



14<sup>th</sup> IEA Heat Pump Conference  
15-18 May 2023, Chicago, Illinois

# Numerical evaluation of simultaneous cooling and heating absorption system using H<sub>2</sub>O/ionic liquid and R32/ionic liquid as working fluids

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## Abstract

H<sub>2</sub>O/LiBr and NH<sub>3</sub>/H<sub>2</sub>O are commonly used as working fluids of absorption system in that they present high solubility of refrigerant in absorbent. However, the conventional working fluids need to be substituted considering causticity and toxicity. In this study, a simultaneous cooling and heating absorption system, which is combination of type 1 and type 2 absorption systems, has been analyzed using the numerical methods to improve the coefficient of performance (COP) for heating/cooling applications. The ionic liquid absorbents including imidazole, which has non-causticity and non-toxicity, are utilized as working fluids. H<sub>2</sub>O and R32 refrigerants are also utilized as working fluids. The thermophysical properties are evaluated by using the non-random two liquid (NRTL) model. The variation of COP is analyzed according to split ratio and generation temperature of each component. It is found that the maximum COP<sub>tot</sub> of H<sub>2</sub>O/LiBr, H<sub>2</sub>O/IL, R32/IL are 0.9000, 0.8481 - 0.9066 and 0.4084, respectively. It is also confirmed that when using H<sub>2</sub>O/IL, better performance of the absorption system is expected than when using R32/IL, and the crystallization, causticity and toxicity problems are also expected to be solved.

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*Keywords: Absorption system, COP, H<sub>2</sub>O, Ionic liquid, R32, Simultaneous cooling and heating.*

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## 1. Introduction

The conventional NH<sub>3</sub>/H<sub>2</sub>O system has problems with refrigerant toxicity, and the H<sub>2</sub>O/LiBr system has problems such as crystallization of the absorbent and corrosion with metals. In addition, international regulations are being strengthened step by step to use low global warming potential (GWP) refrigerants after the Montreal Amendment in 1997, the Beijing Amendment in 1999, and the Kigali Amendment in 2016. For this reason, there is a need for research on a new working fluid of absorption type systems.

Ionic liquids have been attracting attention as working fluids due to their unique properties. Kim et al. [1] showed that ionic liquids can maintain a liquid state even at room temperature or below room temperature. Paulechka et al. [2] found that the vapor pressure of ionic liquids is negligible. Domańska et al. [3] confirmed incombustibility and thermal stability, and Trindade et al. [4] confirmed low melting point and high refrigerant solubility, so that it can exist in a liquid state at room temperature. It is expected that these characteristics solve the problems of the previous absorption systems.

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However, although there is a demand for a simultaneous cooling and heating absorption system in that waste heat can be recovered, there are not many prior studies. In this study, four different working fluids using an ionic liquid as an absorbent were selected based on the previous studies that resulted in a high COP in type 1 absorption system and they were applied to the simultaneous cooling and heating absorption system. Finally, cooling COP, heating COP and total COP were compared according to the variations of split ratio and generation temperature.

## 2. Research method

### 2.1. Selecting working fluid

H<sub>2</sub>O and R32 were selected as the refrigerant, and the reasons are as follows. In the case of H<sub>2</sub>O, the most commercialized working fluid in the previous absorption system is H<sub>2</sub>O/LiBr, R32 refrigerant has a smaller specific volume than H<sub>2</sub>O, which is advantageous for miniaturization. R32 is HFC and has greater solubility in ionic liquids than HFO.

As the absorbent, imidazolium (C<sub>3</sub>H<sub>4</sub>N<sub>2</sub>) ionic liquid was selected. Imidazolium ionic liquid is known as the most stable material among the ionic liquids, and it is easier to obtain necessary physical property data than other ionic liquids because physical properties are measured relatively often. [DMIM][DMP], [EMIM][DMP], and [EMIM][BF<sub>4</sub>] were selected as the absorbent for H<sub>2</sub>O, and [HMIM][Tf<sub>2</sub>N] as the absorbent for R32.

### 2.2 Simulation model

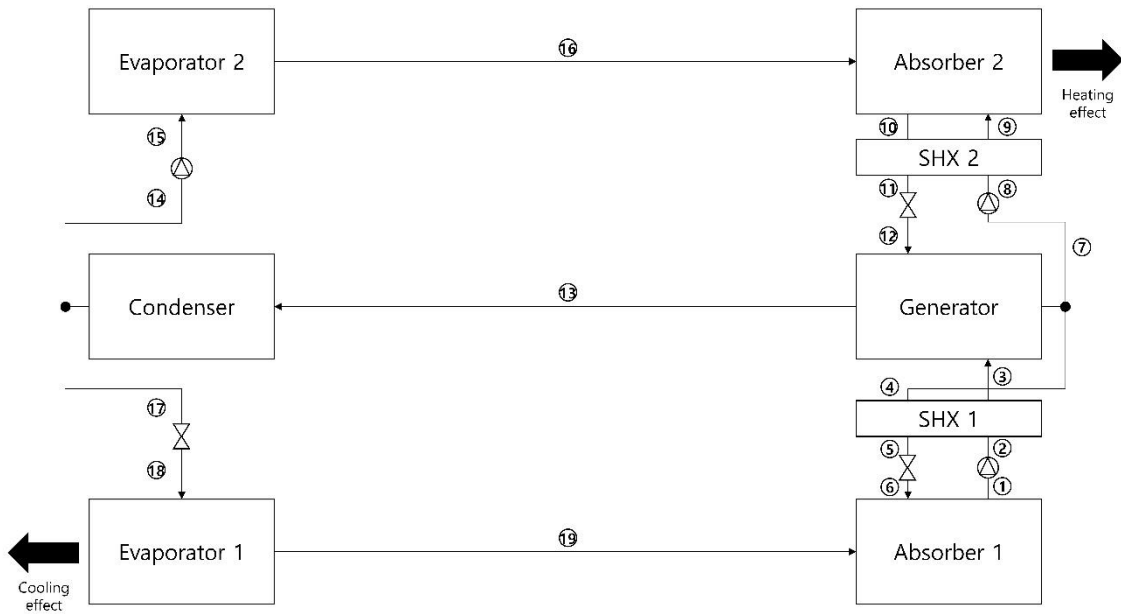


Fig. 1. Schematic diagram of the simultaneous cooling and heating absorption system.

Figure 1 shows the schematic diagram of the simultaneous cooling and heating absorption system. It is a combination of type 1 and type 2 absorption systems. Cooling COP, heating COP and total COP are analyzed under various conditions. To evaluate performance of the system, split ratio and COP were defined as follows;

$$r_g = \frac{\dot{m}_7}{\dot{m}_4 + \dot{m}_7} \quad (1)$$

$$r_c = \frac{\dot{m}_{14}}{\dot{m}_{14} + \dot{m}_{17}} \quad (2)$$

$$COP_c = \frac{\dot{Q}_{eva1}}{\dot{Q}_{gen} + W_{pump}} \quad (3)$$

$$COP_h = \frac{\dot{Q}_{abs2}}{\dot{Q}_{gen} + W_{pump}} \quad (4)$$

$$COP_{tot} = COP_c + COP_h \quad (5)$$

where  $r_g$  is the split ratio of the generator;  $r_c$  is the split ratio of the condenser,  $COP_c$  is cooling COP,  $COP_h$  is heating COP,  $COP_{tot}$  is the total COP,  $\dot{Q}_{gen}$  is the heat absorbed by the generator,  $\dot{Q}_{eva1}$  is the heat absorbed by the low-temperature evaporator,  $\dot{Q}_{abs2}$  is the heat emitted by the high-temperature absorber and  $W_{pump}$  is the pump work.  $COP_c$ ,  $COP_h$  and  $COP_{tot}$  are analyzed under various conditions.

In the previous studies, the correlations for the thermal properties of the refrigerant/ionic liquid solution are established using the VLE (vapor-liquid equilibrium) equation and the NRTL (Non-Random Two-Liquid) model. The NRTL model is a chemical model that uses three interaction parameters to obtain an activity coefficient for the phenomenon of deviating from an ideal solution to which the Raoult's law is applied, and uses it to calculate the VLE equation [5–7].

$$Y_i p \Phi_i = X_i \gamma_i p_i^s \quad (i = 1, 2) \quad (6)$$

$$\Phi_i = \exp \left[ \frac{(B_i - V_i^L)(p - p_i^s)}{RT} \right] \quad (7)$$

$$\ln \gamma_1 = X_2^2 \left[ \tau_{21} \left( \frac{G_{21}}{x_1 + x_2 G_{21}} \right)^2 + \frac{\tau_{12} G_{12}}{(x_2 + x_1 G_{12})^2} \right] \quad (8)$$

$$\ln \gamma_2 = X_1^2 \left[ \tau_{12} \left( \frac{G_{12}}{x_2 + x_1 G_{12}} \right)^2 + \frac{\tau_{21} G_{21}}{(x_1 + x_2 G_{21})^2} \right] \quad (9)$$

$$G_{12} = \exp(-\alpha \tau_{12}), \quad G_{21} = \exp(-\alpha \tau_{21}) \quad (10)$$

$$\tau_{12} = \tau_{12}^0 + \frac{\tau_{12}^1}{T}, \quad \tau_{21} = \tau_{21}^0 + \frac{\tau_{21}^1}{T} \quad (11)$$

where  $Y_i$  is the vapor molar concentration of  $i$ th species;  $X_i$  is the liquid molar concentration of  $i$ th species;  $p$  is the vapor pressure of the solution;  $p_i^s$  is the saturated vapor pressure of  $i$ th species;  $\Phi_i$  is the correction factor for  $i$ th species;  $\gamma_i$  is the activity coefficient for  $i$ th species;  $B_i$  is the second virial coefficient of  $i$ th species;  $V_i^L$  is the saturated molar liquid volume of  $i$ th species;  $R$  is the ideal gas constant (8.314 kJ/kmol·K),  $T$  is the temperature, and  $\alpha$ ,  $\tau_{12}^0$ ,  $\tau_{12}^1$ ,  $\tau_{21}^0$ ,  $\tau_{21}^1$  are adjustable parameters regressed through data from the experimental studies of each solution.

In the simultaneous cooling and heating absorption system, the generator receives waste heat and generates the refrigerant from strong solution. Generated refrigerant moves to the condenser, and the remaining weak solution moves through the splitter to the high temperature solution heat exchanger and the low-temperature solution heat exchanger. In each solution heat exchanger, heat exchange between the strong solution and the dilute solution is performed. After the heat exchange, the weak solutions move to a high-temperature absorber and a low-temperature absorber, respectively. The condenser condenses the generated refrigerant vapor, and the condensed refrigerant moves to the high-temperature evaporator and the low-temperature evaporator through a splitter. Each evaporator evaporates the liquid refrigerant, and a cooling effect corresponding to the cooling load occurs in the low-temperature evaporator. The evaporated refrigerant moves to the absorber and is absorbed by the weak solution to form a strong solution. The strong solution exits the absorber, passes through the solution heat exchanger, and returns to the generator. The simulation conditions for R32/[HMIM][Tf<sub>2</sub>N] and H<sub>2</sub>O/[DMIM][DMP], [EMIM][DMP], [EMIM][BF<sub>4</sub>] are summarized in Table 1 and 2, respectively.

Table 1. Simulation condition of R32/[HMIM][Tf<sub>2</sub>N]

Location	1	10	14, 17	16	19
Temperature	30 °C	77 °C	30 °C	50 °C	5 °C
Pressure	813.2 kPa	3141 kPa	1928 kPa	3141 kPa	813.2 kPa

State	Solution liquid	Solution liquid	Refrigerant liquid	Refrigerant vapor	Refrigerant vapor
Table 2. Simulation condition of H <sub>2</sub> O/[DMIM][DMP], [EMIM][DMP], [EMIM][BF <sub>4</sub> ]					
Location	1	10	14, 17	16	19
Temperature	30 °C	77 °C	30 °C	50 °C	5 °C
Pressure	0.6112 kPa	12.35 kPa	4.247 kPa	12.35 kPa	0.6112 kPa
State	Solution liquid	Solution liquid	Refrigerant liquid	Refrigerant vapor	Refrigerant vapor

### 3. Results

#### 3.1. Effect of split ratio

There are two split ratios in the generator and the condenser, and each value of split ratio has an impact on several performance indicators. The split ratio has an impact on COP<sub>c</sub>, COP<sub>h</sub> and COP<sub>tot</sub> for all four refrigerants/ILs. Simulation results according to the changes in r<sub>g</sub> and r<sub>c</sub> are shown in Figure 2. The COP trends in H<sub>2</sub>O/[DMIM][DMP], H<sub>2</sub>O/[EMIM][DMP] and H<sub>2</sub>O/[EMIM][BF<sub>4</sub>] were compared. As r<sub>g</sub> increases, the COP<sub>c</sub>, COP<sub>h</sub> and COP<sub>tot</sub> increase. As r<sub>c</sub> increases, the COP<sub>c</sub> and COP<sub>tot</sub> decrease while COP<sub>h</sub> increases. To achieve the reasonable level of cooling and heating effects, it is important to choose r<sub>g</sub> and r<sub>c</sub> correctly. The COP trends of R32/[HMIM][Tf<sub>2</sub>N] were different from those of H<sub>2</sub>O/[DMIM][DMP], H<sub>2</sub>O/[EMIM][DMP] and H<sub>2</sub>O/[EMIM][BF<sub>4</sub>]. As r<sub>g</sub> increases, the COP<sub>c</sub>, COP<sub>h</sub> and COP<sub>tot</sub> increase. However, Ass r<sub>c</sub> increases, the COP<sub>c</sub>, COP<sub>h</sub> and COP<sub>tot</sub> decrease.

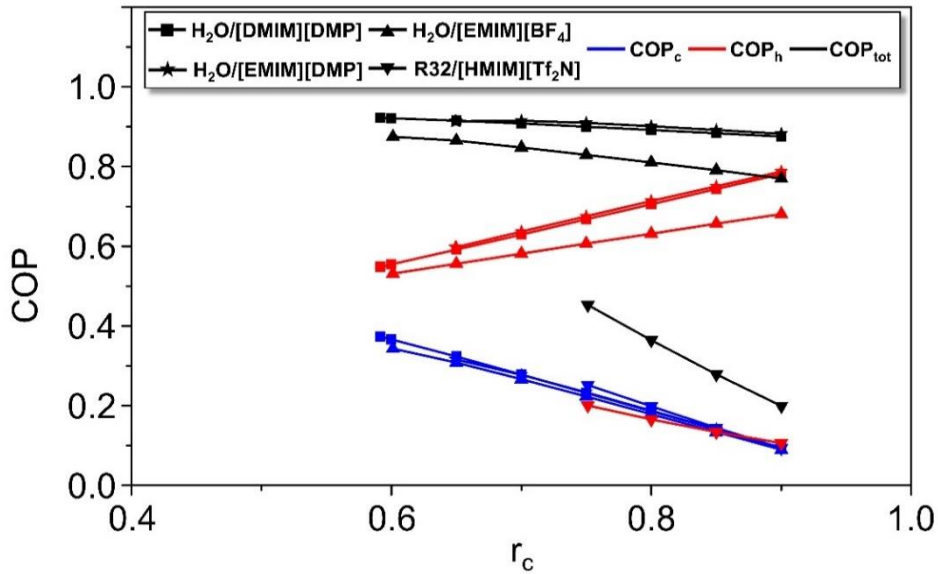


Fig. 2. Simulation result of COP-split ratio for r<sub>g</sub>=0.5.

When H<sub>2</sub>O/IL applied, cooling effect decreases while heating effect increases as r<sub>c</sub> increases. On the other hand, cooling effect increases and heating effect decreases as r<sub>c</sub> decreases. When R32/IL applied, the trend of cooling effect is similar to the result of H<sub>2</sub>O/IL. However, trend of heating effect is opposite. This is because the factors that influence  $\dot{Q}_{abs2}$  are different. In H<sub>2</sub>O/IL system, increasing enthalpy of refrigerant vapor which is point 16 in Figure 1 is a dominant factor to influence  $\dot{Q}_{abs2}$  as r<sub>c</sub> increases. In R32/IL system, increasing enthalpy of solution liquid which is point 10 in Figure 1 is a dominant factor.

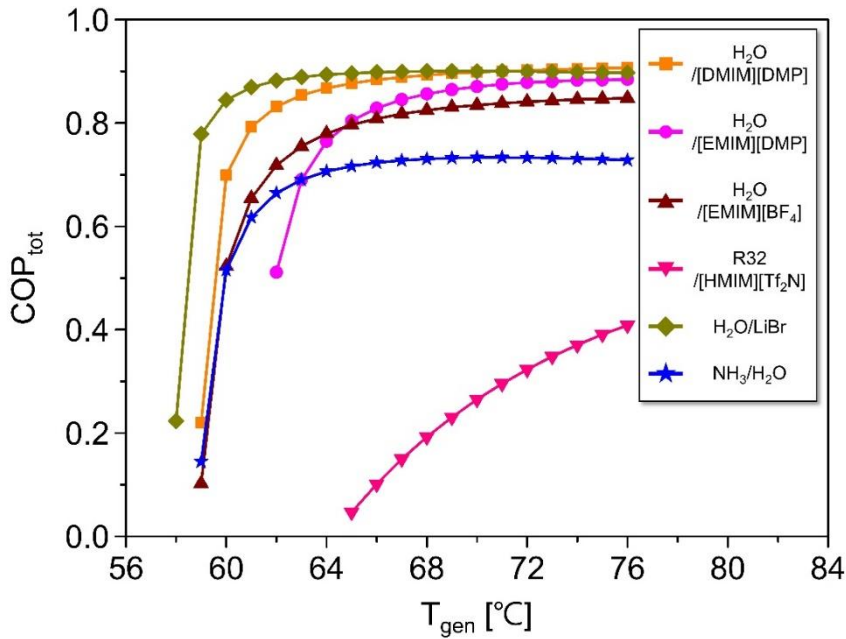


Fig. 3. Simulation result of  $T_{gen}$ - $COP_{tot}$  when  $r_c=0.5$ .

### 3.2. Effect of generation temperature

Figure 3 shows the simulation result of  $T_{gen}$ - $COP_{tot}$  when  $r_c=0.5$ . To show a balanced example of the cooling effect and the heating effect,  $r_c$  is set to 0.5. For all four alternative working fluids,  $COP_{tot}$  increases as the generation temperature increases. As shown in Figure 3, the maximum  $COP_{tot}$  of  $H_2O/LiBr$  was 0.90 and  $NH_3/H_2O$  was 0.73. Compared with  $COP_{tot}$  of  $H_2O/LiBr$ ,  $H_2O/[DMIM][DMP]$  ( $COP_{tot}=0.91$ ),  $H_2O/[EMIM][DMP]$  ( $COP_{tot}=0.88$ ) and  $H_2O/[EMIM][BF_4]$  ( $COP_{tot}=0.85$ ) results in similar performances. Compared with  $COP_{tot}$  of  $H_2O/LiBr$ ,  $R32/[HMIM][Tf_2N]$  ( $COP_{tot}=0.41$ ) performed 45%.

The trend of increasing or decreasing COP can be explained by the different increasing rates of  $\dot{Q}_{gen}$  (heat transfer rate of generator),  $\dot{Q}_{eva1}$  (heat transfer rate of low-temperature evaporator) and  $\dot{Q}_{abs2}$  (heat flow rate of high-temperature absorber), respectively. As  $\dot{Q}_{gen}$  increases, the amount of generated refrigerant increases. Naturally,  $\dot{Q}_{eva1}$  and  $\dot{Q}_{abs2}$  also increase. Therefore, if the rate of increase in the numerators in Eq (3) and (4) are faster than the rate of increase in the denominators, the COP tends to increase, whereas if the rate of increase in the numerators is slower than the rate of increase in the denominators, the COP tends to decrease. For all four working fluids, the rate of increase in the cooling and heating effects is faster than the rate of increase in the amount of heat input to the generator as the generation temperature increases. Therefore,  $COP_{tot}$  increases as the generation temperature increases for all working fluids.

## 4. Conclusion

In this study, four different working fluids were selected for the simultaneous cooling and heating absorption system, and the  $COP_c$ ,  $COP_h$  and  $COP_{tot}$  were compared depending on the variations of the split ratio and generation temperature. From the results, the following conclusions were drawn.

- (1) The  $COP_{tot}$  of  $H_2O/IL$  ranges 0.84–0.90 which is higher value than that of  $R32/IL$ .
- (2) For all four different working fluids,  $COP_{tot}$  increases as generation temperature increases. Maximum  $COP_{tot}$  of  $H_2O/IL$  is estimated 0.85–0.91. Maximum  $COP_{tot}$  of  $R32/IL$  is calculated 0.41, showing 55% lower performance than  $H_2O/IL$ .
- (3)  $COP_{tot}$  of refrigerant/ $IL$  is similar to that of  $H_2O/LiBr$ . Since it can solve the crystallization phenomenon, which is the weakness of  $H_2O/LiBr$ , it is confirmed that the ionic liquid will be a strong alternative to the traditional working fluid.

## Acknowledgements

Some parts of this study are included in ‘Park, S., Choi, H. W., Lee, J. W., Cho, H. U., Lee, N. S., Kang, Y. T. Performance analysis of ionic liquids for simultaneous cooling and heating absorption system’ submitted to Energy.

This study is partially supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIT). (Grant number : NRF-2020R1A5A1018153) and LG Electronics (Grant no. : Q2213281)

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