CHAPTER 4

OPTIMIZATION OF SOLAR WATER HEATER SYSTEM

Referring to Chapter 3, the mathematical models of thermal resistant method and EFMD are developed and validated by the experiment. It is found that the EFMD is accurate and suitable for the prediction more than the thermal resistant method. Therefore, in this chapter, the EFDM is brought to create the modeling of the solar water heater system for investigated the effects of dimensional thermosyphon, as well as number of evacuated tube. It is essential to study number of evacuated tube in order to consider the optimal parameters, which are selected by thermal economics analysis.

4.1 Control parameters and variable parameters

As the main purposes of this research are to study the effects of dimensional thermosyphon and number of evacuated tube in the solar water heater system, three following topics are taken into account: assumptions, control parameter and variable parameter of the solar water heater system.

1) Assumptions of the mathematical model:
   - 1.1) Solar radiation incidents on the surface of evacuated tube collector in all directions around the tube.
   - 1.2) Heat loss of the thermosyphon at adiabatic section is negligible.
   - 1.3) Z_4, Z_5 and Z_6 of thermosyphon are usually neglected due to their relatively small in magnitude.

2) Controlled parameters of the mathematical model:
   - 2.1) The evacuated tube data is used in Table A-1.
   - 2.2) Thermosyphon is made of copper tube.
   - 2.3) R141b is filled in thermosyphon about 70% of evaporator volume.
   - 2.4) Length of adiabatic is 150 mm.
   - 2.5) Water storage tank volume is 100 liters.
   - 2.6) Water flow rate is 0.03 kg/s (Nada et al., 2004).

2.7) Solar intensity and ambient air temperature data is based on Chiang Mai province on February 27, 2014 during 9:00 a.m. to 4:00 p.m. and inputted into the mathematical models.

3) Variable parameters of the mathematical model:

3.1) Thermosyphon diameters of evaporator and condenser section are 1/4, 3/8, 1/2, 5/8, 3/4, 7/8, and 1 inch as shown in Table A-2.

3.2) Evaporator's length is increased from 1000 mm to 1700 mm, 100 mm of the evaporator length step.

3.3) Condenser's length is increased from 50 mm to 150 mm, 10 mm of the condenser length step.

3.4) Number of evacuated tube can be produced the temperature of hot water over 65°C

In this study, selecting optimal variable parameters for the solar water heater system should consider from economics analysis to help making a decision. Thus, there are some assumptions related to economics analysis as followings:

- The interest rate of Minimum Retail Rate (MRR) is 6.5 % per year (Government Savings Bank, 2016).
- Lifetime of solar water heater system is 10 years.
- The resale value of the solar water heater is 15% of first cost.
- The maintenance cost of the solar water heater is 10% of first cost.

4.2 Thermal economics analysis

Proper quantity of variable parameters for thermosyphon's dimensions and number of evacuated tube are selected based on the heat rate of water and the thermal conomics analysis. As a result, Net Saving Method is referred in the thermal economics analysis presented by Soylemez et al. (2003) and shown in Equation (4.1).

$$Net \;\; saving = \frac{year}{1+d} C_p HQ - [1 - R_v (1+d)^{-year}](C_{collector}) \tag{4.1}$$

Where C_p is the price of electric power (Baht/kWh), H is operating lifetime of solar water heater system (hrs/year), Q is an amount of annual total thermal energy stored by the solar water heater (Wh), $C_{collector}$ is the first cost of the solar water heater system (Baht), d is the interest (%) and R_v is the resale value of the solar collector (%), and *year* is lifetime of solar water heater system.

4.3 Results and discussion

Effects of variable parameters analysis are divided into 3 following parts:

4.3.1 Effect of the evaporator length

According to the effect of the evaporator length, an assumption of the mathematical model is that the solar water heater system consists of 5 evacuated tubes because of the water temperature at storage tank over 65°C. Moreover, the condenser length is constant with 80 mm due to it is the length of the industrial product. For the mathematical model results, the maximum temperature of the evaporator, condenser, and water outlet at the storage tank, which is on the evaporator length, is shown in Figure 4.1.

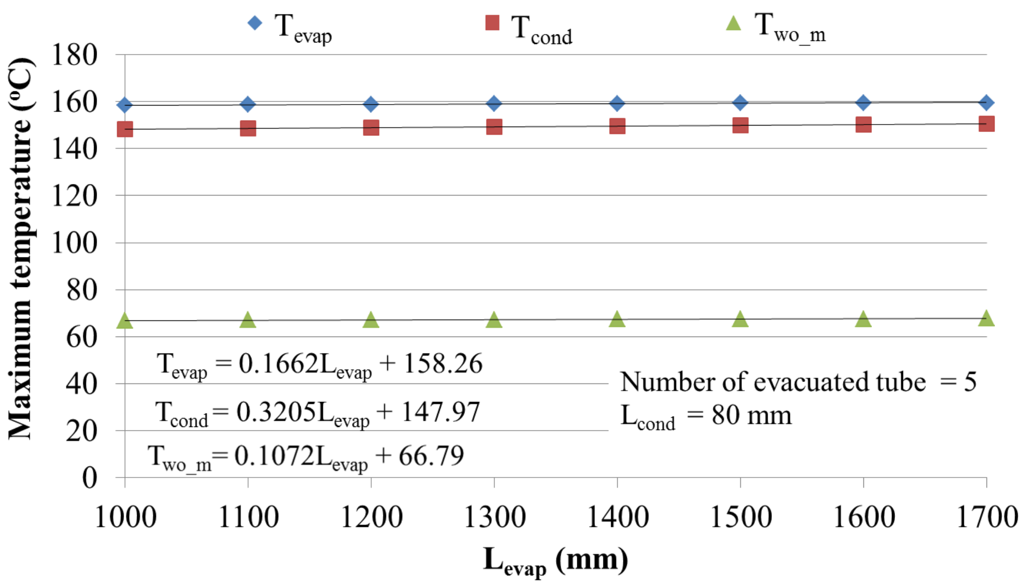

Figure 4.1 Maximum temperature of evaporator length from 1000 mm to 1700 mm

From Figure 4.1, when length of evaporator section is increased, the evaporator temperature is increased non-significant; the evaporator length step is increased 100 mm and it will affect the evaporator temperature to be increased about

0.001%. Thus, the temperature showing correlation of trend line equation can be seen in Figure 4.1. Moreover, temperature of the condenser and the water outlet has the same trend as the evaporator temperature, which a coefficient of the trend line is positive as it shows that the temperature is increased. Therefore, suitable for the evaporator length is selected at 1700 mm because there is an area to receive the thermal energy from inner evacuated tube and the heat transfer is maximum at this length.

4.3.2 Effect of the condenser length

In this part, the effects of the condenser length will be investigated. An assumption of the mathematical model is that the solar water heater system consists of 5 evacuated tubes and the evaporator length is constant with 1700 mm. The maximum temperature of the evaporator, condenser, and water outlet at storage tank, which is on the condenser length, is presented in Figure 4.2.

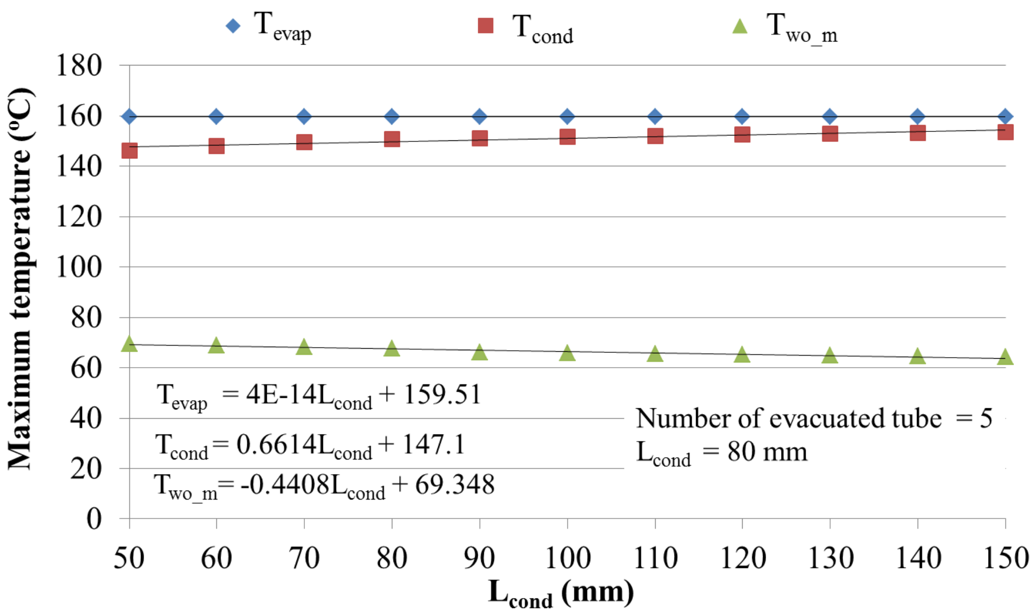

Figure 4.2 Maximum temperature of condenser length from 50 mm to 150 mm

From Figure 4.2, when the length of condenser section is increased, the evaporator temperature is constant. Conversely, when the length of condenser section is increased, the condenser temperature is increased while temperature of the water outlet of storage tank is decreased. It can be noted that the temperature of the water outlet of a storage tank is decreased about 8.37% from the condenser length increasing 50 mm to 150 mm. The water temperature is decreased at the condenser length is increased because the volume of water in the manifold is increased by the condenser length when it is increased. This means increased water volume in the manifold will affect the temperature of the water that slightly decreased. For this reason, the condenser temperature in Figure 4.2 is slightly increased until the condenser length is at 100 mm. After that, it is nearly constant in all length. For temperature of the water outlet, it can be seen that the condenser length is over 100 mm, while temperatures of the water outlet is nearly constant in all the condenser length. Thus, suitable length for the condenser is selected during 50 mm to 100 mm. But, the condenser length in this research is selected at 80 mm because it is the average of condenser length during 50 mm to 100 mm. Thus, it is easy to set the jacket and manifold at the condenser length of 80 mm.

4.3.3 Effect of number of evacuated tube

For the evaluation of thermosyphon diameters and number of evacuated tube, thermoeconomics presented by Soylemez et al. (2003) is used. From Equation (4.1), net saving is calculated from the heat rate of water by converting to the heat energy from electric power (2.78 Baht/kWh), which is deducted by investment cost and maintenance cost of the solar water heater system.

In the previous assumptions of economic analysis, it is assumed that the solar water heater system has operating time for 10 years. Furthermore, the interest and resale value of the solar water heater system is approximately 6.5% and 15%, respectively. In order to analyze net saving, number of evacuated tube and thermosyphon diameter conditions of solar water heater systems are considered at temperature of hot water over 65°C. It is because of personal hygiene and water stored in a hot water storage tank should be equal to 60ºC or higher, which will protect Legionella and other bacterial growth (AS1056.1, 1991). Thus, some thermosyphon diameters and number of evacuated tubes are considered in this study due to they can produce the temperature of hot water over 65ºC, but some parameters that produce temperature of hot water under 65ºC are not considered.

In Figure 4.3 shows net saving of solar water heater system which the x-axis represents number of evacuated tubes, whereas y-axis represents net saving. It can be seen that at small diameter and low number of tubes, the energy price of solar water heater system shows lower net saving. It means that the heat energy cost of solar water heater system is lower compared with investment cost. Furthermore, number of evacuated tubes is increased, thermosyphon diameter is larger, and heat energy cost of solar water heater system is increased by increasing diameter of thermosyphon and number of evacuated tube. This will make net saving increased, but increasing net saving cannot make a right proportion for thermosyphon diameter and number of evacuated tube to be increased.

From Figure 4.3, it shows the maximum of net saving when number of evacuated tubes is increased to 8. Thereafter, these increasing numbers of evacuated tube will make net saving decreased due to the ability in accumulating thermal energy of water is limited. It can also be seen from Figure 4.3 that the evacuated tube solar water heater system at temperature of hot water over 65^{o}C and the maximum value of heat rate of water are obtained at 8 evacuated tubes, 15.88 mm (1/2 inch) of evaporator diameter, and 22.22 mm (3/4 inch) of condenser diameter. Moreover, the solar water heater system is obtained the maximum net saving at 98,078 Baht. These appropriate conditions are studied at Chiang Mai province, Thailand.

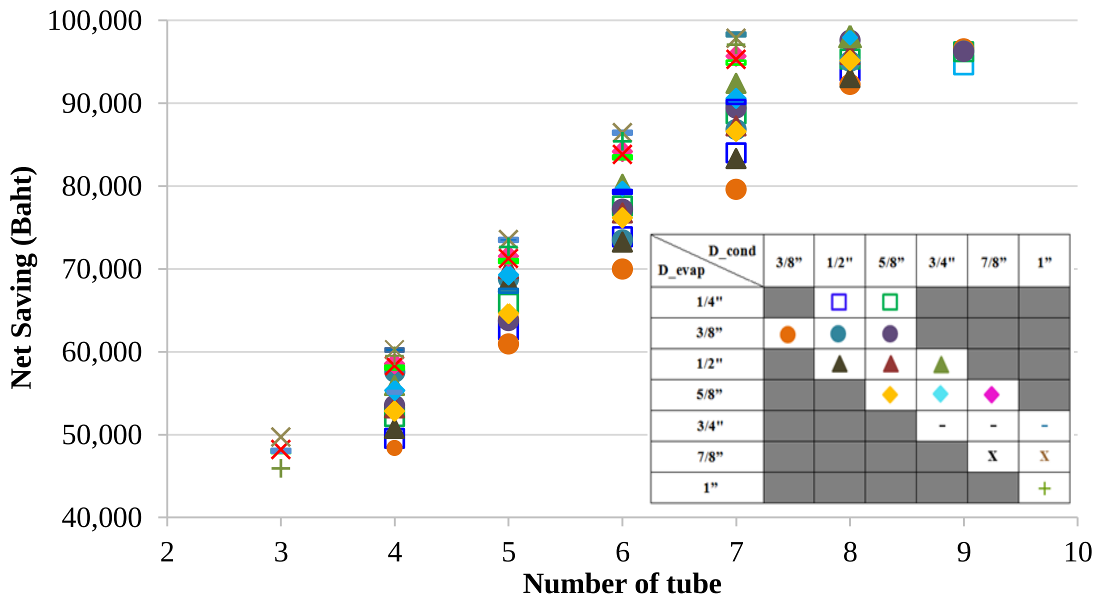

Figure 4.3 Effect of number of tube on the net saving of solar water heater system

4.4 Conclusion

All the results are summarized as follows:

1) When length of evaporator section is increased, temperature of evaporator, condenser, and water outlet are also increased non-significant. Thus, length of the evaporator section is selected at 1700 mm since the maximum length of evaporator has an area to obtain the highest thermal energy from inner evacuated tube.
2) For the effect of condenser length, when the length of condenser section is increased, the evaporator temperature is nearly constants while the condenser temperature and temperature of the water outlet is increased and decreased, respectively. That is to say, temperature of the water outlet is decreased because of the increased volume of water in manifold, by increasing the condenser length. Thus, the condenser length is selected at 80 mm.
3) For the effects of thermosyphon diameters and number of evacuated tube on the net saving in the solar water heater system, it shows that the optimal number of evacuated tube is at 8, diameters of themosyphon are 15.88 mm (1/2 inch) of evaporator diameter, 22.22 mm (3/4 inch) of condenser diameter and the maximum net saving is 98,078 Baht.