Experimental Study and a Simplified Model of a 10 kW_{th} Solar-Absorption Heat Transformer

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Experimental study of a 10 kW_{th} single-stage LiBr-water absorption heat transformer (AHT) to boost up low temperature heat from a solar hot water system having a set of flat-plate solar collectors was carried out. The solar heat could be upgraded for generating hot water up to 100 °C which was around 20 °C higher than that of the input heat. The COP_{AHT} and EER_{AHT} of the AHT were around 0.42 and 4.1, respectively. A simplified model to predict the system performances such as the COP_{AHT} and EER_{AHT} was also developed and the results agreed well with those from the experiments.

Introduction

In general, heat will transfer from a high temperature heat source to a lower temperature heat sink and if we want to reverse the heat direction, a heat driven machine is needed.

Absorption heat transformer (AHT) is one method for upgrading low temperature heat to a higher temperature level. Low temperature heat is absorbed at the AHT generator and the AHT evaporator and then 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. Rivera et al [1] presented a single-stage and advanced AHT operating with water-LiBr and water-Carrol™ mixtures to increase the temperature of the useful heat produced by solar pond. 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. Xuehu et al. [2] 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 °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. The payback was approximately 2 years. Sotsil Silva Sotelo et al. [3] presented an AHT cycle operating with water-Carrol™ 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.

The main objective of this work was to study thermal performance of a10 kW_{th} single-stage LiBr-water absorption heat transformer (AHT) to boost up low temperature heat from a solar hot water system supplying heat from a set of flat-plate solar collectors. A simplified model to predict the system performances such as the COP_{AHT} and EER_{AHT} was also developed.

Solar-Absorption Heat Transformer

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

At the 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 condenser at a condenser temperature (T_C) to be liquid at state 2. After that the absorbate in liquid phase is pumped to the evaporator at state 3 of which the pressure (P_E) is higher than that of the condenser. The evaporator is heated at a medium temperature (T_E) and the absorbate in a form of vapor enters the absorber which has the same pressure as the evaporator at state 4. Meanwhile liquid mixture from the generator, at state 5 is pumped through a heat exchanger (state 6) into the absorber to a high pressure at state 7. In the 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 absorber is then throttled to a low pressure through the heat exchanger at state 9 into the generator again at state 10 and new cycle restarts.

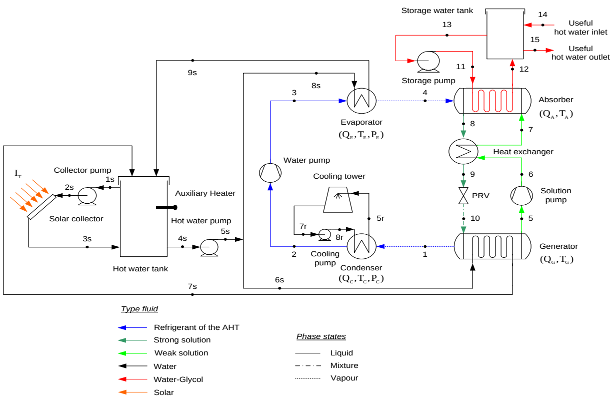

Fig. 1. The schematic diagram of the Solar-AHT.

Fig. 2 also shows the constructed absorption heat transformer and Table 1 gives the specifications of its components.

Fig. 2 The absorption heat transformer.

Table 1 Descriptions of each component in the constructed Solar-AHT.

Devices	Properties
Solar collector	Flat-plate solar collector Area 2.3 $m^2/unit$ $F_R(\tau\alpha)$ = 0.802
	$F_R U_L$ = 10.37 $W/m^2 \cdot K$
Generator	Flooded shell and tube heat exchanger Capacity 10.3 kW Area 1.02 m^2
Condenser	Shell and tube heat exchanger Capacity 10.6 kW Area 0.42 m^2
Absorber	Flooded shell and tube heat exchanger Capacity 10 kW Area 1.44 m^2
Evaporator	Shell and tube heat exchanger Capacity 10.8 kW Area 1.16 m^2
Pressure reducing valve	Capacity 10 kW Pressure ratio 6.00
Hot water tank (Solar water heater)	Capacity 1,500 $liter$
Storage tank(AHT side)	Capacity 200 $liter$

The solar water heating system got solar heat from 10 units of flat-plate solar collectors each in parallel connection. There was an auxiliary heater to control the water temperature in the hot water tank not to be lower than 70 $^{\circ}C$. The study was carried out when the hot water at the storage tank (AHT absorber side) were used and non-used.

Results

Fig. 3 shows the temperature profile of the AHT when the unit got supplied heat form the solar water heating system. The high temperatures at the generator (T_G) and the evaporator (T_E) were nearly constant and the heat rate was around 10 kW for each component. It could be found that T_G and T_E were around 75 $^{\circ}C$ while the temperature T_C at the condenser was around 40 $^{\circ}C$. The absorber generated the output heat at a temperature (T_A) around 100 $^{\circ}C$.

From the experimental results, it could be seen that the maximum temperature of the prototype machine was around 105 $^{\circ}C$ and hot water in storage tank does not used.

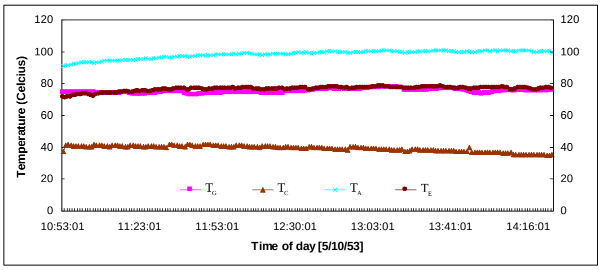

Fig. 3 The temperature profiles of the AHT system for non-used hot water in tank.

Fig. 4 shows COP_{AHT} and energy efficiency ratio (EER_{AHT}) with $(T_{A,i} - T_E)/(T_{G,i} - T_C)$ when water in the storage tank (AHT side) was used and non-used.

In both cases, use and non-use of hot water, when the value of $(T_{A,i} - T_E)/(T_{G,i} - T_C)$ increased the COP_{AHT} and the EER_{AHT} decreased due to lower extracted heat at the absorber. When hot water was used, the COP_{AHT} and EER_{AHT} were higher than those of another case since the hot water temperature in the storage tank was lower thus the absorption could supply more heat. 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:

$$COP_{AHT} = -1.0444(T_{A,i}-T_E)/(T_{G,i}-T_C) + 0.7619. \qquad (1)$$

For non-used hot water condition:

$$COP_{AHT} = -0.9599(T_{A,i}-T_E)/(T_{G,i}-T_C) + 0.5845. \qquad (2)$$

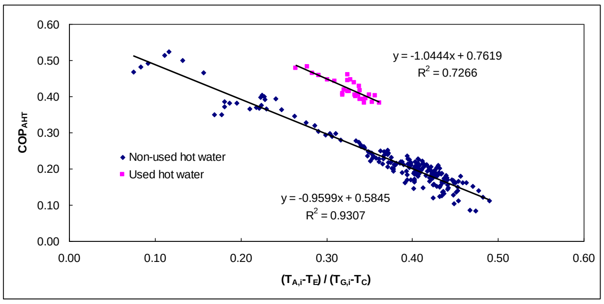

Fig. 4 Effect of $(T_{A,i} - T_E)/(T_{G,i} - T_C)$ on COP_{AHT} of the AHT.

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

For used hot water condition:

$$EER_{AHT} = -10.463(T_{A,i}-T_E)/(T_{G,i}-T_C) + 7.5228. \qquad (3)$$

For non-used hot water condition:

$$EER_{AHT} = -9.4407(T_{A,i}-T_E)/(T_{G,i}-T_C) + 5.6852. \qquad (4)$$

The simulation programs for calculating the temperatures of water in the storage tank and EER are given in Appendixes A and B. Figs. 5 -6 show the system performances. It could be seen that the simulation results agreed well with those of the experimental data.

Fig. 5 shows the simulated results of the EER_{AHT} during an operation when there is no use of generated hot water. This figure also shows the temperature of water-glycol solutions in the storage tank 200 liter. It could be seen that the simulated results agree well with the measured data which increasing hot water temperature effects EER_{AHT} decreased due to a higher pressure at the absorber which reduces the mass flow rate of refrigerant and strong solutions entering to absorber affects to the absorption process.

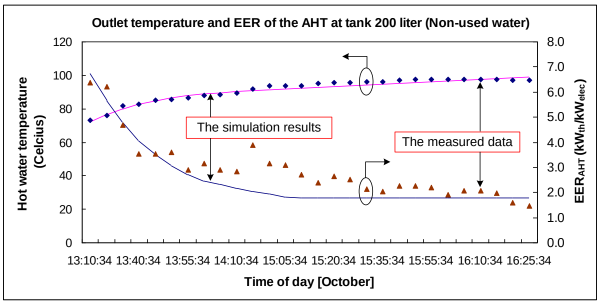

Fig. 5 The measured data and the simulation results of hot water temperature from the AHT (hot water is not used).

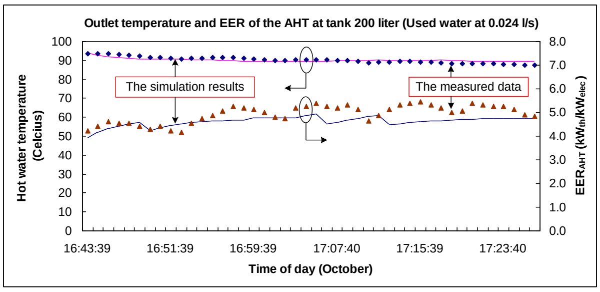

Fig. 6 The measured data and the simulation results comparison of hot water temperature from the AHT at flow rate 0.024 l/s (hot water is used).

Fig. 6 also shows the EER_{AHT} when the generated hot water is used at a flow rate of 0.024 l/s. For used hot water, the EER_{AHT} was higher than that of the non-used hot water because the absorption could extract heat better. This Figure gave the hot water temperature in the storage tank which was nearly constant at 90 °C. The simulated results agreed well with the measured data. The hot water temperature was nearly constant, moreover, it could be seen that the EER_{AHT} was nearly constant too at around 4.1 approximately.

Conclusions

From this study, the conclusions are as follow:

1. A 10 kW_{th} single-stage absorption heat transformer (AHT) to boost up solar heat could be upgraded heat to around 100 °C which increases around 20 °C of input heat.
2. The COP_{AHT} and EER_{AHT} of the Solar-AHT were around 0.42 and 4.1, respectively.

Acknowledgement

The authors would like to thank the Graduate School and Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University for supporting testing facilities. Highly acknowledge to the Office of the Higher Education Commission, Ministry of Education, Thailand under the Project "Development and Upgrading of Renewable Energy and Its Applications" and Daikin Industries (Thailand) Ltd for the budget support.

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Nomenclature

EER	Energy efficiency ratio, (kW_{th}/kW_{elec})
COP	Coefficient of performance, (-)
P	Pressure, (Bar)
Q	Heat rate, (kW)
T	Temperature, (°C)

Greek symbol

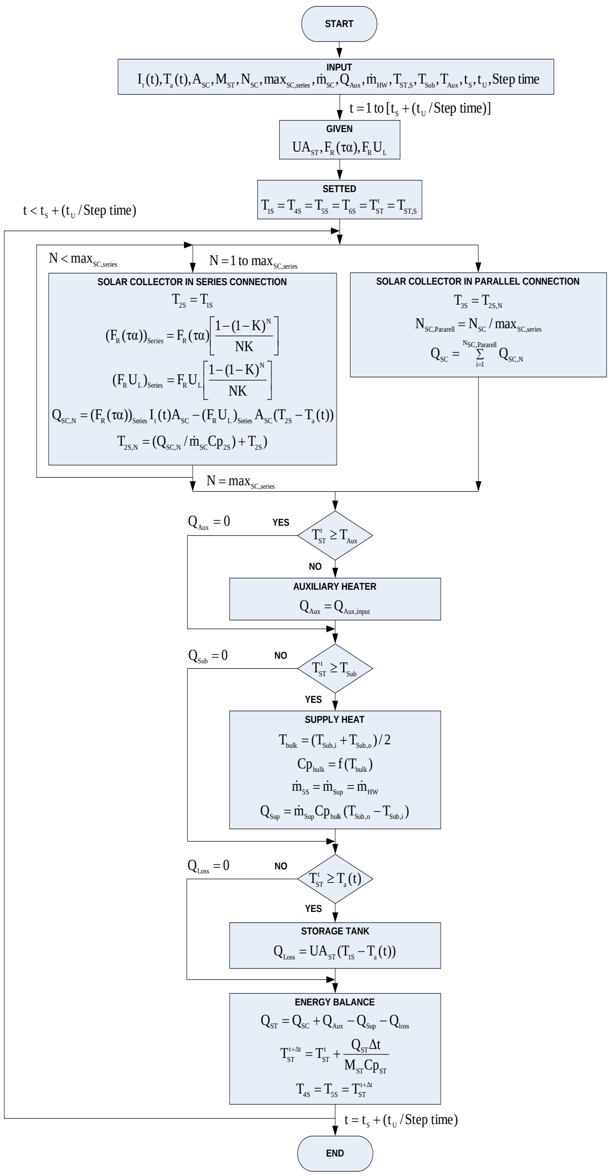
$F_R(\tau\alpha)$	Heat removal factor
$F_R U_L$	Heat loss factor, ($W/m^2 \cdot K$)

Subscript

A	Absorber
AHT	Absorption heat transformer
C	Condenser
Comp	Compressor
E	Evaporator
G	Generator
P	Pump
S	Solar

Appendix

A) Flow chart of simulation the solar water heating system



B) Flow chart of simulation the absorption heat transformer