



13th IEA Heat Pump Conference  
April 26-29, 2021 Jeju, Korea

## Study on a combined absorption heat pump system driven by low temperature heat source

Gabyong Kim<sup>a</sup>, Han Sol Jung<sup>a</sup>, Yong Tae Kang<sup>b\*</sup>

<sup>a</sup> Graduate School of Mechanical Engineering, Korea University, Seoul, 02841, Republic of Korea

<sup>b</sup> Department of Mechanical Engineering, Korea University, Seoul, 02841, Republic of Korea

### Abstract

In this study, type 1 and type 2 combined absorption heat pump system using R32/DMAC is developed for heating and cooling applications. Waste heat from the heat with low temperature (below 90°C) is utilized as the heat source. R32 and an organic fluid of DMAC (Dimethylacetamide) are used as refrigerant and absorbent, respectively. Additionally, the combined heat pump system has two splitters placed after the generator outlet and condenser outlet. Cooling, heating and system coefficient of performance (COP) are calculated according to the change of generator temperature. The maximum cooling COP is estimated as 0.400, the maximum heating COPs with and without superheat are 0.196 and 0.161, respectively. Maximum system COP is estimated as 0.596. It is found that the heating performance of the system is more sensitive to the generator temperature than the cooling performance.

*Keywords:* 1<sup>st</sup> and 2<sup>nd</sup> Type Combined Absorption heat pump, COP, Low temperature heat source, R32

### 1. Introduction

Research and development on low GWP refrigerants have been actively proceeded. In addition, fossil fuels are the main cause of micro dust that directly affects the respiratory diseases, and regulations on the use of fossil fuel are being tightened. International efforts are being made in response to these environmental regulations. After the Fukushima nuclear accident in 2011, Japan declared its de-nuclearization policy and halted the nuclear power plant sequentially, causing the problems in energy supply and demand. To solve this problem, they have introduced Ene-farm that uses hydrogen as an alternative energy. The Ene-farm is a combined fuel cell system that generates 0.7kW of auxiliary power in consideration of economic feasibility, and the waste heat from the electricity production process is used for heating. The amount of waste heat generated in the process in fuel cells takes about 50% of total chemical energy and the operating temperature ranges from 80 to 1300°C depending on electrolyte type of each fuel cell. Waste heat from Ene-farm is only used as a hot water supply device, so its use is limited. In addition, as the operating temperature of the PEMFC is only 70-80°C [1], the waste heat from this is more limited. Furthermore, although research on energy recovery system using solar energy is being actively conducted, its use is also limited because it generates 60 to 70°C when solar energy is collected.

Regarding the development of absorption cycles, working fluid pairs (refrigerant/absorbent) are as important as all the components of absorption cycles. H<sub>2</sub>O/LiBr and NH<sub>3</sub>/H<sub>2</sub>O are most widely used at present. Despite the outstanding performance of the existing pairs, as shown in Table 1, these pairs have some critical disadvantages. H<sub>2</sub>O/LiBr doesn't work under the generator temperature of 90°C and it has the freezing problem under 0°C. To deal with these problems, the use of an alternative refrigerant and absorbent as a working pair for the absorption refrigeration cycle has been proposed. Therefore, in this study, a sorption heat pump that uses waste heat from the low temperature heat source (which is lower than the temperature of 90°C)

\* Corresponding author. Tel.: 82-2-3290-5952; fax: 82-2-922-3260.  
E-mail address: [ytkang@korea.ac.kr](mailto:ytkang@korea.ac.kr).

is proposed. The sorption heat pump system uses alternative refrigerant and organic liquid as absorbent, which can solve the problems mentioned above at the same time.

Table 1 Characteristics of representative refrigerants for absorption refrigeration system

	NH <sub>3</sub> /H <sub>2</sub> O	H <sub>2</sub> O/LiBr
Absorbent	H <sub>2</sub> O	LiBr
Refrigerant	NH <sub>3</sub>	H <sub>2</sub> O
Crystallization	N	Y
Toxicity	Y	N
Flammability	Y	N
Disadvantages	1. Flammable, Explosive, Toxic 2. Regulated by national regulations	1. Frozen/refrigeration system: Not applicable 2. Difficulty in air cooling due to high boiling point of refrigeration

2. Simulation Methodology

2.1. Description of Type 1 and Type 2 combined sorption heat pump

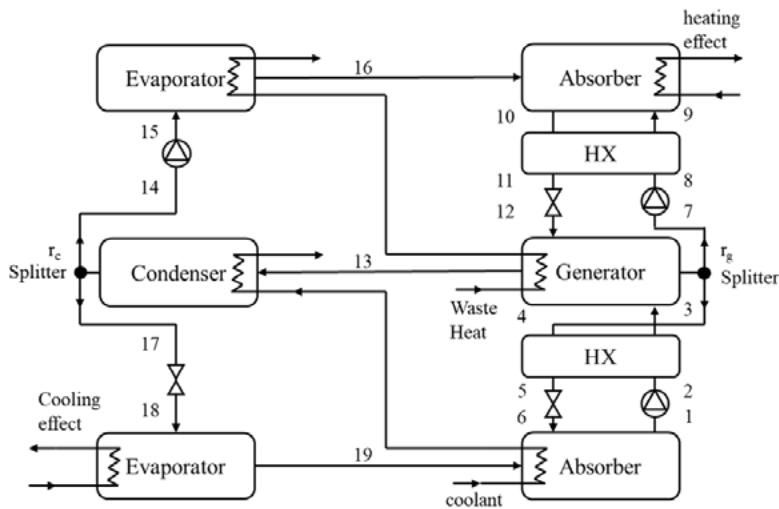


Figure 1. Schematic diagram of type 1 and type 2 combined sorption heat pump cycle

Figure 1 is a schematic diagram of Type 1 and Type 2 combined sorption heat pump system. The refrigerant and absorbent mixed solution is transferred from the low temperature absorber to the generator through the pump and the generated refrigerant which is recovered at the generator by absorbing the waste heat from the low temperature heat source moves to the condenser. Splitter attached to the generator splits the solution to be transferred to the high and low temperature absorbers. The refrigerant transferred to the condenser is fully condensed in the condenser. The liquid refrigerant is transferred to the high temperature evaporator and the low temperature evaporator through a splitter attached to the condenser. The refrigerant transferred to the high temperature evaporator is compressed by a pump, and the refrigerant transferred to the low temperature evaporator is expanded in the expansion valve. In the high temperature evaporator, the residual heat which already supplied to the generator is absorbed by the refrigerant.

The evaporated refrigerant from the high temperature evaporator is absorbed in the high temperature absorber, raises the temperature of the high temperature absorber outlet solution, and transfers heat to the heating target. Whereas, the refrigerant transferred to the low temperature evaporator is evaporated while cooling the target system in the low temperature evaporator and is retrieved to the low temperature absorber.

## 2.2. Selection of refrigerant and absorbent pair

After considering toxicity, safety, stability, flammability and corrosivity problems, R32 which is an alternative refrigerant for R410A and R407C has received much attention in recent years. R32 has about one third lower GWP than that of R410a and has an ODP of zero. Furthermore, R32 requires less charge as it has a 20% higher volumetric capacity. By considering the critical-point which is higher than R410A's, heat capacity and saturation pressure difference, R32 is finally selected. Due to the negligible vapor pressure, good thermal and chemical stability and solubility with many refrigerants, DMAC is considered as a promising absorbent for the combined sorption cycles.

## 2.3. Cycle modelling of the sorption cycle

During the cycle simulation process, the following assumptions are made.

- (1) Steady state.
- (2) The pressure drop is negligible.
- (3) Condensation and evaporation occur completely in condenser and evaporator, respectively.
- (4) The effectiveness of the solution heat exchanger is assumed 0.8. [2]

The entire simulation of the sorption heat pump is carried out using the Engineering Equation Solver (EES).

### 2.3.1. Mass and species conservations

Principles of mass and energy conservations are considered for each component of the system as follows.

- Mass balance

$$0 = \sum \dot{m}_i - \sum \dot{m}_o \quad (1)$$

$$0 = \sum \dot{m}_i(1 - x_i) - \sum \dot{m}_o(1 - x_o) \quad (2)$$

- Energy balance

$$0 = \sum \dot{m}_i h_i - \sum \dot{m}_o h_o + \sum \dot{Q}_i - \sum \dot{Q}_o + \dot{W} \quad (3)$$

- Solution pump

$$h_o = h_i + \frac{\dot{W}_p}{\dot{m}_i} \quad (5)$$

- Expansion valve

For refrigerant and solution pump expansion valves, the isenthalpic processes are assumed.

$$h_o = h_i \quad (6)$$

### 2.3.2. COP

The heat recovered by the high temperature evaporator was excluded from the calculation. This is because the remaining heat is used instead of the heat source for operation.

$$COP_{cooling} = \frac{\dot{Q}_{evap}}{\dot{Q}_{gen} + \dot{W}_{pump}} \quad (7)$$

$$COP_{heating} = \frac{\dot{Q}_{abs,high}}{\dot{Q}_{gen} + \dot{W}_{pump}} \quad (8)$$

$$COP_{system} = \frac{\dot{Q}_{abs,high} + \dot{Q}_{evap}}{\dot{Q}_{gen} + W_{pump}} \quad (9)$$

### 3. Results and discussion

The condenser outlet temperature ( $T_{cond}$ ) and the low temperature absorber outlet temperature ( $T[1]$ ) are set to 30°C, respectively. The low temperature absorber outlet mass flow rate is set to 0.1 (kg/s), and the split ratios of generator and condenser are 0.5, respectively as the base lines as summarized in Table 2.

Table 1 Characteristics of representative refrigerants for absorption refrigeration system

$T_{gen}$ (°C)	$T_{cond}$ (°C)	$T[1]$ (°C)	$T[10]$ (°C)	$m[1]$ (kg/s)	$T_{16}$ (°C)	$r_g r_c$
66~70	30	30	75	0.1	45~50	0.5

#### 3.1. Effect of the generator temperature on the cooling and heating performances

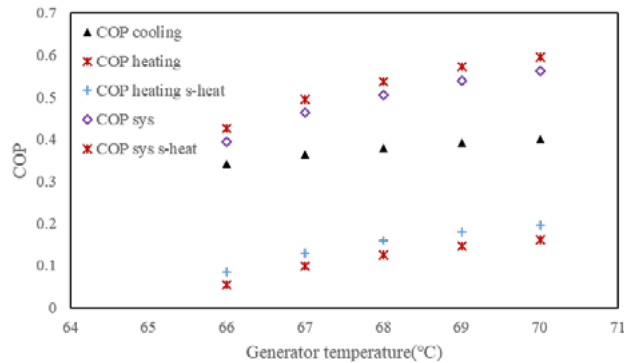


Figure 2. Effect of generator temperature on COP

Figure 2 shows the COPs according to the generator temperature change. As the generator temperature increases, cooling COP ( $COP_{cooling}$ ) and heating COP ( $COP_{heating}$ ) increases. The maximum cooling COP and heating COP are calculated 0.400 and 0.161, respectively, at the generator temperature of 70°C. When heat is recycled in the high temperature evaporator, i.e., when the refrigerant passing through the high temperature evaporator is heated to 50°C, it always shows a higher performance and the maximum heating COP with superheat ( $COP_{heating\ s-heat}$ ) is calculated 0.196 which is 0.035 higher than the heating COP without superheat because the heat recycled in the high temperature evaporator is directly used to increase the heat capacity in the high temperature absorber. Maximum system COP without superheat consideration ( $COP_{sys}$ ) is calculated 0.561 and COP with superheat consideration ( $COP_{sys\ s-heat}$ ) is calculated 0.596 at the temperature of 70°C. When the generator temperature increases 4°C from 66°C, cooling COP, heating COP, and heating COP with superheat increase 17.4%, 197.9%, and 134.0%, respectively. From this result, the heating COPs are more sensitive to the generator temperature than the cooling COP because as the generator temperature increases, the amount of heat delivered to the high temperature absorber by solution increases.

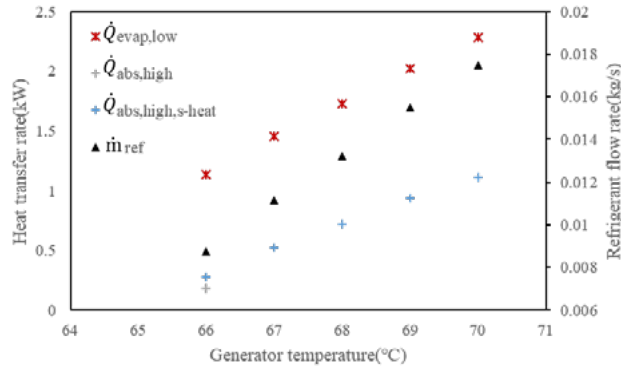


Figure 3. Effect of generator temperature on heat transfer rate and refrigerant generation

Figure 3 shows the heat transfer rate and refrigerant mass flow rate according to the generator temperature. As the generator temperature increases, the total generated refrigerant flow rate ( $\dot{m}_{ref}$ ) and heat transfer rate in low temperature evaporator and high temperature absorber increase. Maximum heat transfer rate of low temperature evaporator ( $\dot{Q}_{evap,low}$ ), high temperature absorber ( $\dot{Q}_{evap,low}$ ) without superheat and high temperature absorber with superheat ( $\dot{Q}_{abs,high,s-heat}$ ) are calculated 2.280kW, 0.9157kW and 1.114kW, respectively. Maximum generated refrigerant flow rate is calculated 0.0175kg/s. When the generator temperature increases from 66(°C) to 70(°C), the generator refrigerant flow rate increases 100.2% at the temperature of 70(°C). It is found that the heat transfer rates are improved, as the generator temperature increases, which makes refrigerant flow rate increase. The results for each state point are summarized in Table 3.

Table 3 Results for the state points of the cycle ( $T_e = 5^\circ\text{C}, T_c = 30^\circ\text{C}$ )

	$T(^{\circ}\text{C})$	$P(\text{kPa})$	$h(\text{kJ/kg})$	$\dot{m}(\text{kg/s})$	Concentration	Quality
[1]	30.0	951.5	212.2	0.1	0.386	
[2]	30.0	1928.0	212.2	0.1	0.386	
[3]	59.8	1928.0	286.0	0.1	0.386	
[4]	70.0	1928.0	305.8	0.09126	0.327	
[5]	38.0	1928.0	225.0	0.09126	0.327	
[6]	37.1	951.5	225.0	0.09126	0.327	
[7]	70.0	1928.0	305.8	0.09126	0.327	
[8]	70.0	2254.0	305.8	0.09126	0.327	
[9]	74.6	2254.0	319.0	0.09126	0.327	
[10]	75.0	2254.0	326.9	0.1	0.386	
[11]	71.0	2254.0	314.8	0.1	0.386	
[12]	65.6	1928.0	314.8	0.1	0.386	
[13]	70.0	1928.0	570.0	0.01749		1.000
[14]	30.0	1928.0	255.3	0.008743		0.000
[15]	30.1	2254.0	255.3	0.008743		0.000
[16]	36.2	2254.0	514.1	0.008743		1.000
[17]	30.0	1928.0	255.3	0.008743		0.000
[18]	5.0	951.5	255.3	0.008743		0.151
[19]	5.0	951.5	516.1	0.008743		1.000

#### 4. Conclusions

The performance of the type 1 and type 2 combined sorption heat pump using the waste heat from the low temperature heat sources according to the change of generator outlet concentration and the split ratio at the

generator is analyzed. The working fluid pair is selected for the sorption heat pump using an alternative refrigerant R32 as refrigerant and organic liquid DMAC as absorbent. The following conclusions are drawn from the present study.

1. Between the generator temperature of 66°C and 70°C, the maximum cooling COP, maximum heating COPs with and without superheat are calculated 0.400, 0.196, and 0.161, respectively when the generator temperature is 70°C. Heating COP is more sensitive to the generator temperature because as the temperature of the generator increases, heat supplied to the refrigerant of the high temperature absorber increases.

2. Heat transfer rate at the low temperature evaporator and high temperature absorber increases as the generator temperature increases because as the generator temperature increases, refrigerant flow rate increases due to the P-T-X equilibrium. Maximum heat transfer rates of low temperature evaporator, high temperature absorbers without and with superheat are calculated 2.280kW, 0.9157kW and 1.114kW, respectively.

### Acknowledgements

This work was supported by Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(MOTIE) (No. 10060218, The development of cooling capacity 200RT class triple effect gas fired absorption chiller).

### References

- [1] Fly, A, Thring, R, H. Temperature regulation in an evaporatively cooled proton exchange membrane fuel cell stack. *International Journal of Hydrogen Energy* 2015; 40:11976-82.
- [2] Wu, W., You, T., Zhang, H., Li, X. Comparisons of different ionic liquids combined with trans-1, 3, 3, 3-tetrafluoropropene (R1234ze (E)) as absorption working fluids. *International Journal of Refrigeration* 2018; 88:45-7.
- [3] Li, X., Zheng, D., Shen, Y., Meng, X., Li, B. Vapor-liquid equilibria of difluoromethane+ N, N-dimethylacetamide, difluoromethane+ dimethylether diethylene glycol and 1, 1-difluoroethane+ dimethylether diethylene glycol systems. *Fluid Phase Equilibria* 2013; 347:15-21.