

UPGRADING OF LOW TEMPERATURE SOLAR HEAT FOR MEDIUM TEMPERATURE APPLICATIONS BY A SOLAR-ABSORPTION HEAT TRANSFORMER ASSISTING WITH A VAPOR COMPRESSION HEAT PUMP

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Abstract

In tropical area, even solar radiation level is rather high but diffuse solar radiation component is also very significant thus only solar flat-plate solar collector could be competitive with conventional energy for heat generation with a temperature not over 70 °C. For higher temperature applications, a technique to boost-up the temperature is needed.

This paper presents simulation results of a H₂O-LiBr absorption heat transformer (AHT) performance having a R123 vapor compression heat pump (VCHP) recovering heat at the AHT condenser which is transferred to the AHT evaporator. The heat capacity at the AHT absorber is 10 kW. The unit is used to upgrade heat from a solar hot water heater of which the heat is supplied by a set of flat-plate solar collectors in parallel connection each having an area of 2 m² with $F_R(\tau\alpha)$ and $F_R U_L$ of 0.802 and 10.37 W/m² · K, respectively. The weather data of Chiang Mai, Thailand are the input information for the calculation.

The AHT could be operated when the hot water temperature from the solar water heating system is over 70 °C. For the AHT with VCHP assisted, the number of the solar collectors is around 30 units which is about 50 % of that without the VCHP. Moreover, the COP of the modified AHT is about 0.8 compared with 0.5 of the conventional AHT when the AHT absorber temperature is in a range of 80-120 °C. The annual cost of the modified unit is also cheaper than the conventional one around 44,075 Baht/y when the operating period of 10 years.

Keywords: Heat transformer; Absorption heat pump; Flat plate solar collector; Simulation

1. Introduction

In tropical area, even solar radiation level is rather high but diffuse solar radiation component is also very significant thus only solar flat-plate solar collector could be competitive with conventional energy for heat generation. Normally, the flat-plate one will not supply heat with a temperature over 70 °C, otherwise its thermal efficiency is very low, therefore, a technique to boost-up the temperature is needed.

Absorption heat transformer (AHT) is a 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 while high temperature heat is delivered at the AHT absorber and there is waste heat rejected at the AHT condenser. Theoretical and experimental studies of the AHT have been reported by various literatures. Kiatsiriroat et al. [1] reported thermal performance of a water-LiBr AHT for upgrading low temperature heat such as waste heat from industrial processes or solar heat. The coefficient of performance (COP) did not exceed 0.5 because there was a high heat rejection at the AHT condenser. Florides et al. [2] 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 m² compound parabolic collector tilted 30° from the horizontal plane and a 600 L hot water storage tank. Xuehu et al. [3] also reported the test results of an industrial-scale water-LiBr AHT in China which was used to recover waste heat released from organic vapor at 98 °C in a synthetic rubber plant. The recovered heat was used to heat hot water from 95 °C to 110 °C. The AHT system was operating with a heat rate of 5,000 kW with a mean COP of 0.47. Rivera et al.

[4] presented a single-stage and advanced AHT operating with water-LiBr and water-CarrolTM 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 °C at COP about 0.48 and 100 °C at COP about 0.33, respectively. Sotsil Silva Sotelo et al. [5] presented an AHT cycle operating with water-CarrolTM 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.

It could be seen that the COP of the H₂O-LiBr AHT could not be over 0.5 due to the heat rejected at the AHT condenser. If this one could be recovered and supplied back to the AHT evaporator then the COP could be increased. Therefore, in this study a method to improve thermal performance of a single-stage H₂O-LiBr AHT by combining a VCHP to recover the heat rejected from the AHT condenser which was supplied back to the AHT evaporator is considered. With this approach, input heat form solar collectors could be supplied at the AHT generator only, thus the number of the solar collectors could be reduced.

2. System Descriptions and Equations

Figure 1 shows a schematic sketch of a solar-absorption heat transformer (Solar-AHT). Solar heat is supplied to the AHT generator and evaporator at a medium temperature (around 60-80 °C) and rejected heat at a lower temperature (around 35-45 °C) at the AHT condenser. A higher temperature heat (around 90-110 °C) is obtained at the AHT absorber.

The basic equations of a solar water heating system as shown in Figure 1 are as follows:

- Solar collector

$$Q_{SC} = \dot{m}_{SC} C_{p_{SC}} (T_{SC,o} - T_{SC,i}), \quad (1)$$

$$Q_{SC} = F_R (\tau\alpha) I_t A_{SC} - F_R U_L A_{SC} (T_{SC,i} - T_a). \quad (2)$$

For solar collectors in series connection,

$$(F_R (\tau\alpha))_{Series} = F_R (\tau\alpha) \left[\frac{1 - (1 - K)^N}{NK} \right], \quad (3)$$

$$(F_R U_L)_{Series} = F_R U_L \left[\frac{1 - (1 - K)^N}{NK} \right], \quad (4)$$

where

$$K = \frac{A_{SC} (F_R U_L)_{Single\ unit}}{\dot{m}_{SC} C_{p_{SC}}}. \quad (5)$$

- Auxiliary heat from electric heater

$$Q_{Aux} = M_{ST} C_{p_{bulk}} \frac{\Delta T}{\Delta t}. \quad (6)$$

- Supplied heat of useful hot water at hot water tank

$$Q_{Sup} = \dot{m}_{Sup} C_{p_{bulk}} (T_{Sup,o} - T_{Sup,i}). \quad (7)$$

- Heat loss at hot water tank

$$Q_{Loss} = UA_{Tank} (T_{Is} - T_a). \quad (8)$$

- Hot water tank

$$Q_{ST} = M_{ST} C_{p_{ST}} \left(\frac{dT}{dt} \right). \quad (9)$$

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

$$T_{ST}^{t+\Delta t} = T_{ST}^t + \frac{Q_{ST} \Delta t}{M_{ST} C_{p_{ST}}}, \quad (10)$$

$$T_{ST}^{t+\Delta t} = T_{ST}^t + \frac{(Q_{SC} - Q_{loss} - Q_{Sup}) \Delta t}{M_{ST} C_{p_{ST}}}. \quad (11)$$

With an auxiliary heater, the temperature becomes,

$$T_{ST}^{t+\Delta t} = T_{ST}^t + \frac{(Q_{SC} + Q_{Aux} - Q_{loss} - Q_{Sup})\Delta t}{M_{ST}Cp_{ST}} \quad (12)$$

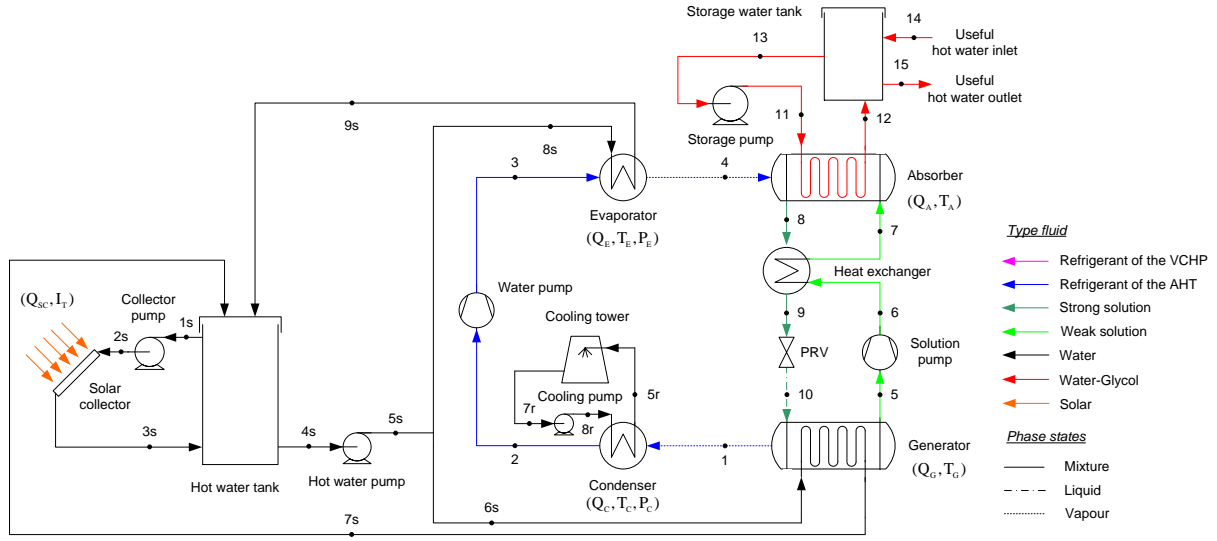


Figure 1. Schematic diagram of a solar absorption heat transformer.

At the AHT generator, binary liquid mixture consists 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 absorbs the absorbate vapor and the weak solution 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.

The basic equations of each component in the AHT cycle as shown in Figure 1 are as follows:

- Generator

$$Q_G = \dot{m}_1 h_1 + \dot{m}_5 h_5 - \dot{m}_{10} h_{10} \quad (13)$$

$$\dot{m}_{10} = \dot{m}_1 + \dot{m}_5 \quad (14)$$

$$\dot{m}_{10} X_{10} = \dot{m}_5 X_5, (X_1 = 0) \quad (15)$$

From equation (2) and (3),

$$\dot{m}_5 = \frac{\dot{m}_1 X_{10}}{X_5 - X_{10}} \quad (16)$$

and

$$\dot{m}_{10} = \frac{\dot{m}_1 X_5}{X_5 - X_{10}} \quad (17)$$

- Condenser

$$Q_C = \dot{m}_{ref} (h_1 - h_2) \quad (18)$$

$$\dot{m}_{ref} = \dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_4 \quad (19)$$

- Pump and solution pump

$$W_P = (P_E - P_C) \frac{v_2 \dot{m}_2}{\eta_P}, \quad (20)$$

$$W_{SP} = (P_E - P_C) \frac{v_5 \dot{m}_5}{\eta_{SP}}, \quad (21)$$

$$h_2 \approx h_3, \quad (22)$$

$$h_5 \approx h_6. \quad (23)$$

- Evaporator

$$Q_E = \dot{m}_{ref} (h_4 - h_3). \quad (24)$$

- Absorber

$$Q_A = \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_8 h_8, \quad (25)$$

$$\dot{m}_8 = \dot{m}_4 + \dot{m}_7, \quad (26)$$

$$\dot{m}_8 X_8 = \dot{m}_7 X_7. \quad (27)$$

- Heat exchanger

$$Q_{HX} = \dot{m}_8 C_{p8} (T_8 - T_9) = \dot{m}_6 C_{p6} (T_7 - T_6) = \epsilon_{HX} (mCp)_{\min} (T_8 - T_6), \quad (28)$$

$$\dot{m}_8 = \dot{m}_9, \quad (29)$$

$$\dot{m}_6 = \dot{m}_7. \quad (30)$$

- Expansion valve

$$h_9 = h_{10}, \text{ (throttling process)}. \quad (31)$$

- Flow ratio (FR)

$$FR_{AHT} = \frac{\dot{m}_8}{\dot{m}_{ref}}. \quad (32)$$

- Coefficient of performance (COP)

$$COP_{AHT} = \frac{Q_A}{Q_E + Q_G + W_P + W_{SP}}. \quad (33)$$

Figure 2 shows a schematic diagram of an AHT coupling with a VCHP which is called compression/absorption heat transformer (CAHT). The heat rejected at the AHT condenser is recovered by the VCHP then the heat is upgraded and generated back to the AHT evaporator. Besides, the number of solar collectors could be less and the overall COP could be increased since the compression work is low compared with the heat loss at the AHT condenser.

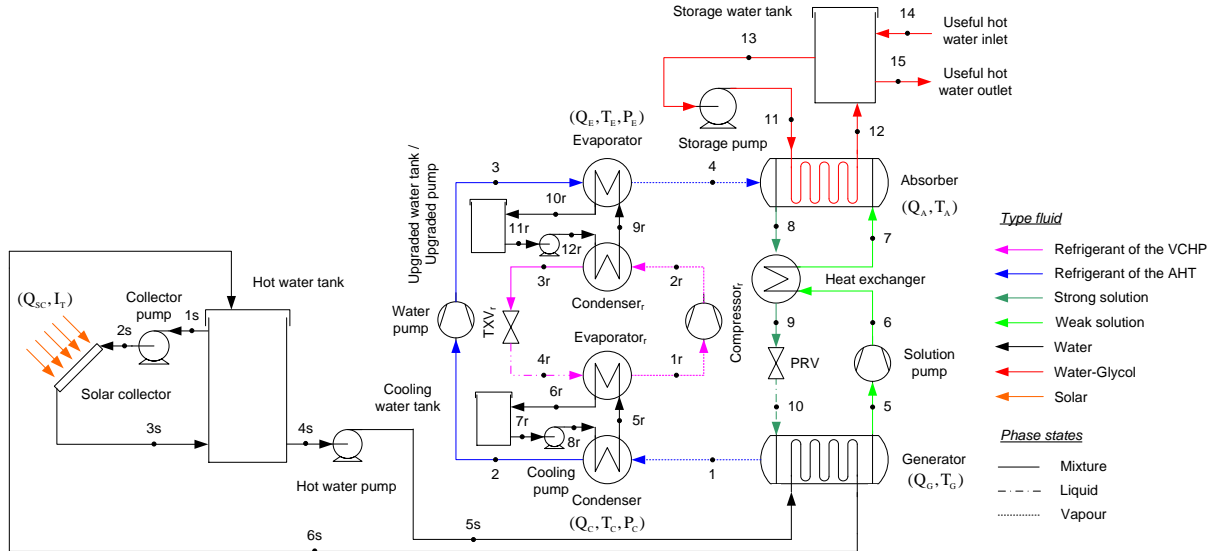


Figure 2. Schematic diagram of a solar vapor compression heat pump-absorption heat transformer.

Then the overall coefficient of performance (COP) of the CAHT will be:

$$\text{COP}_{\text{CAHT}} = \frac{Q_A}{Q_G + W_P + W_{\text{SP}} + W_{\text{Comp}}} \quad (34)$$

3. Operating Conditions and Assumptions

A solar hot water unit is used to supply heat to an AHT and a CAHT. H₂O-LiBr is the working pair of the AHT and R-123 is the refrigerant of the VCHP. The working conditions for the evaluation are:

Solar water heating system

1. The solar radiation (I_T) used for the simulation is the mean solar radiation level of Chiang Mai, Thailand, as shown in appendix, Ref [6].
2. The ambient temperature (T_a) used for the simulation is the mean temperature of Chiang Mai, Thailand, as shown in appendix, Ref [7].
3. Water flow rate (\dot{m}_{SC}) in each solar collector is 0.043 L/s.
4. Hot water tank capacities of the Solar-AHT and the Solar-CAHT are 3,000 L and 1,500 L, respectively.
5. Solar collector is flat-plate type having $F_R(\tau\alpha)$ and $F_R(U_L)$ of 0.802 and 10.37 W/m²·K, respectively, Ref [8].
6. Each collector is in parallel connection and each has an area of 2 m².

The AHT system

1. Useful heat leaving the AHT absorber is 10 kW.
2. Minimum concentration of weak H₂O-LiBr solution (X_{min}) is 45 %LiBr.
3. Maximum flow ratio (FR) for starting is lower than 20.
4. No pressure drops at the AHT condenser, the AHT generator, the AHT evaporator, the AHT absorber and the AHT heat exchanger.
5. Isentropic efficiencies of water pump (η_p) and solution pump (η_{SP}) are 85%.
6. Effectiveness of the AHT heat exchanger (ϵ_{HX}) is 85%.
7. The properties of H₂O-LiBr solution are taken from Refs [9-12].

The VCHP system

In this study, a R-123 VCHP is used to couple with the AHT. In our experiment, the VCHP performance has been undertaken. It could be found that its coefficient of performance (COP_{HP} - a ratio of heat at its condenser and its electrical power consumption) is a function of water temperature entering the VCHP evaporator ($T_{\text{CW},i}$) and water temperature entering the VCHP condenser ($T_{\text{HW},i}$). The performance curve of the R-123 heat pump system is shown in Figure 3.

The COP_{HP} of the R-123 VCHP is in a form of:

$$\text{COP}_{\text{HP}} = -0.0473 (T_{\text{HW},i} - T_{\text{CW},i}) + 2.8824, \quad (\text{kW}_{\text{th}}/\text{kW}_e) \quad (35)$$

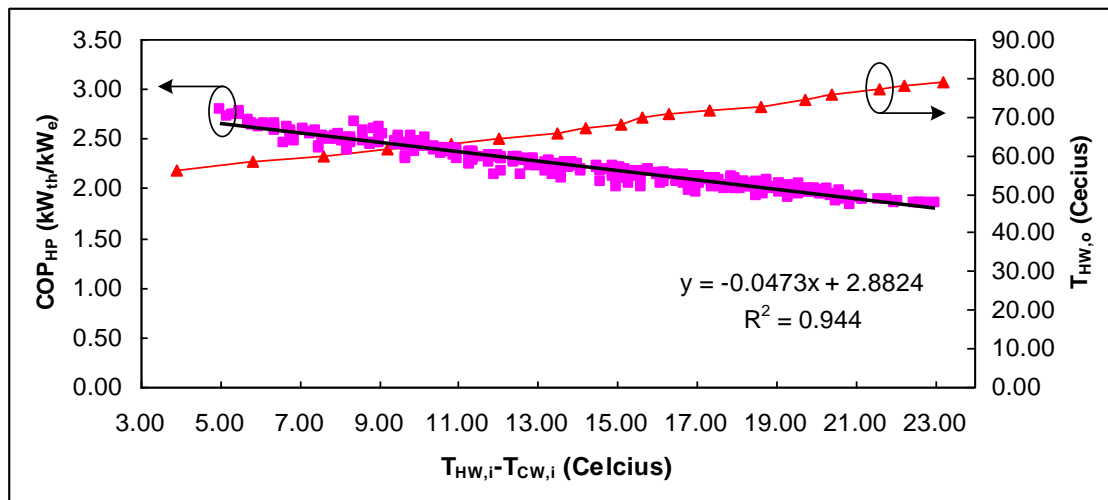


Figure 3. Performance curve of R-123 vapor compression heat pump system.

4. Results and Discussions

Figure 4 shows hot water temperature leaving solar water heating system (T_{HW}) of the Solar-AHT at various numbers of solar collector units between 30-70 units each in parallel connection at 3,000 L of hot water tank with the solar radiation (I_T) and the ambient temperature (T_{amb}) of April, Chiang Mai, Thailand. It could be noted that the AHT could be operated when the hot water temperature from the solar water heating system is over 70°C then the minimum units of solar collectors for supplying heat to the AHT is about 60 units. The system could operate continuously about 8 h/d. The Solar-AHT supplies medium heat at the evaporator and the generator about 20 kW and generates upgraded heat about 10 kW at a higher temperature level at the AHT absorber.

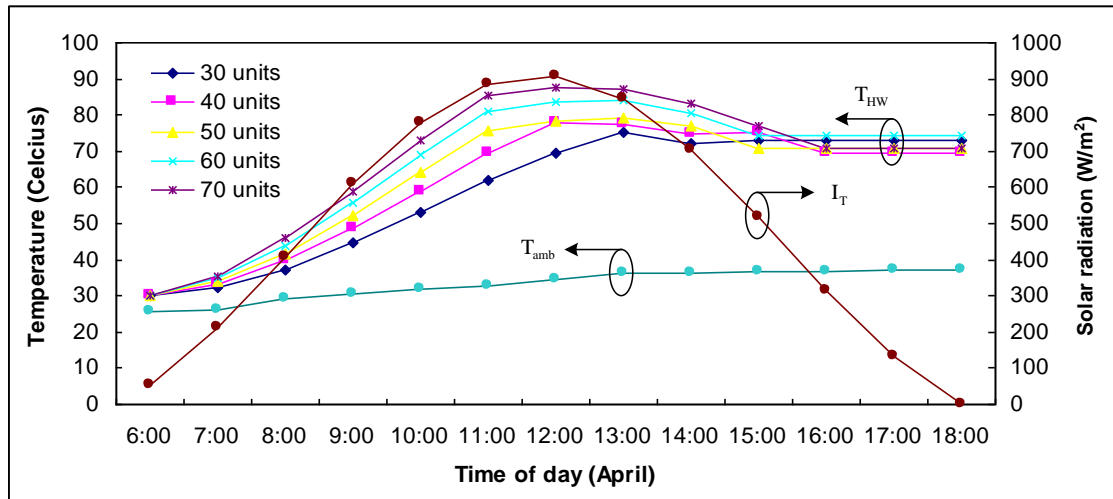


Figure 4. T_{HW} , T_{amb} and I_T of the Solar-AHT at various the number of solar collectors during time of a day in April.

Figure 5 shows temperatures of the Solar-AHT components for 60 units of flat-plate solar collector during a day in April. The AHT could operate at around 11 a.m. when the hot water temperature is over 70°C . It could be seen that the absorption system could upgrade heat at the absorber over 80°C . T_C is nearly constant while T_G , T_E and T_A vary with the hot water temperature leaving the solar water heating system. Figure 6 shows the heat rates for all components of the system.

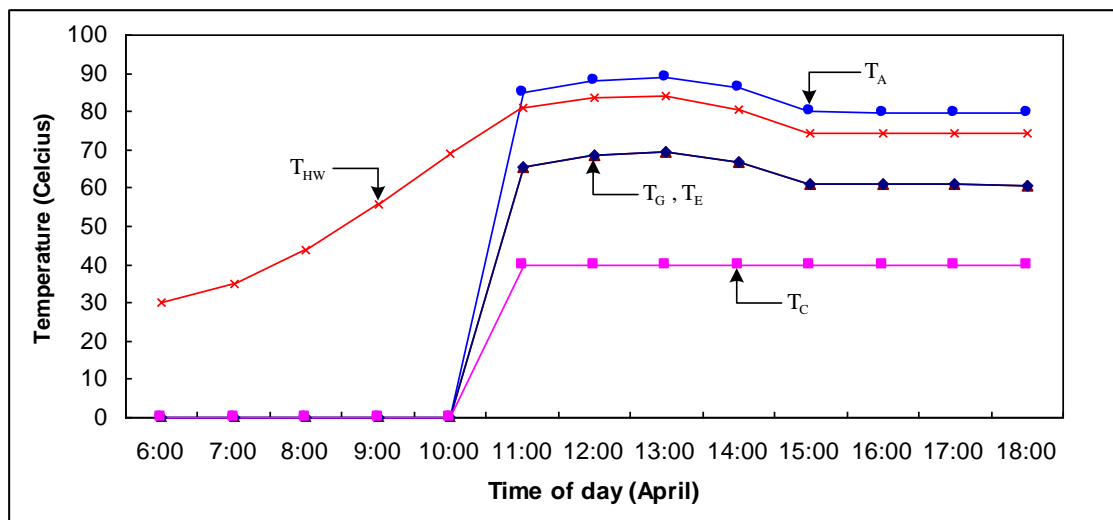


Figure 5. Temperatures of the Solar-AHT components for 60 units of flat-plate solar collectors during time of a day in April.

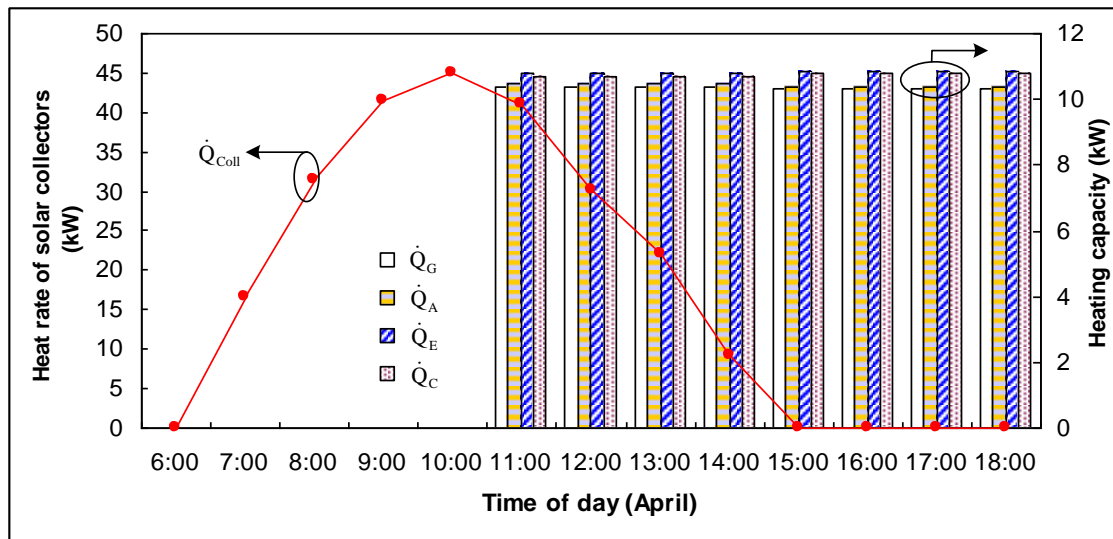


Figure 6. Heat rates at the Solar-AHT components for 60 units of flat-plate solar collectors during time of a day in April.

Figure 7 shows the temperature profiles of the Solar-CAHT components. It could be seen that T_E and T_A are constant while T_G varies with T_{HW} from solar water heating system. The heat rates from solar heat and the heating capacities of the AHT components are shown in Figure 8. It could be noted that the system requires the solar collectors only 30 units.

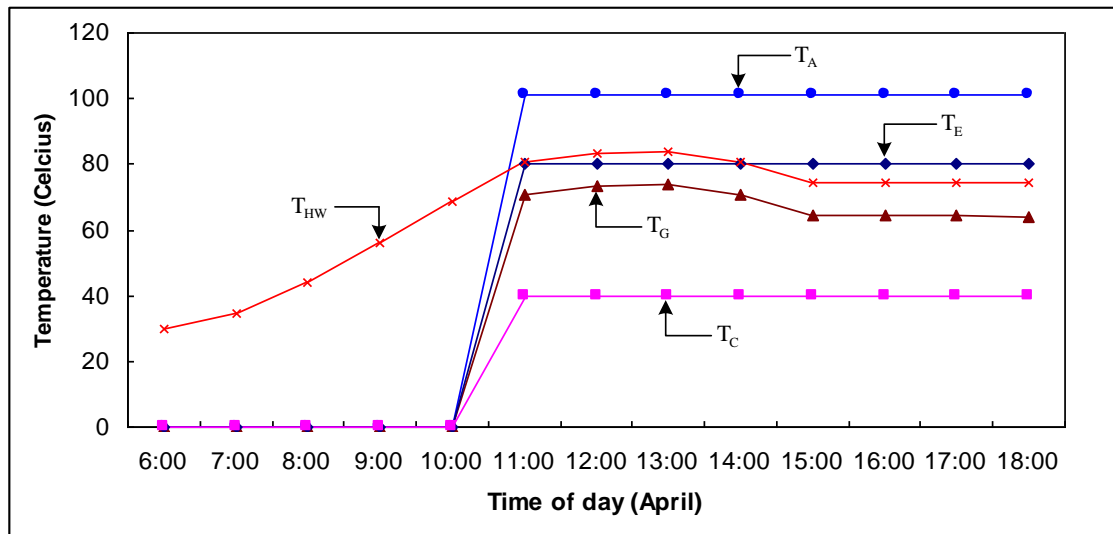


Figure 7. Temperatures of the Solar-CAHT components for 30 units of flat-plate solar collectors during time of a day in April.

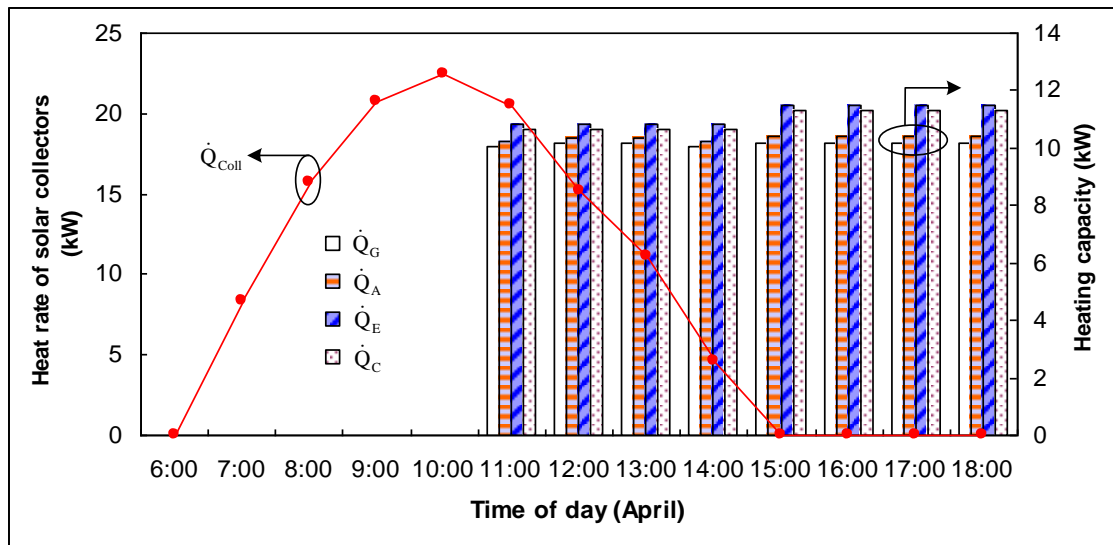


Figure 8. Heat rates of the Solar-CAHT components for 30 units of flat-plate solar collectors during time of a day in April.

Figure 9 shows the overall COP of the normal Solar-AHT and the Solar-CAHT during time of day in April. It could be found that the overall COP of the Solar-CAHT increases around 60% which is 0.8 compared with that of the Solar-AHT which is 0.5. The number of solar collectors is 30 units compared with that of the Solar-AHT which is 60 units.

Table 1 shows the descriptions and costs of the both systems. It could be seen that annual cost of the modified unit is also cheaper than the conventional one about 44,075 Baht/y.

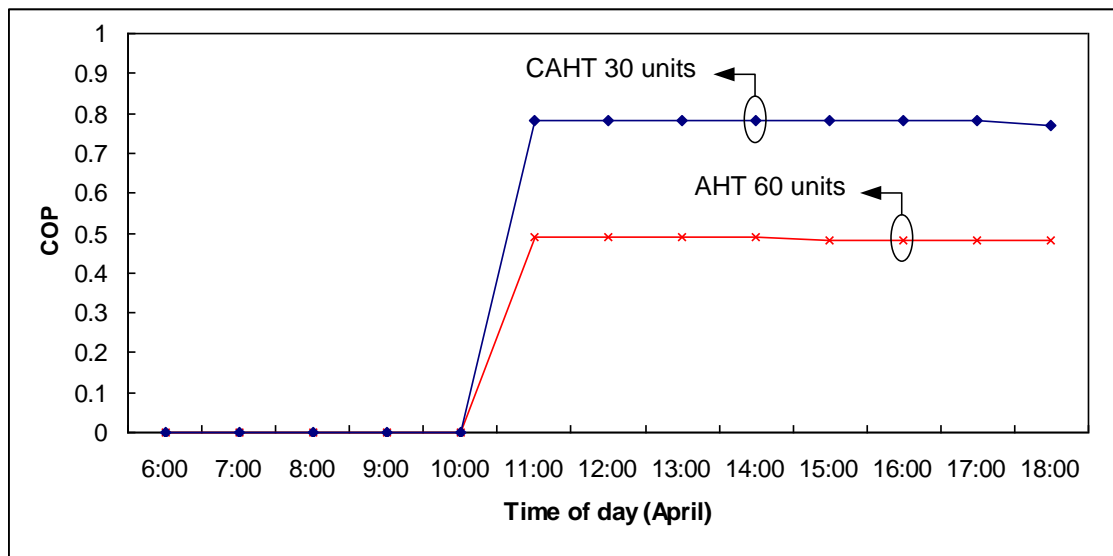


Figure 9. Comparison of the overall COP of the Solar-AHT and the Solar-CAHT on I_T during time of a day in April.

Table 1. Descriptions of the Solar-AHT and the Solar-CAHT components and costs.

Devices	Solar-AHT	Solar-CAHT
Type of solar collectors	Flat-plate	Flat-plate
Solar collector units (2 m ² /unit)	60	30
Capacities of hot water tank (10,000 Baht, L)	3,000	1,500
Hot water flow rate (\dot{m}_{5s} , L/s)	1	0.5
Cost of the absorption machine (Baht)	200,000	200,000
Cost of the vapor compression heat pump ¹ (Baht)	-	150,000
Cost of solar collector (14,000 Baht / units, Baht)	840,000	420,000
Investment cost (Baht)	1,040,000	770,000
Cost of compression work ² (300 d/y, Baht)	-	26,437
Salvage cost (10% of investment cost, Baht)	104,000	77,000
annual cost ³ (AC, Baht)	252,636	208,561

Note: ¹ Heating capacity is 10 kW.

² Electricity cost is 2.978 Baht/kWh [13].

³ Annual discount rate on loans (Minimum Retail Rate, MRR) is 6.45% [14] and uses I_T of 12 months for evaluating.
32.44 Baht = 1 U.S. Dollar

5. Conclusions

From this study, the conclusions are as follows:

1. The overall COP of the Solar-CAHT could be increased around 60% which is around 0.8 compared with around 0.5 of the normal Solar-AHT.
2. For 10 kW heat rate with the absorber temperature over 80 °C, the number of the solar collectors units of the Solar-CAHT could be decreased about 50 % which is 30 units instead of 60 units of the normal Solar-AHT.
3. Annual cost of the Solar-CAHT unit is cheaper than the Solar-AHT unit about 44,075 Baht/y.

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Appendix

A. Enthalpy-Concentration and Temperature for lithium bromide-water solutions [9]

For Concentration $x < 40$ %LiBr

Solution temperature range $15 < t < 165$ °C

$$h = 21.4817157 - 2.38366711X + 3.90458186t + 0.03625001X^2 + 5.25010607 \times 10^{-4}t^2 - 0.0369249939tX, \text{ kJ / kg}$$

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

Solution temperature range $15 < t < 165$ °C

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

$$A_0 = -2024.33$$

$$B_0 = 18.2829$$

$$C_0 = -3.7008214 \text{ E-2}$$

$$A_1 = 163.309$$

$$B_1 = -1.1691757$$

$$C_1 = 2.8877666 \text{ E-3}$$

$$A_2 = -4.88161$$

$$B_2 = 3.248041 \text{ E-2}$$

$$C_2 = -8.1313015 \text{ E-5}$$

$$A_3 = 6.302948 \text{ E-2}$$

$$B_3 = -4.034184 \text{ E-4}$$

$$C_3 = 9.9116628 \text{ E-7}$$

$$A_4 = -2.913705 \text{ E-4}$$

$$B_4 = 1.8520569 \text{ E-6}$$

$$C_4 = -4.4441207 \text{ E-9}$$

B. Solution Temperature-Refrigerant Temperature and Saturation pressure [9]

For Refrigerant $-15 < t' < 110$ °C

Solution temperature $5 < t < 175$ °C

Concentration $45 < X < 70$ %LiBr

$$t = \sum_0^3 B_n X^n + t' \sum_0^3 A_n X^n, \text{ °C}$$

$$t' = (t - \sum_0^3 B_n X^n) / \sum_0^3 A_n X^n, \text{ °C}$$

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

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

$$A_0 = -2.00755$$

$$B_0 = 124.937$$

$$C = 7.05$$

$$A_1 = 0.16976$$

$$B_1 = -7.71649$$

$$D = -1596.49$$

$$A_2 = -3.133362 \text{ E-3}$$

$$B_2 = 0.152286$$

$$E = -104095.5$$

$$A_3 = 1.97668 \text{ E-5}$$

$$B_3 = -7.9509 \text{ E-4}$$

C. Density of lithium bromide-water solutions [10]

For Solution temperature $t < 250$ °C
 Concentration $30 < X < 65$ %LiBr

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

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

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

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

$$M_s = 0.086845, \text{ kg / mole}$$

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

D. Heat capacity of lithium bromide-water solutions [11]

For Solution temperature $40 < t < 210$ °C
 Concentration $40 < X < 65$ %LiBr

$$C_p = (A_0 + A_1 X) + (B_0 + B_1 X)t, \text{ kJ / kg} \cdot ^\circ \text{C}$$

$$A_0 = 3.462023$$

$$B_0 = 1.3499 \text{ E-}3$$

$$A_1 = -2.679895 \text{ E-}2$$

$$B_1 = -6.55 \text{ E-}6$$

E. Entropy of lithium bromide-water solutions [12]

For Solution temperature $40 < t < 210$ °C
 Concentration $40 < X < 65$ %LiBr

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

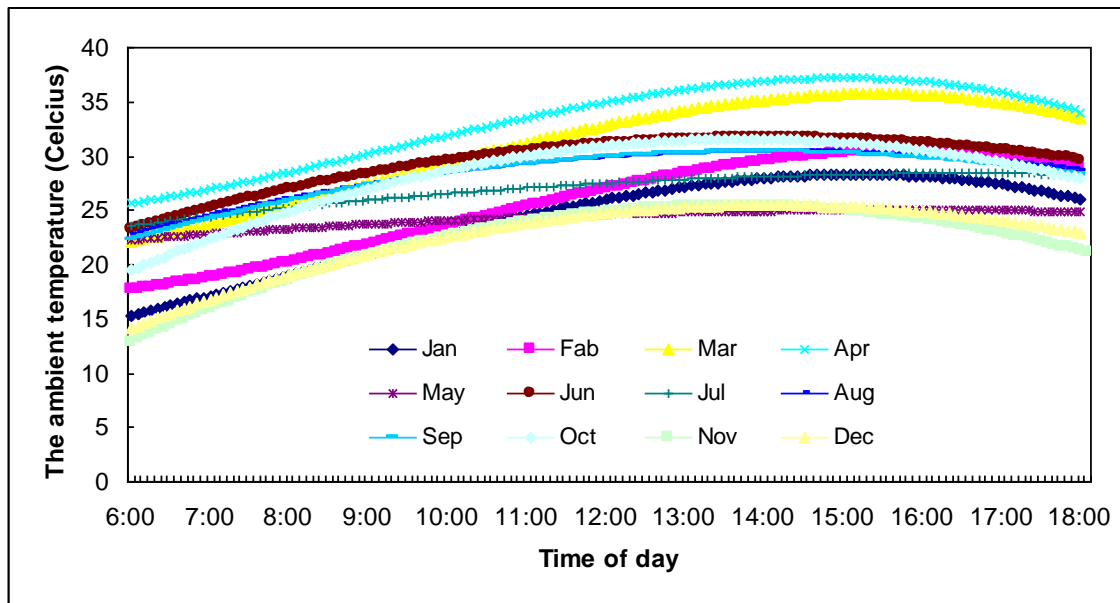
Table of Coefficients B_{ij}

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

F. The average solar radiation of Chiang Mai, Thailand [13].

Month	Jan	Feb	Mar	Apr	May	Jun
I_T (MJ / m ² · 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 · d)	15.66	15.23	15.77	15.73	15.84	16.45

G. The ambient temperature of Chiang Mai, Thailand [14].



Nomenclature

A	area, (m ²)
C _p	heat capacity, (kJ/kg · K)
COP	coefficient of performance
h	enthalpy, (kJ/kg)
LMTD	log mean temperature difference
I _T	solar radiation, (W/m ²)
m	mass flow rate, (kg/s)
N	operation life of the system in consideration, (y)
P	pressure, (bar)
Q	heat rate, (kW)
v	specific volume, (m ³ /kg)
s	entropy, (kJ/kg · K)
T	temperature, (°C)
W	work, (kW)
X	concentrate, (%LiBr)

Greek symbol

η	efficiency, (%)
ε	effectiveness, (%)
ρ	density, (kg/m ³)

Subscript

A	absorber
Aux	auxiliary heat
act	actual
amb	ambient
bulk	bulk temperature
C	condenser
Comp	compressor
Coll	solar collector
CW	cooling water
E	evaporator
H	high

HS	heat source
HW	hot water
HX	heat exchanger
i	inlet
L	low
max	maximum
min	minimum
o	outlet
P	pump
ref	refrigerant
SC	solar collector
SP	solution pump
ST	storage tank
Sup	supply
UF	useful