

CHAPTER 5

Exergy Costing of an Absorption Heat Transformer Coupling with a Vapor Compression Heat Pump

This chapter presents exergy and economics results of the H₂O-LiBr absorption heat transformer (AHT) combining with a R-134A/R-123 two-stage vapor compression heat pump (VCHP) described in the previous Chapter in term of exergy costing (EC).

5.1 Introduction

Exergy is the maximum amount of work that can be done by a subsystem as it approaches thermodynamic equilibrium with its surroundings by a sequence of reversible processes. Exergy has been widely used for assessing and improving sustainability in the characterization of resource and waste. Exergy studies of the AHT have been reported by various literatures. Sozen (2003) reported effect of irreversibilities of an AHT that was used to increase a solar pond's temperature. The exergy losses of the AHT were high at the absorber and the generator. Sencan et al. (2005) presented an exergy analysis of a H₂O-LiBr absorption system. The exergetic efficiency of the system was decreased by increasing the heat source temperature. Rivara et al. (2009) reported the exergy analyses of a single-stage H₂O-LiBr AHT of which the highest exergy coefficient of performance (ECOP) were obtained at the highest solution concentrations at around 0.5.

In this study, the exergy coefficient of performance (ECOP) and the exergy costing (EC) of the normal solar-AHT and the modified solar-CAHT by combining a VCHP to recover and supply the heat rejected from the AHT condenser back to the AHT evaporator is considered.

5.2 Exergy Costing

The exergy in the water stream at each main component of the AHT in Figure 4.1 for the normal solar-AHT and Figure 4.6 for the solar-AHT with the cascade VCHP could be calculated as follows:

- Generator

$$Ex_G = \dot{m}_{6s} (\psi_{5s} - \psi_{6s}) . \quad (5.1)$$

- Condenser

$$Ex_C = \dot{m}_{5r} (\psi_{5r} - \psi_{8r}) . \quad (5.2)$$

- Evaporator

$$Ex_E = \dot{m}_{10r} (\psi_{9r} - \psi_{10r}) . \quad (5.3)$$

- Absorber

$$Ex_A = \dot{m}_{12} (\psi_{12} - \psi_{11}) . \quad (5.4)$$

- Exergetic coefficient of performance (ECOP)

For the AHT and the CAHT, when the pump work is neglected,

$$ECOP_{AHT} = \frac{Ex_A}{Ex_G + Ex_E} . \quad (5.5)$$

$$ECOP_{CAHT} = \frac{Ex_A}{Ex_G + W_{Comp}} . \quad (5.6)$$

The exergy costing could be evaluated from the annual expense of the system, investment cost, fuel and maintenance and salvage value, and the annual exergy output at the absorber. The equations to evaluate the annual cost and the exergy costing are

- Annual cost (AC)

$$AC = C_s(CRF) + AFC + AMC - SV(SFF) , \quad (5.7)$$

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} , \quad (5.8)$$

$$SFF = \frac{i}{(1+i)^N - 1} . \quad (5.9)$$

- Exergy costing (EC)

$$EC = \frac{AC}{Ex_{Output}}. \quad (5.10)$$

Then the EC_{AHT} and EC_{CAHT} will be

$$EC_{AHT} = \frac{AC_{AHT}}{Ex_A}, \quad (5.11)$$

$$EC_{CAHT} = \frac{AC_{CAHT}}{Ex_A}. \quad (5.12)$$

Figure 5.1 shows the steps for calculating the exergy costings of the upgraded hot water at the absorbers of the solar-AHT and the solar-CAHT. Input data of the simulation are the temperature of supplied hot water for the AHT ($T_{HS,i}$) from the solar water heating system as shown in Chapter 4, water flow rate (\dot{m}_{HS}) of the AHT generator and the AHT evaporator each at 0.5 l/s. The working fluids in the two-stage VCHP system are R-134A and R-123. The given data are the operating conditions, the heat exchanger effectiveness (ϵ_{HX}) and the minimum concentration of H₂O-LiBr solution (X_{min}). In the calculations, the properties of working fluid of the AHT system and the VCHP system are calculated to evaluate the annual costs, the exergies and the exergy costings of the upgraded hot water from the CAHT system and the AHT system, respectively.

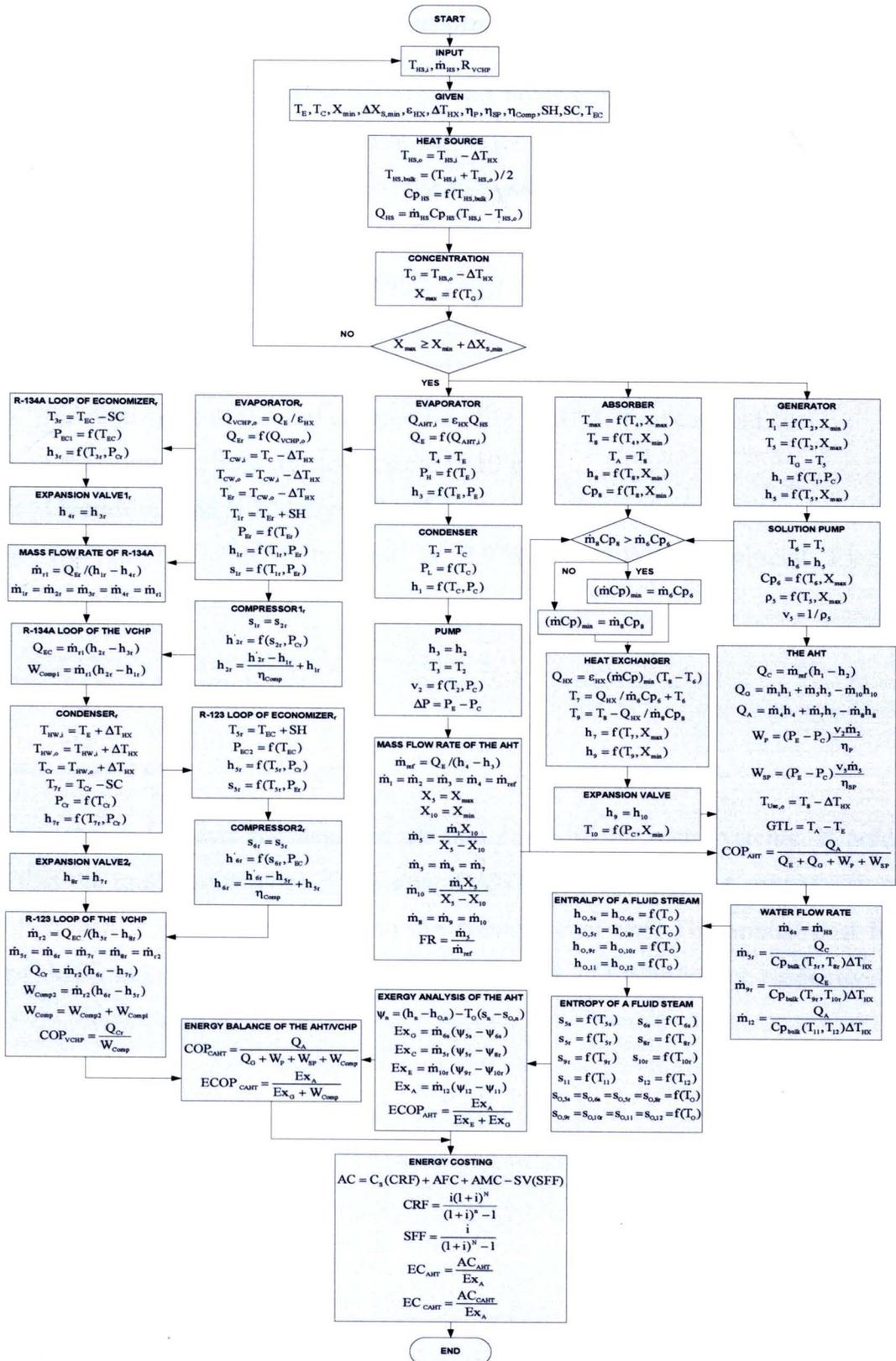


Figure 5.1 Flow chart of the simulation program for evaluating exergy costings of the solar-AHT and the solar-CAHT.

5.3 Operating Conditions and Assumptions

All calculations of the Solar-AHT and Solar-CAHT are based on the systems presented in Figure 4.1 and Figure 4.6. The H₂O-LiBr is the working pair of the AHT and R134a/R-123 is the refrigerant of the two-stage VCHP. The operating conditions for the evaluation are:

1. Annual maintenance cost of each system is 10% of investment cost.
2. Annual discount rate on loans (Minimum Retail Rate, MRR) is 6.45% (Krungthai Bank Public Company Limited, 2010).
3. Salvage value at the end of operation life is 10% of investment cost.
4. Operation life time of each system is 10 y.
5. Operation time is 300 d/y at 8 h/d.
6. The rate of electricity cost is 2.978 Baht/kWh (Provincial Electricity Authority, 2010).

5.4 Results and Discussions

5.4.1 Annual Cost

Table 5.1 shows the descriptions and costs of the both systems. It could be seen that the total annual cost of the solar-CAHT is lower than the annual cost of the modified unit is more beneficial than the conventional one. The annual cost for the solar-CAHT and the solar-AHT are 163,998 and 173,773 Baht/kW·y, respectively.

Table 5.1 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)	35	18
Capacities of hot water tank (l)	3,000	1,500
Hot water flow rate (\dot{m}_{s_s} , 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 (19,000 Baht/unit, Baht)	665,000	342,000
Investment cost (Baht)	875,000	702,000
Cost of electrical power ² (300 d/y, Baht)	15,091	36,690
Maintenance cost (5% of investment cost, Baht)	43,750	35,100
Salvage cost (10% of investment cost, Baht)	87,500	70,200
Annual cost ³ (AC, Baht)	173,773	163,998

Note: ¹ Heating capacity is 10 kW

² Electricity cost is 2.978 Baht/kWh.

³ Annual discount rate on loans (Minimum Retail Rate, MRR) is 6.45% and uses I_r of 12 months for evaluating.

32.44 Baht = 1 U.S. Dollar

5.4.2 Exergy Costing

From the previous results, it could be seen that the solar-CAHT has an advantage in term of the overall COP compared with the normal Solar-AHT. In addition, exergy and economics of the Solar-AHT and the solar-CAHT have been studied at the same useful heat capacity of about 10 kW_{th} at the absorber.

Figure 5.2 shows comparison of exergy coefficient of performance (ECOP) with time of the average day of April. It could be seen that ECOP of the solar-CAHT is lower than that of the solar-AHT at around 50% due to a higher exergy consumption at the compressor of the VCHP. However, for the average day of

September, the operating time of the solar-CAHT is higher than the solar-AHT which is around 5 hr and 2 hr, respectively. Moreover, annual exergy costing of the solar-CAHT is lower than the exergy costing of the modified unit is more beneficial than the conventional one. The annual exergy costing for the solar-CAHT and the solar-AHT are 95,178 and 144,366 Baht/kW·y, respectively.

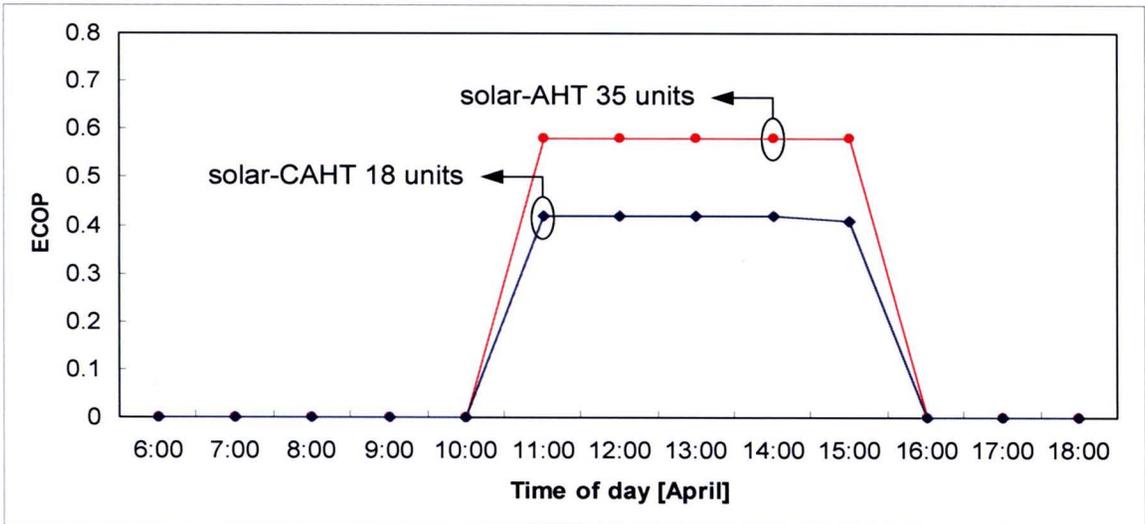


Figure 5.2 Comparison of the overall ECOP of the solar-AHT and the solar-CAHT on I_T during time of the average day of April at hot water temperature leaving the absorber around 90°C .

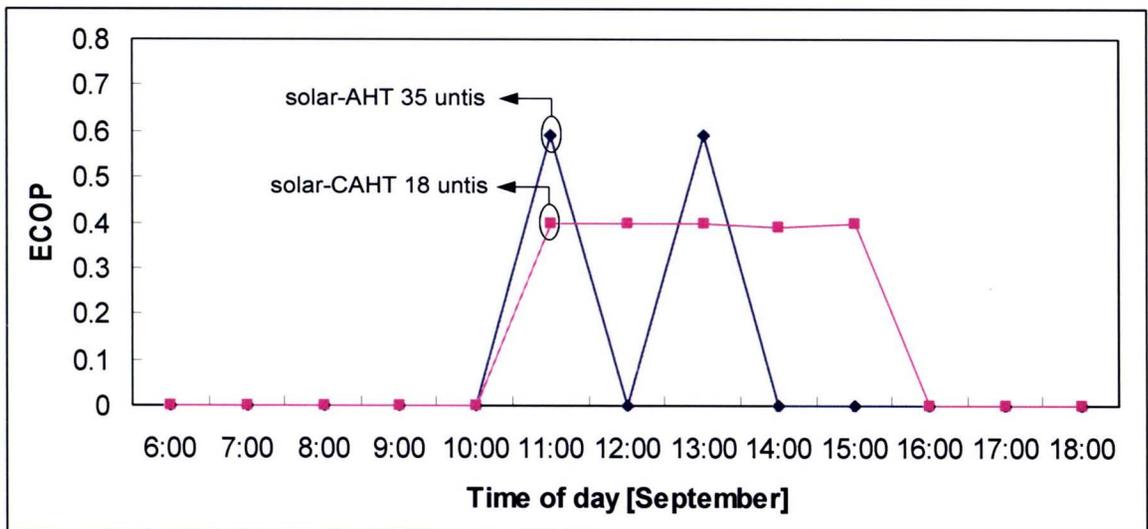


Figure 5.3 Comparison of the overall ECOP of the solar-AHT and the solar-CAHT on I_T during time of the average day of September at hot water temperature leaving the absorber around 90°C .

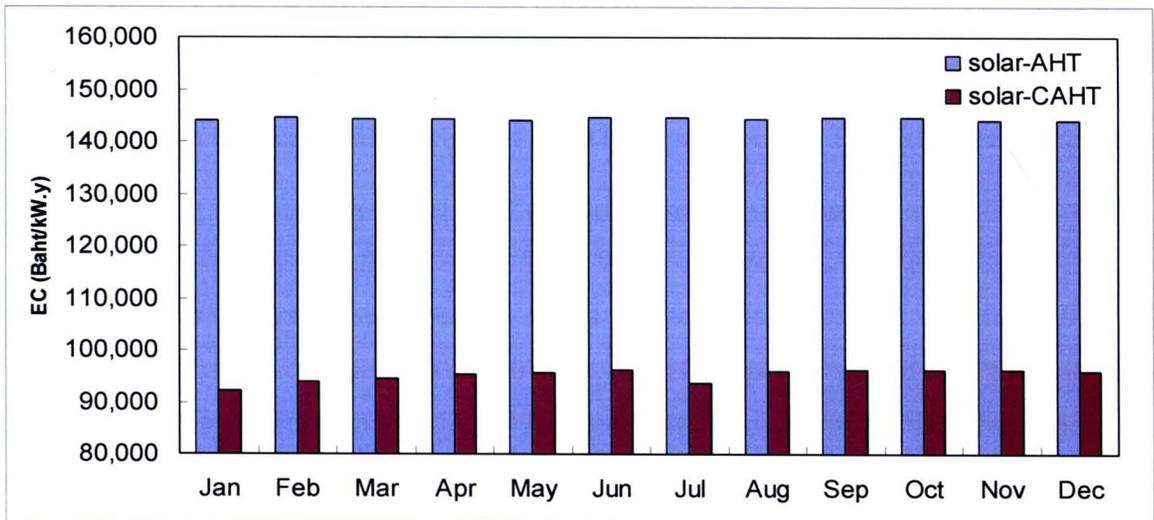


Figure 5.4 Comparison of the exergy costing of the solar-AHT and the solar-CAHT on I_T during time of each month at hot water temperature leaving the absorber around 90°C .

5.5 Conclusions

From this study, the conclusions are as follows:

1. Annual cost of the solar-CAHT unit is cheaper than the solar-AHT unit which is around 163,998 and 173,773 Baht/kW·y, respectively.
2. Exergy coefficient of performance (ECOP) of the solar-CAHT is lower than that of the solar-AHT at around 50% due to a higher exergy consumption at the compressor of the VCHP.
3. The annual exergy costing of the solar-CAHT unit is cheaper than the solar-AHT unit which is around 95,178 and 144,366 Baht/kW·y, respectively