 5.83 \times 10^{-5}$; $k = 39.6$

$\nu_m = 0.62 \times 10^{-5}$ ft^2/sec (from figure 2)

$H_T = 0.0418$

$h_f = 5.65 \times 10^{-6} l\nu_m m/d^4 + 5.02 \times 10^{-13} km^2/ d^4$

$h_f = 1.09 \times 10^{-4} m + 2.62 \times 10^{-13} m^2$

$H_T = h_f$

$0.0418 = 1.09 \times 10^{-4} m + 2.62 \times 10^{-13} m^2$

<u>mass flow rate</u> m = 106.09 lb/hr
Q = 13.37 cm^3/sec

6. Conclusion

The water flow rate of thermosyphon DSWH can be easily evaluated by the Close's model compared to the other models shown in table 2 (Appendix A). The other models are difficult but the error of model is slightly different.

The water flow rate is the one important parameter used to select the suitable tank capacity. In the application that need high water temperature but received small solar insolation, the small storage tank should be designed for circulation the whole of water in tank in many times per day to give the high water temperature.

7. References

[1] Close, D.J. "The performance of solar water heaters with natural circulation" Solar Energy, 1962, Vol 6 ;pp. 33-40

[2] Gupta, C.L., and Garg, H.P. "System design in solar water heaters with natural circulation" Solar Energy, 1968, Vol.12 ;pp. 163-182.

[3] Morrison, G.L., and Ranatunga, D.B.J. "Thermosyphon circulation in solar collectors" Solar Energy, 1980, Vol.24 :pp. 191-198.

[4] Ong, K.S. "A finite-difference method to evaluate the thermal performance of a solar water heater" Solar Energy, 1974, Vol.16 ;pp. 137-147.

[5] Zvirin, Y., Shitzer, A., and Grossman, G. "The natural circulation solar heater-models with linear and non-linear temperature distributions" Int. J. Heat & Mass Tranfer, 1977, Vol.20 ;pp. 997-999.

[6] Pannigul, P. A study of temperature and flow distribution in a natural circulation solar water heating system. 1999, Master thesis, AIT, Bangkok, Thailand.

Nomenclatures

d	diameter of connecting pipe (ft)
f	Darcy Weisbach friction factor
g	acceleration of gravity (ft^2/s)
h_1	vertical height of water inlet of collector (ft)
h_2	vertical height of water outlet of collector (ft)
h_3	vertical height of water inlet of storage tank (ft)
h_5	vertical height of water outlet of storage tank (ft)
h_5	vertical height of maximum water level in tank (ft)
h_f	head loss due to friction (ft)
H_T	thermosyphon driving head (ft)
l	length of pipe through which flow passes (ft)
m	water mass flow rate (lb/hr)
Q	flow rate (cm^3/sec)
S_1	Specific gravity of water at inlet of collector
S_2	Specific gravity of water at outlet of collector
SG	Specific gravity of water
t_1	inlet water temperature of collector(°F)
t_2	outlet water temperature of collector(°F)
t_m	mean water temperature between collector inlet and outlet(°C)
u	thermosyphon velocity (ft/s)
ν_m	kinematic viscosity (ft^2/sec)

Appendix A

Table 2 Comparison experimental and predicted of water flow rate and outlet water temperature with earlier studies

Description	Present study			Previous study			
	DSWH no1	DSWH no2.	DSWH no.3	Gupta and Garg (1968)	Ong (1974)	Zvirin et al (1977)	Morrison and Ranatunga (1980)
Collector area (m^2)	1.42	1.42	1.99	1	NA	3	0.72
Storage tank capacity (liters)	200	200	216	200	NA	140	262
Maximum flowrate (cm^3/sec) (Experimental)	12.5	10.48	13.47	13	4.98	15.8	10
Maximum flowrate (cm^3/sec) (Predicted)	12.1	12.4	11.43	NA	3.7	10.8	7
Maximum difference of flowrate (experimental VS predicted)	39%	33%	30%	NA	34%	33%	43%
Maximum outlet water temperature of collector (°C)	59.4	60.1	58.7	62	57	68	NA

NA : not available