Final Report

Use of Absorption Heat Transformer for Upgrading Low Temperature Solar Heat

Submitted to

Daikin Industries Thailand

Prof. Dr. T. Kiatsiriroat

Department of Mechanical Faculty of Engineering

Chiang Mai University

March 2011

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In this study, a concept in using solar heat form a solar water heating system having a set of flat-plate solar collectors as a heat source to an AHT where the heat could be upgraded to a higher temperature is presented. Two phases of the study each of 6 months have been carried out with the details as follows:

The 1st phase (Past Study: April-September 2010)

A H_2O-LiBr AHT and a solar water heating system having a set of flat-plate solar collector have been designed and constructed to generate heat at a high temperature. Models for predicting thermal performances of the AHT and the solar collectors at various operating conditions have been developed.

The 2nd Phase (Present Study: October 2010-March 2011)

In this phase, a simplified model of the AHT and the solar water heating system has been performed and the simulated results from the model are found to agree well with the experimental data. The models are also used to evaluate the possibility of the solar-AHT to replace or partial support the boiler for high temperature hot water generation. A case study of a hospital is undertaken. It is found that there is a high potential to use the AHT to generate hot water at around 85 °C. Two sets of 10 kW_{th} AHT are running in parallel as a partial support of a boiler to generate hot water and it could be found that the combined system could save fuel cost of which the short payback is obtained compared with the boiler only.

ACKNOWLEDGEMNTS

The authors would like to acknowledge Daikin Industries (Thailand) Ltd for partial support fund and Grateful thanks to Department of Mechanical Engineering, Chiang Mai University for offering some measuring instruments of this study.

CHAPTER 1

Introduction

1.1 Absorption Heat Transformer

Generally, heat will transfer from a high temperature heat source to a lower temperature heat sink. If we want to reverse the heat direction, a heat driven machine is needed and an absorption heat transformer, one type of heat pump, could be used. Absorption heat transformer (AHT) sometimes is called as Absorption heat pump type II. The unit could generate heat at a high temperature (over $100^{\circ}C$) from a medium temperature heat source (around 60-80$^{\circ}C$) such as waste heat from industrial processes or solar heat. Figure 1.1 shows the concept of an AHT.

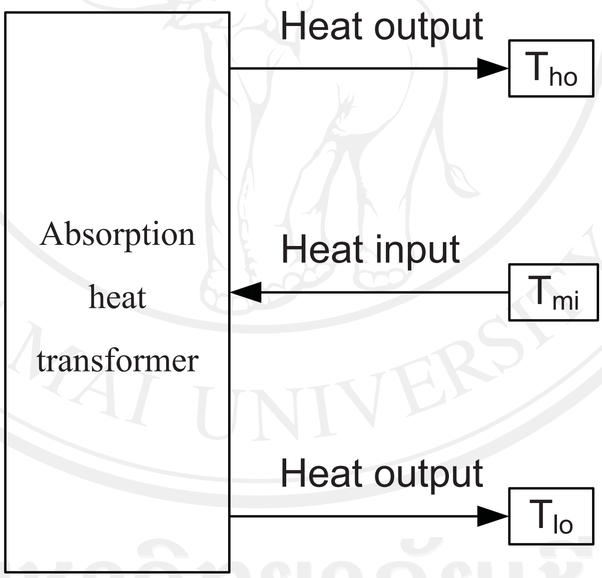


Figure 1.1 A concept of boosting heat to a higher temperature level by AHT.

A schematic sketch and P-T-X diagram of the AHT are shown in Figure 1.2 and Figure 1.3, respectively. At the AHT generator, a binary liquid mixture consisting of a volatile component (absorbate) and a less volatile component (absorbent) is heated at a medium temperature. Part of the absorbate boils at a low pressure (P_C) and a generator temperature (T_G) at state 1. The vapor condenses in the AHT condenser at a condenser temperature (T_C) to be liquid at state 2. After that the absorbate in liquid phase is pumped to the AHT evaporator at state 3 of which the pressure (P_E) is higher than that of the AHT condenser. The

AHT evaporator is heated at a medium temperature (T_E) and the absorbate in a form of vapor enters the AHT absorber which has the same pressure as the AHT evaporator at state 4. Meanwhile liquid mixture from the AHT generator, at state 5 is pumped through a heat exchanger (state 6) into the AHT absorber to a high pressure at state 7. In the AHT absorber, the strong solution (X_{max}) absorbs the absorbate vapor and the weak solution (X_{min}) leaves the absorber at state 8. During absorption process, heat is released at a high temperature (T_A) which is higher than those at the generator and the evaporator. This liberated heat is the useful output of the AHT. The weak solution at state 8 from the AHT absorber is then throttled to a low pressure through the AHT heat exchanger at state 9 into the AHT generator again at state 10 and new cycle restarts.

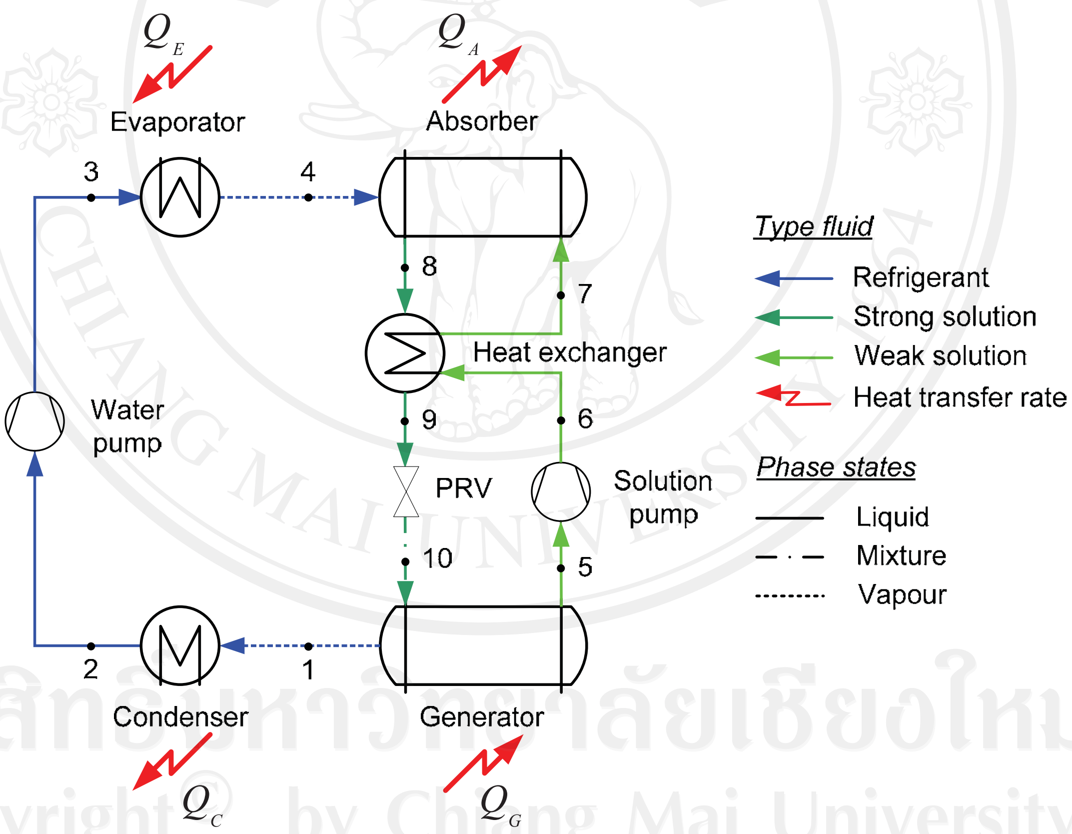


Figure 1.2 Schematic diagram of an Absorption Heat Transformer (AHT).

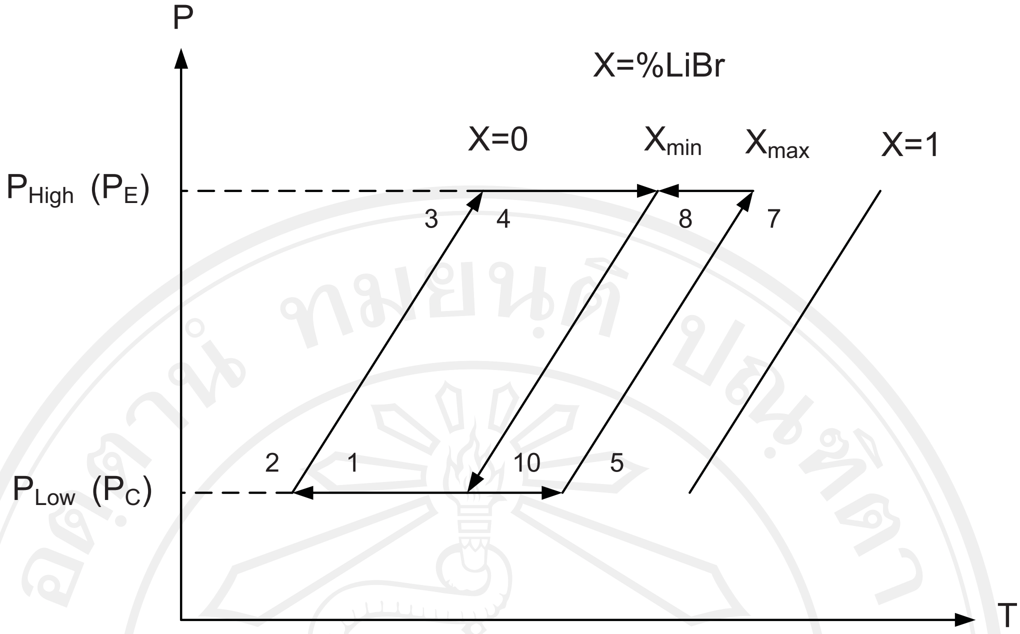


Figure 1.3 The P-T-X diagram of an absorption heat transformer.

The basic equations for the behavior of each component in the AHT cycle are as follows:

- Generator

$$Q_G = \dot{m}_1 h_1 + \dot{m}_5 h_5 - \dot{m}_{10} h_{10}\,, \tag{1}$$

$$\dot{m}_{10} = \dot{m}_1 + \dot{m}_5\,, \tag{2}$$

$$\dot{m}_{10} X_{10} = \dot{m}_5 X_5\,, (X_1 = 0)\,. \tag{3}$$

From equation (2) and (3),

$$\dot{m}_5 = \frac{\dot{m}_1 X_{10}}{X_5 - X_{10}}\,, \tag{4}$$

and

$$\dot{m}_{10} = \frac{\dot{m}_1 X_5}{X_5 - X_{10}}\,. \tag{5}$$

- Condenser

$$Q_C = \dot{m}_{ref}\,(h_1 - h_2)\,, \tag{6}$$

$$\dot{m}_{ref} = \dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_4\,. \tag{7}$$

- Pump and solution pump

$$W_P = (P_E - P_C)\frac{v_2 \dot{m}_2}{\eta_P}, \tag{8}$$

$$W_{SP} = (P_E - P_C)\frac{v_5 \dot{m}_5}{\eta_{SP}}, \tag{9}$$

$$h_2 \approx h_3, \tag{10}$$

$$h_5 \approx h_6. \tag{11}$$

- Evaporator

$$Q_E = \dot{m}_{ref}(h_4 - h_3). \tag{12}$$

- Absorber

$$Q_A = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_8 h_8, \tag{13}$$

$$\dot{m}_8 = \dot{m}_4 + \dot{m}_7, \tag{14}$$

$$\dot{m}_8 X_8 = \dot{m}_7 X_7. \tag{15}$$

- Heat exchanger

$$Q_{HX} = \dot{m}_8 Cp_8 (T_8 - T_9) = \dot{m}_6 Cp_6 (T_7 - T_6) = \varepsilon_{HX} (mCp)_{min} (T_8 - T_6), \tag{16}$$

$$\dot{m}_8 = \dot{m}_9, \tag{17}$$

$$\dot{m}_6 = \dot{m}_7. \tag{18}$$

- Expansion valve

$$h_9 = h_{10} \quad \text{(Throttling process)}. \tag{19}$$

- Coefficient of performance (COP)

$$COP_{AHT} = \frac{Q_A}{Q_E + Q_G + W_P + W_{SP}}. \tag{20}$$

1.2 Solar Water Heating System

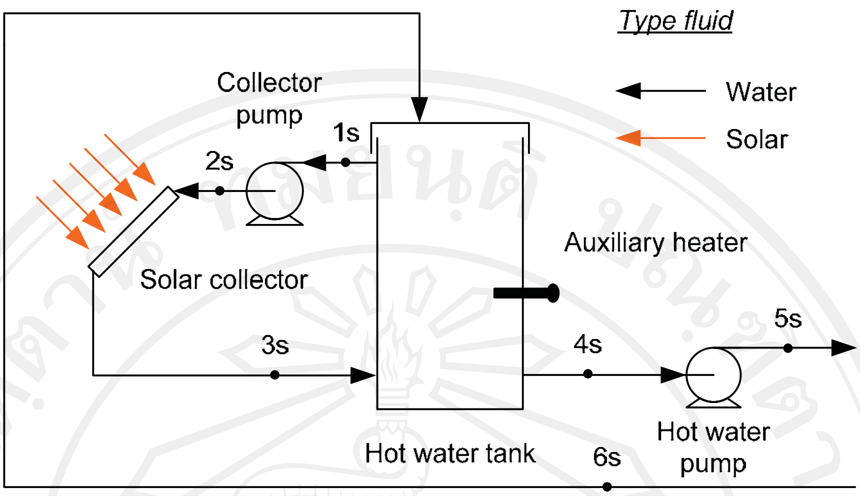


Figure 1.4 Schematic diagram of a solar water heating system.

Figure 1.4 shows a schematic diagram for evaluating the normal solar water heating system. In this calculation, the heat transfer rate from the solar collector (Q_{SC}) is calculated by:

- Solar radiation

For solar time, standard time and longitude used to find,

$$\text{Solar time - Standard time} = 4(L_{Std} - L_{Loc}) + E, \tag{21}$$

when,

$$E = 9.87\sin(2B) - 7.53\cos B - 1.5\sin B, \tag{22}$$

$$B = \frac{360(n-1)}{365}. \tag{23}$$

For total daily extraterrestrial radiation on a horizontal surface over a day (H_o),

$$H_o = \frac{24\times 3600}{\pi} G_{sc}[1 + 0.033\cos\left(\frac{360n}{365}\right)]\times\left[\cos\varphi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\varphi\sin\delta\right], \tag{24}$$

when,

$$\delta = 23.45\sin\left[\frac{360(284+n)}{365}\right], \tag{25}$$

$$\omega_s = \cos^{-1}\left[\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta}\right] = \cos^{-1}(-\tan\varphi\tan\delta). \tag{26}$$

For daily diffuse solar radiation (H_d),

$$\frac{H_d}{H_o} = -4.6408 + 26.5495\left(\frac{H}{H_o}\right) - 28.3422\left(\frac{H}{H_o}\right)^2 - 31.4546\left(\frac{H}{H_o}\right)^3 + 46.4421\left(\frac{H}{H_o}\right)^4, \quad (27)$$

and total daily solar radiation hour (H),

$$H = H_b + H_d. \quad (28)$$

For Julian date of each month as shown in Table 1.1,

Table 1.1 Julian date of each month

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Date of month	17	16	16	15	15	11	17	16	15	15	14	10
Julian date (n)	17	47	75	105	135	162	198	228	258	288	318	344

(Duffie and Beckman, 1980)

For solar radiation hour (I),

$$\frac{I}{H} = \frac{\pi}{24} \times \frac{(a + b\cos\omega)(\cos\omega - \cos\omega_s)}{\sin\omega_s - \frac{2\pi\omega_s \cos\omega_s}{360}}, \quad (29)$$

when,

$$a = a_1 + a_2 \sin(\omega_s - 60^\circ), \quad (30)$$

$$b = b_1 + b_2 \sin(\omega_s - 60^\circ). \quad (31)$$

For the constant of a_1, a_2, b_1, b_2 each province as shown in Table 1.2,

Table 1.2 The constant of a_1, a_2, b_1, b_2 for some main provinces in Thailand.

Province	a_1	a_2	b_1	b_2
Chiang Mai	0.514	0.228	0.512	0.033
Ubon Ratchathani	0.760	– 0.031	0.207	0.238
Had Yai	0.307	– 0.124	0.417	0.007
Bangkok	0.792	– 0.250	0.189	0.471

(Naris Pratinthong, 1996)

For diffuse solar radiation hour (I_d),

$$\frac{I_d}{H_d} = \frac{\pi}{24} \times \frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \dfrac{2\pi\omega_s \cos\omega_s}{360}} . \tag{32}$$

Where, direct solar radiation hour (I_b),

$$I_b = I - I_d . \tag{33}$$

For solar radiation hour on the inclined plane (I_t),

$$I_t = I_b R_b + I_d \frac{1+\cos\beta}{2} , \tag{34}$$

and,

$$I_t = I_b R_b + I_d \frac{1+\cos\beta}{2} + \rho_g (I_b + I_d)\left(\frac{1-\cos\beta}{2}\right), \tag{35}$$

when,

$$R_b = \frac{\cos\theta}{\cos\theta_z} , \tag{36}$$

$$\begin{aligned}\cos\theta = {} & \sin\delta\sin\varphi\cos\beta - \sin\delta\cos\varphi\sin\beta\cos\gamma + \cos\delta\cos\varphi\cos\beta\cos\omega \\ & + \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} , \tag{37}$$

$$\cos\theta_z = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega . \tag{38}$$

- Solar collector

$$Q_{SC} = \dot{m}_{SC} Cp_{SC} (T_{SC,o} - T_{SC,i}) , \tag{39}$$

$$Q_{SC} = F_R (\tau\alpha) I_t A_{SC} - F_R U_L A_{SC} (T_{SC,i} - T_a) , \tag{40}$$

For solar collectors in series connection,

$$(F_R (\tau\alpha))_{Series} = F_R (\tau\alpha)\left[\frac{1-(1-K)^N}{NK}\right], \tag{41}$$

$$(F_R U_L)_{Series} = F_R U_L \left[\frac{1-(1-K)^N}{NK}\right], \tag{42}$$

Where,

$$K = \frac{A_{SC}(F_R U_L)_{Single\ unit}}{\dot{m}_{SC} Cp_{SC}} . \tag{43}$$

- Supplied heat of useful hot water at storage tank

$$Q_{Sup} = \dot{m}_{Sup} Cp_{bulk} (T_{Sup,o} - T_{Sup,i}) . \tag{44}$$

- Heat loss at storage tank

$$Q_{Loss} = UA_{Tank}(T_{1s} - T_a) \ . \tag{45}$$

- Storage tank

$$Q_{ST} = M_{ST} Cp_{ST} \left(\frac{dT}{dt}\right) . \tag{46}$$

Using numerical method, the water temperature could be calculated from,

$$T_{ST}^{t+\Delta t} = T_{ST}^{t} + \frac{Q_{ST}\Delta t}{M_{ST} Cp_{ST}} , \tag{47}$$

With an auxiliary heater, the temperature becomes,

$$T_{ST}^{t+\Delta t} = T_{ST}^{t} + \frac{(Q_{SC} + Q_{Aux} - Q_{loss} - Q_{Sup})\Delta t}{M_{ST} Cp_{ST}} . \tag{48}$$

The auxiliary heat is on when the temperature is less than a set point.

Figure 1.4 shows a schematic diagram of the AHT when it is coupled with a solar water heating system and the whole unit is called Solar-Absorption Heat Transformer (Solar-AHT) which is considered in this study. The solar heat from the solar water heating system is supplied to the AHT generator and the AHT evaporator. The solar heat is upgraded to a high temperature and released at the AHT absorber.

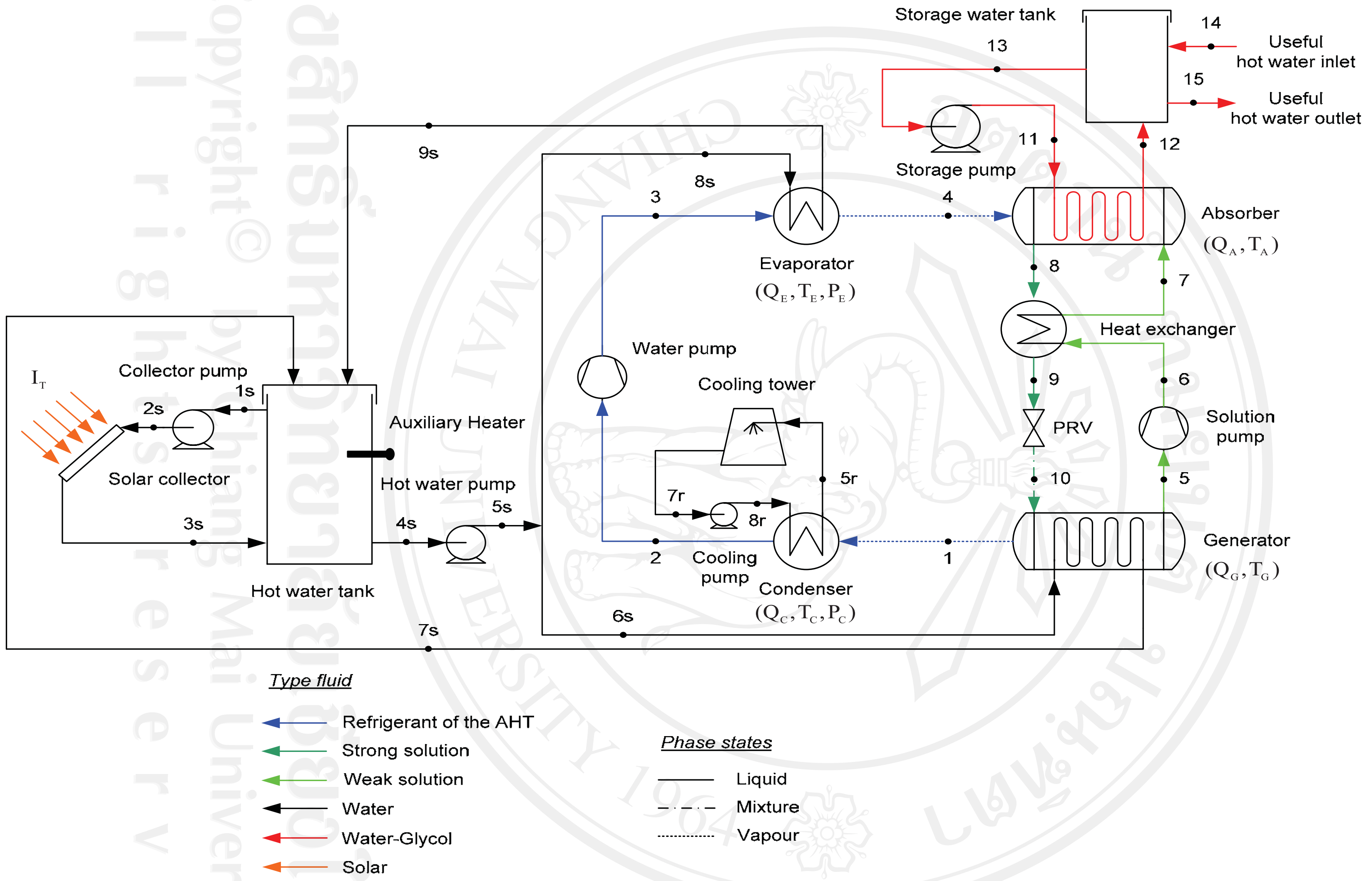


Figure 1.4 Schematic diagram of a Solar-AHT.

1.3 Literature Review

Absorption heat transformer (AHT) is one method for upgrading low temperature heat to a higher temperature level. In a conventional AHT, low temperature heat is absorbed at the AHT generator and the AHT evaporator and the heat is delivered at the AHT absorber at a higher temperature, while the AHT condenser rejects heat at a lower temperature. Theoretical and experimental studies of the AHT have been reported by various literatures. Florides et al. [1] modeled and simulated an absorption solar cooling system in Cyprus which used 3 types of solar collectors, flat plate solar collectors, compound parabolic collectors (CPC) and evacuated tube collectors for comparison by the TRNSYS simulation program. It could be seen that the compound parabolic collector was appropriate for solar absorption cooling in a house during the whole year. The final optimized system consisted of a 15 m^2 compound parabolic collector tilted 30° from the horizontal plane and a 600 L hot water storage tank. Rivera et al. [2] presented a single-stage and advanced AHT operating with water-LiBr and water-Carrol^{TM} mixtures to increase the temperature of the useful heat produced by solar ponds. The results showed that the single-stage and the double AHT increased solar pond's temperature until 50 $^\circ$C at COP about 0.48 and 100 $^\circ$C at COP about 0.33, respectively. Xuehu et al. [3] reported the test results of the first industrial-scale water-LiBr AHT in China to recover waste heat released from an organic vapor at 98 $^\circ$C in a synthetic rubber plant. The recovered heat was used to heat hot water from 95 $^\circ$C to 110°C. The AHT system was operating with a heat rate of 5,000 kW with a mean COP of 0.47. The payback was approximately 2 years. Sotsil Silva Sotelo et al. [4] presented an AHT cycle operating with water-Carrol^{TM} mixture which had a higher solubility than aqueous Lithium Bromide mixture. It could be found that the coefficient of performance was higher and less crystallization risk was obtained compared with the water-Lithium Bromide solution.

In this study, thermal performance of a single-stage H_2O-LiBr AHT coupling with a set of flat-plate solar collectors (Solar-AHT) has is experimentally and theoretically studied. A model is developed to predict performance of the solar-AHT at various operating conditions. Moreover, a case study to evaluate a possibility of this technique to generate high hot water temperature instead of a boiler is carried out.

1.4 Research Methodology

The study is separated into 3 parts:

The first part

The first one is to set up an experimental test of a H_2O-LiBr AHT of which the heat capacity is not over 10 kWth. A set of flat-plate solar collectors is not over 20 m^2 with an auxiliary heater is used to produce hot water at various temperature from 60-80 °C which is supplied at the AHT generator and the AHT evaporator. The COP of the cycle, the heat rates at the generator, the evaporator and the absorber and the consumed electrical power at various input hot water temperatures are recorded.

The second part

The second part is to develop a simplified model from the experimental results in the first part for predicting performance of the AHT and the solar collectors at various operating conditions.

The final part

In this phase, the models are also used to evaluate the possibility of the solar-AHT to replace or partial support the boiler for high temperature hot water generation. A case study of a hospital is undertaken. The economic analysis of the solar-AHT for generating high temperature hot water is considered compared with that of the boiler.

1.5 Objectives of the Study

The objectives of the study are:

1. To develop a simplified model of a H_2O-LiBr AHT for upgrading low temperature solar heat from flat-plate solar collector.
2. To evaluate the possibility of the solar-AHT to replace or partial support the boiler for high temperature hot water generation in a hotel or a hospital.

1.4 Benefits from the Research Study

The benefits from the study are:

1. There is a demonstration of an AHT unit which can be used for upgrading low temperature solar heat. The unit could be tested as a testing facility for other research activities or public training.

2. There is a simplified model that can be used to predict the AHT performance for upgrading low temperature heat such as solar heat and industrial waste heat for high temperature applications.

CHAPTER 2

Evaluation of Solar-AHT Thermal Performance

In this chapter, a method to evaluate thermal performances of any H_2O-LiBr solar-AHT similar to that given in Figure 1.4 is presented. The developed model is divided into 2 sections. The first one is for the solar water heating system and the other one is for the solar-AHT.

For the solar water heating system (SWHS), its equations as shown in chapter 1 are used to simulate heating performance with various numbers of solar collector units and tank capacities. The calculation steps of the solar water heating system are shown in Figure 2.1.

For the solar-AHT system, its equations in chapter 1 and properties of H_2O-LiBr solutions as shown in appendix are taken for evaluating the system performance when the temperatures of hot water entering the generator and the evaporator, the mass flow rate, the temperature of cooling water entering the condenser and the solar radiation are prescribed. The suitable operating condition is selected at the solar radiation and the ambient temperature of Chiang Mai, Thailand. The calculation steps of the AHT system are shown in Figure 2.2.

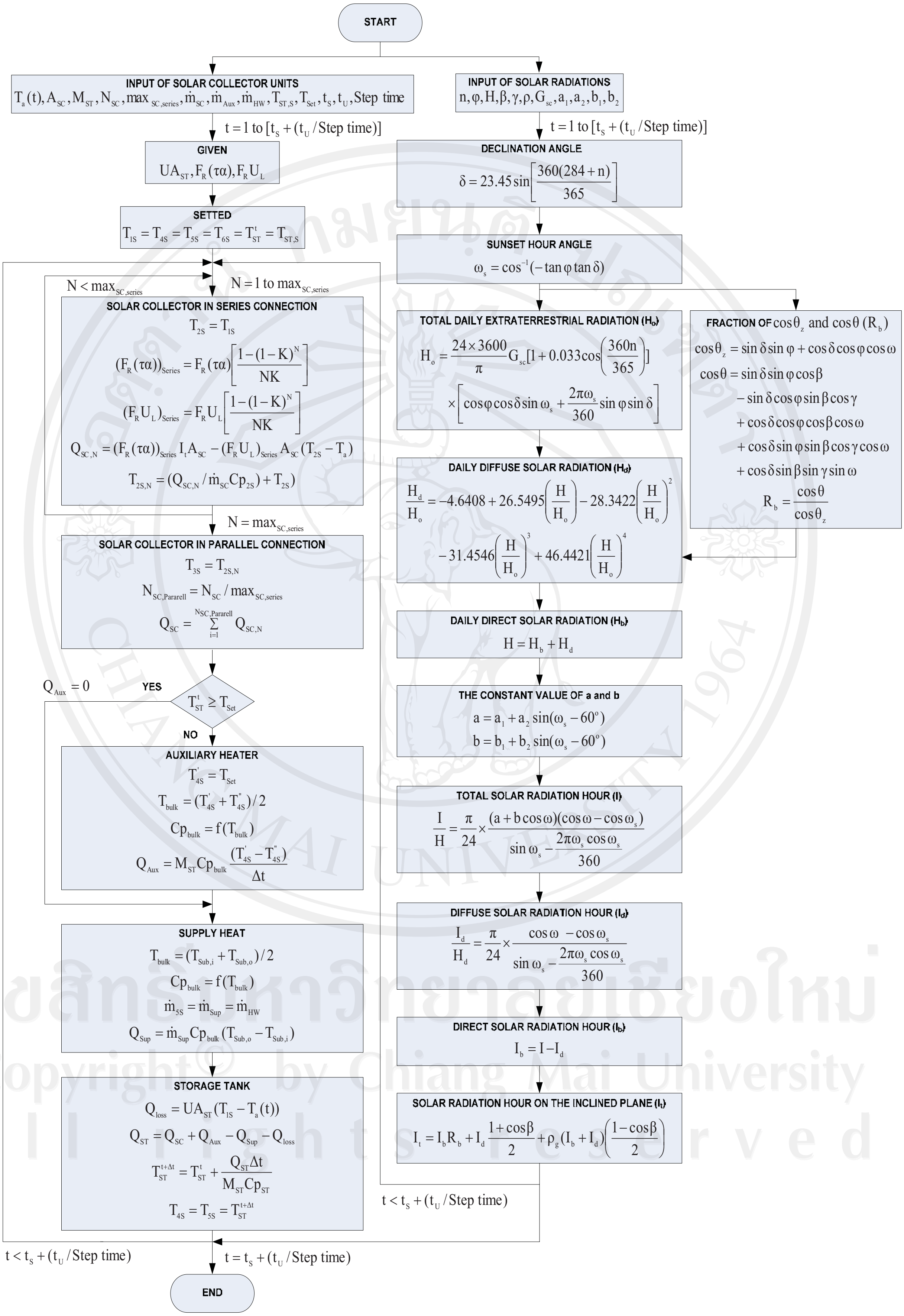


Figure 2.1 Flow chart of the simulation program for evaluating the solar water heating system.

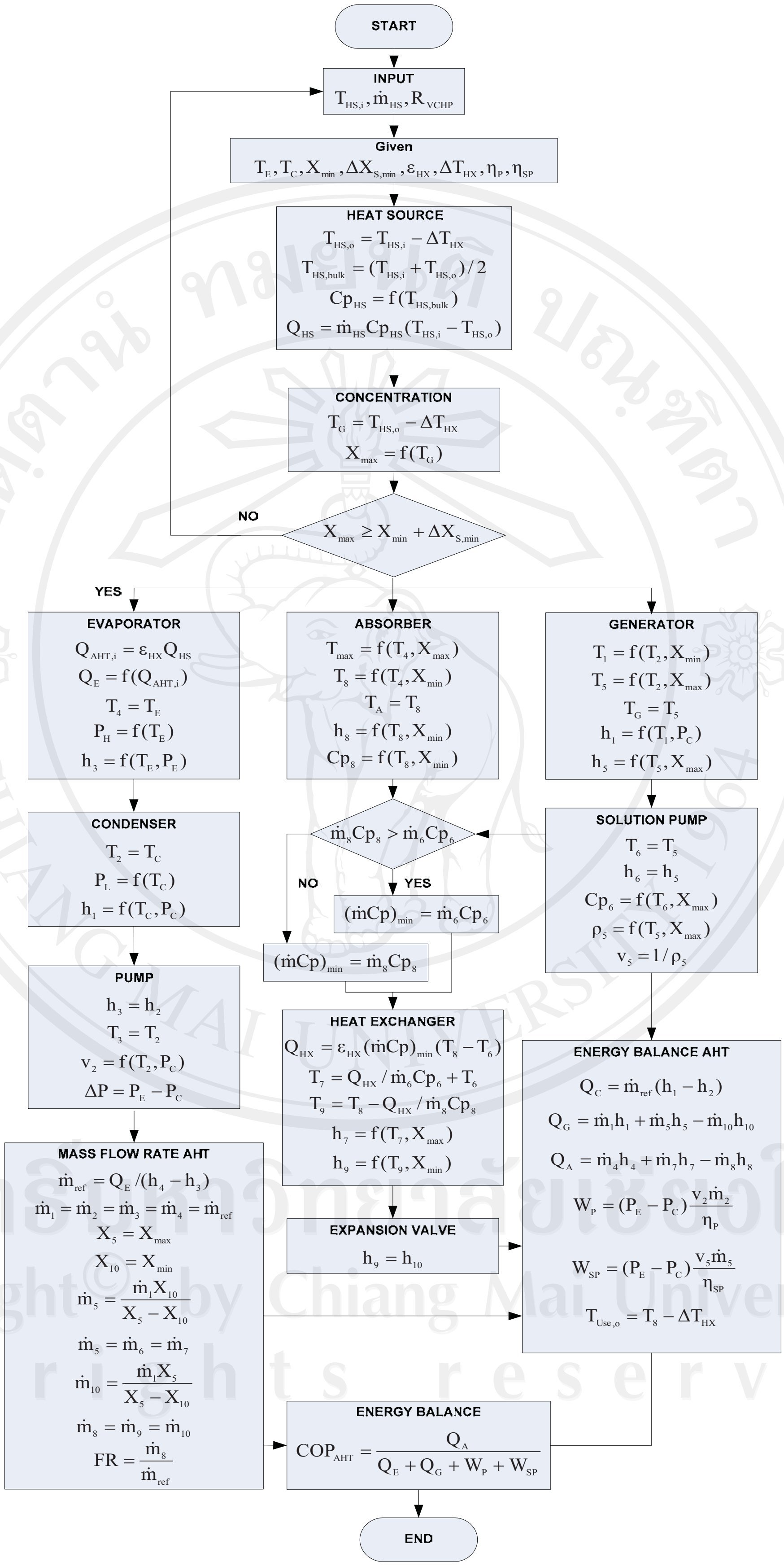


Figure 2.2 Flow chart of the simulation program for evaluating the AHT performance.

2.1 Operating Conditions of the Solar-AHT

All calculations of the solar-AHT are based on the system presented in Figure 1.4. The H_2O-LiBr solution is the working pair of the AHT. The working conditions for the evaluation are:

<u>Solar water heating system</u>

1. The solar radiation (I_T) used for the simulation is the mean solar radiation level of Chiang Mai, Thailand, as shown in appendix [5].
2. The ambient temperature (T_a) used for the simulation is the mean temperature of Chiang Mai, Thailand, as shown in appendix [6].
3. Supplied water flow rate $(\dot{m}_{SC})$ to each solar collector is $0.043\ \mathrm{L/s}$.
4. Supplied heat of the AHT is hot water temperature (T_{5S}) from the flat-plate solar collector water heating system.
5. Useful water temperature leaving solar water heating system $(T_{ST}^{t+\Delta t})$ equal heat source temperature entering the AHT (T_{5S}).
6. Assumptions $F_R(\tau\alpha)$ and $F_R(U_L)$ of solar collector of 2.3 m^2/unit are constants which are 0.802 and $10.37\ \mathrm{W/m^2 \cdot K}$, respectively [7].
7. Assumptions volume capacity and UA_{ST} of storage tank are 3,000 L and $3\ \mathrm{W/^\circ C}$.

<u>The AHT system</u>

1. Useful heat leaving the absorber is about $10\ \mathrm{kW}$.
2. Minimum concentration of weak H_2O-LiBr solution (X_{min}) is 45 %LiBr (by mass).
3. Maximum flow ratio (FR) for starting is around 20 %LiBr (by mass).
4. No pressure drops at the condenser, the generator, the evaporator, the absorber and the heat exchanger.
5. Isentropic efficiency of water pump (η_P) and solution pump (η_{SP}) is 85%.
6. Effectiveness of the heat exchanger (ε_{HX}) is 85%.
7. Temperature difference between the outlet supplied hot water and the generator is 5 $^\circ C$.
8. Temperature difference between the outlet useful water and the absorber is 5 $^\circ C$.
9. Temperature difference between the outlet cooling water and the condenser is 5 $^\circ C$.

10. Temperature difference between the outlet supplied hot water and the evaporator is 5 $^{\circ}C$.
11. The properties of H_2O-LiBr solution are shown in appendix.

2.2 Thermal Performance of the Solar-AHT

In this section, the performance of a solar-AHT with flat-plate solar collectors for generating hot water is considered. In our calculation, $F_R(\tau\alpha)$ and $F_R U_L$ of each flat-plate solar collector are 0.802 and 10.37 $W/m^2 \cdot K$, respectively [7].

Figure 2.3 shows the temperature of each component and the maximum percentage of LiBr concentration of the AHT with various values of supplied hot water temperature. It could be seen that the AHT could operate when the supplied hot water temperature is over about 75 $^{\circ}C$ and the minimum percentage of LiBr concentration (X_{min}) at 45 %. It could be noted that the absorber temperature (T_A), the generator temperature (T_G), the evaporator temperature (T_E) and the maximum concentration (X_{max}) increase with the supplied hot water temperature while the condenser temperature (T_C) is nearly constant.

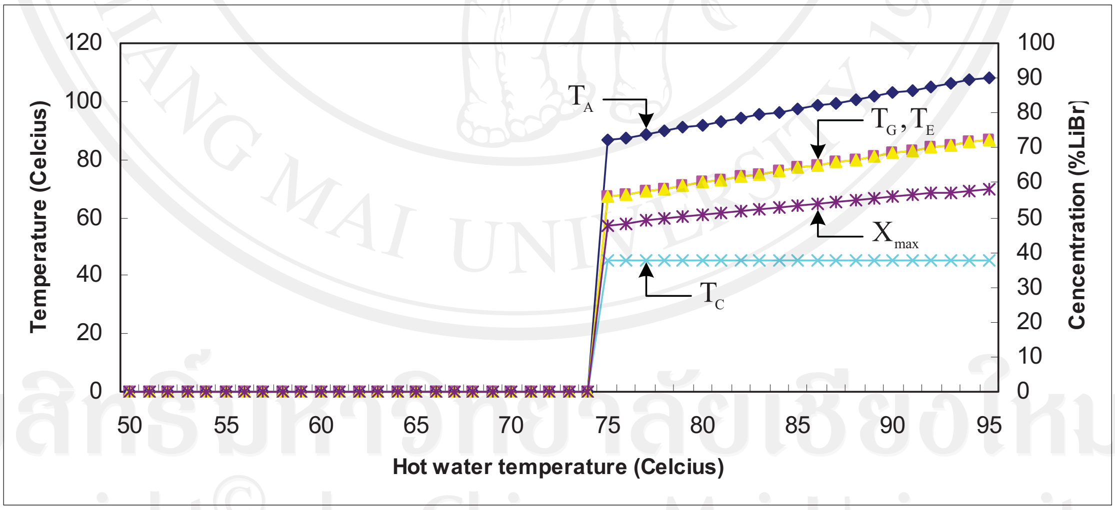


Figure 2.3 The temperature of each component and the maximum percentage of LiBr concentration of the AHT at various values of supplied hot water temperature.

Figure 2.4 shows the results of the system performance with the solar radiation (I_T) and the ambient temperature (T_a) of Chiang Mai, Thailand in April. The solar water heating system has 50 units of flat-plate solar collector units and a 3,000 liter hot water tank to generate heat about 20 kW to the AHT. It could be seen that the system could operate around 3.5 hours during 11 a. m. – 15.00 p.m. when the supplied hot water temperature is over 75 °C .

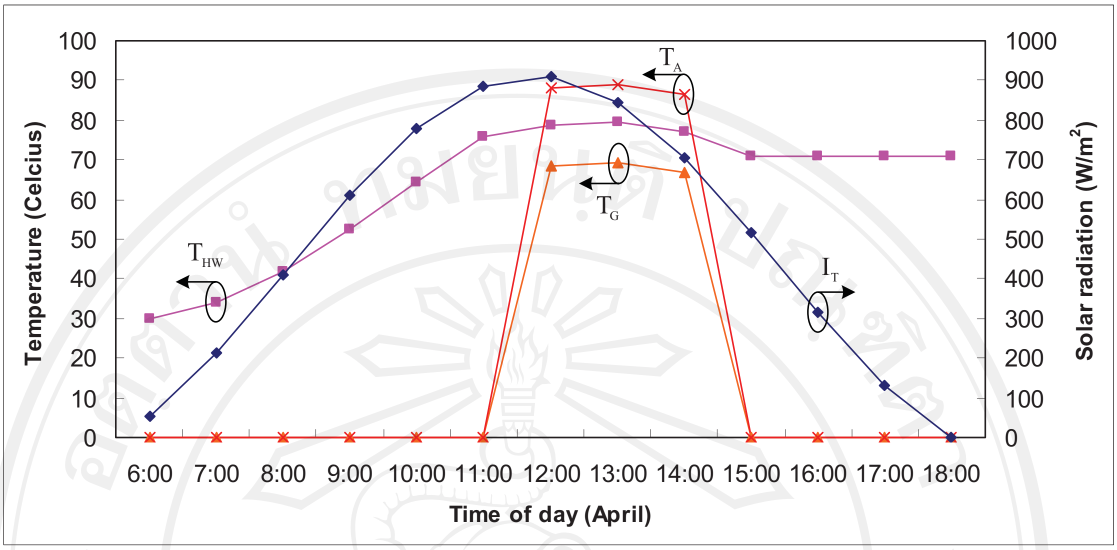


Figure 2.4 Thermal performance of the Solar-AHT in April.

Figure 2.5 shows the performance of the system similar to the previous case but there is an auxiliary heater in the storage tank operating when the temperature is less than 75 °C . It could be seen that the solar-AHT system operating in April could operate continuously between 10.00 a.m. to 18.00 p.m. and the overall COP shown in Figure 2.6 is nearly constant around 0.5.

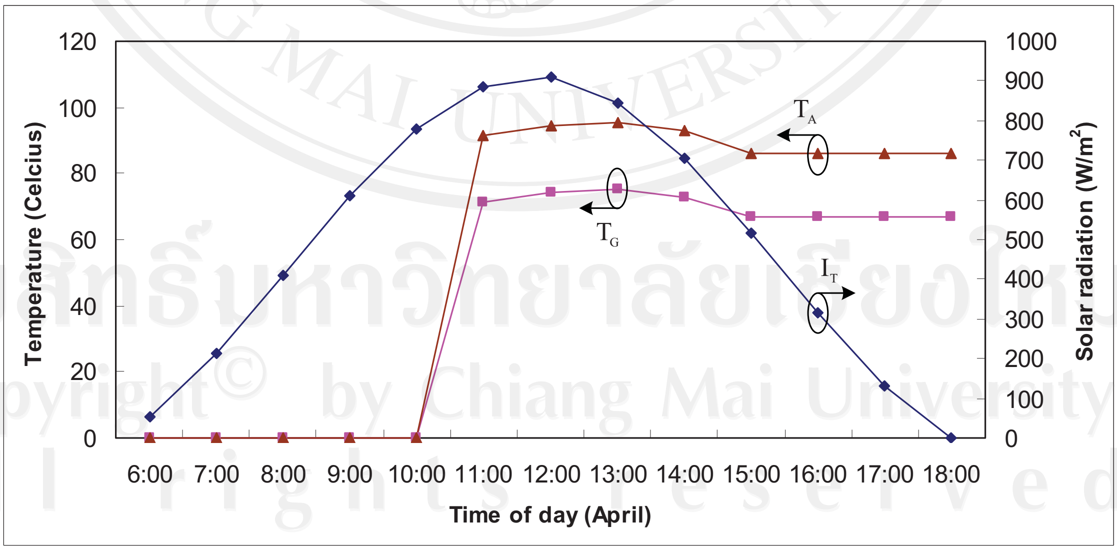


Figure 2.5 The generator and the absorber temperatures during a day in April when there is an auxiliary heater in the storage tank.

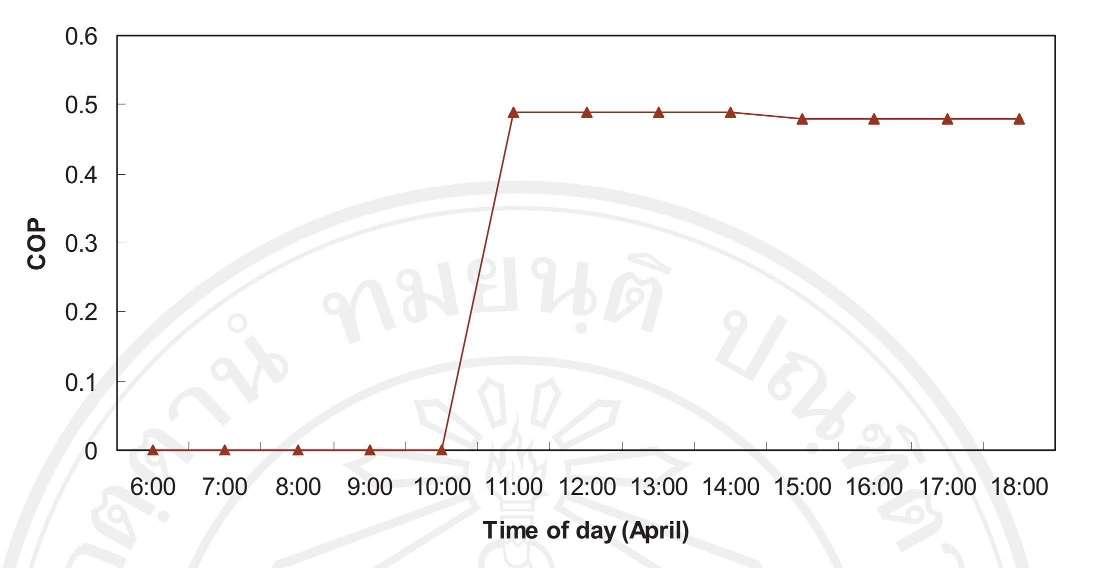


Figure 2.6 The COP of the Solar/AHT during a day in April when there is an auxiliary heater in the storage tank.

CHAPTER 3

Design and Construction of a Solar-AHT

In this chapter, design and construction of a Solar-Absorption Heat Transformer (Solar-AHT) for upgrading solar heat is presented. The constructed unit will be undertaken as an experimental one for verifying the validation of the model developed in the previous chapter.

Similar to the system described in Figure 1.4, the specifications of all component of the constructed Solar-AHT are given in Table 3.1.

Table 3.1 Descriptions of all components in the constructed Solar-AHT.

Devices	Type	Material	Properties
1. Solar collector	Flat-plate solar collector	Copper and Aluminium	• Area 2.3 m^2 / unit • 10 units • $F_R(\tau\alpha) = 0.802$ • $F_R U_L = 10.37\ W/m^2 \cdot K$
2. Generator	Flooded shell and tube heat exchanger	Iron and copper	• Capacity 10.3 kW • Weak solution 50 %LiBr • Strong solution 55 %LiBr • Generator temperature 85 $^{\circ}C$ • Tube diameter 4/8 in • Number of Tube passes 4 • Length 1.24 m • Area 1.02 m^2
3. Condenser	Shell and tube heat exchanger	Iron and copper	• Capacity 10.6 kW • Condenser temperature 55 $^{\circ}C$ • Tube diameter 4/8 in • Number of Tube passes 2 • Length 1.01 m • Area 0.42 m^2
4. Absorber	Flooded shell	Iron and	• Capacity 10 kW

Devices	Type	Material	Properties
	and tube heat exchanger	copper	• Weak solution 50 %LiBr • Strong solution 55 %LiBr • Absorber temperature 115 °C • Tube diameter 3/4 in • Number of Tube passes 6 • Length 1.1 m • Area 1.44 m^2
5. Evaporator	Shell and tube heat exchanger	Iron and copper	• Capacity 10.8 kW • Evaporator temperature 85 °C • Tube diameter 4/8 in • Number of Tube passes 9 • Length 0.94 m • Area 1.16 m^2
6. Pressure relief device	Orifice type	Bronzed	• Capacity 10 kW • Pressure ratio 6.00
7. Lithium bromide	-	Lithium bromide-water solution	• Main content 50-55% • Light yellow transparent liquid • Chloride = 0.05% max • Sulphate = 0.05% max • Bromate = Non reaction • Ca = 0.0001% max • Mg = 0.0001% max • Na = 0.03% max • PH = 9.0-10.5 • Lithium chromate = 0.2-0.3%
8. Solution pump	Inline pump	Stainless steel and ceramic	• Flow rate 0.6-3.7 m^3/h • Maximum head 6 m • Maximum temperature 110 °C • Maximum pressure 10 bar • Capacity 78 W

Devices	Type	Material	Properties
			• Current 0.34 A • Voltage 230 V
9. Hot water tank	Vertical tank	Stainless steel and insulator	• Capacity 1,500 liter • Thickness of insulator 1 in

Figure 3.1 shows a set of flat-plate solar collectors having 10 units of solar collectors (1 unit = 2.3 m^2) each is allocated in parallel connection. When the hot water temperature leaving the solar hot water system (SWHS) is lower than the minimum temperature for boiling the H_2O-LiBr solutions in the absorption system (around 75^{o}C), two auxiliary heaters, an electrical heater and a LPG burner are assisted as shown in Figure 3.2 and Figure 3.3, respectively.

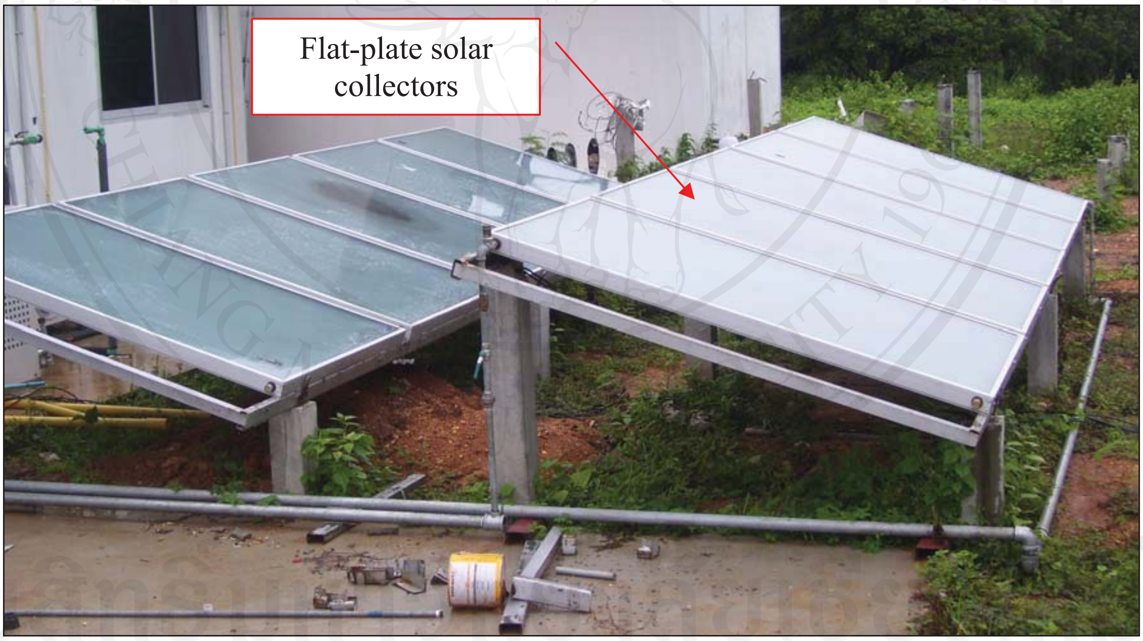


Figure 3.1 A set of flat-plate solar collectors.

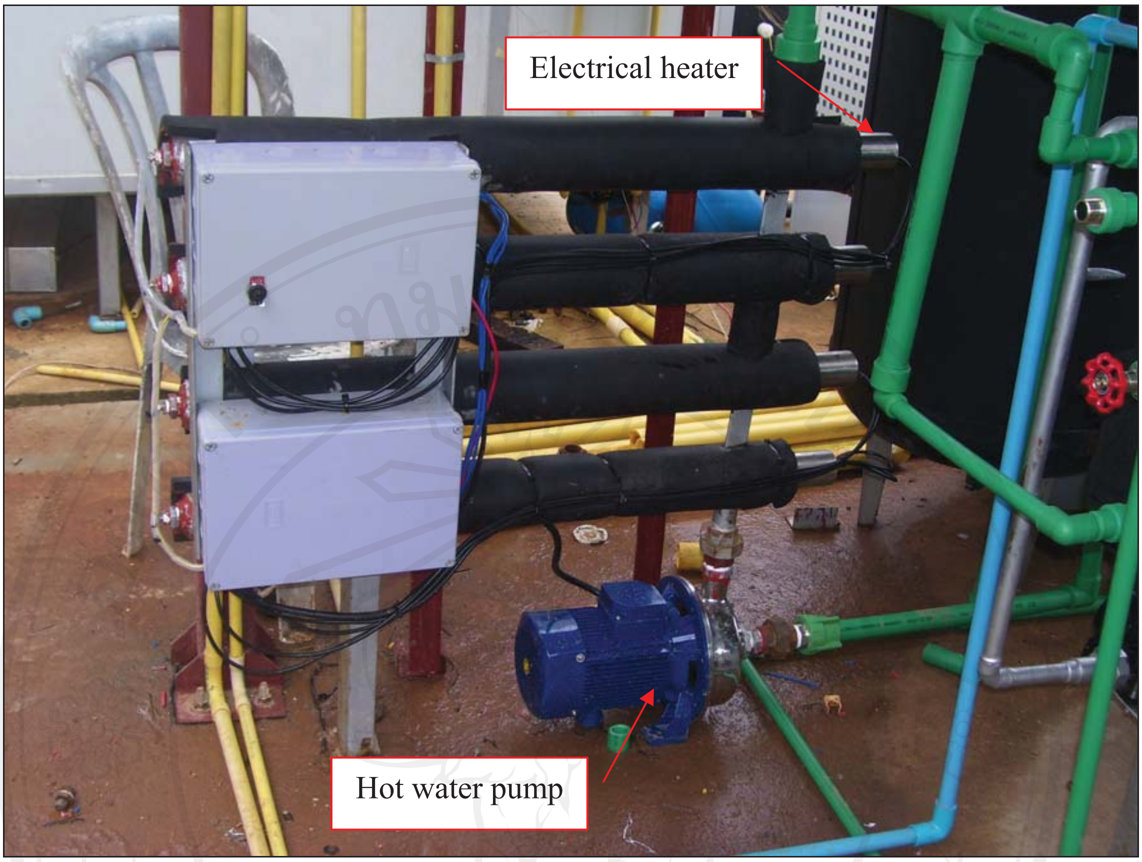


Figure 3.2 Electrical auxiliary heater and hot water pump.

a) Hot water tank at 1,500 liter of capacity b) LPG burner

Figure 3.3 LPG burner and hot water tank.

Figure 3.4 shows the positions and the features of the AHT main components. The generator and the condenser are installed in one shell including the absorber and the evaporator. The last two main components are allocated at the lower part of the machine.

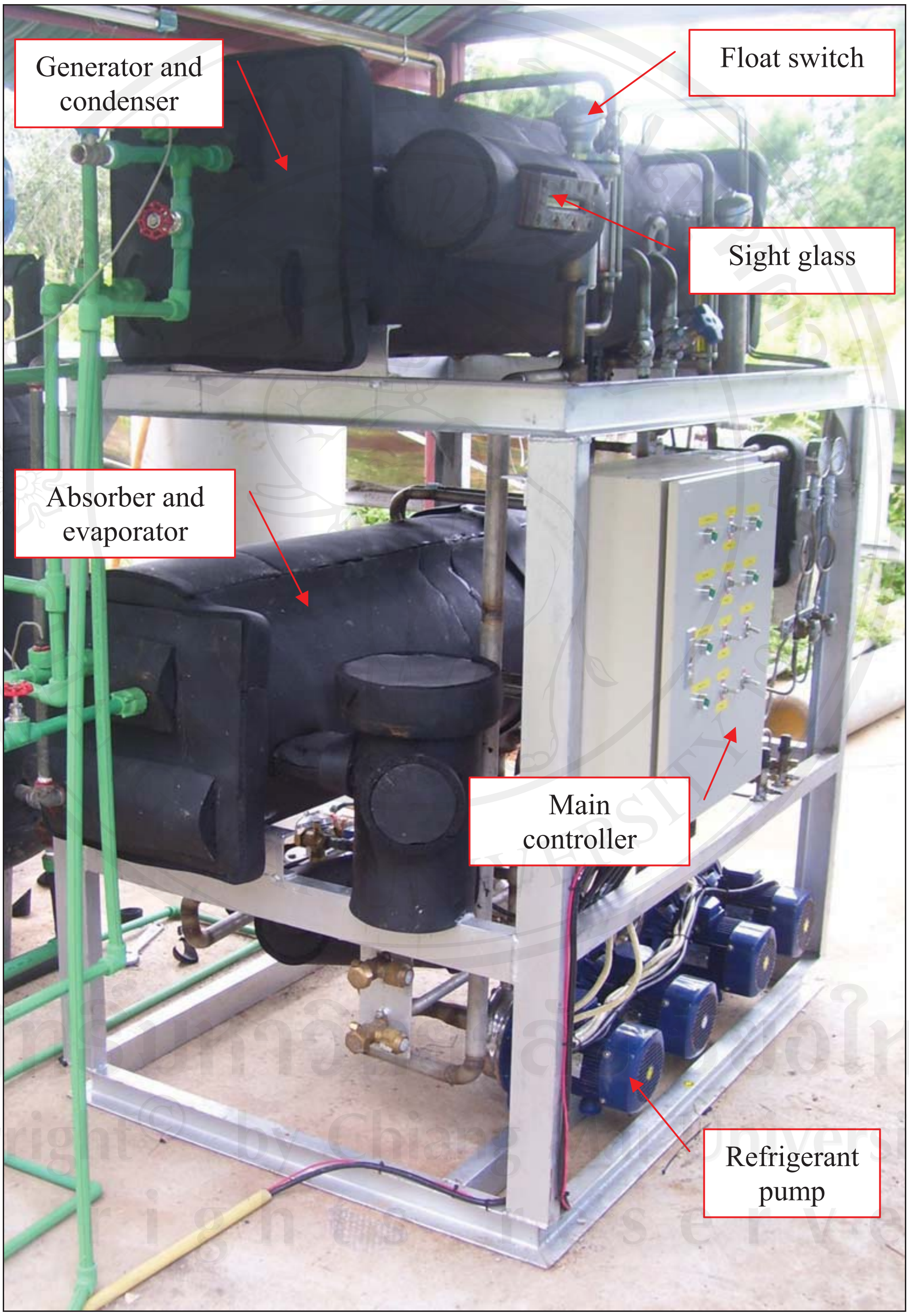


Figure 3.4 Side view of the absorption heat transformer.

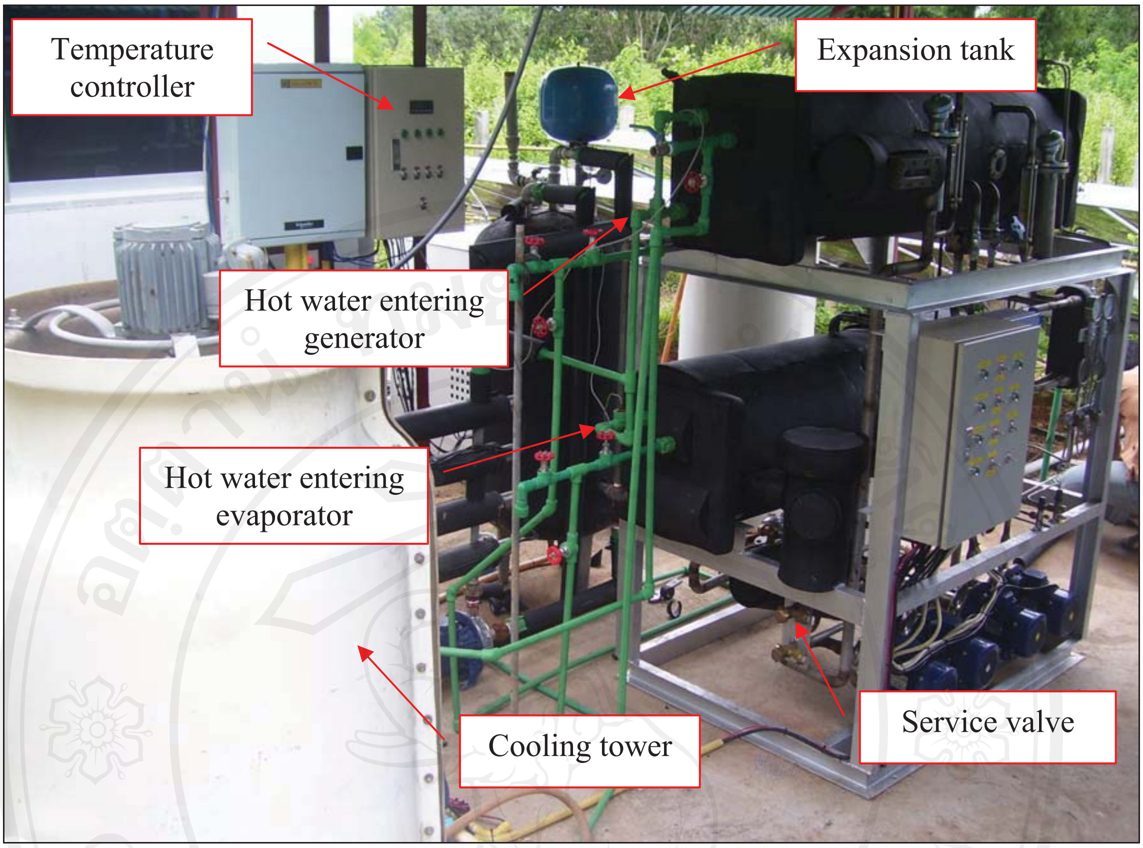


Figure 3.5 Front view of the absorption heat transformer.

Figure 3.5 and Figure 3.6 show the auxiliary components such as cooling tower, temperature controller and others. Solution pumps are used for circulating and spraying LiBr-H_2O solutions at the absorber and the generator. The level switch is used to control the solution levels in the main components.

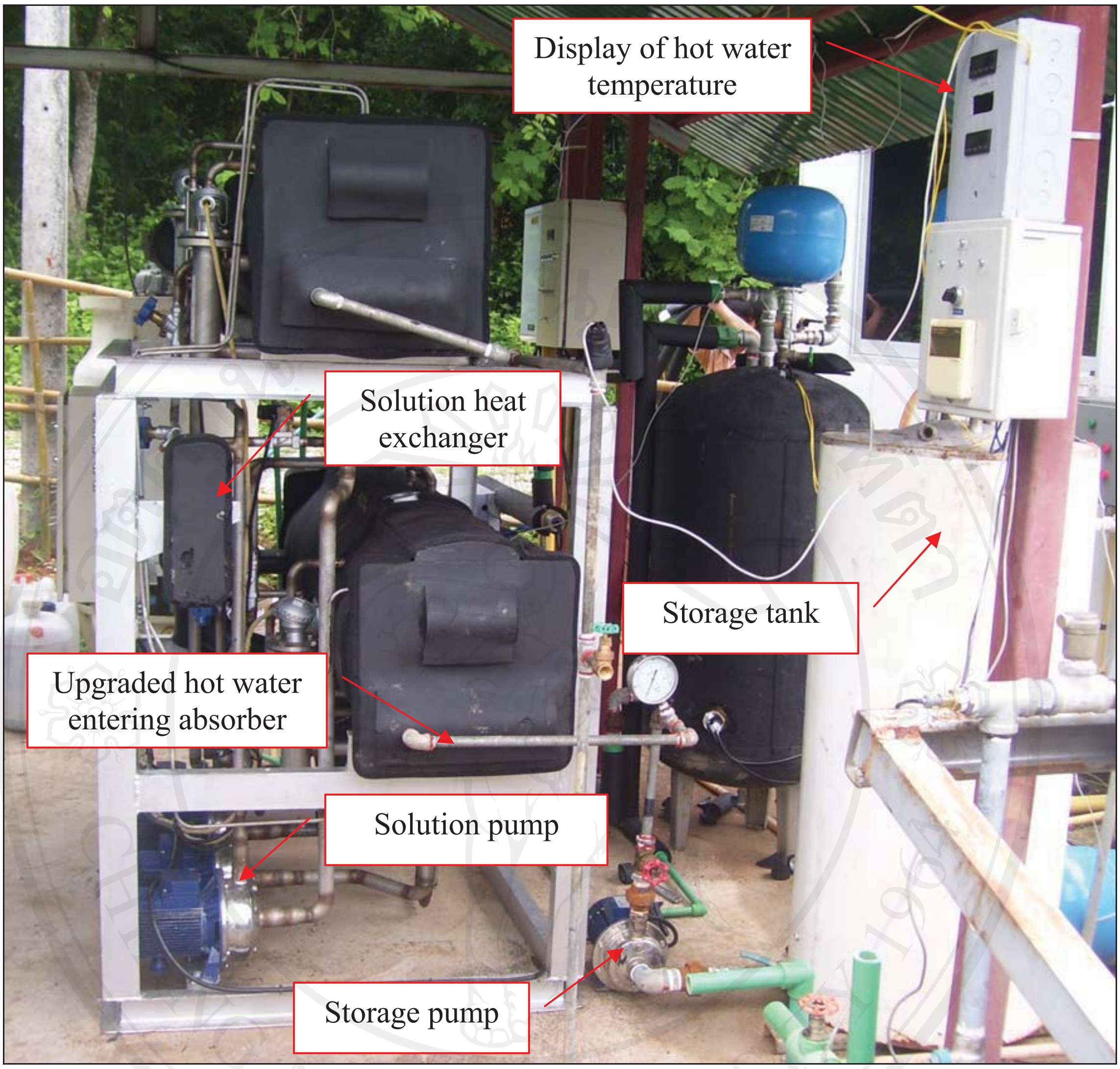


Figure 3.6 Right side view of the absorption heat transformer.

The constructed unit will be operated to verify the models developed in the previous chapter. Moreover, it could be set up as a demonstration unit that is used to upgrade low solar temperature heat.

CHAPTER 4

Experimental Procedures

The constructed absorption heat transformer system will be tested its thermal performances firstly with an electrical heater. For the second case, the AHT will be used to upgrade heat from the installed flat-plate solar collectors. The details of the positions of the measuring sensors and the testing procedures are given as follows:

4.1 Absorption Heat Transformer

Figure 4.1 shows the measuring positions of the sensors for the absorption heat transformer with supplied heat from an electrical heater. The objective of this experiment is to find out the thermal performances of the heat transformer system. The details of the instruments and the testing procedure are shown in Table 4.1-Table 4.4.

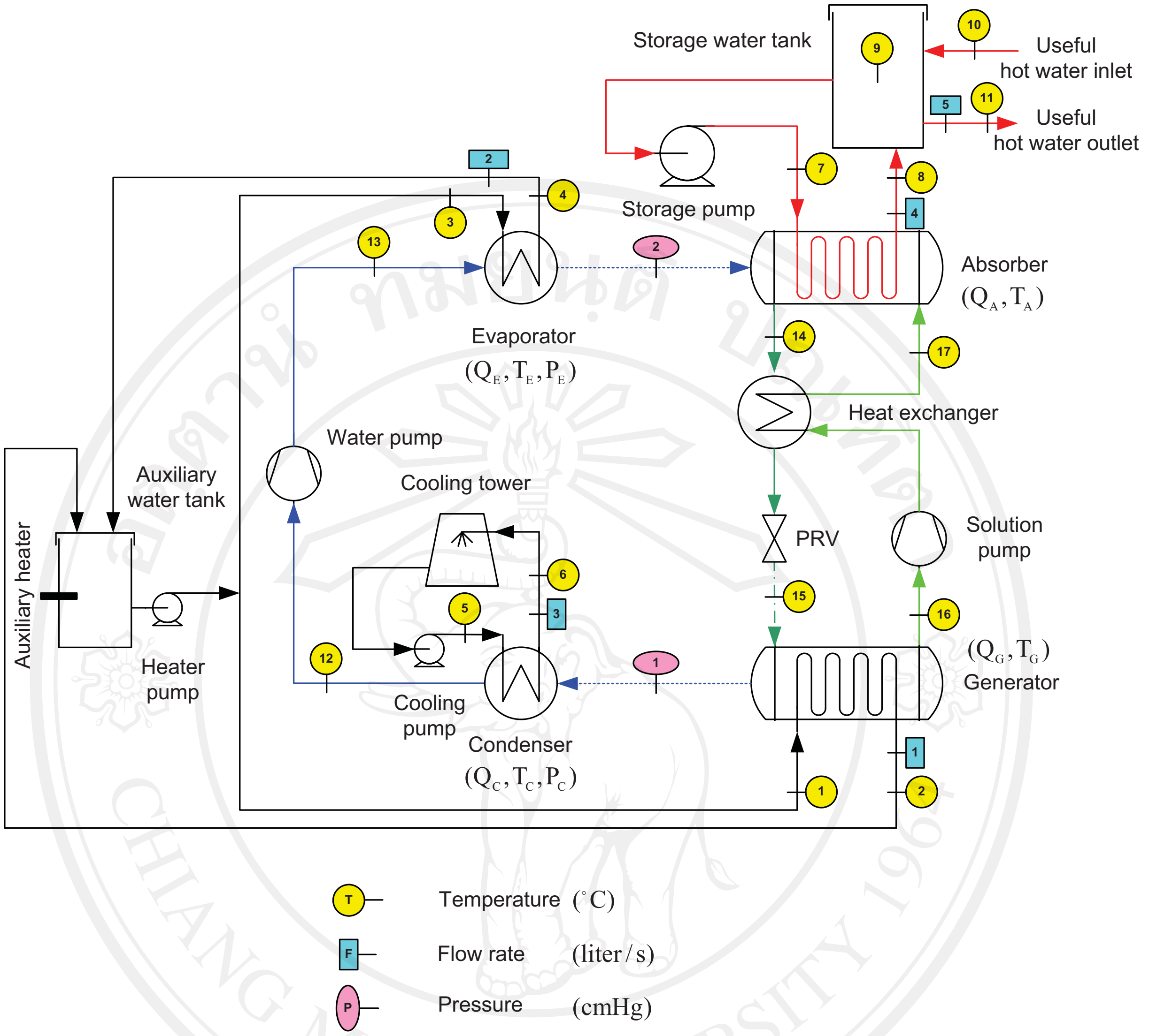


Figure 4.1 Measuring positions of the absorption heat transformer in the experiment.

Table 4.1 Descriptions of the temperature records.

Temperature (˚C)	Position*	Frequency	Instrument
1. Hot water entering generator	Number 1	Record continuously every 5 min for 4 h.	1. Computer 2. Data logger 3. Thermo couple
2. Hot water leaving generator	Number 2		
3. Hot water entering evaporator	Number 3		
4. Hot water leaving evaporator	Number 4		
5. Cooling water entering condenser	Number 5		
6. Cooling water leaving condenser	Number 6		
7. Useful water entering absorber	Number 7		
8. Useful water leaving absorber	Number 8		
9. Useful water in storage tank	Number 9		
10. Useful water entering storage tank	Number 10		
11. Useful water leaving storage tank	Number 11		
12. Refrigerant leaving condenser	Number 12		
13. Refrigerant entering evaporator	Number 13		
14. Weak solution leaving absorber	Number 14		
15. Weak solution entering generator	Number 15		
16. Strong solution leaving generator	Number 16		
17. Strong solution entering absorber	Number 17		

*Remark * Positions shown in Figure 4.1.*

Table 4.2 Descriptions of the pressure records.

Pressure (cmHg)	Position*	Frequency	Instrument
1. Refrigerant entering condenser 2. Refrigerant leaving evaporator	Number 1 Number 2	Record continuously every 5 min for 1 h.	Pressure gage

*Remark * Positions shown in Figure 4.1.*

Table 4.3 Descriptions of water flow rate records.

Flow rate (liter/s)	Position *	Frequency	Instrument
1. Water leaving generator 2. Water leaving evaporator 3. Water leaving condenser 4. Water leaving absorber 5. Water leaving storage water tank	Number 1 Number 2 Number 3 Number 4 Number 5	Record continuously every day.	Beaker/Flow meter

*Remark * Positions shown in Figure 4.1.*

Table 4.4 Descriptions of the electric power records.

Parameters	Position	Frequency	Instrument
1. Current (A) 2. Voltage (V) 3. Power (W)	Power supply of the AHT system	Record continuously every 5 min for 1 h.	Power meter

4.2 Solar-Absorption Heat Transformer

Figure 4.2 shows the measuring positions of the instruments for the Solar-AHT. The details of the instruments and the testing procedures are shown in Table 4.5-Table 4.8.

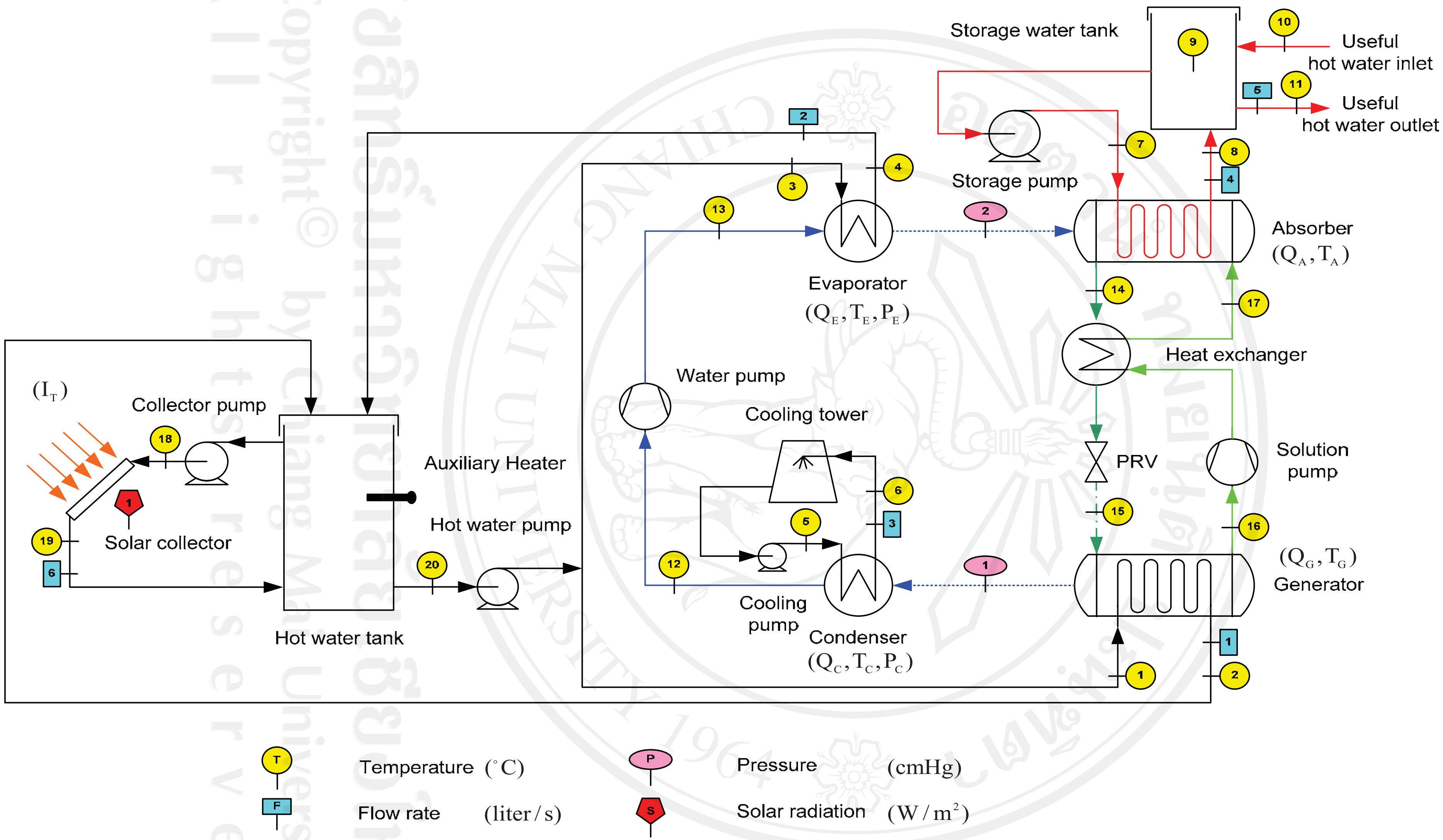


Figure 4.2 Measuring positions of a Solar-Absorption Heat Transformer (Solar-AHT) in the experiment.

Table 4.5 Descriptions of the temperature records.

Temperature (°C)	Position*	Frequency	Instrument
1. Hot water entering generator	Number 1	Record continuously every 5 min for 4 h.	1. Computer 2. Data logger 3. Thermo couple
2. Hot water leaving generator	Number 2		
3. Hot water entering evaporator	Number 3		
4. Hot water leaving evaporator	Number 4		
5. Cooling water entering condenser	Number 5		
6. Cooling water leaving condenser	Number 6		
7. Useful water entering absorber	Number 7		
8. Useful water leaving absorber	Number 8		
9. Useful water in storage tank	Number 9		
10. Useful water entering storage tank	Number 10		
11. Useful water leaving storage tank	Number 11		
12. Refrigerant leaving condenser	Number 12		
13. Refrigerant entering evaporator	Number 13		
14. Weak solution leaving absorber	Number 14		
15. Weak solution entering generator	Number 15		
16. Strong solution leaving generator	Number 16		
17. Strong solution entering absorber	Number 17		
18. Hot water entering solar collectors	Number 18		
19. Hot water leaving solar collectors	Number 19		
20. Hot water leaving hot water tank	Number 20		

*Remark * Positions shown in Figure 4.2*

Table 4.6 Descriptions of the pressure records.

Pressure (cmHg)	**Position***	**Frequency**	**Instrument**
1. Refrigerant entering condenser	Number 1	Record continuously every 5 min for 1 h.	Pressure gage
2. Refrigerant leaving evaporator	Number 2		

*Remark * Locations shown in Figure 4.2*

Table 4.7 Descriptions of water flow rate records.

Flow rate (liter/s)	**Position** *	**Frequency**	**Instrument**
1. Water leaving generator 2. Water leaving evaporator 3. Water leaving condenser 4. Water leaving absorber 5. Water leaving storage tank 6. Water leaving solar collector	Number 1 Number 2 Number 3 Number 4 Number 5 Number 6	Record continuously every day.	Beaker/Flow meter

*Remark * Positions shown in Figure 4.2*

Table 4.8 Descriptions of the electric power records.

Parameters	**Position**	**Frequency**	**Instrument**
1. Current (A) 2. Voltage (V) 3. Power (W)	Power supply of the AHT system	Record continuously every 5 min for 1 h.	Power meter

CHAPTER 5

Experimental Results, System Modeling and Simulation

In this chapter, experiment testing results of the absorption heat transformer with supplied heat from an auxiliary heater and a set of flat-plate solar collectors are presented. The results are used to develop simplified models of the AHT system.

5.1 Output Temperature of the AHT

Figure 5.1 shows the temperature profile of the AHT with time of day by supplied heat form auxiliary heater of about 20 kW of which around 10 kW to the generator (T_G) and the rest to the evaporator (T_E). It could be found that T_G and T_E are around 75 °C while there is cooling water releases heat at the condenser at a lower temperature (T_C) around 40 °C. The output heat form the absorption system is delivered at the absorber at a higher temperature (T_A) around 100 °C.

From the experiment results, it could be seen that the maximum temperature of the prototype machine is around 105 °C.

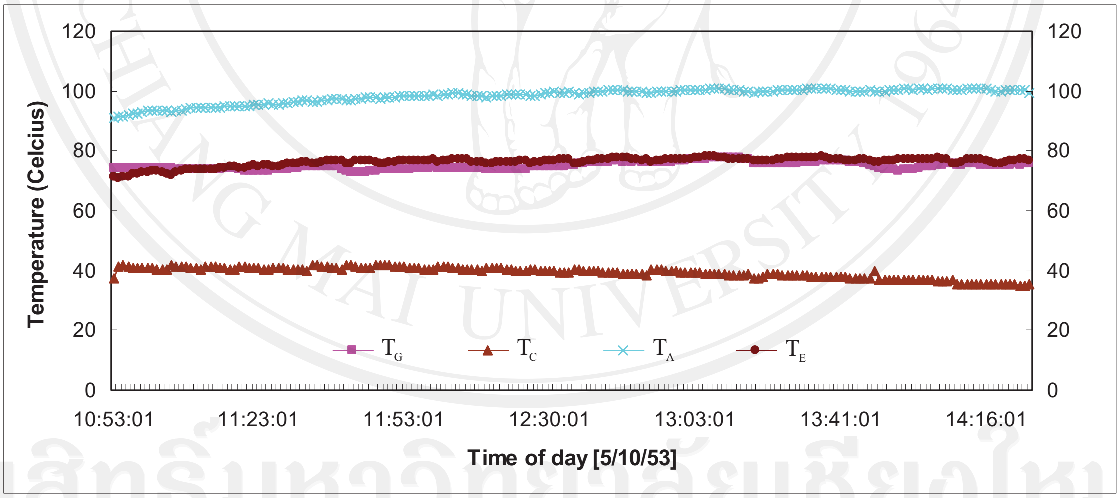


Figure 5.1 The temperature profiles of the AHT system.

Figure 5.2 shows the electric power consumption of the AHT which comes from pumps and control system. It could be seen that the average electric power consumption is nearly constant around 2.11 kW_e.

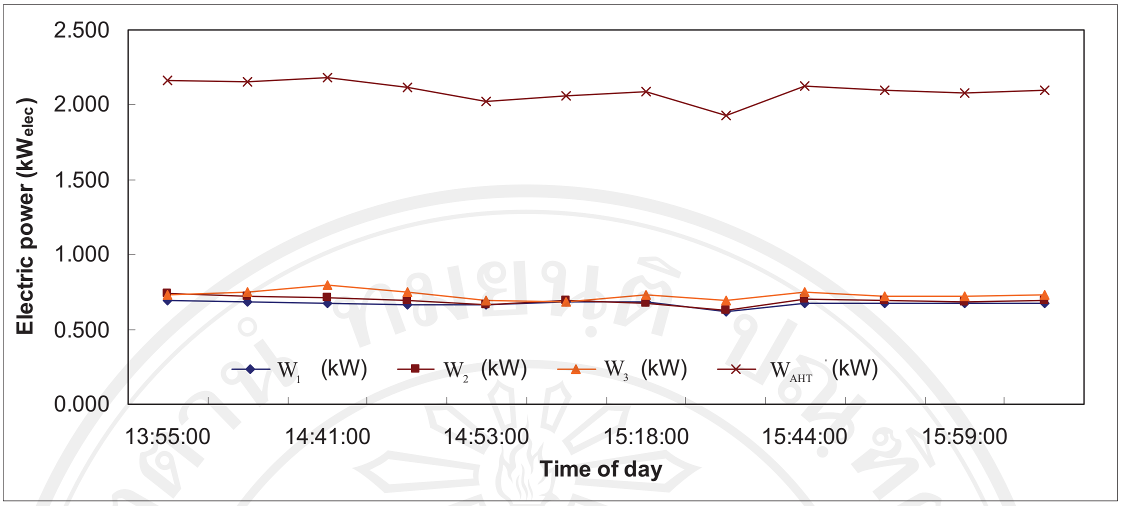


Figure 5.2 The electric power of the AHT system.

5.2 Performance Curve of the AHT

For the solar water heating system coupled with an AHT or Solar-AHT, the solar heat is obtained from 10 units of flat-plate solar collector each in parallel connection for generating hot water and using an auxiliary heater when water temperature in the tank is lower than the set temperature at 70 °C. Use and non-use hot water conditions are considered to see the influence of the hot water temperature in the storage tank on the coefficient of performance (COP_{AHT}) of the AHT. Figures 5.2 and 5.3 show COP_{AHT} and energy efficiency ratio (EER_{AHT}) with $T_{A,i} - T_E / T_{G,i} - T_C$. The hot water storage capacity is 200 liter.

In both cases, use and non-use of hot water, when the value of $T_{A,i} - T_E / T_{G,i} - T_C$ increases the COP_{AHT} and EER_{AHT} decrease. For the hot water use condition, the COP_{AHT} and EER_{AHT} are higher than that of the other case since the hot water temperature in the storage tank seems to be lower thus the AHT performance is better. The empirical correlations of the COP_{AHT} with $T_{A,i} - T_E / T_{G,i} - T_C$ for both cases could be:

For used hot water condition:

$$COP_{AHT} = -1.0444(T_{A,i} - T_E)/(T_{G,i} - T_C) + 0.7619. \quad (5.1a)$$

For non-used hot water condition:

$$COP_{AHT} = -0.9599(T_{A,i} - T_E)/(T_{G,i} - T_C) + 0.5845. \quad (5.1b)$$

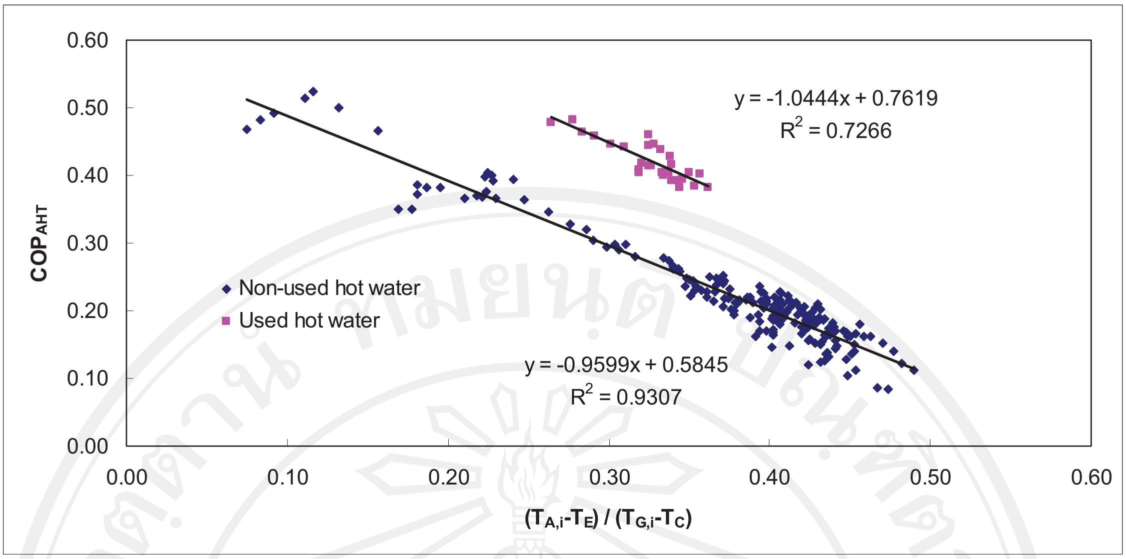


Figure 5.3 Effect of $T_{A,i}$ - T_E / $T_{G,i}$ - T_C on COP_{AHT} of the AHT.

The empirical correlations of the EER_{AHT} ($\frac{\dot{Q}_A}{W_{elec}}$, kW_{th}/kW_e) with $T_{A,i}$ - T_E / $T_{G,i}$ - T_C for both cases could be:

For used hot water condition:

$$EER_{AHT} = -10.463(T_{A,i} - T_E)/(T_{G,i} - T_C) + 7.5228. \qquad (5.2a)$$

For non-used hot water condition:

$$EER_{AHT} = -9.4407(T_{A,i} - T_E)/(T_{G,i} - T_C) + 5.6852. \qquad (5.2b)$$

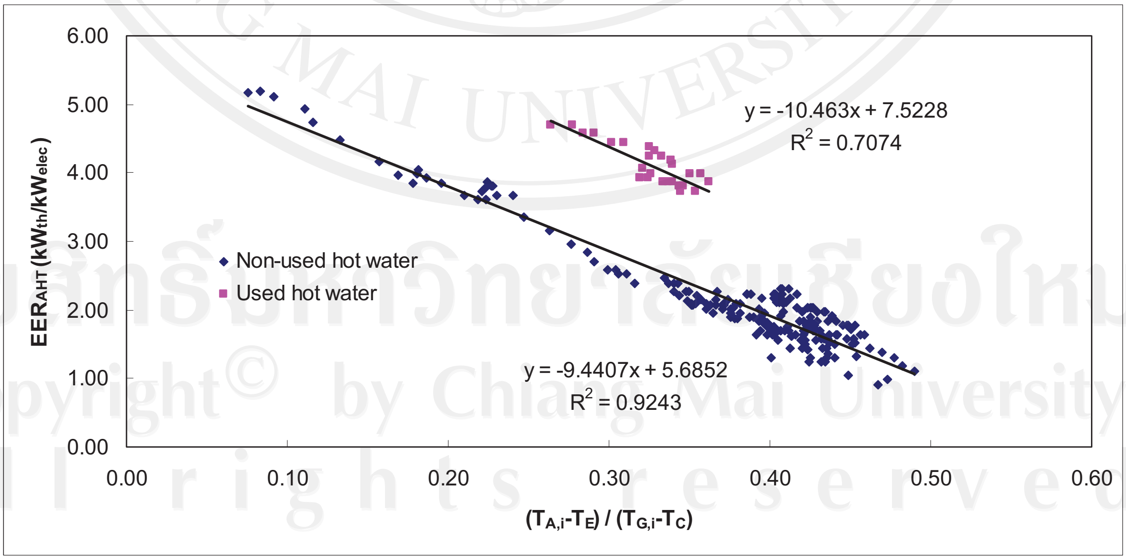


Figure 5.4 Effect of $T_{A,i}$ - T_E / $T_{G,i}$ - T_C on EER_{AHT} of the AHT.

Figure 5.5 shows the temperature profile of the absorption machine. It could be seen that the boosted temperature of the AHT in term of gross temperature lift (GTL) which is the different temperature at the absorber and the evaporator (T_A - T_E) could be increased around 20 °C while T_A is nearly constant at around 90 °C when the supplied heat temperatures at the generator (T_G) and the evaporator temperature are around 70 °C while the condensing temperature (T_C) is around 38 °C. The heating capacities of all main components are shown in Figure 5.6.

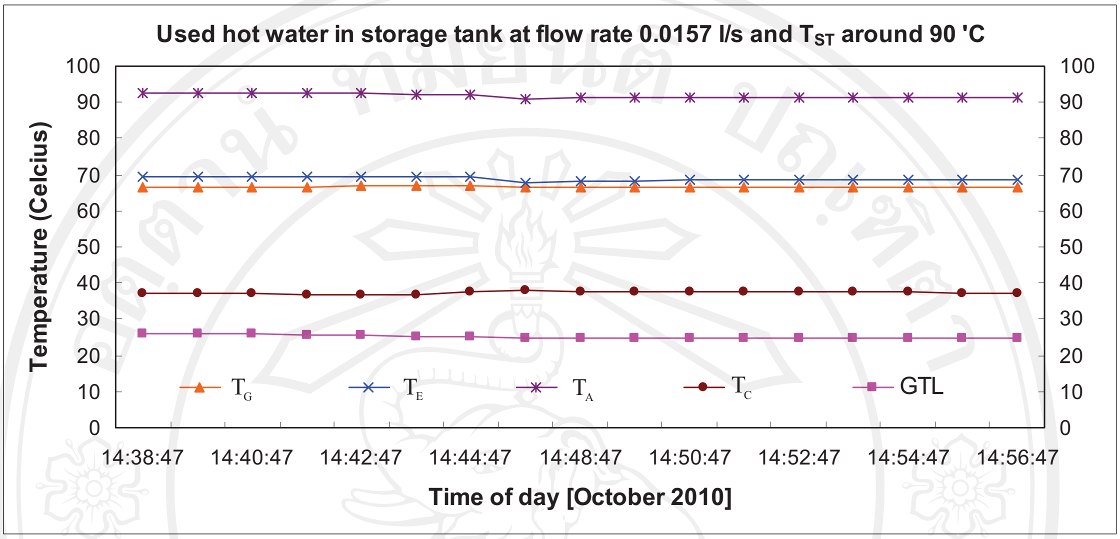


Figure 5.5 Temperature profile of the AHT with used hot water condition.

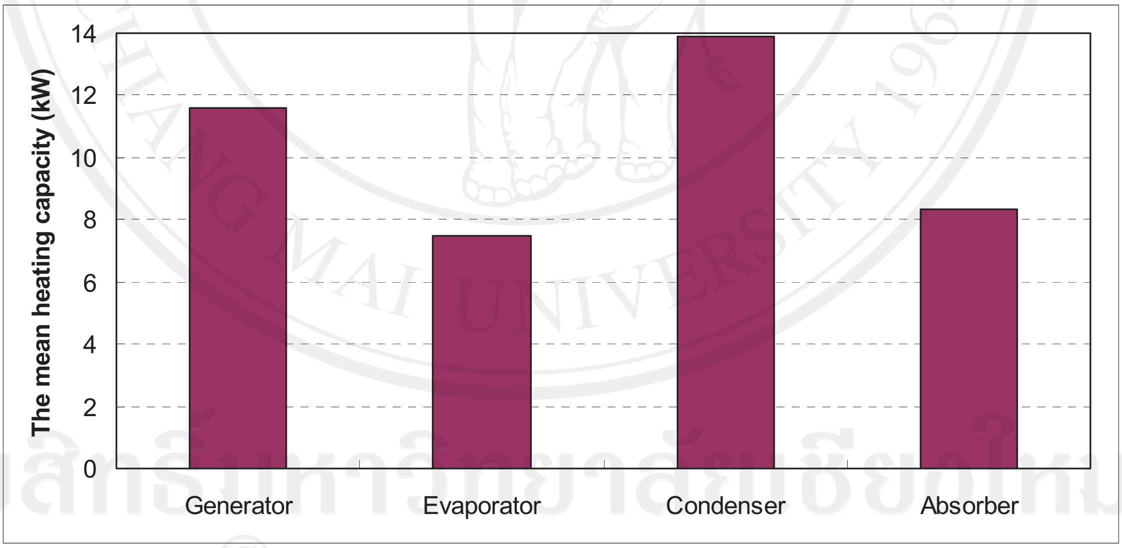


Figure 5.6 Heating capacities of the main components of the AHT with used hot water condition.

Figure 5.7 shows the strong (X_{max}) and weak (X_{min}) concentrations of H_2O-LiBr solutions and the overall COP including the electric power consumption of the AHT. It could be seen that the thermal COP of the prototype is around 0.44 at 0.53 and 0.45 of X_{max} and X_{min}, respectively and when the total electric power consumption of the all pumps and control system is considered then the overall COP is around 0.41.

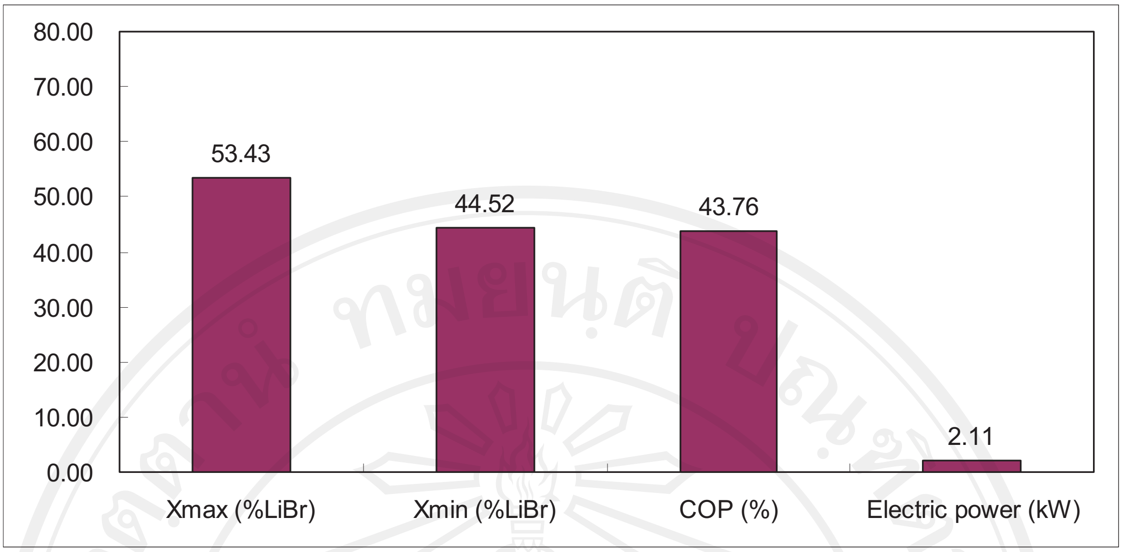


Figure 5.7 Comparison performance curve of heat pump with use and non-use of hot water.

5.3 The Solar-AHT System

5.3.1 System Simulation of the Solar-AHT

The solar-AHT system given in Figure 1.4, when hot water is non-used and used, is considered in this part. With the models of the solar hot water system and the AHT as described before and with the information data of the solar radiation and the ambient air temperature then the system performance could be evaluated. With the load profile of hot water consumption and the size of water storage, the upgraded hot water temperature and the heat rate could be predicted. The maximum temperature of the hot water is limited at 105 °C. The steps for the calculation are given in Figure 5.8 and Figure 5.9.

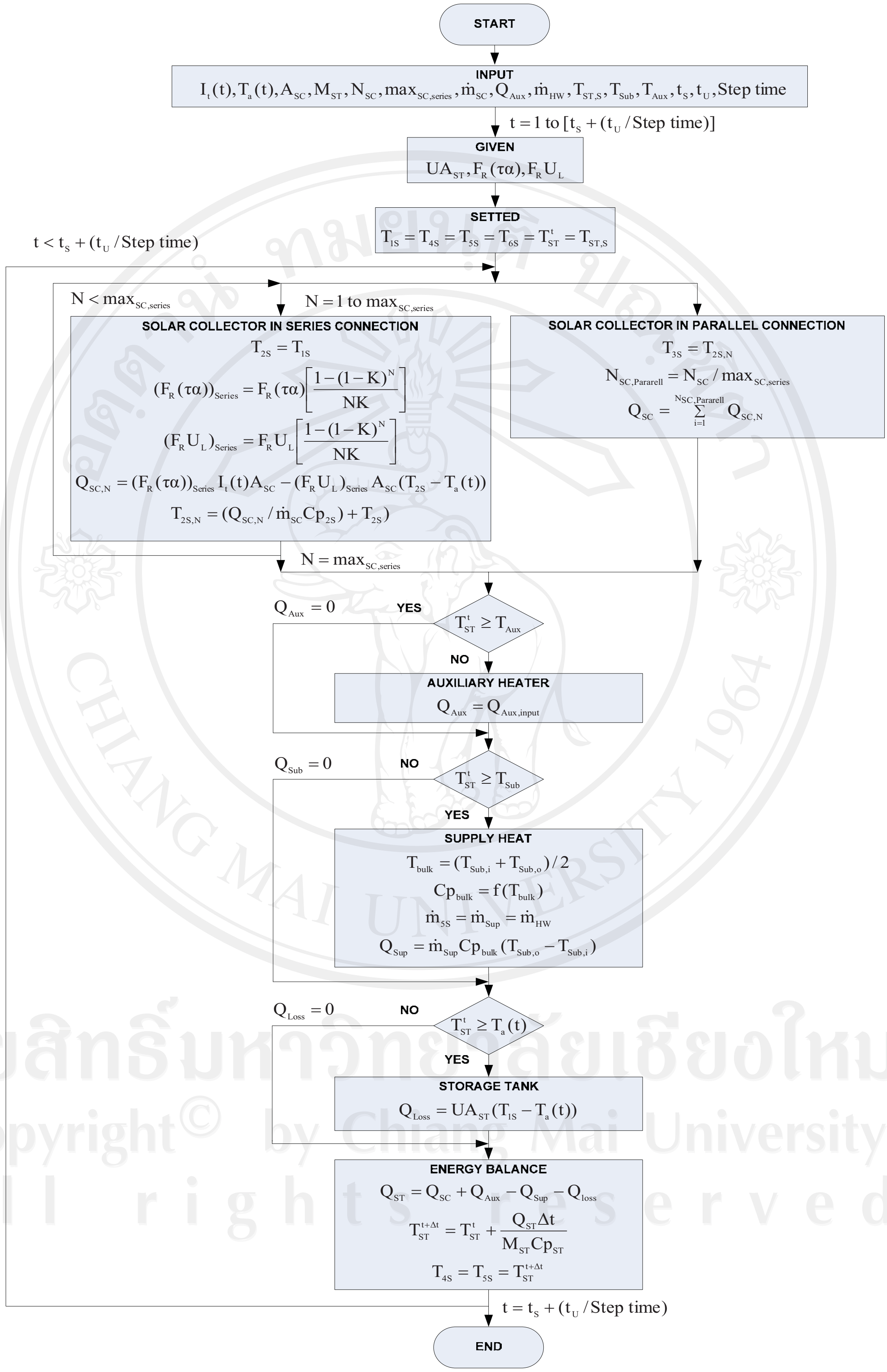


Figure 5.8 Flow chart of the solar water heating system for calculating the supplied heat to the AHT.

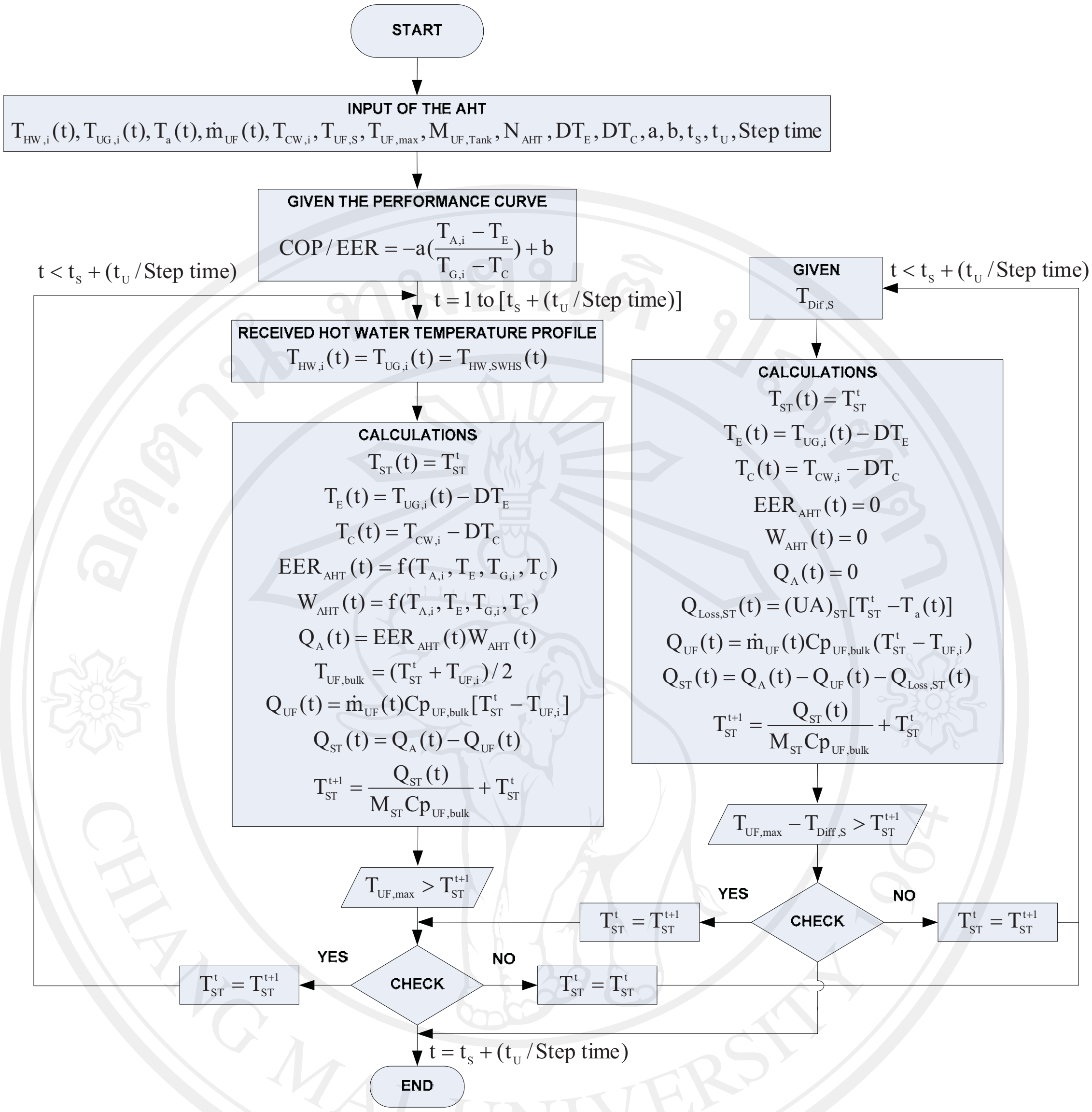


Figure 5.9 Flow chart of the absorption system with used and non-used hot water conditions.

5.4 Simulation Results

Figure 5.10 shows the simulated results of the $EER_{solar\text{-}AHT}$ during an operation when there is no use of generated hot water. This Figure also shows the hot water temperature in the storage tank 200 liter. It could be seen that the simulated results agree well with the measured data. Increasing hot water temperature results in decreasing $EER_{solar\text{-}AHT}$ due to a high pressure at the absorber which increases different pressure between high side and low side pressure and reduces the strong solution entering to absorber including affects to the absorption process.

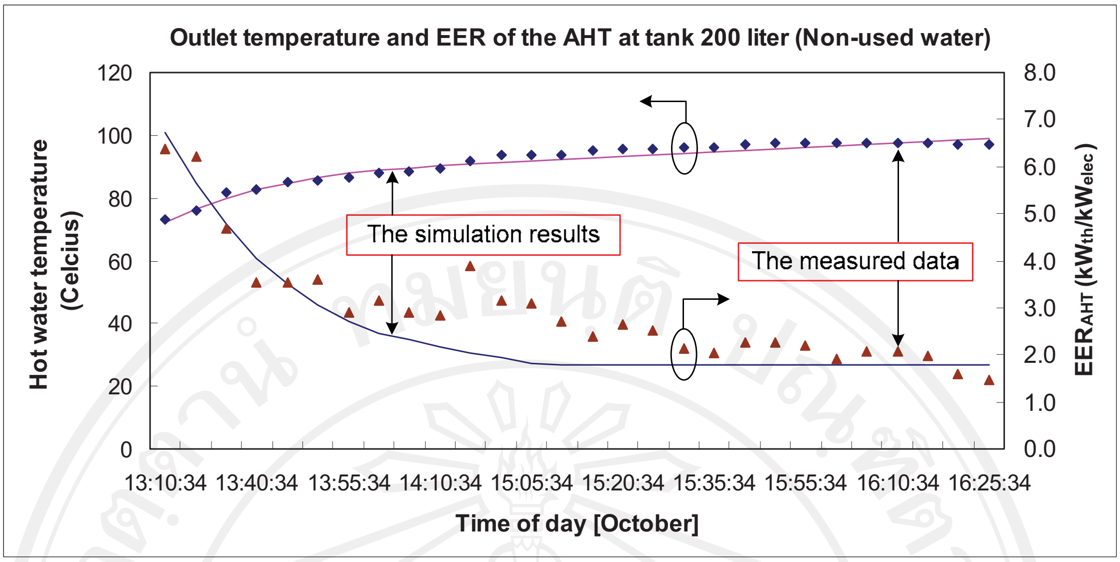


Figure 5.10 Comparison of the measured data and the simulation results of hot water temperature from the solar-AHT (the hot water is not used, 6/10/53).

Figure 5.11 also shows the $EER_{solar\text{-}AHT}$ when the generated hot water is used at a flow rate of 0.024 l/s. It could be noted that for used hot water condition the absorption unit could generate higher heat rate then the $EER_{solar\text{-}AHT}$ is higher than that of the non-used case. This Figure also shows the hot water temperature in the storage tank which was nearly constant at 90 °C and the $EER_{solar\text{-}AHT}$ is also nearly constant at around 4.1. The simulated results agreed well with the measured data.

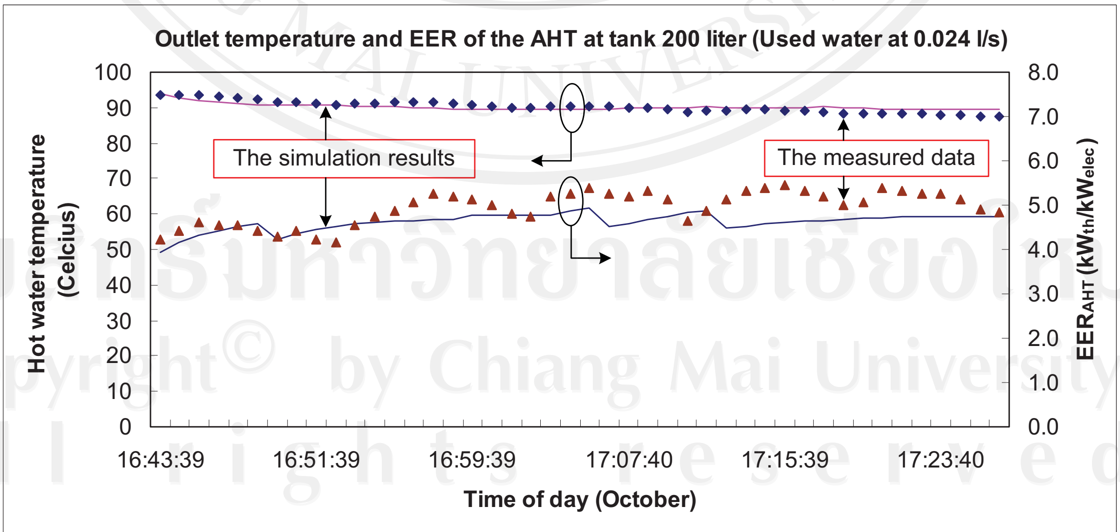


Figure 5.11 The measured data and the simulation results comparison of hot water temperature from the solar-AHT at flow rate 0.024 l/s (the hot water is used, 3/11/53).

It could be seen that the simplified models could be used to simulate the performances of the solar absorption system that is used to boost up a low temperature heat to a higher temperature heat. Possibility study in using this concept for generating hot water to replace boiler in a hospital or a hotel then is carried out. The details are explained in the next Section.

CHAPTER 6

Case Study

In hotel or hospital, boiler is normally used to generate heat in a form of hot water of which its temperature does not exceed 90°C thus the solar-AHT could be used to replace or partial support the boiler for this application. Therefore, not just only the fossil fuel could be saved even the green house gas emission due to the fuel combustion could be reduced.

In this chapter, a solar-AHT is used to partially support a boiler for generating hot water at around 85 °C in a hospital. The energy saving and the economic analysis for the solar-AHT are considered when compared with the steam boiler.

6.1 Hot Water Generating for a Hospital

A hospital in Chiang Mai is selected for the simulation. A boiler using diesel and heavy oil at around 326 l/d and 2,523 l/d, respectively is taken to generate steam at about 150 °C. The conditions for the simulation are:

- Operating period 15 h/d.
- Profile of hot water consumption as in **Error! Reference source not found.**
- Initial temperature of hot water ($T_{HW,S}$) in a storage tank is at 30 °C and the maximum temperature is at 85 °C.
- The rate of hot water consumption is around 35,000 l/d.
- Fill-in water temperature ($T_{Sup,i}$) is at 27 °C.

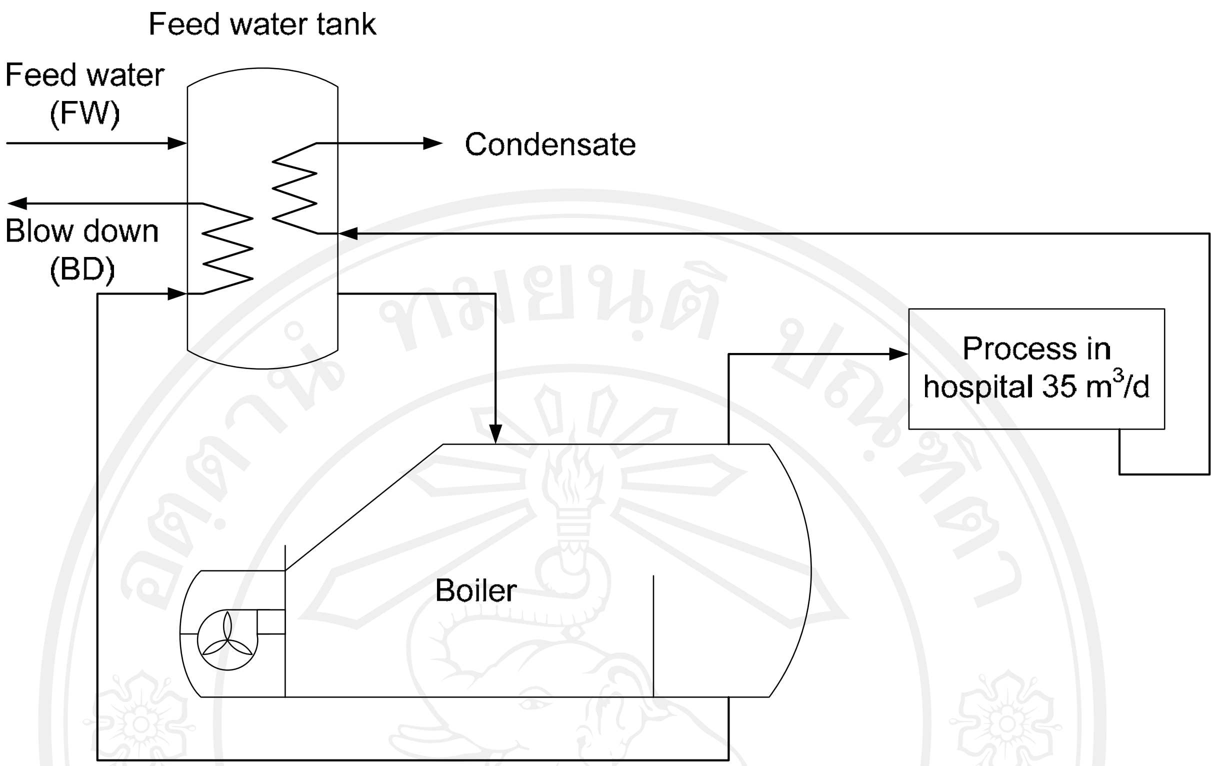
Table 6.1 Profile of hot water consumption for laundry in a hospital.

Date	Diesel (liter)	Heavy oil (liter)	Fraction
1	300	2,500	12.00%
2	300	2,300	13.04%
3	300	2,000	15.00%
4	100	2,400	4.17%
5	300	2,200	13.64%
6	300	3,200	9.38%
7	400	3,000	13.33%
8	500	2,200	22.73%
9	500	2,200	22.73%
10	200	2,600	7.69%

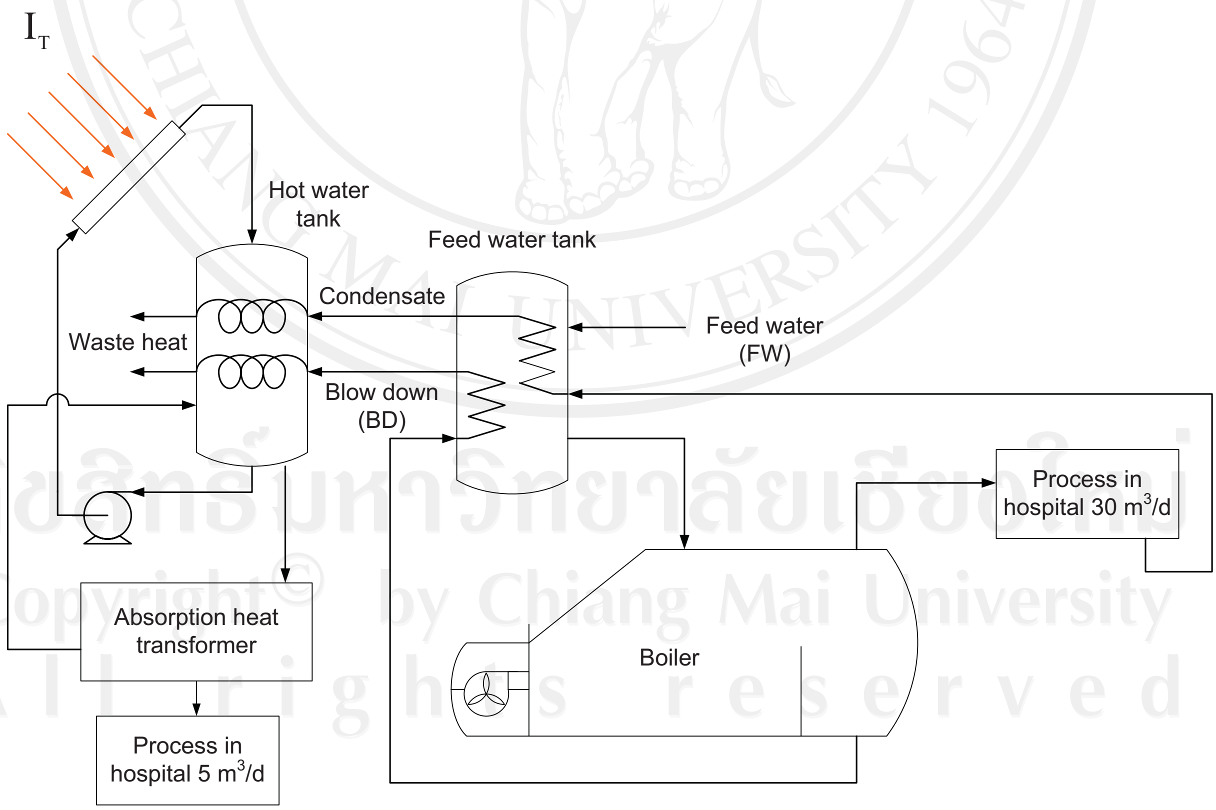
Date	Diesel (liter)	Heavy oil (liter)	Fraction
11	300	2,600	11.54%
12	300	2,400	12.50%
13	400	3,200	12.50%
14	200	1,600	12.50%
15	300	3,000	10.00%
16	300	3,000	10.00%
17	300	2,400	12.50%
18	200	2,200	9.09%
19	700	2,400	29.17%
20	200	2,600	7.69%
21	400	2,800	14.29%
22	500	2,500	20.00%
23	300	2,500	12.00%
24	300	2,400	12.50%
25	200	2,400	8.33%
26	200	2,800	7.14%
27	300	3,000	10.00%
28	400	2,600	15.38%
29	400	2,400	16.67%
30	200	2,000	10.00%
31	500	2,800	17.86%
Average (l/d)	326	2,523	13.08%
			2,848
Total (l/m)	10,100	78,200	88,300

From the simulation, it is noted that with the rate of 85 °C hot water consumption at 35,000 l/d if only a solar-AHT is used as a heat generator, over 15 sets of solar-AHT as described in the previous chapter to boost up the water temperature is needed. Each set has 20 solar collectors having solar collector area of 40 m^2 thus the total solar collector area for this purpose is 600 m^2 at least which is rather high.

In this case study, a solar-AHT is conducted to work with the boiler as described above to reduce the fossil fuel. Figure 6.1 shows the schematic sketch of the solar-AHT working with the boiler to generate steam. The solar-AHT is devoted to generate 5 m^3/d of 85 °C hot water while the boiler supplies 30 m^3/d of 85 °C hot water.



a) Steam generation by boiler at 35 m^3/d.



b) Steam and hot water generation by boiler and the solar-AHT at 30 and 5 m^3/d, respectively.

Figure 6.1 The schematic sketch of the solar-AHT and the hospital boiler to generate steam/hot water in the studied hospital.

6.2 Economic Analysis

From the simulation result, 2 sets of 10 kW_{th} (max) AHT are used to generate hot water of 5,000 liter/d at around 85 $^{\circ}$C. The payback periods for boiler only and boiler with solar-AHT could be calculated as follows:

Boiler

Feed water temperature	60	$^{\circ}$C
Efficiency of boiler	80	%
Operate at pressure gauge	5	kg/cm^2
Operate at absolute pressure	6	kg/cm^2
Saturated temperature	431.98	K
	158.83	$^{\circ}$C
Feed water		
Volume	137	m^3
EC	2,150	ms/cm
Fuel	9,390	liter
Blow down		
EC	11,860	ms/cm
C.O.C (N)	5.52	
% Blow down	18.13	%
Feed water : Blow down 1,000 liter :	$\frac{1{,}000 \times 18.13}{100}$	l/m^3
	181.28	l/m^3
Feed water : Steam 1,000 liter :	$\frac{1{,}000 \times 81.87}{100}$	l/m^3
	818.72	l/m^3
Enthalpy of saturated water at 158.83 $^{\circ}$C and 6 kg/cm^2	670.38	kJ/kg
Enthalpy of saturated steam at 158.83 $^{\circ}$C and 6 kg/cm^2	2,756.14	kJ/kg
Enthalpy of feed water at 60 $^{\circ}$C	251.18	kJ/kg
Gross heat of combustion of heavy oil	39,774.60	kJ/liter
Gross heat of combustion of diesel	44,800.00	kJ/liter
Fraction of diesel to heavy oil (Table 6.1)	13.08	%
Total heat	181.28x670.38 + 818.72x2,756.14 – 1,000x251.18	kJ/ton

	2,126,851.54	kJ/ton
	507,989.76	kcal/ton
Total heat require	$\frac{2,126,851.54\text{x}100}{80}$	kJ/ton
	2,658,564.43	kJ/ton
Fuel rate of diesel	$\frac{2,658,564.43\text{x}13.08}{44,800.00\text{x}100}$	liter/ton of steam
	7.76	liter/ton of steam
	$\frac{7.76}{(1-13.08/100)}$	liter/ton of FW
	9.48	liter/ton of FW
Fuel rate of heavy oil	$\frac{2,658,564.43\text{x}86.92}{39,774.60\text{x}100}$	liter/ton of FW
	58.10	liter/ton of steam
	$\frac{58.10}{(1-13.08/100)}$	liter/ton of FW
	70.96	liter/ton of FW
Total fuel rate	7.76 + 58.10	liter/ton of steam
	65.86	liter/ton of steam
	9.48 + 70.96	liter/ton of FW
	80.44	liter/ton of FW
Average fuel rate data from hospital	2,848	liter/d
Total feed water per day	$\frac{2,848}{80.44}$	ton of FW/d
	35.40	ton of FW/d
Total blow down per day	$\frac{35.40\text{x}18.13}{100}$	ton of BD/d
	6.42	ton of BD/d
Cost of the heavy oil	8	Baht/liter
Total cost of heavy oil	$2,848\text{x}8\text{x}(1-\frac{13.08}{100})$	Baht/d
	19,804	Baht/d
	19,804x365	Baht/y
	7,228,406	Baht/y

Cost of diesel	29.99	Baht/liter
Total cost of diesel	$2{,}848 \times 29.99 \times \frac{13.08}{100}$	Baht/d
	11,172	Baht/d
	11,172x365	Baht/y
	4,077,717	Baht/y
Total cost of fuel oil	11,172 + 19,804	Baht/d
	30,976	Baht/d
	30,976 x365	Baht/y
	11,306,123	Baht/y
Number of operating hours in a day	15	h
Electrical power of the controller units	0.935	kW_e
Electrical power of fan	1.4	kW_e
Electrical power of boiler	1.4 + 0.935	kW_e
	2.335	kW_e
	2.335x15	kW_e
	35.03	kW_e
Number of operation days in a year	365	d/y
Number units of boiler	1.00	Unit
Initial cost of boiler (2.5 Ton/h)	1,500,000	Baht
Period of operation (5:00 – 17:00 o'clock)		
Time 9.00 - 22.00 o'clock	8 h	
Time 22.00 - 9.00 o'clock	4 h	
Total electrical power in a year		
Time 9.00 - 22.00 o'clock	2.335x8x365	kW-h/y
	6,818.20	kW-h/y
Time 22.00 - 9.00 o'clock	2.335x4x365	kW-h/y
	3,409.10	kW-h/y
Total	10,227.30	kW-h/y
Electricity Charges (Time of Use Rate:TOU)		
Time 9.00 - 22.00 o'clock	2.695	Baht/kW-h
Time 22.00 - 9.00 o'clock	1.1914	Baht/kW-h
Ft (Update Jan-Apr 2009)	0.9255	Baht/kW-h

Peak demand charge per month	132.93	Baht/kW-h
Electricity charge during 9.00 - 22.00 o'clock	6,818.20x2.695	Baht/y
	18,375.05	Baht/y
Electricity charge during 22.00 - 9.00 o'clock	3,409.10x1.1914	Baht/y
	4,061.60	Baht/y
Total electricity charge	22,436.65	Baht/y
Ft (Update Jan-Apr 2009)	10,227.30x0.9255	Baht/y
	9,465.37	Baht/y
Peak demand charge	2.335x132.93x12	Baht/y
	3,724.70	Baht/y
Electrical cost	22,436.65 + 9,465.37 + 3,724.70	Baht/y
	35,626.72	Baht/y
Vat 7%	35,626.72x0.07	Baht/y
	2,493.87	Baht/y
Total electrical cost	35,626.72 + 2,493.87	Baht/y
	38,120.59	Baht/y
Total cost of fuel and electricity	11,306,123 + 38,120.59	Baht/y
	11,344,243.65	Baht/y

Use of the solar-AHT combining with boiler

Average fuel rate data from hospital	2,413	liter/d
Total feed water per day	$\frac{2,413}{80.44}$	ton of FW/d
	30.00	ton of FW/d
Total blow down per day	$\frac{30.00x18.13}{100}$	ton of BD/d
	5.44	ton of BD/d
Cost of the heavy oil	8	Baht/liter
Total cost of heavy oil	$2,413x8x(1-\frac{13.08}{100})$	Baht/d
	18,065	Baht/d
	18,065x365	Baht/y
	6,593,743	Baht/y
Cost of diesel	29.99	Baht/liter

Total cost of diesel	$2{,}413 \times 8 \times (1 - \frac{13.08}{100})$	Baht/d
	4,645	Baht/d
	4,645x365	Baht/y
	1,695,247	Baht/y
Total cost of fuel oil	18,065 + 4,645	Baht/d
	22,710	Baht/d
	22,710x365	Baht/y
	8,288,990	Baht/y
Total electrical cost of the AHT	91,838.93	Baht/y
Total cost of fuel and electricity	8,288,990 + 91,838.93	Baht/y
	8,380,829.14	Baht/y
Number units of the AHT	2	Units
Initial cost of the AHT	400,000	Baht/y
Cost of the solar collector	20,000	Baht/unit
The number of solar collector unit	40	units
Initial cost of the solar collectors	800,000	Baht
Saving cost	11,344,243.65 - 8,380,829.14	Baht/y
	2,963,414.51	Baht/y
Maintenance cost which is 3 % of the Solar-AHT	1,200,000x0.03	Baht/y
	36,000.00	Baht/y
Annual cost saving	2,963,414.51 - 36,000.00	Baht/y
	2,927,414.51	Baht/y
Pay back period	$\frac{2{,}927{,}414.51}{400{,}000 + 600{,}00}$	y
	0.41	y
	4.92	m

From the economic analyses, it could be seen that the concept of using absorption unit to boost up high temperature water when high amount of hot water is needed. The payback period compared with using only boiler is less than 0.5 year.

CHAPTER 7

Conclusion

In this study, a concept of using absorption heat transformer (AHT) to boost up high heat temperature is presented. LiBr-Water solution has been selected as the working fluid for the AHT. An experimental setup was constructed to find out the performance of the AHT. One unit of 10 kW_{th} (max) absorption heat transformer is used to upgrade heat from a set of flat-plate solar collector unit including auxiliary heater when solar heat is low. It could be seen that the AHT give better EER_{AHT} when the upgraded water in storage tank is used because of the better extracted heat at the absorber. A set of simplified models and the steps of calculation for simulating performances of the AHT and the solar water heating system have been developed and the simulated results agree quite well with the measured data.

The models are also used to evaluate the possibility of this technique and it could be found that the solar-AHT could be used to replace or partial support the boiler for high temperature hot water generation. A case study of a hospital is undertaken. It is found that there is a high potential to use the AHT to generate hot water at around 85 $^{\circ}C$. Two sets of 10 kW_{th} AHT are running in parallel with a boiler to generate hot water of about 5 m^3/d and it could be found that the combined system could save fuel cost of which the payback is 5 month compared with the boiler only.

NOMENCLATURE

Nomenclature

A	Area, (m^2)
Cp	Heat capacity, $(kJ/kg \cdot K)$
COP	Coefficient of performance, (-)
DT	Differential temperature, $(^{\circ}C)$
E	Equation of time, (-)
ER	Energy ratio, (kW_{th}/kW_e)
G_{sc}	Solar constant, (W/m^2)
h	Enthalpy, (kJ/kg)
H	Total daily solar radiation, $(MJ/m^2\text{-day})$
H_o	Total extraterrestrial radiation on a horizontal surface over a day, $(MJ/m^2\text{-day})$
H_d	Daily diffuse solar radiation, $(MJ/m^2\text{-day})$
L	Longitude, (°)
LMTD	Log mean temperature difference, (-)
I	Total solar radiation, (W/m^2)
I_b	Direct solar radiation, (W/m^2)
I_t	Solar radiation on the inclined plane, (W/m^2)
I_d	Diffuse solar radiation, (W/m^2)
m	Mass flow rate, (kg/s)
M	Mass capacity, (liter)
n	Julian date, (days)
N	Number, (Units)
P	Pressure, (bar)
Q	Heat rate, (kW)
R	Refrigerant, (-)
s	Entropy, $(kJ/kg \cdot K)$
SC	Subcooling, $(^{\circ}C)$
SH	Superheating, $(^{\circ}C)$

SWHS	Solar water heating system, (-)
t	Time, (s)
T	Temperature, ($^\circ$C)
U	Overall heat transfer coefficient, ($W/m^2 \cdot K$)
v	Specific volume, (m^3/kg)
W	Work, (kW)
X	Concentrate, (%LiBr)
Greek symbol	
η	Efficiency, (%)
ε	Effectiveness, (%)
ρ	Density, (kg/m^3)
φ	Latitude angle, (°)
δ	Declination angle, (°)
ω	Hour angle, (°)
ω_s	Sunset hour angle, (°)
θ	Angle of incidence, (°)
θ_z	Zenith angle, (°)
ρ_g	Ground and concrete reflectance
γ	Azimuth angle, (°)
Subscript	
A	Absorber
Aux	Auxiliary heat
act	Actual
bulk	Bulk temperature
C	Condenser
Comp	Compressor
CW	Cooling water
Diff	Different
e	Super heat
E	Evaporator

Gly	Glycol
H	High
HS	Heat source
HW	Hot water
HX	Heat exchanger
i	Inlet
L	Low
Loc	Local
max	Maximum
min	Minimum
o	Outlet
P	Pump
r	Compression cycle
ref	Refrigerant
S	Start
SC	Solar collector
SP	Solution pump
ST	Storage tank
Std	Standard
Sup	Supply
U	Stop using time
UF	Useful

REFERENCES

[1] Florides, GA, Kalogirou, SA, Tassou, SA,Wrobel, LC. Modeling and Simulation of an Absorption Solar Cooling System for Cyprus. Solar Energy, Vol. 72, pp. 43-51, 2002.

[2] Rivera, W, Cardoso, M.J., Romero R.J. Single-Stage and Advanced Absorption Heat Transformers Operating with Lithium Bromide Mixtures Used to Increase Solar Pond's Temperature. Solar Energy Materials & Solar Cells, Vol. 70, pp. 321-333, 2001.

[3] Xuehu, Ma, Jiabin, C, Songping Li, Qingyun, Sha, Aiming, L, Wei, Li, Jiayan, Z, Guojun, Z, Zhihao, F. Application of absorption heat transformer to recover waste heat from a synthetic rubber plant. Appl Therm Eng, Vol. 25, pp. 797-806, 2002.

[4] Sotelo, S.S, Romero, R.J. Improvement of Recovery Energy in the Absorption Heat Transformer Process Using Water-Carrol™ for Steam Generation. In: Proceeding of The ninth International Conference on Chemical & Process Engineering 9, Italy, 2009.

[5] NASA Surface meteorology and Solar Energy. RETScreen Data. Online, http://eosweb.larc.nasa.gov/sse/RETScreen/. July, 2010.

[6] Thai Meteorological Department. The ambient temperature at Chiang Mai. Online, http://www.tmd.go.th/thailand.php. July, 2010.

[7] M.Burapha and T.Kiatsiriroat, (2008). Simplified Model of Solar Water Heating with Heat Pump Assisted, The journal of industrial technology, Volume 2, Page 15-23.

[8] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). Refrigerants. Atlanta, 2001.

[9] Khairulin, R.A, Gruzdev, V.A, Stankus, S.V, Verba, O.I. Experimental study of the density of aqueous solutions of lithium bromide at temperature of up to 250 $^{\circ}C$ in the range of mass concentrations from 30 to 65 %. Thermophysics and Aeromechanics, Vol. 13, pp. 575-583, 2006.

[10] Kaita, Y. Thermodynamic properties of lithium bromide-water solutions at high temperatures. Int J of Refrigeration, Vol. 24, pp. 374-390, 2000.

[11] Feuerecker, G, Scharfe, J, Greiter, I, Frank, C, Alfeld, G. Measurement of thermophysical properties of LiBr-solutions at high temperatures and concentrations. International Absorption Heat Pump Conference ASME, Vol. 31, pp. 493-499, 1993.

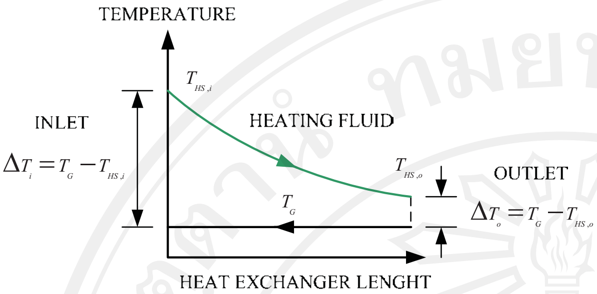
[12] Fuels - Higher Calorific Values. Online, http://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html. January, 2010.

[13] Retail oil prices. Online, http://www.eppo.go.th/retail_prices.html. January, 2010.

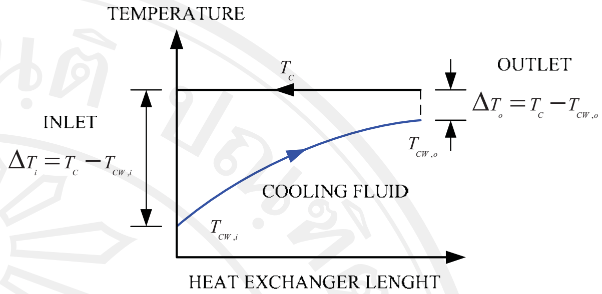
[14] Retail boiler prices. Boonyium & Associates, Limited, http://www.boonyium.com. February, 2011.

APPENDIX

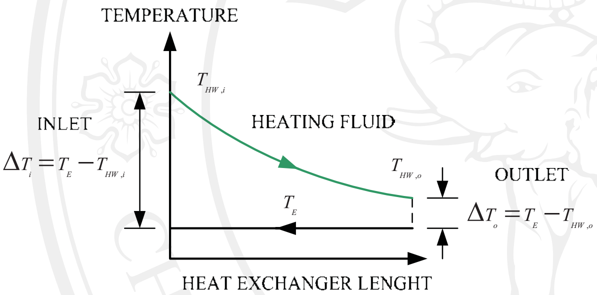
A. Temperature Profiles of the AHT Cycle



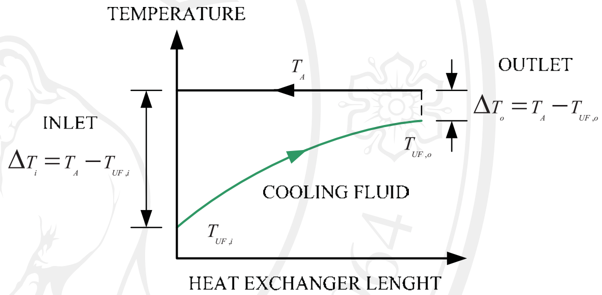
Generator



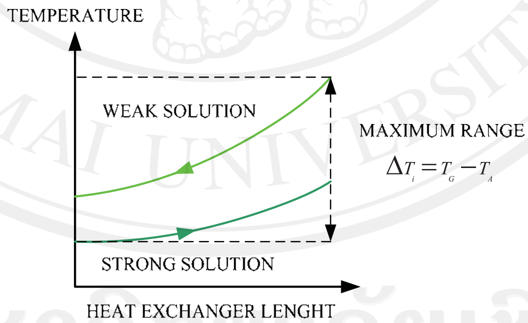
Condenser



Evaporator



Absorber



Heat exchanger

B. Properties of Aqueous Lithium Bromide Solutions

B.1 Enthalpy-Concentration-Temperature for Aqueous Lithium Bromide Solutions [8]

For Concentration x < 40 %LiBr

Solution temperature range $15 < t < 165\ ^\circ C$

$$h = 21.4817157 - 2.38366711X + 3.90458186t + 0.03625001X^2 + 5.25010607\times10^{-4}t^2 - 0.0369249939tX,\ kJ/kg$$

For Concentration $40 \le x < 70$ %LiBr

Solution temperature range $15 < t < 165\ ^\circ C$

$$h = \sum_0^4 A_n X^n + t\sum_0^4 B_n X^n + t^2\sum_0^4 C_n X^n,\ kJ/kg$$

A_0 = -2024.33	B_0 = 18.2829	C_0 = -3.7008214 E-2
A_1 = 163.309	B_1 = -1.1691757	C_1 = 2.8877666 E-3
A_2 = -4.88161	B_2 = 3.248041 E-2	C_2 = -8.1313015 E-5
A_3 = 6.302948 E-2	B_3 = -4.034184 E-4	C_3 = 9.9116628 E-7
A_4 = -2.913705 E-4	B_4 = 1.8520569 E-6	C_4 = -4.4441207 E-9

B.2 Solution Temperature-Refrigerant Temperature and Saturation pressure [8]

For Refrigerant $-15 < t' < 110\ ^\circ C$

Solution temperature $5 < t < 175\ ^\circ C$

Concentration $45 < X < 70$ %LiBr

$$t = \sum_0^3 B_n X^n + t'\sum_0^3 A_n X^n,\ ^\circ C$$

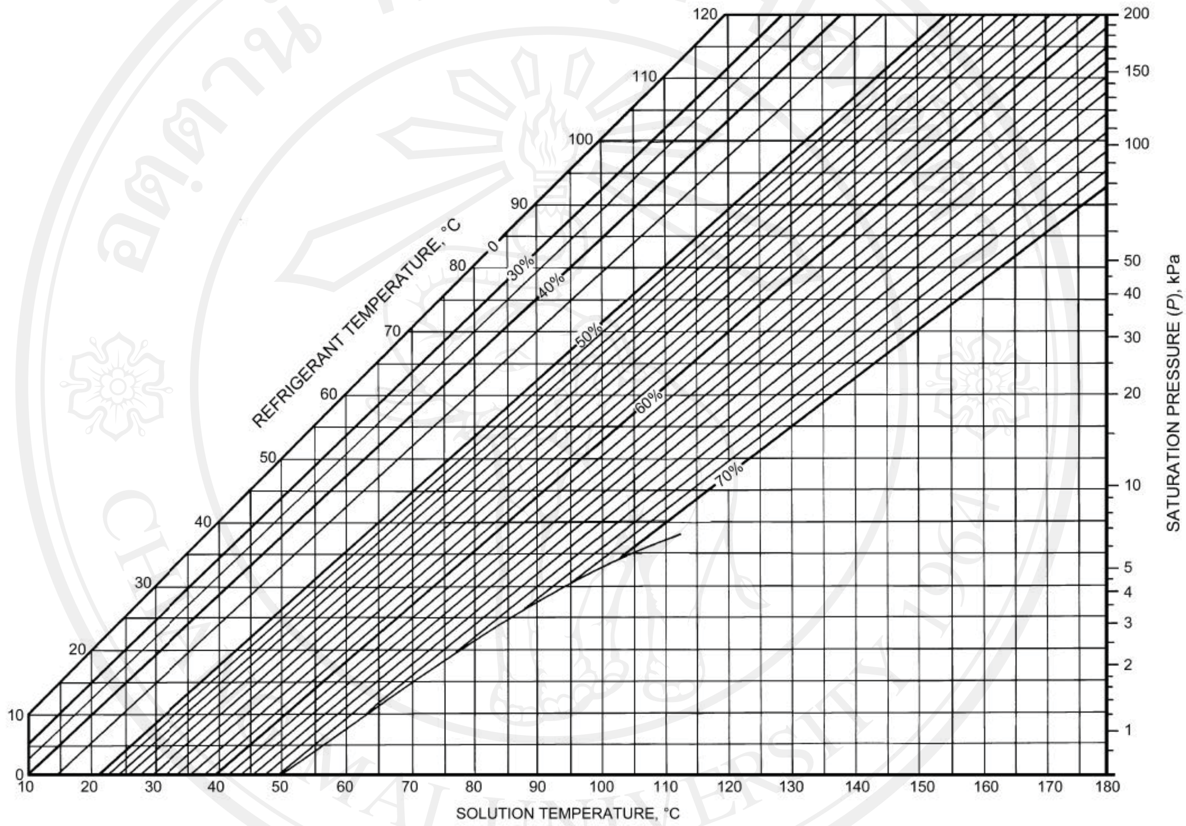
$$t' = (t - \sum_0^3 B_n X^n)/\sum_0^3 A_n X^n,\ ^\circ C$$

$$\log P = C + D/T' + E/T'^2,\ P = kPa;\ T' = K$$

$$T' = \frac{-2E}{D + [D^2 - 4E(C - \log P)]^{0.5}}$$

A_0 = -2.00755	B_0 = 124.937	C = 7.05
A_1 = 0.16976	B_1 = -7.71649	D = -1596.49
A_2 = -3.133362 E-3	B_2 = 0.152286	E = -104095.5
A_3 = 1.97668 E-5	B_3 = -7.9509 E-4	

B.3 Equilibrium Chart for Aqueous Lithium Bromide Solutions [8]



B.4 Density of Aqueous Lithium Bromide Solutions [9]

For Solution temperature $t < 250\ ^\circ C$

Concentration $30 < X < 65$ %LiBr

$$\rho(t,m) = \rho_0(t)[1 + d_0(t)m + d_1(t)m^{1.5} + d_2(t)m^2],\ kg/m^3$$

$$m = w/M_s(1-w),\ mole/kg$$

$$d_j(t) = \sum_{i=0}^{4} C_{ji} t^i$$

$$\rho_0(t) = \text{ Density of pure water, } kg/m^3$$

$$M_s = 0.086845,\ kg/mole$$

Table of Coefficients C_{ji}

j/i	0	1	2	3	4
0	6.9979 E-2	-9.36591 E-5	1.1770035 E-6	-2.829722 E-9	7.963374 E-12
1	-7.30855 E-3	1.78947 E-5	-3.458841 E-8	-8.88725 E-10	1.085224 E-12
2	1.811867 E-4	-1.9292 E-6	-1.565022 E-8	2.082693 E-10	-3.761121 E-13

B.5 Heat Capacity of Aqueous Lithium Bromide Solutions [10]

For Solution temperature $40 < t < 210\ ^\circ C$

Concentration $40 < X < 65$ %LiBr

$$Cp = (A_0 + A_1 X) + (B_0 + B_1 X)t,\ kJ/kg - ^\circ C$$

A_0 = 3.462023 B_0 = 1.3499 E-3

A_1 = -2.679895 E-2 B_1 = -6.55 E-6

B.6 Entropy of lithium bromide-water solutions [11]

For Solution temperature $40 < t < 210\ ^\circ C$

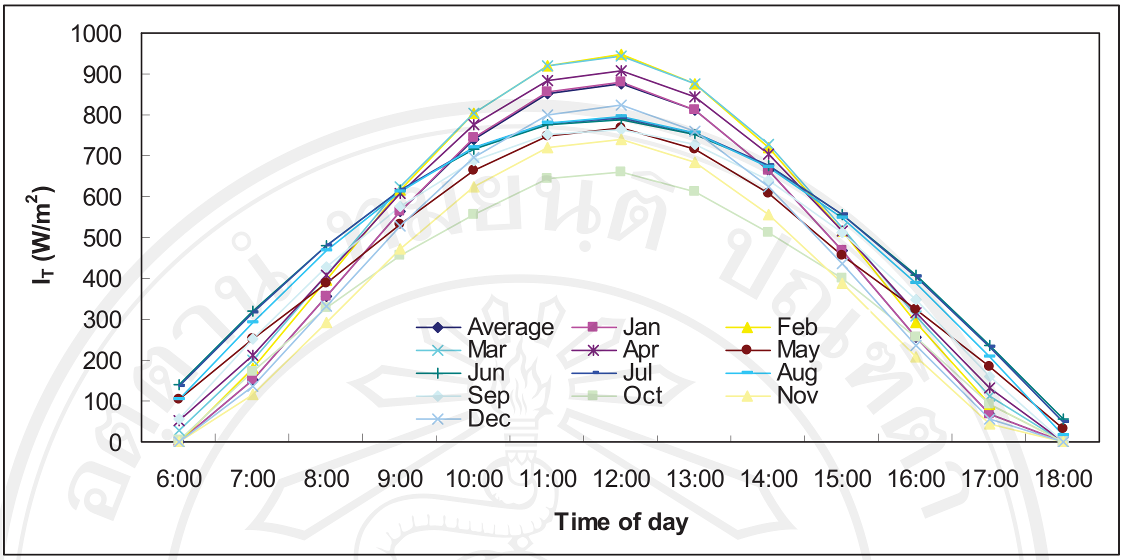
Concentration $40 < X < 65$ %LiBr

$$S = \sum_{i=0}^{3}\sum_{j=0}^{3} B_{ij} X^j T^i,\ kJ/kg \cdot K$$

Table of Coefficients B_{ij}

i	B_{i0}	B_{i1}	B_{i2}	B_{i3}
0	5.127558 E-01	-1.393954 E-02	2.924145 E-05	9.035697 E-07
1	1.226780 E-02	-9.156820 E-05	1.820453 E-08	-7.991806 E-10
2	-1.364895 E-05	1.068904 E-07	-1.381109 E-09	1.529784 E-11
3	1.021501 E-08	0	0	0

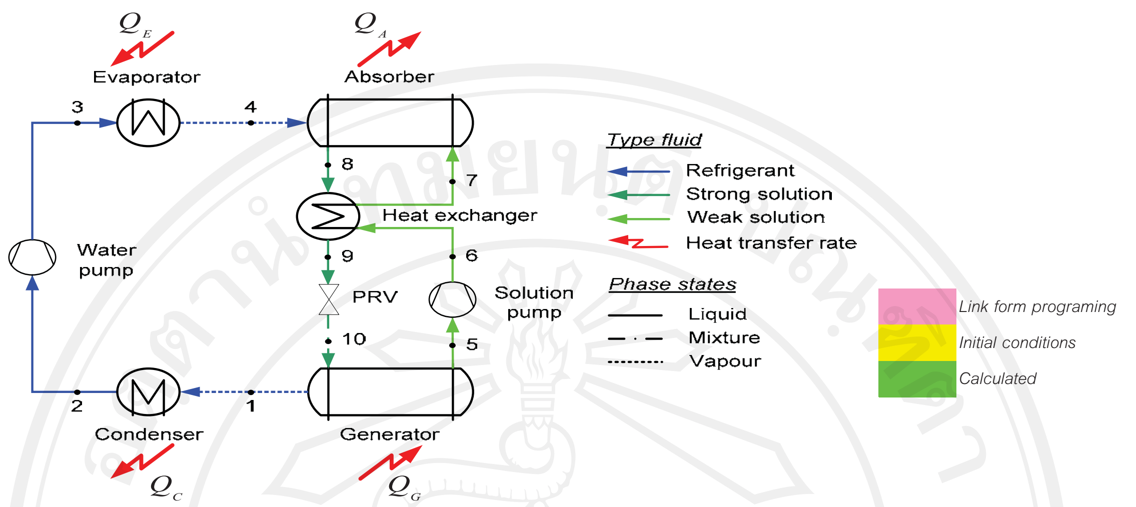
C. The average solar radiation of Chiang Mai, Thailand [5].



Month	Jan	Feb	Mar	Apr	May	Jun
I_T $(MJ/m^2 \cdot d)$	17.82	20.34	21.71	22.36	19.69	16.88
Month	Jul	Aug	Sep	Oct	Nov	Dec
I_T $(MJ/m^2 \cdot d)$	15.66	15.23	15.77	15.73	15.84	16.45
$I_{T,Average}$ $(MJ/m^2 \cdot d)$	17.79					

D. Thermodynamics design

LITHIUH BROMIDE-WATER ABSORPTION HEAT PUMP FOR TEMPEATURE BOOSTING OF LOW GRADE HEAT



Initial condition											
Refrigerant is solution :		WATER	LiBr								
Waste heat			WATER								
Temperature waste heat (T_{WH})			60	65	70	75	80	85	90	95	('C)
Δ T Condenser $_C$ and Evaporator $_A$			5	('C)							
Δ T Evaporator $_C$ and Condenser $_A$			-5	('C)							
Δ T Heat exchanger			5	('C)							
Δ T Drop of fluid			5	('C)							
Refrigerant vapor is 100% water (X) :			1	(mass water / mass liquid)							
Adiabatic (Heat transfer efficiency) :			100%								
Effectiveness			70%								
X1	*เท่ากับ*		0	(mass water / mass liquid)							
X5	*เท่ากับ*		0.55	(mass water / mass liquid)							
X8	*เท่ากับ*		0.50	(mass water / mass liquid)							
Cooling fluid			WATER								
Cooling temperature inlet ($T_{en,in}$)			30	('C)							
Cooling temperature outlet ($T_{en,in}$)			35	('C)							

Assump

Steady state

No pressure change except though flow errestrictors and pump

State at points 2 , 5 , 8 are saturated liquid

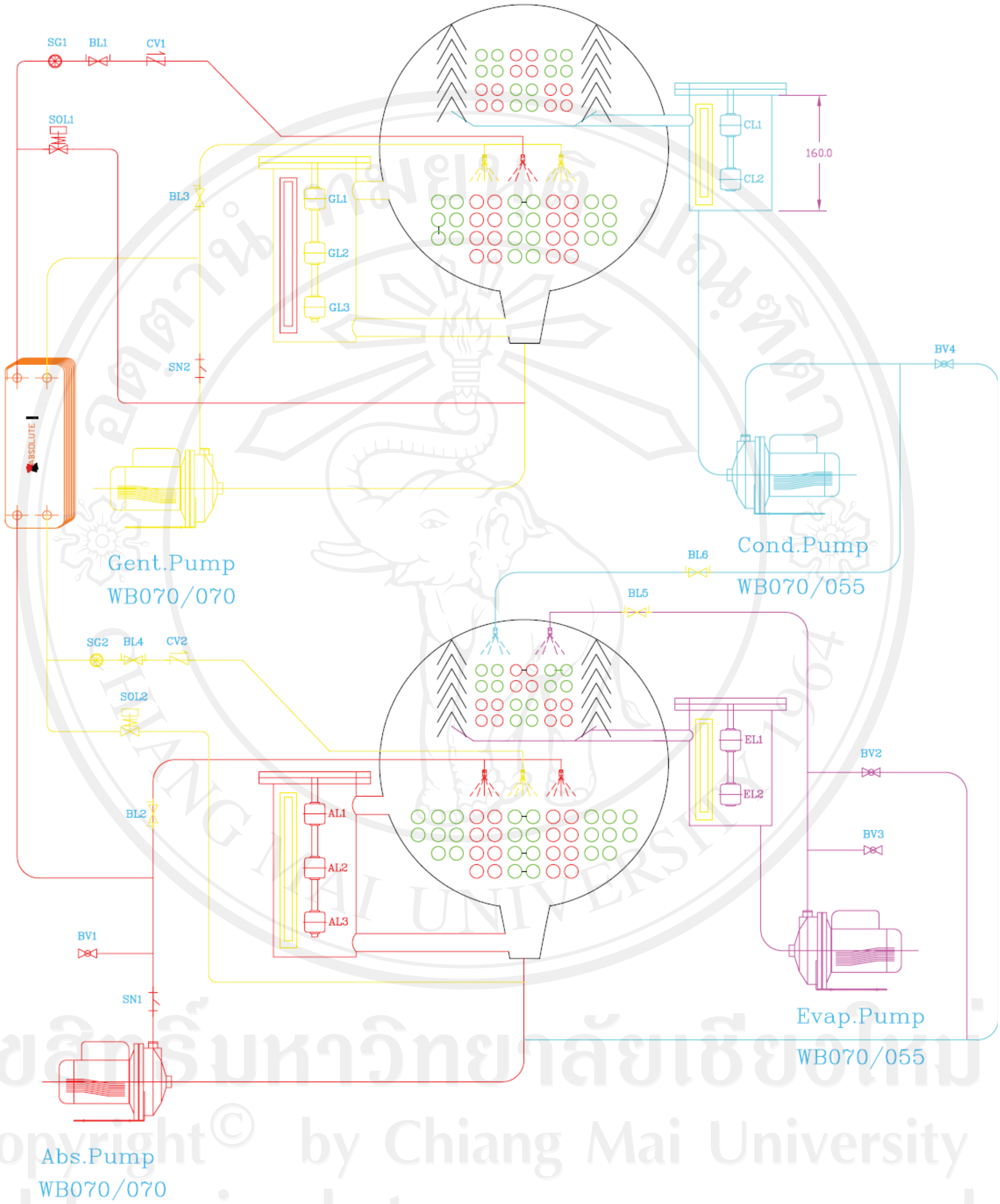
Flow restrictors and adiabatic

Pump is Isentropic

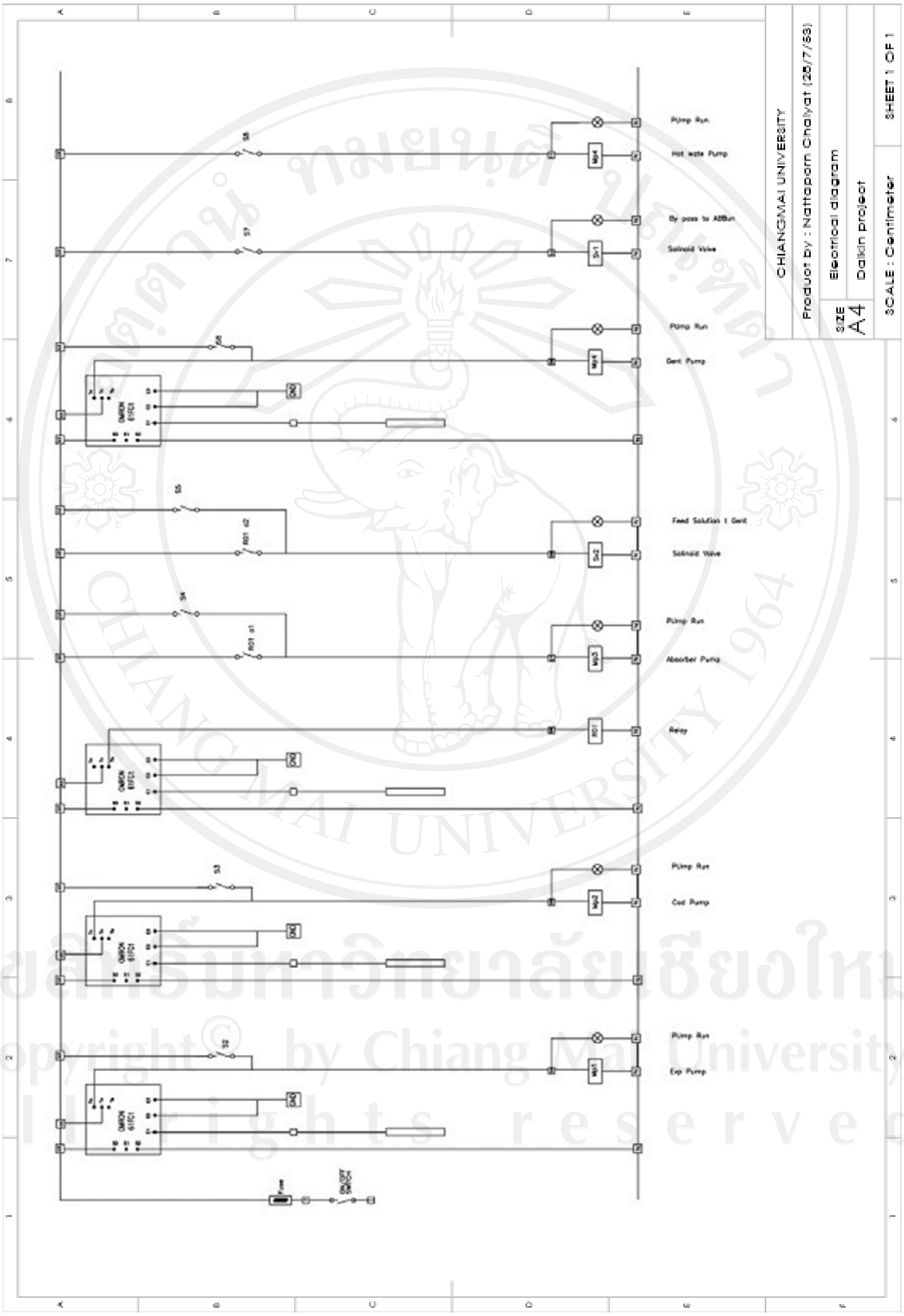
Waste heat									
Heating capacity of waste heat for design	20.00								(kW)
Temperature waste heat inlet	60.00	65.00	70.00	75.00	80.00	85.00	90.00	95.00	('C)
Temperature at each component									
Evaporator (T4)	50.00	55.00	60.00	65.00	70.00	75.00	80.00	85.00	('C)
Condenser (T2)	40								('C)
Absorber (T8)	0.00	0.00	0.00	0.00	0.00	104.28	109.87	115.46	('C)
Minimum temperature to boil water at the generator (T_{min})	74.49	74.49	74.49	74.49	74.49	74.49	74.49	74.49	('C)
Generator (T5)	50.00	55.00	60.00	65.00	70.00	75.00	80.00	85.00	('C)
Pressure of Absorption									('C)
High Pressure (Water at the evaporator)	0.00	0.00	0.00	0.00	0.00	38.60	47.41	57.87	(kPa)
	0.00	0.00	0.00	0.00	0.00	0.39	0.47	0.58	(Bar, Ab)
	0.00	0.00	0.00	0.00	0.00	-0.39	-0.47	-0.58	(Bar, G)
Low Pressure (Water at the condenser)	0.00	0.00	0.00	0.00	0.00	5.63	5.63	5.63	(kPa)
	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06	(Bar, Ab)
	0.00	0.00	0.00	0.00	0.00	-0.94	-0.94	-0.94	(Bar, G)
Pressure ratio	0.00	0.00	0.00	0.00	0.00	6.86	8.42	10.28	
Pressure differential	0.00	0.00	0.00	0.00	0.00	0.33	0.42	0.52	(Bar, Ab)
At evaporator and condenser									
Q'e	0.00	0.00	0.00	0.00	0.00	10.00	10.00	10.00	(kW)
	0.00	0.00	0.00	0.00	0.00	2.84	2.84	2.84	(TR)
T4	0.00	0.00	0.00	0	0	75	80	85	('C)
hv4	0.00	0.00	0.00	0.00	0.00	2634.60	2643.02	2651.33	(kJ/kg)
s2	0.00	0.00	0.00	0.00	0.00	0.57	0.57	0.57	(kJ/kg-'C)
h2	0.00	0.00	0.00	0.00	0.00	167.53	167.53	167.53	(kJ/kg)
Isentropic process (s2=s3)	0.00	0.00	0.00	0.00	0.00	0.57	0.57	0.57	(kJ/kg-'C)
T2	0.00	0.00	0.00	0.00	0.00	40.00	40.00	40.00	('C)
T3 = T2	0.00	0.00	0.00	0.00	0.00	40.00	40.00	40.00	('C)
hl3	0.00	0.00	0.00	0.00	0.00	167.53	167.53	167.53	(kJ/kg)
T1	0.00	0.00	0.00	0.00	0.00	75.00	80.00	85.00	(kJ/kg)
h1	0.00	0.00	0.00	0.00	0.00	2634.60	2643.02	2651.33	(kJ/kg)
m'ref = m'1 = m'2 = m'3 = m'4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0041	0.0040	0.0040	(kg/s)
	0.0000	0.0000	0.0000	0.0000	0.0000	0.2432	0.2424	0.2416	(kg/min)
	0.0000	0.0000	0.0000	0.0000	0.0000	14.5922	14.5426	14.4940	(kg/hr)
At generator									
Tg	0.00	0.00	0.00	0.00	0.00	75.00	80.00	85.00	('C)
hv3	0.00	0.00	0.00	0.00	0.00	2634.60	2643.02	2651.33	(kJ/kg)
m'5 = m'6 = m'7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0405	0.0404	0.0403	(kg/s)
m'8 = m'9 = m'10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0446	0.0444	0.0443	(kg/s)

At heat exchanger									
T5	0.00	0.00	0.00	0.00	0.00	75.00	80.00	85.00	('C)
h5	0.00	0.00	0.00	0.00	0.00	166.10	176.47	186.84	(kJ/kg)
s5	0.00	0.00	0.00	0.00	0.00	0.47	0.50	0.53	(kJ/kg-'C)
Isentropic process (s5=s6)	0.00	0.00	0.00	0.00	0.00	0.47	0.50	0.53	(kJ/kg-'C)
T6 = T5 (S=f(T,X))	0.00	0.00	0.00	0.00	0.00	75.00	80.00	85.00	('C)
T8	0.00	0.00	0.00	0.00	0.00	104.28	109.87	115.46	('C)
h8	0.00	0.00	0.00	0.00	0.00	223.71	236.12	248.54	(kJ/kg)
Thorting process (h8=h9)	0.00	0.00	0.00	0.00	0.00	223.71	236.12	248.54	(kJ/kg)
T8	0.00	0.00	0.00	0.00	0.00	104.28	109.87	115.46	('C)
Effectivness	70%								
Effectivness =	Q_{actual} / $((m' Cp)_{min} * (T_{hot,in} - T_{cold,in}))$								
Q_{actual} =	Effectiveness * $((m' Cp)_{min} * (T_{hot,in} - T_{cold,in}))$								
Hot fulid									
m'8 = m'9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0446	0.0444	0.0443	(kg/s)
Cp8	0.00	0.00	0.00	0.00	0.00	2.23	2.23	2.24	(kJ/kg-'C)
m'8*Cp8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0994	0.0993	0.0992	(kJ/s-'C)
Cold fulid									
m'5 =m'6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0405	0.0404	0.0403	(kg/s)
Cp6	0.00	0.00	0.00	0.00	0.00	2.06	2.07	2.07	(kJ/kg-'C)
m'6* Cp6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0836	0.0835	0.0834	(kJ/s-'C)
$(m"Cp)_{min}$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0836	0.0835	0.0834	(kJ/s-'C)
Capacity of heat exchanger (Q_{max})	0.00	0.00	0.00	0.00	0.00	2.45	2.49	2.54	(kW)
Capacity of heat exchanger (Q_{actual})	0.00	0.00	0.00	0.00	0.00	1.71	1.75	1.78	(kW)
$T_{cold,out}$ = T7 =	$(Q_{actual}$ / m'6* Cp6) +T6								
	0.00	0.00	0.00	0.00	0.00	95.50	100.91	106.32	('C)
$T_{hot,out}$ = T9 =	T8 - $(Q_{actual}$ / m'8* Cp8)								
	0.00	0.00	0.00	0.00	0.00	87.04	92.28	97.53	('C)
h7	0.00	0.00	0.00	0.00	0.00	208.63	219.88	231.12	(kJ/kg)
h9	0.00	0.00	0.00	0.00	0.00	204.24	216.23	228.24	(kJ/kg)
h10 = h9	0.00	0.00	0.00	0.00	0.00	204.24	216.23	228.24	(kJ/kg)
At solution pump									
Different of pressure	0.00	0.00	0.00	0.00	0.00	0.33	0.42	0.52	(Bar)
Density	0.00	0.00	0.00	0.00	0.00	1122.77	1119.27	1115.69	(kg/m^3)
Specific volume	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0009	0.0009	(m^3/kg)
Capacity of solution pump	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0004	0.0005	(kW)
At pump									
Different of pressure	0.00	0.00	0.00	0.00	0.00	0.33	0.42	0.52	(Bar)
Density	0.00	0.00	0.00	0.00	0.00	992.18	992.18	992.18	(kg/m^3)
Specific volume	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0010	0.0010	(m^3/kg)
Capacity of the pump	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0004	0.0005	(kW)
Capacity of element									
Absorber	0.00	0.00	0.00	0.00	0.00	9.16	9.07	8.97	(kW)
Generator	0.00	0.00	0.00	0.00	0.00	8.31	8.20	8.09	(kW)
Evaporator	0.00	0.00	0.00	0.00	0.00	10.00	10.00	10.00	(kW)
Condenser	0.00	0.00	0.00	0.00	0.00	10.00	10.00	10.00	(kW)
COP									
$Q_a / (Q_g + Q_e + W_P + W_{SP})$	0.0000	0.0000	0.0000	0.0000	0.0000	0.5004	0.4982	0.4960	(-)

E. Diagram of the AHT



F. Electrical diagram of the AHT



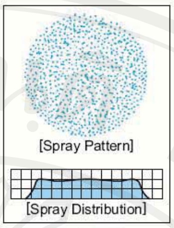
G. Specifications of each components in the AHT

- Nozzles
- Solenoid valves
- Check valves
- Solution pumps
- H_2O-LiBr solutions
- Balancing valve
- Level switch

Nozzles

Wide-angle Type Full Cone Spray Nozzles

BBXP



[Features]

- Wide spray angle full cone spray nozzle with uniform spray distribution throughout pattern area.
- Spray angle of 120° allows to cover large spray area than any other nozzles.
- Spray capacity from small to medium is available.
- X-shaped whirler enables to enlarge free passage diameter for minimal clogging.

[Standard Pressure]

0.2MPa for the nozzle of spray capacity code of 020~060.
0.35MPa for the nozzle of spray capacity code of over 10.

Full Cone

[Applications]

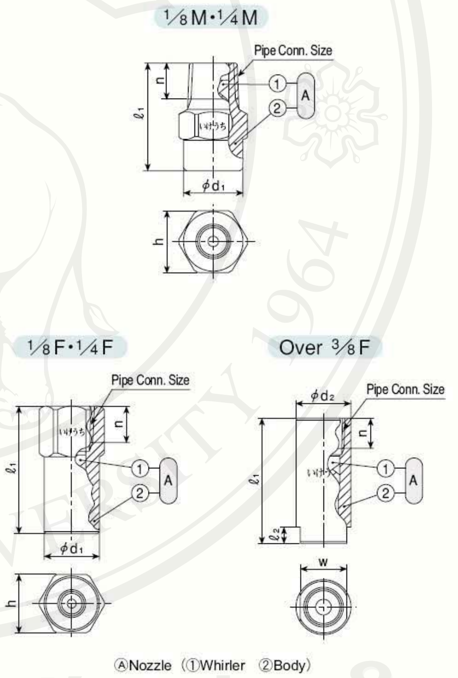
Washing : Gasses, incinerator fumes, machineries, eliminators, screen, tanks, gravels, stones, sand, etc.
Cooling : Gasses, machineries, tanks, steels, etc.
Spraying : Waste water treatment, aeration, foam breaking, fire extinguishing, dust suppression, sea water desalination, etc.

BBXP-series

	BBXP-series
Structure	• One-piece structure with X-shaped whirler.
Material	• Nozzle body of smaller than 1" pipe conn. size : B (Brass) or S303 (Stainless steel 303) (SCS13) • Nozzle body of larger than 1½" pipe conn. size : S316 (Stainless steel 316) (SCS14) • Optional material : S316L (SCS16) or others

Series	Pipe Conn. Size	Dimensions(mm)							Mass(g)	
		ℓ_1	ℓ_2	h	w	ϕd_1	ϕd_2	n	B	SUS
BBXP	⅛M	21	—	12	—	11.5	—	7	11.5	11
	¼M	29	—	14	—	13.5	—	10.5	21	19.5
	⅛F	27	—	12	—	11.5	—	7	20	19
	¼F	36.5	—	17	—	16	—	10.5	70	66
	⅜F	45.5	6	—	17	—	20	11	80	75
	½F	56	8	—	22	—	25	14	150	140
	¾F	73	10	—	27	—	32	15	320	300
	1F	94	14	—	34	—	40	17	625	585
	1½F	131	20	—	50	—	58	19	—	1760
	2F	168	24	—	60	—	70	23	—	2980
	2½F	199	27	—	80	—	90	27	—	5890
	3F	220	30	—	90	—	105	30	—	9400
	4F	278	40	—	115	—	130	36	—	16100

[Note] Appearance and dimensions may be slightly changed depending on materials and nozzle codes.



Spray Capacity Code	Pipe Conn. Size				Spray Angle			Spray Capacity (ℓ/min)									Mean Drop. Dia. (μm)	Free Pass. Dia. (mm)
	⅛M	¼M	⅛F	¼F	0.05 MPa	0.2 MPa	0.5 MPa	0.03 MPa	0.05 MPa	0.1 MPa	0.15 MPa	0.2 MPa	0.35 MPa	0.5 MPa	0.7 MPa	1 MPa		
015	○		○		—	120°	112°	—	—	1.09	1.32	1.50	1.88	2.18	2.50	2.89	300	0.8
020	○		○		110°	120°	112°	—	1.06	1.46	1.75	2.00	2.51	2.91	3.34	3.86	~	1.2
030	○		○		112°	120°	113°	—	1.59	2.18	2.63	3.00	3.77	4.36	5.00	5.79	340	1.3
040		○		○	110°	120°	112°	—	2.12	2.91	3.51	4.00	5.03	5.81	6.67	7.72	350	1.3
050		○		○	112°	120°	113°	—	2.65	3.64	4.38	5.00	6.28	7.27	8.34	9.64	~	1.5
060		○		○	114°	120°	114°	2.51	3.18	4.37	5.26	6.00	7.54	8.72	10.0	11.6	430	1.8

70

Wide-angle Type / Full Cone Spray Nozzles
BBXP-series

Full Cone

Spray Capacity Code	Pipe Conn. Size									Spray Angle			Spray Capacity (ℓ/min)									Mean Drop. Dia. (μm)	Free Pass. Dia. (mm)
	⅜F	½F	¾F	1F	1½F	2F	2½F	3F	4F	0.15 MPa	0.35 MPa	0.7 MPa	0.03 MPa	0.05 MPa	0.1 MPa	0.15 MPa	0.2 MPa	0.35 MPa	0.5 MPa	0.7 MPa	1 MPa		
10	○									123°	120°	111°	3.34	4.21	5.79	6.98	7.96	10.0	11.6	13.3	15.3	340	1.9
12	○									124°	120°	112°	4.00	5.06	6.95	8.37	9.55	12.0	13.9	15.9	18.4		2.3
14	○									124°	120°	112°	4.67	5.90	8.10	9.77	11.1	14.0	16.2	18.6	21.5	~	2.6
16	○									125°	120°	113°	5.33	6.74	9.25	11.2	12.7	16.0	18.5	21.2	24.6		2.6
18		○								123°	120°	111°	6.00	7.58	10.4	12.6	14.3	18.0	20.8	23.9	27.6	420	2.9
20		○								123°	120°	111°	6.67	8.43	11.6	14.0	15.9	20.0	23.1	26.5	30.7	~	2.9
23		○								124°	120°	112°	7.67	9.69	13.3	16.0	18.3	23.0	26.6	30.5	35.3		2.9
26		○								124°	120°	112°	8.67	11.0	15.1	18.1	20.7	26.0	30.1	34.5	39.9	480	3.5
30			○							123°	120°	111°	10.0	12.6	17.4	20.9	23.9	30.0	34.7	39.8	46.0	~	3.8
40			○							124°	120°	112°	13.3	16.9	23.2	27.9	31.8	40.0	46.3	53.1	61.4		4.1
50			○							125°	120°	113°	16.7	21.0	29.0	34.9	39.8	50.0	57.8	66.3	76.7	580	4.7
60				○						124°	120°	112°	20.0	25.3	34.7	41.9	47.7	60.0	69.4	79.6	92.1	~	5.3
80				○						125°	120°	113°	26.7	33.7	46.3	55.8	63.7	80.0	92.5	106	123	630	5.7
100					○					123°	120°	111°	33.3	42.1	57.9	69.8	79.6	100	115	135	155	~	6.2
150					○					124°	120°	112°	50.0	63.2	86.9	105	120	150	175	200	230		7.5
200						○				124°	120°	112°	66.7	84.3	115	140	160	200	230	265	310	710	9.0
300						○				125°	120°	113°	100	125	175	210	240	300	350	400	460	900	11.5
400							○			124°	120°	112°	135	170	235	280	320	400	465	530	615	~	13.4
500							○			125°	120°	113°	170	210	290	350	400	500	580	665	770	1000	18.4
600								○		124°	120°	112°	200	255	350	420	480	600	695	795	920	~	16.0
700								○		125°	120°	113°	235	295	405	490	550	700	810	930	1070	1100	17.2
900									○	124°	120°	112°	300	380	520	630	720	900	1041	1195	1380	~	19.3
1200									○	125°	120°	113°	400	505	695	840	955	1200	1390	1590	1840	1200	22.4

How to order Please inquire or order for a specific nozzle on this coding system.

〈Example〉…⅛MBBXP015B

⅛M	BBXP	015	B
Pipe Conn. Size		Spray Capacity Code	Material
⅛M		015	B
~		~	S303
4F		1200	S316

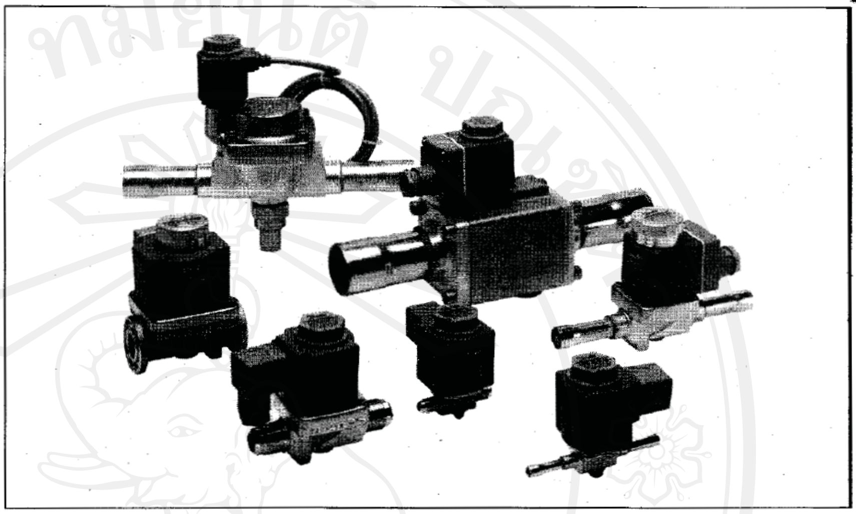
71

Solenoid valves

Danfoss

Solenoid valves type EVR 2 → 40 – NC / NO

Introduction



EVR is a direct or servo operated solenoid valve for liquid, suction, and hot gas lines with fluorinated refrigerants.

EVR valves are supplied complete or as separate components, i.e. valve body, coil and flanges, if required, can be ordered separately.

Features

- *Complete range of solenoid valves for refrigeration, freezing and air conditioning plant*
- *Supplied both normally closed (NC) and normally open (NO) with de-energized coil*
- *Wide choice of coils for a.c. and d.c.*
- *Suitable for all fluorinated refrigerants*
- *Designed for media temperatures up to 105°C*
- *MOPD up to 25 bar with 12 W coil*
- *Flare connections up to 5/8 in.*
- *Solder connections up to 2 1/8 in.*
- *Extended ends for soldering make installation easy*
  It is not necessary to dismantle the valve when soldering in.
- *EVR are also available with flange connections*

Approvals

DnV, Det norske Veritas, Norway
DSRK, Deutsche Schiffs-Revision und -Klassifikation, Germany
Öve, Austria
Polski Rejestr Statków, Poland
FIMKO, Finland
SEV, Switzerland
MRS, Maritime Register of Shipping, Russia
SZU, Czech Republic

Versions with UL and CSA approval can be supplied to order.

Technical data

Refrigerants
R 22, R 134a, R 404A, R 12, R 502 etc.

Temperature of medium
–40 → +105°C with 10 W or 12 W coil.
Max. 130°C during defrosting.

Ambient temperature and enclosure for coil
See "Coils for solenoid valves".

Danfoss

Solenoid valves, type EVR 2 → 40 - NC / NO

Technical data
(continued)

Type	Opening differential pressure with standard coil Δp bar Min.	Max. (MOPD) liquid [2] a.c.	Max. (MOPD) liquid [2] d.c.	Temperature of medium °C	Max. working pressure PB bar	k_v value [1] m^3/h
EVR 2	0.0	25	14	−40 → 105	35	0.16
EVR 3	0.0	21	18	−40 → 105	35	0.27
EVR 6	0.05	21	18 [3]	−40 → 105	35	0.8
EVR 10	0.05	21	18 [3]	−40 → 105	35	1.9
EVR 15	0.05	21	18 [3]	−40 → 105	32	2.6
EVR 20	0.05	21 [4]	16 [4] [5]	−40 → 105	32	5.0
EVR 22	0.05	21 [4]	16 [4] [5]	−40 → 105	32	6.0
EVR 25	0.07	21	14	−40 → 105	28	10.0
EVR 32	0.07	21	14	−40 → 105	28	16.0
EVR 40	0.07	21	14	−40 → 105	28	25.0

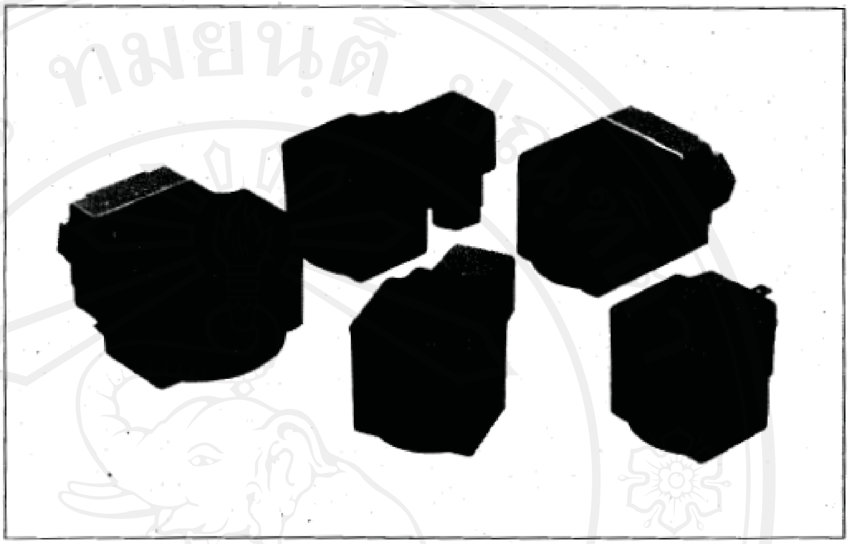
Type	Rated capacity [6] kW														
	Liquid					Suction vapour					Hot gas				
	R 22	R 134a	R 404A	R 12	R 502	R 22	R 134a	R 404A	R 12	R 502	R 22	R 134a	R 404A	R 12	R 502
EVR 2	3.2	2.9	2.2	2.4	2.1						1.5	1.2	1.2	0.95	1.1
EVR 3	5.4	5.0	3.8	4.1	3.6						2.5	2.0	2.0	1.6	1.9
EVR 6	16.1	14.8	11.2	12.6	10.7	1.8	1.3	1.6	1.2	1.5	7.4	5.9	6.0	4.9	5.6
EVR 10	38.2	35.3	26.7	29.8	25.4	4.3	3.1	3.9	2.8	3.6	17.5	13.9	14.3	11.6	13.4
EVR 15	52.3	48.3	36.5	39.2	34.8	5.9	4.2	5.3	4.0	4.9	24.0	19.0	19.6	15.8	18.3
EVR 20	101.0	92.8	70.3	78.4	67.0	11.4	8.1	10.2	7.6	9.4	46.2	36.6	37.7	30.3	35.2
EVR 22	121.0	111.0	84.3	94.1	80.3	13.7	9.7	12.2	9.1	11.2	55.4	43.9	45.2	36.7	42.3
EVR 25	201.0	186.0	141.0	152.0	134.0	22.8	16.3	20.4	14.5	18.7	92.3	73.2	75.3	60.6	70.4
EVR 32	322.0	297.0	225.0	243.0	214.0	36.5	26.1	32.6	23.2	30.0	148.0	117.0	120.0	97.0	113.0
EVR 40	503.0	464.0	351.0	380.0	334.0	57.0	40.8	51.0	36.3	46.8	231.0	183.0	188.0	152.0	176.0

1) The k_v value is the water flow in m^3/h at a pressure drop across valve of 1 bar, ρ = 1000 kg/m^3.
2) MOPD for media in gas form is approx. 1 bar greater.
3) EVR (NO): 21 bar.
4) EVR (NO): 19 bar.
5) 13 bar, if d.c. coils is used for the a.c. version of EVR 20 and 22.
6) Rated liquid and suction vapour capacity is based on evaporating temperature t_e = −10°C, liquid temperature ahead of valve t_l = +25°C, and pressure drop in valve Δp = 0.15 bar.
Rated hot gas capacity is based on condensing temperature t_c = +40°C, pressure drop across valve Δp = 0.8 bar, hot gas temperature t_h = +65°C, and subcooling of refrigerant Δt_{sub} = 4 K.

 Catalogue RK.00.H5.02 109

Danfoss

Coils for solenoid valves



Features

- *Encapsulated coils with long operating life, even under extreme conditions*
- *Standard coils for a.c. or d.c.*
- *Standard coils available with 3-core cable, terminal box or DIN plugs*
- *Standard coils from 12 V to 420 V, 50, 60 or 50/60 Hz*
- *Standard coils dimensioned for max. opening differential pressure (MOPD) of up to 21 bar*
- *Coils can be fitted or removed without the use of tools*

Technical data

Ambient temperature
10 or 12 W a.c. coil
for NC (normally closed) valve:
–40 → +80°C

10 W a.c. coil
for NO (normally open) valve:
–40 → +55°C

20 W d.c. coil
for NC and NO valve:
–40 → +50°C

Permissible voltage variation
10 and 12 W a.c. coils: +10 → –15%
Double frequency coils: ±10%
20 W d.c. coils: ±10%.

Enclosure
IP 67 with cable or terminal box
IP 20 with DIN plugs and protective cap
IP 65 with DIN socket
IP 00 with DIN plugs.

Approvals
See under the required solenoid valve.

Connection

3-core cable
The external thread in the screwed cable entry suits flexible steel hose or corresponding cable protection.

Terminal box
Leads are connected to terminal screws in the terminal box. The box is fitted with a Pg 13.5 screwed entry for 6 → 14 mm cable.
Max. lead cross section: 2.5 mm^2.

DIN plugs
The three pins on the coil can be fitted with spade tabs, 6.3 mm wide (to DIN 46247).
The two current carrying pins can also be fitted with spade tabs, 4.8 mm wide.
Max. lead cross section: 1.5 mm^2.
Use of the protective cap supplied will prevent inadvertent contact with live parts.

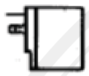
DIN socket
(to DIN 43650)
Leads are connected in the socket. The socket is fitted with a Pg 11 screwed entry for 6 → 12 mm.

Danfoss

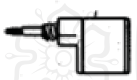
Coils for solenoid valves

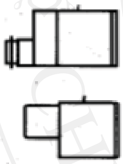
Ordering

Standard coils

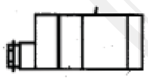


Valve type	Voltage V	Frequency Hz	Code no. With DIN plugs IP 00	Code no. With DIN plugs and protective cap IP 20	Appendix no. 1)	Power consumption
Alternating current a.c.			MOPD = 25 bar			
EVR 2 EVH 2	24	50	42N7408	42N7476	16	Holding: 10 W 21 VA Inrush: 44 VA
	115	50	42N7412	42N7475	22	
	220-230	50	42N7401	42N7471	31	
	240	50	42N7402	42N7472	33	
	380-400	50	42N7404	42N7473	37	
	420	50	42N7405	42N7474	38	
	110	50/60	42N7430	42N7478	21	
	220-230	50/60	42N7432	42N7479	32	





Valve type	Voltage V	Frequency Hz	Code no. With 1 m 3-core cable IP 67	Code no. With terminal box IP 67 2)	Code no. With DIN plugs and protective cap IP 20	Appendix no. 1)	Power consumption
Alternating current a.c.			MOPD = 21 bar 3)				
EVR 3 → 40 (NC) EVR 6 → 22 (NO) 3) EVH 3 → 10 EVRC 3) EVRA EVRAT 3) EVRS / EVRST 3) PKVD EVM (NC) EVSI 3)	12	50	18Z6256	18Z6706	18Z6181	15	Holding: 10 W 21 VA Inrush: 44 VA
	24	50	18Z6257	18Z6707	18Z6182	16	
	42	50	18Z6258	18Z6708	18Z6183	17	
	48	50	18Z6259	18Z6709	18Z6184	18	
	115	50	18Z6261	18Z6711	18Z6186	22	
	220-230	50	18Z6251	18Z6701	18Z6176	31	
	240	50	18Z6252	18Z6702	18Z6177	33	
	380-400	50	18Z6253	18Z6703	18Z6178	37	
	420	50	18Z6254	18Z6704	18Z6179	38	
	24	60	18Z6265	18Z6715	18Z6190	14	
	115	60	18Z6260	18Z6710	18Z6185	20	
	220	60	18Z6264	18Z6714	18Z6189	29	
	240	60	18Z6263	18Z6713	18Z6188	30	
	110	50/60	18Z6280	18Z6730	18Z6192	21	
	220-230	50/60	18Z6282	18Z6732	18Z6193	32	
Direct current d.c.			MOPD = 18 bar 3)				Coil type I
EVR 2 → 15 (NC) EVR 25 → 40 (NC / NO) 3) EVR 6 → 15 (NO) 3) EVH 3 → 10 EVRC 10 → 15 EVRA 3 → 15 (NC) EVRA 25 → 40 (NC) 3) EVRAT 10 → 15 (NC) 3) EVRS / EVRST 3) PKVD EVM (NC / NO) 3) EVSI 3)	12			18Z6856		01	20 W
	24			18Z6857		02	
	48			18Z6859		04	
	110			18Z6860		06	
	115			18Z6861		07	
	220			18Z6851		09	
Direct current d.c.			MOPD = 16 bar 3)				Coil type II
EVR 20 → 22 (NC / NO) 3) EVRC 20 EVRA 20 EVRAT 20	12			18Z6886		01	20 W
	24			18Z6887		02	
	48			18Z6889		04	
	110			18Z6890		06	
	115			18Z6891		07	
	220			18Z6881		09	



1) Appendix no. clearly indicates type of current, voltage and frequency.
2) When replacing a coil with terminal box, it is sufficient to change the coil unit itself. Therefore order coil with DIN plugs and protective cap.
3) See "Opening differential pressure" under "Technical data" for the valve concerned.

Check valves

Danfoss

Check valves type NRV and NRVH

Introduction

Check valves, type NRV and NRVH can be used in liquid, suction and hot gas lines in refrigeration and air conditioning plant with fluorinated refrigerants.

NRV and NRVH can also be supplied with oversize connections providing flexibility in the use of check valves.

Features

- *The valve ensures only correct flow direction*
- *Both straightway and angleway versions*
- *Prevents back-condensation from warm to cold evaporator*
- *Built-in damping piston* that makes the valves suitable for installation in lines where pulsation can occur, e.g. in the discharge line from the compressor.
- *NRVH is supplied with spring to Δp = 0.3 bar* Used in refrigeration plant with compressors connected in parallel.
- *Oversize connections* provide flexibility in use.

Technical data

Temperature of the medium
–50 → +140°C

Max. working pressure
6 → 35: PB = 28 bar

Max. test pressure
6 → 35: p' = 36,4 bar

Dimensioning and selection

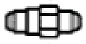
When dimensioning and selecting check valves to be mounted into the compressor discharge line, it is important to be aware of the following: The differential pressure across the check valve must always be higher than the given minimum pressure drop at which the valve is completely open. This also applies to lowest capacities for compressors with capacity regulation.

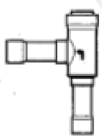
In refrigeration plant with compressors connected in parallel, it is advantageous to use NRVH equipped with a stronger spring than NRV.
With check valve, type NRVH, resonance problems can be avoided at partial load in the refrigeration plant. The differential pressure across NRVH at partial load must not be lower than minimum pressure drop for NRVH with completely open valve.

Danfoss

Check valves, type NRV and NRVH

Ordering





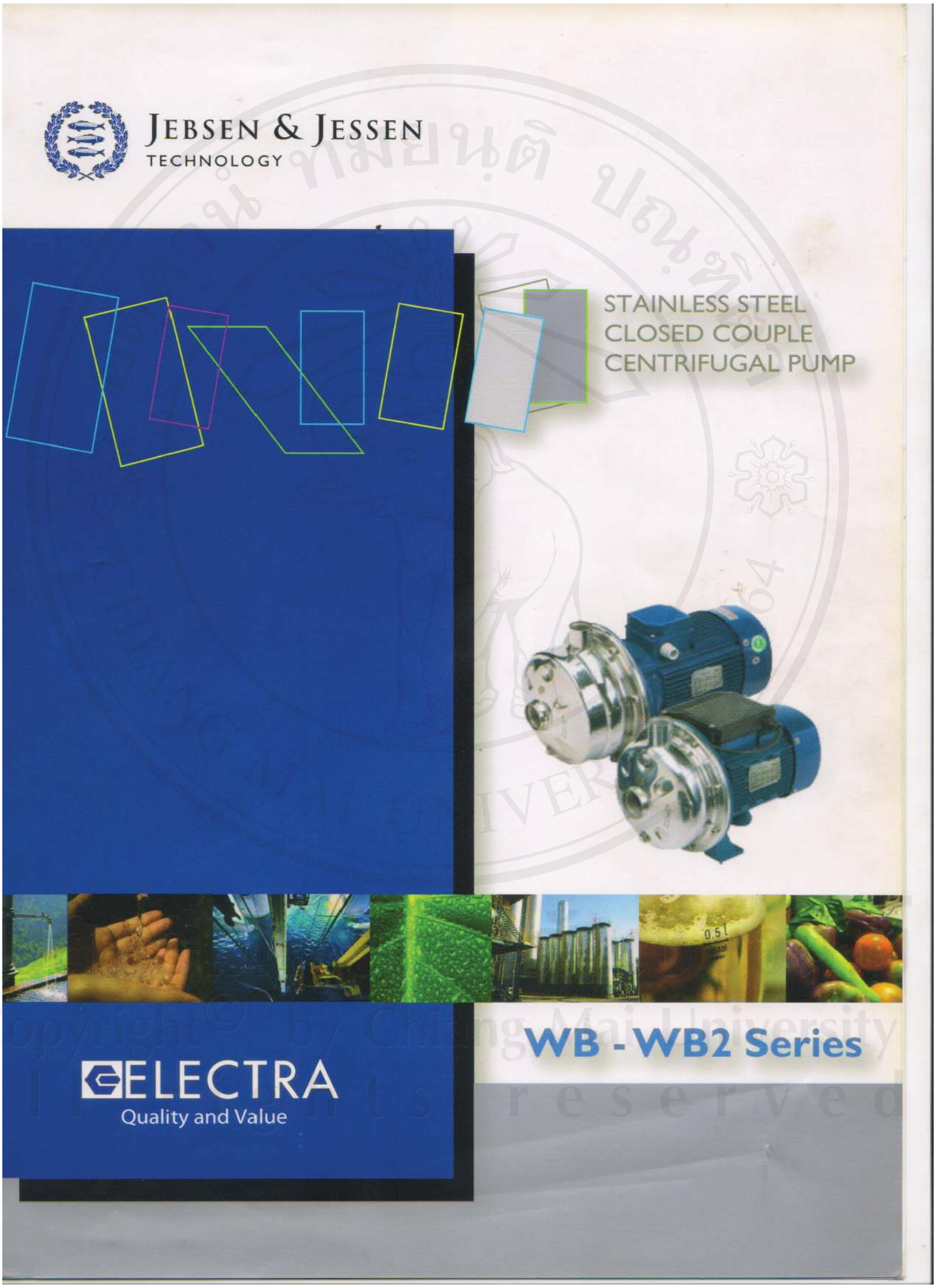
Type	Version		Connection in. Size	Connection in. Code no.	Connection mm Size	Connection mm Code no.	Pressure drop across valve Δp [2]) bar	k_v value [3]) m^3/h
NRV 6	Straight-way	Flare	1/4	20-1040	6	20-1040	0.07	0.56
NRV 10			3/8	20-1041	10	20-1041		1.43
NRV 12			1/2	20-1042	12	20-1042	0.05	2.05
NRV 16			5/8	20-1043	16	20-1043		3.6
NRV 19			3/4	20-1044	19	20-1044		5.5
NRV 6s		Solder ODF	1/4	20-1010	6	20-1014	0.07	0.56
NRV 6s [1])			3/8	20-1057	10	20-1050		
NRVH 6s [1])			3/8	20-1069	10	20-1062	0.3	
NRV 10s			3/8	20-1011	10	20-1015	0.07	1.43
NRVH 10s			3/8	20-1046	10	20-1036	0.3	
NRV 10s [1])			1/2	20-1058	12	20-1051	0.07	
NRVH 10s [1])			1/2	20-1070	12	20-1063	0.3	
NRV 12s			1/2	20-1012	12	20-1016	0.05	2.05
NRVH 12s			1/2	20-1039	12	20-1037	0.3	
NRV 12s [1])			5/8	20-1052	16	20-1052	0.05	
NRVH 12s [1])			5/8	20-1064	16	20-1064	0.3	
NRV 16s			5/8	20-1018	16	20-1018	0.05	3.6
NRVH 16s			5/8	20-1038	16	20-1038	0.3	
NRV 16s [1])					18	20-1053	0.05	
NRVH 16s [1])					18	20-1065	0.3	
NRV 16s [1])			3/4	20-1059	19	20-1059	0.05	5.5
NRVH 16s [1])			3/4	20-1071	19	20-1071	0.3	
NRV 19s					18	20-1017	0.05	
NRVH 19s					18	20-1008	0.3	
NRV 19s			3/4	20-1019	19	20-1019	0.05	
NRVH 19s			3/4	20-1023	19	20-1023	0.3	
NRV 19s [1])			7/8	20-1054	22	20-1054	0.05	
NRVH 19s [1])			7/8	20-1066	22	20-1066	0.3	
NRV 22s	Angleway		7/8	20-1020	22	20-1020	0.04	8.5
NRVH 22s			7/8	20-1032	22	20-1032	0.3	
NRV 22s [1])			1 1/8	20-1060	28	20-1055	0.04	
NRVH 22s [1])			1 1/8	20-1072	28	20-1067	0.3	
NRV 28s			1 1/8	20-1021	28	20-1025	0.04	19.0
NRVH 28s			1 1/8	20-1029	28	20-1033	0.3	
NRV 28s [1])			1 3/8	20-1056	35	20-1056	0.04	
NRVH 28s [1])			1 3/8	20-1068	35	20-1068	0.3	
NRV 35s			1 3/8	20-1026	35	20-1026	0.04	29.0
NRVH 35s			1 3/8	20-1034	35	20-1034	0.3	
NRV 35s [1])			1 5/8	20-1061	42	20-1027	0.04	
NRVH 35s [1])			1 5/8	20-1073	42	20-1035	0.3	

[1]) Oversize connections

[2]) Δp = the minimum pressure at which the valve is completely open.
The NRVH with a stronger spring is used in the discharge line from compressors connected in parallel.

[3]) The k_v value is the flow of water in m^3/h at a pressure drop across valve of 1 bar, $\rho = 1000\ kg/m^3$.

Solution pumps



ELECTRA

WB-WB2 Series

Stainless Steel Threaded Centrifugal Pumps

Wide range of pumps for domestic and industrial applications.

Single - impeller (WB) and Twin - impellers (WB2) models are available as standard design for temperatures upto 110 °C.

Part	Material *
Casing	304 Stainless Steel
Impeller	304 Stainless Steel
Wear Ring	304 Stainless Steel
Shaft	304 Stainless Steel

* 316 L Stainless Steel available on request.

MARKET SECTORS

Domestic used, HVAC, Light Industries

APPLICATIONS

Electra WB - WB2 series is suitable for handling clear liquid without abrasives, non-aggressive. Mainly used in following applications:

- Water Supply
- Pressure Boosting
- Cooling System
- Chiller System
- Industrial used

SPECIFICATIONS

Capacity : up to 16 m^3/hr
Head : up to 60 m
Operating Temperature : -10 °C to 110 °C
Operating Pressure : up to 8 Bar
Mechanical Seal made of CARBON / CERAMIC / EPDM
Alternative meterials are available upon application.
Protection Level : IP55
Insulation Level : Class F
Continuous duty
Standard Voltage : Single phase 220/240 V 50 Hz
Three phase 380/415 V 50 Hz

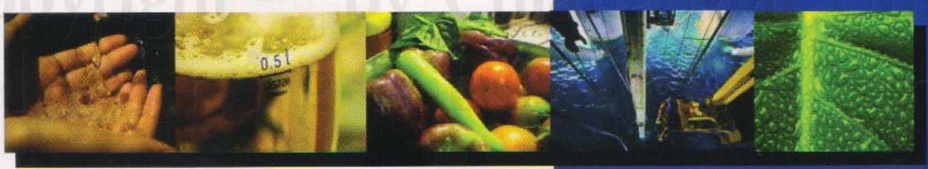
IDENTIFICATION CODE

WB2 | 70 / 150 D

WB Series name — WB2
2 : Twin impellers, Blank : single impeller

Norminal flow : 70 L / Min — 70

Rated motor power x 100 (kW) — 150 D
D : Single phase, Blank : Three phase

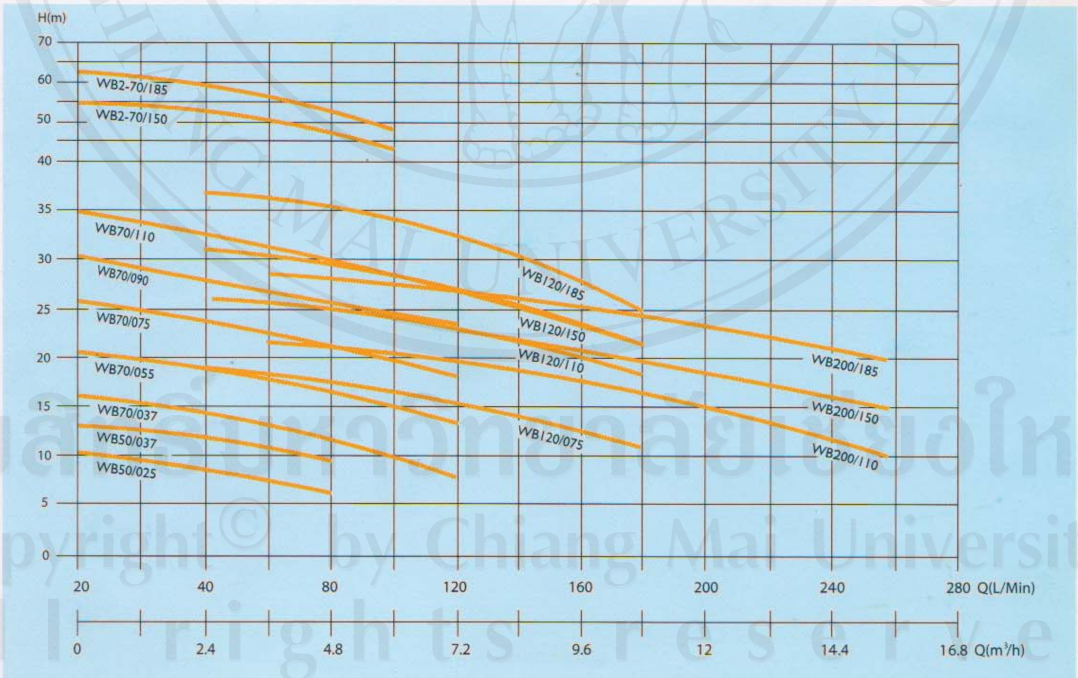


ELECTRA

WB-WB2 Series
HYDRAULIC PERFORMANCE TABLE -2800 rpm 50 Hz

Model		Power		Current (A)		Capacity													
						l/min	20	40	60	80	100	120	140	160	180	200	220	240	260
Single Phase 220V 50Hz	Three phase 380V 50Hz	kW	HP	Single Phase 220V 50Hz	Three phase 380V 50Hz	m^3/h	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12	13.2	14.4	15.6
						Head (m)													
WB2-70/150D	WB2-70/150	1.5	2.0	8.8	3.12		54	52	50	47	43								
WB2-70/185D	WB2-70/185	1.85	2.5	11.04	3.98		61	58	56	52	48								
WB50/025D	WB50/025	0.25	0.33	1.83	0.67		9.5	8.5	7.5	6.5									
WB50/037D	WB50/037	0.37	0.5	2.48	1.07		12.5	11.5	10	9									
WB70/037D	WB70/037	0.37	0.5	2.25	0.95		16	15	13.5	13	11.5	10							
WB70/055D	WB70/055	0.55	0.75	3.35	1.28		19	18	17	16	15	14							
WB70/075D	WB70/075	0.75	1.0	4.45	1.88		25	24	22.5	22	20	19							
WB70/090D	WB70/090	0.90	1.2	5.42	2.15		29	28	27	26	24	23							
WB70/110D	WB70/110	1.10	1.5	6.24	2.48		33	32	31	30	28.5	27							
WB120/075D	WB120/075	0.75	1.0	4.45	1.88			19	17.5	17	15.8	15	14	12	11				
WB120/110D	WB120/110	1.10	1.5	6.24	2.48			26	25	24	23	22	21	20	18				
WB120/150D	WB120/150	1.5	2.0	8.8	3.12			31	30	29	28	27	25	24	21				
WB120/185D	WB120/185	1.85	2.5	11.04	3.98			37	35.5	34	33	32	30	28	15				
WB200/110D	WB200/110	1.10	1.5	6.24	2.48				21	20.5	20	19	18	17	16	15	13	12	9
WB200/150D	WB200/150	1.50	2.0	8.8	3.12				25.5	25	24	23	20	21.5	21	20	18	17	15
WB200/185D	WB200/185	1.85	2.5	11.04	3.98				28.5	28	27.5	27	26.5	26	25	24	23	22	21

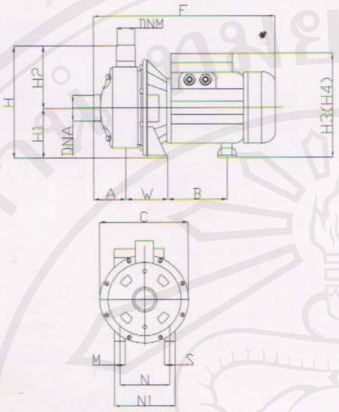
OPERATING CHARACTERISTICS AT 50 Hz



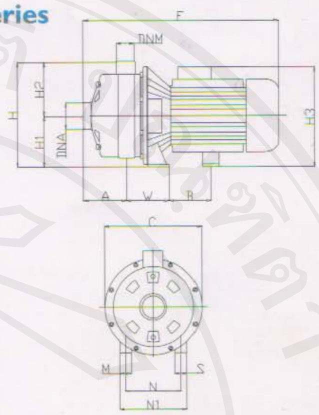
ELECTRA

DIMENSION (MM)

WB Series



WB2 Series



Model		Dimensions (mm)																
Single phase	Three phase	A	C	F	H	H1	H2	*H3	*H4	M	N	N1	S	W	B	DNA	DNM	Weight Kg
WB50/025D	WB50/025	52	170	302	196	88	108	208	181	30	100	130	7	80	82	G1 1/4"	G1"	5.1
WB50/037D	WB50/037	52	170	302	196	88	108	208	181	30	100	130	7	80	82	G1 1/4"	G1"	6.1
WB70/037D	WB70/037	52	213	315	232	108	124	241	213	39	120	158	9	92	82	G1 1/4"	G1"	8.1
WB70/055D	WB70/055	52	213	315	232	108	124	241	213	39	120	158	9	92	82	G1 1/4"	G1"	8.8
WB70/075D	WB70/075	52	213	315	232	108	124	241	213	39	120	158	9	92	82	G1 1/4"	G1"	10
WB70/090D	WB70/090	52	213	315	232	108	124	241	213	39	120	158	9	92	82	G1 1/4"	G1"	11
WB70/110D	WB70/110	52	235	386	252	120	132	234	234	39	140	180	9	94	82	G1 1/4"	G1"	14.6
WB120/075D	WB120/075	52	213	315	232	108	124	241	213	39	120	158	9	92	82	G1 1/4"	G1"	10
WB120/110D	WB120/110	52	213	370	232	108	124	224	224	39	120	158	9	92	82	G1 1/4"	G1"	11.6
WB120/150D	WB120/150	52	235	386	252	108	132	234	234	39	140	180	9	94	82	G1 1/4"	G1"	15.8
WB120/185D	WB120/185	52	235	386	252	120	132	234	234	39	140	180	9	94	82	G1 1/4"	G1"	17
WB200/110D	WB200/110	52	213	370	232	108	124	224	224	39	120	158	9	92	82	G1 1/2"	G1"	11.6
WB200/150D	WB200/150	52	213	370	232	108	124	224	224	39	120	158	9	92	82	G1 1/2"	G1"	15
WB200/185D	WB200/185	52	213	370	232	108	124	224	224	39	120	158	9	92	82	G1 1/2"	G1"	16
WB2-70/150D	WB2-70/150	87	235	416	252	120	132	234	234	39	140	180	9	94	82	G1 1/4"	G1"	17.8
WB2-70/185D	WB2-70/185	87	235	416	252	120	132	234	234	39	140	180	9	94	82	G1 1/4"	G1"	19.6

H3 for motors on single phase
H4 for motors on three phase

Distributor :

We reserve the rights to change subjects without notice.

JJTECH/2T202/V-09

H2O-LiBr solutions

Technical Data Sheet

Lithium Bromide

February 2010

PRODUCT DESCRIPTION

Lithium Bromide provides the following product characteristics

Lithium Bromide	
Molecular Formula	LiBr
CAS No.	7550-35-8
Appearance	Light Yellow Transparent Liquid
Main Content	50-55%
Chloride	0.05% max
Sulphate(SO42-)	0.05% max
Bromate	Non Reaction
Ca	0.0001% max
Mg	0.0001% max
Na	0.03% max
PH	9.0-10.5
Lithium Chromate*	0.20%-0.30%
Packing	Colored PE drum, 300kgs/drum

Application:

Absorbent or refrigerant, dehydrogenant & dilatability property of organic fiber. Catalyst and depressant in medicine & electrolyte of super battery.

Balancing valve

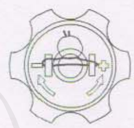
Balancing valve STV 10-50

Areas of Use

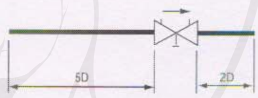
The balancing valve STV is used to adjust and balance the flow in heating and cooling systems. Examples of usage areas include mains, paths, branch lines, shunt groups and cooling baffles.

Description

STV is a threaded valve without a drain. The valve is equipped with self-sealing measuring sockets, placed at a 45° angle in relation to the wheel centre. The wheel is equipped with a digital display. The valve is set at the desired flow or kv–value according to the diagram by means of the wheel. When the value of the valve is set, it is locked. This is done by screwing down the inner spindel to its end position with a 3 mm Allen key . After locking, the valve can be closed but cannot however be opened at a higher kv value than the one set. The wheel can be sealed according to the figure.



Installation
To avoid turbulence which can affect the measuring accuracy the valve should not be assembled close to bends, branch lines and other valves directly before or after the valve according to the figure.

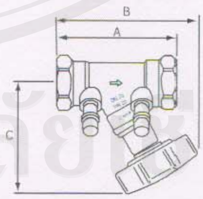


Technical Data

Dimension	10 - 50
Pressure class	PN20
Material	Dezincification resistance brass Gaskets EPDM

Design

	Dim	A	B	C	Weight/kg
STV 10	10	80	108	95	0,45
STV 15	15	86	111	95	0,53
STV 20	20	90	114	95	0,58
STV 25	25	102	120	96	0,77
STV 32	32	120	126	96	1,20
STV 40	40	132	138	108	1,50
STV 50	50	154	148	111	2,30



All measurements in mm

Ordering Codes

Part No.	Type	Description
3250001	STV 10	Threaded withour a drain
3250101	STV 15	
3250201	STV 20	
3250301	STV 25	
3250401	STV 32	
3250501	STV 40	
3250601	STV 50	
4051801	AV 15	Drain valve

We reserve the right to alter information without notice

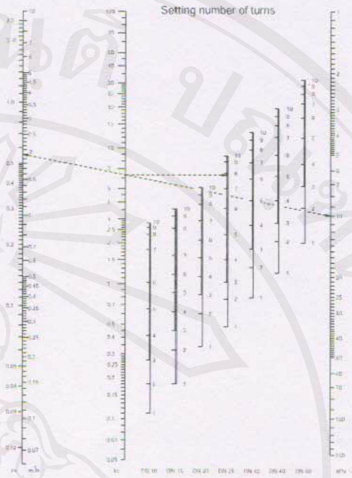
AB Markaryds Metallarmatur • S-285 32 Markaryd
Phone +46 433 73700 • Fax +46 433 73798 • E-mail info@mma.se • www.mma.se

May -03

Balancing valve STV 10-50

Pre-setting

By means of the wheel, the valve is set at the desired flow or kv-value according to the diagram. For a larger diagram see page 4:50. When the value of the valve is set, it is locked. This is done by screwingdown the inner spindle to its end position with a 3 mm Allen key. After locking, the valve can still be closed but cannot however be opened at a higher kv value than the one set.



k_V-value

No. of turns	DN 10	DN 15	DN 20	DN 25	DN 32	DN 40	DN 50
1	0,11	0,18	0,34	0,48	0,79	1,20	2,00
2	0,18	0,32	0,60	0,77	1,32	2,05	3,60
3	0,27	0,45	0,83	1,03	1,80	2,80	5,20
4	0,41	0,62	1,13	1,50	2,70	4,10	7,60
5	0,65	0,86	1,55	2,30	4,10	6,20	11,90
6	1,02	1,17	2,10	3,60	5,90	8,90	16,70
7	1,78	1,62	2,90	5,00	7,80	12,00	21,20
8	2,30	2,55	3,85	6,50	9,70	14,70	25,00
9	2,60	3,15	4,50	7,90	11,50	17,10	28,60
10	2,80	3,55	5,10	8,80	13,10	19,50	31,50

Flow measuring

The measuring instrument is connected to the measuring socket of the valve. The instrument is pre-programmed with the characteristics of all our adjustment valves and proving rings.
Other valve manufacturors' data is also added to the instrument. Values for pressure drop and flow can be read directly on the display.
If you do not have access to the MMA instrument some other brands can be used. The flow can then be read from the pressure drop diagram found in the operating instructions.

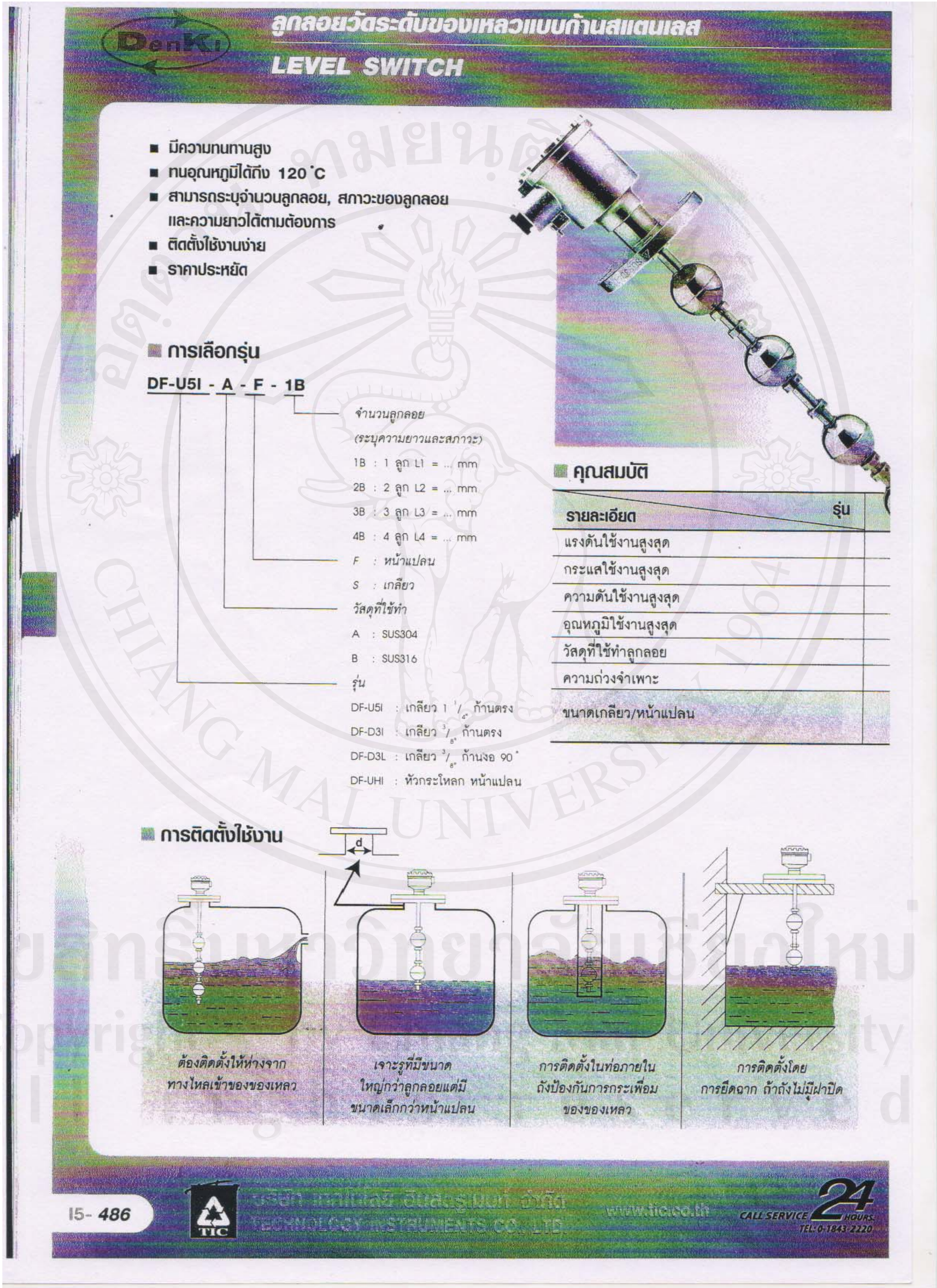
Accuracy
Accuracy is greatest when the valve is fully open. The smaller the opening, the importance of manufacturing tolerances increases, as variations in measurements are then greater percentage-wise. It is better to choose a valve that has a pre-set value above three turns.

We reserve the right to alter information without notice

May -03

AB Markaryds Metallarmatur • S-285 32 Markaryd
Phone +46 433 73700 • Fax +46 433 73798 • E-mail info@mma.se • www.mma.se

Level switch



ลูกลอยวัดระดับของเหลวแบบก้านสแตนเลส
LEVEL SWITCH

- มีความทนทานสูง
- ทนอุณหภูมิได้ถึง 120 °C
- สามารถระบุจำนวนลูกลอย, สภาวะของลูกลอย และความยาวได้ตามต้องการ
- ติดตั้งใช้งานง่าย
- ราคาประหยัด

การเลือกรุ่น

DF-U5I - A - F - 1B

จำนวนลูกลอย
(ระบุความยาวและสภาวะ)
1B : 1 ลูก L1 = ... mm
2B : 2 ลูก L2 = ... mm
3B : 3 ลูก L3 = ... mm
4B : 4 ลูก L4 = ... mm
F : หน้าแปลน
S : เกลียว
วัสดุที่ใช้ทำ
A : SUS304
B : SUS316
รุ่น
DF-U5I : เกลียว 1 1/2" ก้านตรง
DF-D3I : เกลียว 3/8" ก้านตรง
DF-D3L : เกลียว 3/8" ก้านงอ 90°
DF-UHI : หัวกระโหลก หน้าแปลน

คุณสมบัติ

รายละเอียด \ รุ่น	
แรงดันใช้งานสูงสุด	
กระแสใช้งานสูงสุด	
ความดันใช้งานสูงสุด	
อุณหภูมิใช้งานสูงสุด	
วัสดุที่ใช้ทำลูกลอย	
ความถ่วงจำเพาะ	
ขนาดเกลียว/หน้าแปลน	

การติดตั้งใช้งาน

d

ต้องติดตั้งให้ห่างจากทางไหลเข้าของของเหลว

เจาะรูที่มีขนาดใหญ่กว่าลูกลอยแต่มีขนาดเล็กกว่าหน้าแปลน

การติดตั้งในท่อภายในถังป้องกันการกระเพื่อมของของเหลว

การติดตั้งโดยการยึดฉาก ถ้าถังไม่มีฝาปิด

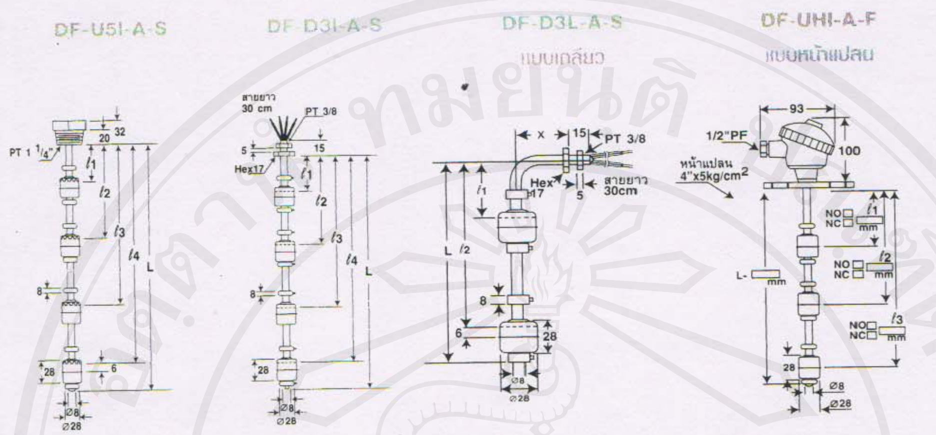
IS- 486

TIC

บริษัท เทคโนโลยี อินสตรูเมนท์ จำกัด
TECHNOLOGY INSTRUMENTS CO., LTD.
www.tic.co.th

CALL SERVICE 24 HOURS
TEL. 0-1843-2220

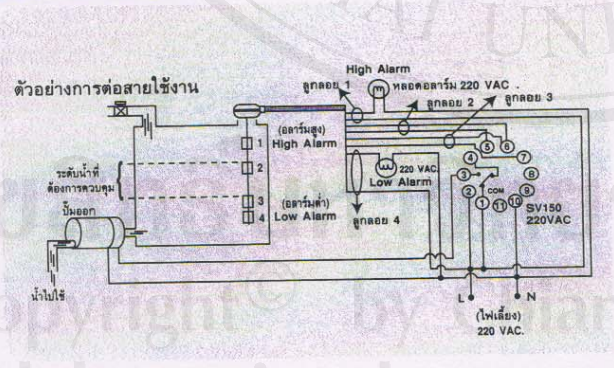
ลูกลอยวัดระดับของเหลวแบบก้านสแตนเลส
LEVEL SWITCH



DF-U5I-A-S	DF-D3I-A-S	DF-D3L-AS	DF-UHI-A-F
240 VAC / 200 VDC			
0.5 A (ต้องใช้ร่วมกับ Magnetic ถ้านำไปควบคุมมอเตอร์)			
10 Bar			
-10°C ถึง 120°C			
สแตนเลส SUS304 หรือ SUS316			
0.8			
1 1/4" PT	3/8" PT		หน้าแปลน : 4" x 5 kg / cm²

*** เหมาะสำหรับใช้ในโรงงานอุตสาหกรรม หรือตามบ้านเรือนเพื่อใช้ควบคุมระดับของเหลวหลายระดับ มีความคงทน ทนต่อการกัดกร่อน ใช้งานได้ยาวนานและมี ราคาประหยัด**

ตัวอย่างการใช้งาน



จากรูปเป็นการต่อควบคุมปั๊มน้ำแบบปั๊มออกไปใช้งานใช้เครื่องควบคุมรุ่น SV150 220 VAC ลูกลอยลูกที่ 2 และ 3 ให้สัญญาณแก่เครื่องควบคุมปั๊มน้ำ ส่วนลูกลอยลูกที่ 1 เป็นลูกลอยใช้ เพื่อเตือนถ้าน้ำเต็มถังส่วนลูกที่ 4 เป็นลูกลอยใช้ เพื่อเตือนเมื่อระดับของน้ำลดลงต่ำกว่าต้องการ

H. The data records

- The electrical consumption of the AHT with supplied heat by auxiliary heater
- The electrical consumption of the Solar-AHT
- The volume flow rate of the AHT
- The temperature record of the AHT on 15/10/1553 (Non-used hot water in tank)
- The temperature record of the AHT on 15/10/1553 (Used hot water in tank)

Table H.1 The electrical consumption of the AHT with supplied heat by auxiliary heater.

Date 7/10/2010 (The AHT with auxiliary heater 21 kW)

Time	$T_{HW,i}$ ('C)	$T_{CW,i}$ ('C)	$T_{UG,o}$ ('C)	P_H (cmHg)	P_L (cmHg)	V_1 (V)	V_2 (V)	V_3 (V)	I_1 (A)	I_2 (A)	I_3 (A)	W_1 (kW)	W_2 (kW)	W_3 (kW)	W_{AHT} (kW)
13:55:00	75.6	24.1	55.7	-65	-68	221.5	221.8	227.9	4.27	4.21	4.13	0.694	0.739	0.733	2.166
13:57:00	75.4	24.8	61.7	-61	-67	221.9	231.2	227.8	4.24	4.20	4.13	0.682	0.725	0.749	2.156
14:41:00	83.6	27.0	73.8	-55	-65	225.9	232.3	232.6	4.11	4.19	4.18	0.678	0.708	0.799	2.185
14:50:00	83.0	26.6	76.2	-54	-65	225.3	232.9	232.5	4.11	4.08	4.19	0.669	0.696	0.747	2.112
14:53:00	83.1	26.5	78.0	-52	-65	226.7	233.7	233.0	4.09	4.03	4.17	0.665	0.667	0.690	2.022
15:07:00	78.6	26.5	80.2	-51	-65	226.7	233.8	233.7	4.15	4.11	4.11	0.682	0.694	0.688	2.064
15:18:00	77.9	26.6	80.9	-50	-65	227.5	234.7	234.7	4.14	4.09	4.14	0.684	0.678	0.727	2.089
15:23:00	77.9	26.8	82.5	-49	-65	227.1	234.3	234.2	3.90	3.89	4.02	0.614	0.627	0.690	1.931
15:44:00	78.4	26.5	83.9	-50	-65	227.9	234.6	234.8	4.11	4.14	4.09	0.676	0.702	0.749	2.127
15:49:00	78.5	26.6	84.2	-48	-65	226.0	232.6	232.8	4.12	4.14	4.08	0.678	0.696	0.725	2.099
15:59:00	78.5	26.8	85.2	-48	-65	226.7	233.8	233.7	4.15	4.05	4.03	0.674	0.680	0.720	2.074
16:05:00	78.3	26.8	85.6	-48	-65	226.8	233.9	233.2	4.12	4.10	4.08	0.676	0.691	0.732	2.099
Average	79.1	26.3	-	-	-	225.8	232.5	232.6	4.13	4.10	4.11	0.673	0.692	0.729	2.094

Table H.2 The electrical consumption of the Solar-AHT.

Date 14/10/2010 (The Solar-AHT)

Time	$T_{HW,i}$	$T_{CW,i}$	$T_{UG,o}$	P_H	P_L	V_1	V_2	V_3	I_1	I_2	I_3	W_1	W_2	W_3	W_{AHT}
	('C)	('C)	('C)	(cmHg)	(cmHg)	(V)	(V)	(V)	(A)	(A)	(A)	(kW)	(kW)	(kW)	(kW)
11:02:00	66.2	26.8	62.1	-63	-70	225.9	231.9	230.5	3.94	4.07	4.12	0.647	0.669	0.720	2.036
11:06:00	66.2	26.8	62.5	-63	-70	225.2	230.4	230.8	4.27	4.18	4.08	0.712	0.665	0.731	2.108
11:10:00	66.1	27.1	63.1	-62	-70	225.3	231.7	230.7	4.21	4.14	4.28	0.710	0.710	0.782	2.202
11:19:00	65.8	26.7	66.6	-62	-70	225.6	231.4	230.8	4.24	4.11	4.28	0.712	0.708	0.782	2.202
11:24:00	65.6	26.8	67.5	-61	-70	225.7	231.6	230.9	4.28	4.12	4.24	0.723	0.704	0.784	2.211
11:30:00	65.6	26.9	68.7	-60	-70	226.6	232.4	231.2	4.11	4.02	4.19	0.690	0.686	0.771	2.147
11:36:00	66.2	26.7	69.4	-60	-70	227.3	232.2	232.5	4.25	4.15	4.33	0.718	0.786	0.718	2.222
11:41:00	66.0	26.5	70.6	-60	-70	227.5	233.0	232.5	4.31	4.11	4.17	0.769	0.702	0.749	2.220
11:53:00	66.4	26.8	71.8	-59	-70	229.3	235.0	234.0	4.21	4.11	4.20	0.753	0.720	0.761	2.234
12:13:00	68.1	27.0	74.2	-58	-70	225.0	231.2	229.5	4.20	4.12	4.30	0.702	0.716	0.774	2.192
12:30:00	69.5	26.7	75.7	-57	-70	224.7	230.7	229.3	4.25	4.19	4.13	0.714	0.712	0.739	2.165
13:45:00	74.9	27.6	83.4	-52	-70	224.9	231.0	229.9	4.24	4.12	4.34	0.712	0.710	0.755	2.177
Average	**67.2**	**26.9**	**-**	**-**	**-**	**226.1**	**231.9**	**231.1**	**4.21**	**4.12**	**4.22**	**0.714**	**0.707**	**0.756**	**2.176**

Table H.3 The volume flow rate of the AHT.

Hot water leaving a set of solar collector

Bigger volume 20.00 gallon
75.71 liter

Times	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
21/9/2010	75.71	168	0.45	27.04	0.82	988.04	0.45
21/9/2010	75.71	169	0.45	26.88	0.82	988.04	0.44
21/9/2010	75.71	170	0.45	26.72	0.81	988.04	0.44
Average	**75.71**	**169.00**	**0.45**	**26.88**	**0.82**	**988.04**	**0.44**

Note : * At water temperature around 50 Celcius

Hot water leaving the AHT evaporator

Bigger volume 75.71 liter

Time	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
21/9/2010	75.71	373	0.2030	12.1783	0.3702	971.79	0.1972
21/9/2010	75.71	375	0.2019	12.1133	0.3683	971.79	0.1962
21/9/2010	75.71	373	0.2030	12.1783	0.3702	971.79	0.1972
Average	**75.71**	**373.67**	**0.2026**	**12.1566**	**0.3696**	**971.7904**	**0.1969**

Note : * at water temperature around 80 Celcius

Hot water leaving the AHT generator

Bigger volume 75.71 liter

Time	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
21/9/2010	75.71	325	0.2329	13.9769	0.4249	971.79	0.2264
21/9/2010	75.71	320	0.2366	14.1953	0.4316	971.79	0.2299
21/9/2010	75.71	320	0.2366	14.1953	0.4316	971.79	0.2299
Average	**75.71**	**321.67**	**0.2354**	**14.1225**	**0.4294**	**971.7904**	**0.2287**

Note : * at water temperature around 80 Celcius

Hot water leaving the AHT condenser

Bigger volume 75.71 liter

Time	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
21/9/2010	75.71	60	1.2618	75.7082	2.3017	992.22	1.2520
21/9/2010	75.71	60	1.2618	75.7082	2.3017	992.22	1.2520
21/9/2010	75.71	60	1.2618	75.7082	2.3017	992.22	1.2520
Average	**75.71**	**60.00**	**1.2618**	**75.7082**	**2.3017**	**992.2164**	**1.2520**

Note : * at water temperature around 40 Celcius

Hot water leaving the AHT absorber

Bigger volume 75.71 liter

Time	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
21/9/2010	75.71	195	0.3882	23.2948	0.7082	961.89	0.3735
21/9/2010	75.71	195	0.3882	23.2948	0.7082	961.89	0.3735
21/9/2010	75.71	195	0.3882	23.2948	0.7082	961.89	0.3735
Average	**75.71**	**195.00**	**0.3882**	**23.2948**	**0.7082**	**961.8879**	**0.3735**

Note : * at water temperature around 95 Celcius

Volume of upgraded water in storage tank

Glycol-Water (140/60) 200.00 liter

Hot water leaving the storage tank

Bigger volume 19.50 liter

Time	Volume of hot water	Record time	Volume flow rate			Density*	Mass flow rate
	(liter)	(s)	(liter/s)	(liter/min)	(m^3/h)	(kg/m^3)	(kg/s)
8/10/2010	19.50	1243	0.0157	0.9413	0.0286	961.89	0.0151
8/10/2010	19.50	1243	0.0157	0.9413	0.0286	961.89	0.0151
8/10/2010	19.50	1243	0.0157	0.9413	0.0286	961.89	0.0151
Average	**19.50**	**1243.00**	**0.0157**	**0.9413**	**0.0286**	**961.8879**	**0.0151**

Note : * at water temperature around 95 Celcius

Table H.4 The temperature record of the AHT on 15/10/1553 (Non-used hot water in tank).

Unit : Celcius

Time	$TG_{HW,i}$	$TG_{HW,o}$	$TE_{HW,i}$	$TE_{HW,o}$	$TC_{CW,i}$	$TC_{CW,o}$	$TA_{UG,i}$	$TA_{UG,o}$	T_{ST}	$T_{UF,i}$	$T_{UF,o}$	T_{amb}	T_{Gen}	T_{Cond}	T_{Ab}	T_{Evap}
13:45:12	71.50	60.90	71.70	56.40	26.10	27.20	59.30	67.60	65.50	38.40	40.80	36.00	60.70	31.30	71.00	52.80
13:50:12	72.60	61.60	72.90	58.50	27.00	28.40	59.70	69.50	70.30	41.10	42.00	36.30	61.50	31.70	73.20	55.60
13:55:12	73.90	62.30	74.20	60.00	27.40	29.00	63.60	71.30	72.60	42.10	41.80	33.60	61.90	32.20	75.10	57.30
14:00:12	74.50	62.50	74.60	61.90	27.20	30.10	67.40	74.00	74.50	41.90	41.10	34.00	62.00	32.20	77.10	58.80
14:05:12	75.20	63.00	75.30	63.30	27.00	29.90	68.80	75.40	77.20	42.90	41.00	33.00	62.30	32.30	78.30	60.20
14:10:12	75.70	62.60	75.80	63.40	27.30	29.80	70.90	76.40	78.60	43.90	41.10	34.60	61.80	36.50	79.20	60.90
14:15:12	75.90	62.90	76.10	64.70	27.30	29.80	73.30	78.30	80.10	45.00	40.70	34.70	62.20	36.20	80.60	62.10
14:20:12	76.30	62.80	76.50	64.40	27.20	30.20	74.20	78.80	81.80	46.60	40.80	34.30	62.20	37.50	80.90	62.00
14:25:12	76.90	63.20	77.00	65.80	27.40	30.20	75.80	80.20	82.80	47.30	40.50	35.10	62.70	37.00	82.30	63.50
14:30:12	77.10	63.30	77.30	66.90	27.20	30.10	77.10	81.30	84.20	47.10	38.20	32.00	63.20	36.50	83.10	64.30
14:35:12	77.60	63.60	77.70	68.50	27.20	30.20	77.90	81.80	85.30	46.90	38.00	34.50	63.60	36.00	83.50	64.50
14:40:12	78.20	63.90	78.30	67.10	27.00	29.70	79.20	82.50	85.90	47.20	37.20	32.80	64.20	35.60	84.10	65.30
14:45:12	78.30	64.30	78.50	69.70	27.00	29.70	80.20	83.20	86.80	47.10	37.90	32.10	64.70	35.20	84.70	65.00
14:50:12	78.40	63.50	78.60	67.00	27.20	30.30	80.60	83.60	87.10	48.90	37.20	32.70	64.00	35.70	84.80	65.10
14:55:12	78.40	63.40	78.60	68.50	27.40	30.40	81.50	84.80	87.90	49.50	38.10	33.70	63.70	35.50	86.30	66.30
15:00:12	78.80	64.10	79.00	68.30	27.50	30.50	81.90	85.10	89.00	49.70	38.60	34.50	64.50	35.30	86.40	66.20
15:05:12	78.60	64.80	78.90	70.80	26.80	29.50	82.60	85.00	89.30	49.50	35.00	31.70	65.20	35.00	86.10	65.50
15:10:12	78.40	64.40	78.50	67.50	26.70	29.70	83.30	85.50	89.50	50.30	32.70	32.10	64.70	34.60	86.60	66.00
15:15:12	78.20	64.50	78.40	68.50	26.60	29.70	83.40	86.50	90.20	50.90	32.00	32.00	64.50	34.40	87.90	67.20
15:20:12	78.10	64.60	78.30	65.00	26.50	30.10	83.50	86.20	91.20	50.10	31.40	30.00	65.00	35.50	87.00	64.70
15:25:12	78.00	64.80	78.10	68.20	26.90	30.00	84.60	87.50	91.50	51.50	30.90	30.20	65.20	35.00	88.80	66.70

Table H.4 The temperature record of the AHT on 15/10/1553 (Non-used hot water in tank,Continued).

Time	$T_{Gen,i,HX}$	$T_{Gen,o,HX}$	$T_{Ab,o,HX}$	$T_{Coll,i}$	$T_{Coll,o}$	$T_{HW,i,aux}$	I_T
	('C)	('C)	('C)	('C)	('C)	('C)	(W/m^2)
13:45:12	58.30	65.10	62.70	58.10	61.60	59.40	1,020.81
13:50:12	59.00	66.80	63.80	58.80	63.40	60.40	1,109.98
13:55:12	59.40	67.90	64.70	59.90	64.10	61.40	954.78
14:00:12	59.50	69.20	65.20	60.50	64.40	61.90	1,025.69
14:05:12	59.70	69.80	65.60	61.20	64.90	62.70	1,008.28
14:10:12	59.20	70.30	65.50	61.70	65.10	63.00	984.08
14:15:12	59.90	71.20	66.10	62.30	65.10	63.20	619.53
14:20:12	59.80	71.40	66.30	62.70	66.20	63.70	650.11
14:25:12	60.30	72.50	67.10	63.30	66.30	64.20	897.88
14:30:12	60.60	73.20	67.50	63.50	64.30	64.20	554.35
14:35:12	61.20	73.80	68.30	63.90	65.60	64.80	713.38
14:40:12	61.60	74.20	68.70	64.40	66.20	65.10	506.58
14:45:12	62.10	74.60	69.10	64.60	66.70	65.50	617.41
14:50:12	61.40	74.80	69.10	65.00	66.30	65.90	314.01
14:55:12	61.00	75.60	69.40	65.10	67.60	66.00	792.99
15:00:12	61.70	75.90	69.80	65.40	67.50	66.50	453.50
15:05:12	62.50	75.90	70.10	64.80	65.10	66.20	136.94
15:10:12	62.10	76.30	70.40	63.60	63.40	65.80	104.67
15:15:12	62.00	77.10	70.60	62.40	62.00	65.60	86.84
15:20:12	62.30	78.00	72.50	61.00	60.50	65.40	82.80
15:25:12	62.60	79.30	73.10	59.80	59.40	65.20	79.41

Table H.5 The temperature record of the AHT on 15/10/1553 (Used hot water in tank).

Unit : Celcius

Time	$TG_{HW,i}$	$TG_{HW,o}$	$TE_{HW,i}$	$TE_{HW,o}$	$TC_{CW,i}$	$TC_{CW,o}$	$TA_{UG,i}$	$TA_{UG,o}$	T_{ST}	$T_{UF,i}$	$T_{UF,o}$	T_{amb}	T_{Gen}	T_{Cond}	T_{Ab}	T_{Evap}
15:36:55	77.9	65.50	78.10	67.80	26.50	29.40	80.90	86.60	90.20	29.90	83.70	29.20	65.60	36.60	88.20	66.30
15:37:55	77.9	65.60	78.10	67.50	26.50	29.40	80.80	86.50	90.30	29.90	83.60	29.10	65.50	36.40	88.20	66.50
15:38:55	77.9	65.70	78.10	67.70	26.40	29.30	80.70	86.50	89.50	29.90	83.50	30.90	65.70	36.30	88.20	66.30
15:39:55	77.8	65.70	78.10	67.50	26.30	29.30	80.50	86.30	89.80	30.00	83.20	30.00	65.60	36.20	88.00	66.20
15:40:55	77.8	65.70	78.00	67.70	26.30	29.20	80.30	86.20	89.10	30.10	83.20	28.60	65.70	36.00	88.00	66.20
15:41:55	77.9	65.80	78.10	67.80	26.30	29.10	80.20	86.10	90.00	30.10	83.10	30.20	65.70	35.90	87.90	66.20
15:42:55	77.90	65.80	78.10	67.60	26.20	29.00	80.10	86.00	89.70	30.10	83.00	29.60	65.70	35.70	87.80	66.00
15:43:55	77.90	65.80	78.00	67.40	26.20	29.00	79.70	85.90	89.60	30.10	82.90	29.70	65.70	35.50	87.70	66.10
15:44:55	77.70	65.80	77.90	67.20	26.10	28.90	79.60	85.70	89.50	30.10	82.90	31.40	65.80	35.40	87.50	65.80
15:45:55	77.80	65.90	78.00	67.10	26.10	28.90	79.50	85.50	89.40	30.10	82.60	29.80	65.80	35.20	87.40	65.90
15:46:55	77.80	66.00	78.00	67.20	26.20	29.00	79.30	85.30	88.90	30.30	82.80	30.80	66.30	35.50	87.50	65.80
15:47:55	77.80	66.10	78.00	67.50	26.10	28.90	79.20	85.20	90.20	31.00	83.00	29.90	67.20	36.20	88.00	65.70
15:48:55	77.80	66.10	78.00	66.50	26.10	29.10	79.10	85.00	90.10	31.10	83.00	33.70	67.20	37.70	87.80	65.50
15:52:55	77.60	65.60	77.90	66.10	26.20	29.10	78.60	84.50	89.00	31.30	82.50	35.30	66.80	38.10	87.40	64.30
15:53:55	77.50	65.60	77.80	66.40	26.20	29.10	78.60	84.70	89.50	31.20	82.30	33.70	66.90	38.00	87.50	64.50
15:54:55	77.60	65.60	77.80	66.60	26.20	29.00	78.50	84.60	89.50	31.60	82.50	29.90	67.40	38.50	87.80	64.80
15:55:55	77.50	65.60	77.80	66.50	26.20	29.00	78.30	84.60	88.70	31.20	82.30	33.10	66.70	37.70	87.50	64.80
15:56:55	77.50	65.70	77.80	66.70	26.10	29.00	78.10	84.50	89.60	31.60	82.30	31.80	67.50	38.20	87.80	64.80
15:57:55	77.50	65.70	77.80	66.80	26.20	29.00	78.00	84.50	89.20	31.60	82.30	31.40	67.50	38.10	87.70	64.90
15:58:55	77.40	65.80	77.70	66.60	26.20	29.00	77.80	84.40	88.90	31.50	82.20	32.20	67.40	37.80	87.60	64.80
15:59:55	77.30	65.80	77.60	66.70	26.10	29.00	77.70	84.40	88.70	31.40	82.10	32.60	67.40	37.60	87.40	64.80

Table H.5 The temperature record of the AHT on 15/10/2010 (Used hot water in tank, Continued).

Time	$T_{Gen,i,HX}$	$T_{Gen,o,HX}$	$T_{Ab,o,HX}$	$T_{Coll,i}$	$T_{Coll,o}$	$T_{HW,i,aux}$	I_T
	('C)	('C)	('C)	('C)	('C)	('C)	(W/m^2)
15:36:55	62.80	78.10	72.00	56.90	56.60	65.00	35.24
15:37:55	62.90	78.10	71.90	56.90	56.40	65.00	35.03
15:38:55	62.80	78.00	71.90	56.60	56.20	65.00	35.46
15:39:55	62.90	78.00	71.80	56.50	56.00	65.00	35.88
15:40:55	63.00	77.90	71.80	56.20	55.80	65.00	36.94
15:41:55	63.10	77.90	71.80	56.00	55.50	65.00	38.00
15:42:55	63.00	77.70	71.70	55.70	55.30	65.00	39.07
15:43:55	63.10	77.70	71.80	55.60	55.10	65.00	40.76
15:44:55	62.70	77.40	71.40	55.10	54.70	64.80	42.25
15:45:55	62.60	77.30	71.40	55.10	54.60	64.80	43.74
15:46:55	62.90	77.30	71.50	54.80	54.40	64.90	45.01
15:47:55	62.90	77.30	71.40	54.70	54.20	64.90	46.71
15:48:55	63.00	77.00	71.20	54.60	54.00	64.90	47.77
15:52:55	62.50	76.60	71.00	53.70	53.30	64.80	52.65
15:53:55	62.50	76.70	71.10	53.60	53.00	64.80	54.78
15:54:55	62.80	76.80	71.10	53.40	53.00	64.80	56.48
15:55:55	62.70	76.60	71.10	53.10	52.60	64.70	58.39
15:56:55	62.80	76.70	71.00	52.90	52.50	64.70	60.30
15:57:55	62.80	76.70	71.00	52.80	52.30	64.70	62.21
15:58:55	62.90	76.60	71.10	52.60	52.10	64.70	63.91
15:59:55	62.80	76.60	71.00	52.40	51.90	64.70	65.82

Other measured data as shown in Table H.1 – H.5 save in the CD-ROM.

K. Calculation from the data records

Example for calculating performance of a tested the AHT on 15/10/2010 at 13:45:12 o'clock:

- $\rho_{Gly\text{-}Water}$
  - $= \rho(T_{ST})$; From Table H.4
  - $= \rho(65.5)$; (kg/m^3), Programming
  - $= 1{,}073.31$; (kg/m^3)
- $Cp_{Gly\text{-}Water}$
  - $= Cp(T_{ST})$; From Table H.4
  - $= Cp(65.5)$; ($kJ/kg{\cdot}K$), Programming
  - $= 3.26$; ($kJ/kg{\cdot}K$)
- $\dot{Q}_{ST}$
  - $= V_{ST}Cp_{Gly-Water}(T_{ST} - T'_{ST})\rho_{Gly-Water} / \Delta t1000$; From Table H.3 and H.4
  - $= 200 \times 3.26 \times (65.5 - 62.3) \times 1{,}073.31 / (5 \times 60 \times 1000)$; (kW)
  - $= 15.15$; (kW)
- $T_{UF,bulk}$ (For used hot water in storage tank)
  - $= (T_{UF,i} + TG_{UF,o}) / 2$; From Table H.4
  - $= (29.9 + 83.7) / 2$; ($^{\circ}C$)
  - $= 56.8$; ($^{\circ}C$)
- $\rho_{UF,bulk}$ (For used hot water in storage tank)
  - $= \rho(T_{UF,bulk})$; From Table H.4
  - $= \rho(56.8)$; (kg/m^3), Programming
  - $= 984.77$; (kg/m^3)
- $Cp_{Gly\text{-}Water}$ (For used hot water in storage tank)
  - $= Cp(T_{UF,bulk})$; From Table H.4
  - $= Cp(56.8)$; ($kJ/kg{\cdot}K$), Programming
  - $= 4.18$; ($kJ/kg{\cdot}K$)
- $\dot{Q}_{ST}$ (For used hot water in storage tank)
  - $= \dot{V}_{UF}Cp_{UF,bulk}(T_{UF,o} - T_{UF,i})\rho_{UF,bulk} / 1000$; From Table H.3 and H.4

= 0.00186 x 4.18 x (83.7 – 29.9) x 984.77 / 1000 ; (kW)

= 4.19 ; (kW)

- $TG_{HW,bulk}$

$= (TG_{HW,i} + TG_{HW,o})/2$; From Table H.4

= (71.50 + 60.90) /2 ; (°C)

= 66.2 ; (°C)

- $\Delta T_{HW,G}$

$= TG_{HW,i} - TG_{HW,o}$; From Table H.4

= 71.50 – 60.90 ; (°C)

= 10.6 ; (°C)

- $Cp_{HW,G}$

$= Cp(TG_{HW,bulk})$; From Table H.4

= Cp(66.2) ; (kJ/kg·K), Programming

= 4.19 ; (kJ/kg·K)

- $\rho_{HW,G}$

$= \rho(TG_{HW,bulk})$; From Table H.4

= ρ(66.2) ; (kg/m³), Programming

= 979.86 ; (kg/m³)

- $\dot{Q}_G$

$= \dot{V}_G Cp_{HW,G} \Delta T_{HW,G} \rho_{HW,G} /1000$; From Table H.3 and H.4

= 0.2354 x 4.19 x 10.6 x 979.86 / 1000 ; (kW)

= 10.24 ; (kW)

- $TE_{HW,bulk}$

$= (TE_{HW,i} + TE_{HW,o})/2$; From Table H.4

= (71.70 + 56.40) / 2 ; (°C)

= 64.05 ; (°C)

- $\Delta T_{HW,E}$

$= TE_{HW,i} - TE_{HW,o}$; From Table H.4

= 71.70 – 56.40 ; (°C)

= 15.3 ; (°C)

- $Cp_{HW,E}$

  $= Cp(TE_{HW,bulk})$; From Table H.4

  $= Cp(64.05)$; (kJ/kg·K), Programming

  $= 4.19$; (kJ/kg·K)

- $\rho_{HW,E}$

  $= \rho(TE_{HW,bulk})$; From Table H.4

  $= \rho(64.05)$; (kg/m³), Programming

  $= 981.03$; (kg/m³)

- $\dot{Q}_E$

  $= \dot{V}_E Cp_{HW,E} \Delta T_{HW,E} \rho_{HW,E} / 1000$; From Table H.3 and H.4

  $= 0.2026 \times 4.19 \times 15.3 \times 981.03 / 1000$; (kW)

  $= 12.73$; (kW)

- $TC_{CW,bulk}$

  $= (TC_{CW,i} + TC_{CW,o}) / 2$; From Table H.4

  $= (26.10 + 27.20) / 2$; (°C)

  $= 26.65$; (°C)

- $\Delta T_{CW,C}$

  $= TC_{CW,o} - TC_{CW,i}$; From Table H.4

  $= 27.20 - 26.10$; (°C)

  $= 1.1$; (°C)

- $Cp_{CW,C}$

  $= Cp(TC_{CW,bulk})$; From Table H.4

  $= Cp(26.65)$; (kJ/kg·K), Programming

  $= 4.18$; (kJ/kg·K)

- $\rho_{HW,C}$

  $= \rho(TC_{CW,bulk})$; From Table H.4

  $= \rho(26.65)$; (kg/m³), Programming

  $= 996.57$; (kg/m³)

- $\dot{Q}_C$

$= \dot{V}_C Cp_{CW,C} \Delta T_{CW,C} \rho_{CW,C} / 1000$; From Table H.3 and H.4

= 1.2618 x 4.18 x 1.1 x 996.57 / 1000 ; (kW)

= 6.94 ; (kW)

- $TA_{UG,bulk}$

$= (TA_{UG,i} + TA_{UG,o}) / 2$; From Table H.4

= (59.30 + 67.60) / 2 ; (°C)

= 63.45 ; (°C)

- $\Delta T_{UG,A}$

$= TA_{UG,o} - TA_{UG,i}$; From Table H.4

= 67.60 – 59.30 ; (°C)

= 8.3 ; (°C)

- $Cp_{UG,A}$

$= Cp(TA_{UG,bulk})$; From Table H.4

= Cp(63.45) ; (kJ/kg·K), Programming

= 3.25 ; (kJ/kg·K)

- $\rho_{UG,G}$

$= \rho(TA_{UG,bulk})$; From Table H.4

= ρ(63.45) ; (kg/m³), Programming

= 1073.65 ; (kg/m³)

- $\dot{Q}_A$

$= \dot{V}_A Cp_{UG,A} \Delta T_{UG,A} \rho_{UG,A} / 1000$; From Table H.3 and H.4

= 0.3882 x 3.25 x 8.3 x 1073.65 / 1000 ; (kW)

= 11.24 ; (kW)

- HR_{UG}

$= \dot{Q}_A / (\dot{Q}_G + \dot{Q}_E)$; From calculation

= 11.24 / (10.27 + 12.73) ; (-)

= 0.49 ; (-)

- EER_{AHT}

$= \dot{Q}_A / W_{AHT}$; From Table H.1

= 11.24 / 2.094 ; (kW_{th}/kWe)

$= 5.33$; (kW_{th}/kWe)

- P_{Low}

$= P(T_{Cond})$; From Table H.4

$= Cp(31.3)$; (kPa), Programming

$= 4.82$; (kPa)

- P_{High}

$= P(T_{Evap})$; From Table H.4

$= Cp(66.3)$; (kPa), Programming

$= 14.87$; (kPa)

- X_{max}

$= X(T_{Gen},T_{Cond})$; From Table H.4

$= X(60.7,31.3)$; (%), Programming

$= 52.97$; (%)

- X_{min}

$= X(T_{Ab},T_{Evap})$; From Table H.4

$= X(71.0,52.8)$; (%), Programming

$= 44.97$; (%)

- h_1

$= h(T_{Gen})$; From Table H.4

$= h(60.7)$; (kJ/kg), Programming

$= 2{,}610.05$; (kJ/kg)

- h_2

$= h(T_{Cond})$; From Table H.4

$= h(31.3)$; (kJ/kg), Programming

$= 131.17$; (kJ/kg)

- $\dot{m}_{ref}$

$= \dot{Q}_C / (h_1 - h_2)$; From calculation

$= 6.94 / (2{,}610.05 - 131.17)$; (kg/s)

$= 0.0028$; (kg/s)

- $\dot{m}_5$

$= \dot{m}_{ref} X_{min} / (X_{max} - X_{min})$; From calculation

$= 0.0028 \times 44.97 / (52.97 - 44.97)$; (kg/s)

= 0.0157 ; (kg/s)

- $\dot{m}_8$

= $\dot{m}_{ref} X_{max} / (X_{max} - X_{min})$; From calculation

= 0.0028 x 52.97 / (52.97 – 44.97) ; (kg/s)

= 0.0185 ; (kg/s)

- ρ_2

= $\rho(T_{Cond})$; From Table H.4

= $\rho(31.3)$; (kg/m^3), Programming

= 995.21 ; (kg/m^3)

- ν_2

= 1 / ρ_2 ; From calculation

= 1 / 995.21 ; (m^3/ kg)

= 0.0010 ; (m^3/ kg)

- ρ_5

= $\rho(T_{Gen}, X_{max})$; From Table H.4

= $\rho(60.7)$; (kg/m^3), Programming

= 1,143.99 ; (kg/m^3)

- ν_5

= 1 / ρ_5 ; From calculation

= 1 / 1,143.99 ; (m^3/ kg)

= 0.0009 ; (m^3/ kg)

- W_P

= $(P_{High} - P_{Low}) \nu_2 \dot{m}_{ref} 1000 / \eta_P 100$; From calculation

= (14.87 – 4.82) x 0.0010 x 0.0028 x 1000 / 0.8 / 1000 ; (W)

= 0.00035 ; (W)

- W_{SP}

= $(P_{High} - P_{Low}) \nu_5 \dot{m}_5 1000 / \eta_{SP} 100$; From calculation

= (14.87 – 4.82) x 0.0009 x 0.0159 x 1000 / 0.8 / 1000 ; (W)

= 0.00173 ; (W)

- COP_{AHT}

= $\dot{Q}_A / (\dot{Q}_G + \dot{Q}_E + W_P + W_{SP})$; From calculation

$= 11.24 / (10.24 + 12.73 + 0.00035/1000 + 0.00173/1000)$; (-)

$= 0.49$; (-)

- $(T_{A,i} - T_E) / (T_{G,i} - T_C)$

  $= (59.3 - 52.8) / (71.5 - 31.3)$; From calculation

  $= 0.16$; (-)

Table K.1 The calculation results of the AHT from data recorder (Non-used water in tank).

Time	$\rho_{Gly-Water}$	$Cp_{Gly-Water}$	Q'_{ST}	$TG_{HW,bulk}$	$\Delta T_{HW,G}$	$Cp_{HW,G}$	$\rho_{HW,G}$	Q'_G	$TE_{HW,bulk}$	$\Delta T_{HW,E}$	$Cp_{HW,E}$	$\rho_{HW,E}$	Q'_E
	(kg/m³)	(kJ/kg-K)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)
13:45:12	1073.31	3.26	15.15	66.20	10.60	4.19	979.86	10.24	64.05	15.30	4.19	981.03	12.73
13:50:12	1072.51	3.28	11.90	67.10	11.00	4.19	979.36	10.62	65.70	14.40	4.19	980.14	11.98
13:55:12	1072.11	3.28	8.96	68.10	11.60	4.19	978.81	11.20	67.10	14.20	4.19	979.36	11.80
14:00:12	1071.77	3.29	7.57	68.50	12.00	4.19	978.58	11.58	68.25	12.70	4.19	978.72	10.55
14:05:12	1071.29	3.30	7.30	69.10	12.20	4.19	978.24	11.77	69.30	12.00	4.19	978.13	9.96
14:10:12	1071.03	3.31	6.54	69.15	13.10	4.19	978.22	12.64	69.60	12.40	4.19	977.96	10.29
14:15:12	1070.75	3.31	6.07	69.40	13.00	4.19	978.07	12.54	70.40	11.40	4.19	977.51	9.46
14:20:12	1070.43	3.32	5.79	69.55	13.50	4.19	977.99	13.02	70.45	12.10	4.19	977.48	10.04
14:25:12	1070.24	3.32	5.38	70.05	13.70	4.19	977.71	13.21	71.40	11.20	4.19	976.93	9.29
14:30:12	1069.97	3.33	5.16	70.20	13.80	4.19	977.62	13.31	72.10	10.40	4.19	976.52	8.62
14:35:12	1069.76	3.33	4.92	70.60	14.00	4.19	977.39	13.50	73.10	9.20	4.19	975.94	7.63
14:40:12	1069.64	3.34	4.61	71.05	14.30	4.19	977.13	13.78	72.70	11.20	4.19	976.17	9.29
14:45:12	1069.47	3.34	4.41	71.30	14.00	4.19	976.99	13.49	74.10	8.80	4.19	975.35	7.29
14:50:12	1069.41	3.34	4.13	70.95	14.90	4.19	977.19	14.36	72.80	11.60	4.19	976.12	9.62
14:55:12	1069.25	3.34	3.98	70.90	15.00	4.19	977.22	14.46	73.55	10.10	4.19	975.67	8.37
15:00:12	1069.03	3.35	3.89	71.45	14.70	4.19	976.90	14.17	73.65	10.70	4.19	975.62	8.87
15:05:12	1068.97	3.35	3.70	71.70	13.80	4.19	976.76	13.30	74.85	8.10	4.19	974.90	6.71
15:10:12	1068.93	3.35	3.51	71.40	14.00	4.19	976.93	13.49	73.00	11.00	4.19	976.00	9.12
15:15:12	1068.79	3.35	3.41	71.35	13.70	4.19	976.96	13.20	73.45	9.90	4.19	975.73	8.21
15:20:12	1068.59	3.36	3.36	71.35	13.50	4.19	976.96	13.01	71.65	13.30	4.19	976.79	11.03
15:25:12	1068.52	3.36	3.23	71.40	13.20	4.19	976.93	12.72	73.15	9.90	4.19	975.91	8.21

Table K.1 The calculation results of the AHT (Non-used water in tank, Continued).

Time	$TC_{CW,bulk}$	$\Delta T_{CW,C}$	$Cp_{CW,C}$	$\rho_{HW,C}$	Q'_C	$TA_{UG,bulk}$	$\Delta T_{UG,A}$	$Cp_{UG,A}$	$\rho_{UG,A}$	Q'_A	HR_{UG}	EER_{AHT}
	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	(-)	(-)
13:45:12	26.65	1.10	4.18	996.57	6.94	63.45	8.30	3.25	1073.65	11.24	0.49	5.33
13:50:12	27.70	1.40	4.18	996.28	8.83	64.60	9.80	3.25	1073.46	13.29	0.59	6.30
13:55:12	28.20	1.60	4.18	996.14	10.09	67.45	7.70	3.26	1072.99	10.47	0.46	4.97
14:00:12	28.65	2.90	4.18	996.01	18.28	70.70	6.60	3.28	1072.44	9.00	0.41	4.27
14:05:12	28.45	2.90	4.18	996.06	18.28	72.10	6.60	3.28	1072.20	9.02	0.41	4.28
14:10:12	28.55	2.50	4.18	996.03	15.76	73.65	5.50	3.29	1071.92	7.53	0.33	3.57
14:15:12	28.55	2.50	4.18	996.03	15.76	75.80	5.00	3.30	1071.54	6.86	0.31	3.25
14:20:12	28.70	3.00	4.18	995.99	18.91	76.50	4.60	3.30	1071.41	6.31	0.27	2.99
14:25:12	28.80	2.80	4.18	995.96	17.65	78.00	4.40	3.31	1071.14	6.05	0.27	2.87
14:30:12	28.65	2.90	4.18	996.01	18.28	79.20	4.20	3.31	1070.92	5.78	0.26	2.74
14:35:12	28.70	3.00	4.18	995.99	18.91	79.85	3.90	3.31	1070.80	5.37	0.25	2.55
14:40:12	28.35	2.70	4.18	996.09	17.02	80.85	3.30	3.32	1070.61	4.55	0.20	2.16
14:45:12	28.35	2.70	4.18	996.09	17.02	81.70	3.00	3.32	1070.45	4.14	0.20	1.96
14:50:12	28.75	3.10	4.18	995.98	19.54	82.10	3.00	3.32	1070.37	4.14	0.17	1.96
14:55:12	28.90	3.00	4.18	995.93	18.91	83.15	3.30	3.33	1070.17	4.56	0.20	2.16
15:00:12	29.00	3.00	4.18	995.90	18.91	83.50	3.20	3.33	1070.11	4.42	0.19	2.10
15:05:12	28.15	2.70	4.18	996.15	17.03	83.80	2.40	3.33	1070.05	3.32	0.17	1.57
15:10:12	28.20	3.00	4.18	996.14	18.92	84.40	2.20	3.33	1069.93	3.04	0.13	1.44
15:15:12	28.15	3.10	4.18	996.15	19.55	84.95	3.10	3.33	1069.83	4.29	0.20	2.03
15:20:12	28.30	3.60	4.18	996.11	22.70	84.85	2.70	3.33	1069.85	3.74	0.16	1.77
15:25:12	28.45	3.10	4.18	996.06	19.55	86.05	2.90	3.34	1069.61	4.02	0.19	1.91

Table K.1 The calculation results of the AHT (Non-used water in tank, Continued).

Time	P_{Low}		P_{High}		X_{max}	X_{min}	h_1	h_2	m'_{ref}	m'_5	m'_8	ρ_2	v_2	ρ_5
	(kPa)	(PSI)	(kPa)	(PSI)	(%LiBr)	(%LiBr)	(kJ/kg)	(kJ/kg)	(kg/s)	(kg/s)	(kg/s)	(kg/m^3)	(m^3/kg)	(kg/m^3)
13:45:12	4.82	0.70	14.87	2.16	52.97	44.97	2610.05	131.17	0.0028	0.0157	0.0185	995.21	0.0010	1143.99
13:50:12	4.93	0.72	17.01	2.47	53.16	44.43	2611.44	132.84	0.0036	0.0181	0.0217	995.08	0.0010	1143.50
13:55:12	5.07	0.74	18.43	2.67	53.07	44.47	2612.14	134.93	0.0041	0.0211	0.0251	994.92	0.0010	1143.32
14:00:12	5.07	0.74	19.76	2.87	53.12	44.7	2612.31	134.93	0.0074	0.0392	0.0466	994.92	0.0010	1143.25
14:05:12	5.10	0.74	21.09	3.06	53.22	44.51	2612.83	135.35	0.0074	0.0377	0.0451	994.89	0.0010	1143.06
14:10:12	6.44	0.93	21.78	3.16	50.33	44.59	2611.96	152.90	0.0064	0.0498	0.0562	993.47	0.0010	1143.92
14:15:12	6.33	0.92	23.00	3.34	50.75	44.65	2612.66	151.65	0.0064	0.0469	0.0533	993.57	0.0010	1143.69
14:20:12	6.79	0.99	22.90	3.32	49.91	44.9	2612.66	157.08	0.0077	0.0690	0.0767	993.11	0.0010	1143.72
14:25:12	6.61	0.96	24.50	3.55	50.52	44.76	2613.53	154.99	0.0072	0.0558	0.0630	993.29	0.0010	1143.44
14:30:12	6.44	0.93	25.40	3.68	51.12	44.72	2614.39	152.90	0.0074	0.0519	0.0593	993.47	0.0010	1143.11
14:35:12	6.26	0.91	25.63	3.72	51.66	44.83	2615.08	150.81	0.0077	0.0504	0.0581	993.64	0.0010	1142.81
14:40:12	6.13	0.89	26.56	3.85	52.24	44.67	2616.12	149.14	0.0069	0.0407	0.0476	993.78	0.0010	1142.36
14:45:12	5.99	0.87	26.21	3.80	52.75	45.23	2616.99	147.47	0.0069	0.0415	0.0484	993.92	0.0010	1141.94
14:50:12	6.16	0.89	26.32	3.82	52.07	45.22	2615.78	149.56	0.0079	0.0523	0.0602	993.75	0.0010	1142.51
14:55:12	6.09	0.88	27.76	4.03	52.02	45.33	2615.26	148.72	0.0077	0.0520	0.0596	993.82	0.0010	1142.68
15:00:12	6.03	0.87	27.64	4.01	52.58	45.46	2616.64	147.89	0.0077	0.0489	0.0566	993.89	0.0010	1142.10
15:05:12	5.93	0.86	26.79	3.89	53.14	45.73	2617.85	146.63	0.0069	0.0425	0.0494	993.99	0.0010	1141.54
15:10:12	5.80	0.84	27.40	3.97	53.11	45.71	2616.99	144.96	0.0077	0.0473	0.0549	994.13	0.0010	1141.82
15:15:12	5.73	0.83	28.88	4.19	53.13	45.7	2616.64	144.13	0.0079	0.0486	0.0565	994.20	0.0010	1141.92
15:20:12	6.09	0.88	25.86	3.75	52.73	46.77	2617.50	148.72	0.0092	0.0722	0.0813	993.82	0.0010	1141.78
15:25:12	5.93	0.86	28.25	4.10	53.14	46.54	2617.85	146.63	0.0079	0.0558	0.0637	993.99	0.0010	1141.54

Note : The number in table reference Figure 1.4

Table K.1 The calculation results of the AHT (Non-used water in tank, Continued).

Time	v5	W_P	W_{SP}	COP_{AHT}	$(T_{A,i}-T_E)/(T_{G,i}-T_C)$
	(m^3/kg)	(W)	(W)	(-)	(-)
13:45:12	0.0009	0.00035	0.00173	0.49	0.16
13:50:12	0.0009	0.00054	0.00239	0.59	0.10
13:55:12	0.0009	0.00068	0.00307	0.46	0.15
14:00:12	0.0009	0.00136	0.00629	0.41	0.20
14:05:12	0.0009	0.00148	0.00659	0.41	0.20
14:10:12	0.0009	0.00124	0.00835	0.33	0.26
14:15:12	0.0009	0.00134	0.00854	0.31	0.28
14:20:12	0.0009	0.00156	0.01215	0.27	0.31
14:25:12	0.0009	0.00162	0.01091	0.27	0.31
14:30:12	0.0009	0.00177	0.01076	0.26	0.32
14:35:12	0.0009	0.00187	0.01067	0.25	0.32
14:40:12	0.0009	0.00177	0.00910	0.20	0.33
14:45:12	0.0009	0.00175	0.00917	0.20	0.35
14:50:12	0.0009	0.00201	0.01154	0.17	0.36
14:55:12	0.0009	0.00209	0.01231	0.20	0.35
15:00:12	0.0009	0.00208	0.01157	0.19	0.36
15:05:12	0.0009	0.00181	0.00972	0.17	0.39
15:10:12	0.0009	0.00208	0.01118	0.13	0.39
15:15:12	0.0009	0.00230	0.01232	0.20	0.37
15:20:12	0.0009	0.00229	0.01561	0.16	0.44
15:25:12	0.0009	0.00222	0.01364	0.19	0.42

Note : The number in table reference Figure 1.4

Table K.2 The calculation results of the AHT from data recorder (Used water in tank).

Time	$\rho_{UF,bulk}$	$Cp_{UF,bulk}$	Q'_{ST}	$TG_{HW,bulk}$	$\Delta T_{HW,G}$	$Cp_{HW,G}$	$\rho_{HW,G}$	Q'_{gen}	$TE_{HW,bulk}$	$\Delta T_{HW,E}$	$Cp_{HW,E}$	$\rho_{HW,E}$	Q'_{E}
	(kg/m³)	(kJ/kg-K)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)
15:36:55	984.77	4.18	4.19	71.70	12.40	4.19	976.76	11.95	72.95	10.30	4.19	976.03	8.54
15:37:55	984.80	4.18	4.18	71.75	12.30	4.19	976.73	11.85	72.80	10.60	4.19	976.12	8.79
15:38:55	984.82	4.18	4.18	71.80	12.20	4.19	976.70	11.76	72.90	10.40	4.19	976.06	8.62
15:39:55	984.87	4.18	4.15	71.75	12.10	4.19	976.73	11.66	72.80	10.60	4.19	976.12	8.79
15:40:55	984.85	4.18	4.14	71.75	12.10	4.19	976.73	11.66	72.85	10.30	4.19	976.09	8.54
15:41:55	984.87	4.18	4.13	71.85	12.10	4.19	976.67	11.66	72.95	10.30	4.19	976.03	8.54
15:42:55	984.90	4.18	4.12	71.85	12.10	4.19	976.67	11.66	72.85	10.50	4.19	976.09	8.70
15:43:55	984.92	4.18	4.11	71.85	12.10	4.19	976.67	11.66	72.70	10.60	4.19	976.17	8.79
15:44:55	984.92	4.18	4.11	71.75	11.90	4.19	976.73	11.47	72.55	10.70	4.19	976.26	8.87
15:45:55	985.00	4.18	4.09	71.85	11.90	4.19	976.67	11.47	72.55	10.90	4.19	976.26	9.04
15:46:55	984.90	4.18	4.09	71.90	11.80	4.19	976.64	11.37	72.60	10.80	4.19	976.23	8.95
15:47:55	984.68	4.18	4.05	71.95	11.70	4.19	976.61	11.27	72.75	10.50	4.19	976.14	8.71
15:48:55	984.65	4.18	4.04	71.95	11.70	4.19	976.61	11.27	72.25	11.50	4.19	976.44	9.54
15:52:55	984.73	4.18	3.99	71.60	12.00	4.19	976.81	11.56	72.00	11.80	4.19	976.58	9.79
15:53:55	984.80	4.18	3.98	71.55	11.90	4.19	976.84	11.47	72.10	11.40	4.19	976.52	9.45
15:54:55	984.65	4.18	3.97	71.60	12.00	4.19	976.81	11.56	72.20	11.20	4.19	976.47	9.29
15:55:55	984.80	4.18	3.98	71.55	11.90	4.19	976.84	11.47	72.15	11.30	4.19	976.49	9.37
15:56:55	984.70	4.18	3.95	71.60	11.80	4.19	976.81	11.37	72.25	11.10	4.19	976.44	9.20
15:57:55	984.70	4.18	3.95	71.60	11.80	4.19	976.81	11.37	72.30	11.00	4.19	976.41	9.12
15:58:55	984.75	4.18	3.95	71.60	11.60	4.19	976.81	11.18	72.15	11.10	4.19	976.49	9.21
15:59:55	984.80	4.18	3.95	71.55	11.50	4.19	976.84	11.08	72.15	10.90	4.19	976.49	9.04

Table K.2 The calculation results of the AHT (Used water in tank, Continued).

Time	$T_{CW,bulk,C}$	$\Delta T_{CW,C}$	$Cp_{CW,C}$	$\rho_{HW,C}$	Q'_{Cond}	$T_{UG,bulk,A}$	$\Delta T_{UG,A}$	$Cp_{UG,A}$	$\rho_{UG,G}$	Q'_{Ab}	HR_{UG}	HR_{ST}	EER_{AHT}
	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	('C)	('C)	(kJ/kg-K)	(kg/m³)	(kW)	(-)	(-)	(-)
15:36:55	27.95	2.90	4.18	996.21	15.24	83.75	5.70	3.33	1070.06	7.88	0.38	0.17	3.74
15:37:55	27.95	2.90	4.18	996.21	15.24	83.65	5.70	3.33	1070.08	7.88	0.38	0.16	3.74
15:38:55	27.85	2.90	4.18	996.23	15.24	83.60	5.80	3.33	1070.09	8.02	0.39	0.16	3.80
15:39:55	27.80	3.00	4.18	996.25	15.77	83.40	5.80	3.33	1070.13	8.02	0.39	0.16	3.80
15:40:55	27.75	2.90	4.18	996.26	15.24	83.25	5.90	3.33	1070.16	8.15	0.40	0.17	3.87
15:41:55	27.70	2.80	4.18	996.28	14.72	83.15	5.90	3.33	1070.17	8.15	0.40	0.16	3.87
15:42:55	27.60	2.80	4.18	996.31	14.72	83.05	5.90	3.32	1070.19	8.15	0.40	0.16	3.87
15:43:55	27.60	2.80	4.18	996.31	14.72	82.80	6.20	3.32	1070.24	8.56	0.42	0.16	4.06
15:44:55	27.50	2.80	4.18	996.33	14.72	82.65	6.10	3.32	1070.27	8.42	0.41	0.16	3.99
15:45:55	27.50	2.80	4.18	996.33	14.72	82.50	6.00	3.32	1070.30	8.28	0.40	0.16	3.93
15:46:55	27.60	2.80	4.18	996.31	14.72	82.30	6.00	3.32	1070.34	8.28	0.41	0.16	3.93
15:47:55	27.50	2.80	4.18	996.33	14.72	82.20	6.00	3.32	1070.36	8.28	0.41	0.17	3.93
15:48:55	27.60	3.00	4.18	996.31	15.77	82.05	5.90	3.32	1070.38	8.14	0.39	0.15	3.86
15:52:55	27.65	2.90	4.18	996.29	15.24	81.55	5.90	3.32	1070.48	8.14	0.38	0.14	3.86
15:53:55	27.65	2.90	4.18	996.29	15.24	81.65	6.10	3.32	1070.46	8.42	0.40	0.14	3.99
15:54:55	27.60	2.80	4.18	996.31	14.72	81.55	6.10	3.32	1070.48	8.41	0.40	0.16	3.99
15:55:55	27.60	2.80	4.18	996.31	14.72	81.45	6.30	3.32	1070.50	8.69	0.42	0.15	4.12
15:56:55	27.55	2.90	4.18	996.32	15.24	81.30	6.40	3.32	1070.53	8.83	0.43	0.15	4.19
15:57:55	27.60	2.80	4.18	996.31	14.72	81.25	6.50	3.32	1070.54	8.96	0.44	0.15	4.25
15:58:55	27.60	2.80	4.18	996.31	14.72	81.10	6.60	3.32	1070.56	9.10	0.45	0.15	4.32
15:59:55	27.55	2.90	4.18	996.32	15.24	81.05	6.70	3.32	1070.57	9.24	0.46	0.15	4.38

Table K.2 The calculation results of the AHT (Used water in tank, Continued).

Time	P_{Low}		P_{High}		X_{max}	X_{min}	h_1	h_2	m'_{ref}	m'_5	m'_8	ρ_2	ν_2	ρ_5
	(kPa)	(PSI)	(kPa)	(PSI)	(%LiBr)	(%LiBr)	(kJ/kg)	(kJ/kg)	(kg/s)	(kg/s)	(kg/s)	(kg/m^3)	(m^3/kg)	(kg/m^3)
15:36:55	6.47	0.94	27.76	4.03	52.38	46.45	2618.54	153.32	0.0062	0.0484	0.0546	993.43	0.0010	1141.56
15:37:55	6.40	0.93	28.01	4.06	52.45	46.32	2618.37	152.49	0.0062	0.0467	0.0529	993.50	0.0010	1141.60
15:38:55	6.37	0.92	27.76	4.03	52.62	46.45	2618.71	152.07	0.0062	0.0465	0.0527	993.54	0.0010	1141.44
15:39:55	6.33	0.92	27.64	4.01	52.63	46.4	2618.54	151.65	0.0064	0.0476	0.0540	993.57	0.0010	1141.49
15:40:55	6.26	0.91	27.64	4.01	52.8	46.4	2618.71	150.81	0.0062	0.0448	0.0509	993.64	0.0010	1141.38
15:41:55	6.23	0.90	27.64	4.01	52.86	46.34	2618.71	150.40	0.0060	0.0424	0.0483	993.68	0.0010	1141.36
15:42:55	6.16	0.89	27.40	3.97	52.98	46.41	2618.71	149.56	0.0060	0.0421	0.0481	993.75	0.0010	1141.32
15:43:55	6.09	0.88	27.52	3.99	53.11	46.29	2618.71	148.72	0.0060	0.0404	0.0464	993.82	0.0010	1141.28
15:44:55	6.06	0.88	27.15	3.94	53.22	46.36	2618.88	148.31	0.0060	0.0403	0.0462	993.85	0.0010	1141.18
15:45:55	5.99	0.87	27.27	3.96	53.34	46.24	2618.88	147.47	0.0060	0.0388	0.0447	993.92	0.0010	1141.13
15:46:55	6.09	0.88	27.15	3.94	53.42	46.36	2619.75	148.72	0.0060	0.0391	0.0451	993.82	0.0010	1140.83
15:47:55	6.33	0.92	27.03	3.92	53.48	46.71	2621.30	151.65	0.0060	0.0411	0.0471	993.57	0.0010	1140.32
15:48:55	6.87	1.00	26.79	3.89	52.58	46.73	2621.30	157.92	0.0064	0.0511	0.0575	993.03	0.0010	1140.64
15:52:55	7.02	1.02	25.40	3.68	52.12	47.26	2620.61	159.59	0.0062	0.0602	0.0664	992.89	0.0010	1140.98
15:53:55	6.98	1.01	25.63	3.72	52.23	47.19	2620.78	159.17	0.0062	0.0580	0.0642	992.92	0.0010	1140.90
15:54:55	7.17	1.04	25.97	3.77	52.2	47.17	2621.64	161.26	0.0060	0.0561	0.0621	992.74	0.0010	1140.63
15:55:55	6.87	1.00	25.97	3.77	52.31	47	2620.43	157.92	0.0060	0.0529	0.0589	993.03	0.0010	1140.99
15:56:55	7.06	1.02	25.97	3.77	52.44	47.17	2621.81	160.01	0.0062	0.0554	0.0616	992.85	0.0010	1140.51
15:57:55	7.02	1.02	26.09	3.78	52.5	47.05	2621.81	159.59	0.0060	0.0516	0.0576	992.89	0.0010	1140.49
15:58:55	6.91	1.00	25.97	3.77	52.62	47.06	2621.64	158.34	0.0060	0.0506	0.0565	993.00	0.0010	1140.51
15:59:55	6.83	0.99	25.97	3.77	52.75	46.94	2621.64	157.50	0.0062	0.0500	0.0562	993.07	0.0010	1140.47

Note : The number in table reference Figure 1.4

Table K.2 The calculation results of the AHT (Used water in tank, Continued).

Time	v_5	W_P	W_{SP}	COP_{AHT}	$(T_{A,i}-T_E)/(T_{G,i}-T_C)$
	(m^3/kg)	(W)	(W)	(-)	(-)
15:36:55	0.0009	0.00166	0.01129	0.38	0.35
15:37:55	0.0009	0.00168	0.01105	0.38	0.34
15:38:55	0.0009	0.00166	0.01090	0.39	0.35
15:39:55	0.0009	0.00171	0.01111	0.39	0.34
15:40:55	0.0009	0.00166	0.01048	0.40	0.34
15:41:55	0.0009	0.00161	0.00994	0.40	0.33
15:42:55	0.0009	0.00159	0.00979	0.40	0.33
15:43:55	0.0009	0.00161	0.00949	0.42	0.32
15:44:55	0.0009	0.00158	0.00930	0.41	0.33
15:45:55	0.0009	0.00159	0.00904	0.40	0.32
15:46:55	0.0009	0.00158	0.00902	0.41	0.32
15:47:55	0.0009	0.00155	0.00933	0.41	0.32
15:48:55	0.0009	0.00161	0.01117	0.39	0.34
15:52:55	0.0009	0.00143	0.01213	0.38	0.36
15:53:55	0.0009	0.00145	0.01184	0.40	0.36
15:54:55	0.0009	0.00142	0.01156	0.40	0.35
15:55:55	0.0009	0.00144	0.01107	0.42	0.34
15:56:55	0.0009	0.00147	0.01149	0.43	0.34
15:57:55	0.0009	0.00143	0.01079	0.44	0.33
15:58:55	0.0009	0.00143	0.01057	0.45	0.33
15:59:55	0.0009	0.00149	0.01048	0.46	0.32

Note : The number in table reference Figure 1.4

Other calculation results as shown in Table K.1 – K.2 save in the CD-ROM.