THERMAL ANALYSIS OF A NOVEL SINGLE-EFFECT ABSORPTION REFRIGERATION SYSTEM USING WATER/IONIC LIQUID AS WORKING FLUIDS

by

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Based on the demand of improving the cooling performance of traditional absorption refrigeration system, a novel single-effect refrigeration system with assisted compressors using water/ionic liquids as working fluids was comprehensively analyzed. In present work, four kind of ionic liquids:1-butyl-3-methylimidazolium dibutylphosphate [BMIM][DBP], 1-methyl-3-methylimidazolium dimethylphosphate[MMIM][DMP],1-ethyl-3-methylimidazolium dimethylphosphate [EMIM][DMP], and 1-ethyl-3-methylimidazolium acetate [EMIM][AC], which was studied as working fluid in absorption system at the first time, was modeled and simulated in both systems.Thermodynamic properties of new single-effect refrigeration system were numerically analyzed by non-random two-liquid models and the mass and energy conservation equations. The effects of compression ratio(pr) and temperature on the COP and exergetic efficiency (ECOP) were graphed and discussed. The simulating results showed the potential of ionic liquids to be used as substitute for traditional working fluids. Moreover, comparison results suggested the system with auxiliary compressors was better than the traditional system for its lower heat source temperature and higher cooling performance. It was better to increase the compression ratio of the compressor located between the absorber and the evaporator than to increase the compression ratio of the compressor located between the generator and the condenser.

Key words: *single-effect refrigeration system, ionic liquids, compression ratio, COP, exergetic efficiency*

Introduction

Single-effect absorption refrigeration system (SEARS) has been widely used in refrigeration industry and studied by numerical researchers for it can take advantages of low grade heat sources such as solar power [1] and waste heat power [2]. To achieve higher utilization of low grade energy, selection of working fluid of system has significant influence to heat source temperature and the COP of system. A considerable number of researchers have analyzed the heat performance of SEARS with lithium bromide or ammonia, which was most commonly used, as absorbents [3, 4]. However, the problems of them like crystallization and corrosivity were inevitable [5, 6].

Recently, ionic liquid (IL), which evades these shortcomings, has gained a booming concern for its potentials to substitute traditional absorbents [7]. Yokozeki [8] calculated binary-pairs, including commonly pairs and some new pairs, for vapor-absorption refrigeration

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cycle based on the equations of state for the first time, and demonstrated the thermodynamically-consistent EOS model. Ren and Zhang [9] measured thermodynamic properties of the mixing process of [EMIM][DMP] with water, ethanol or methanol, and correlated the results by non-random two-liquid (NRTL) equations, which had a deviation less than 2%. The results indicated that [EMIM][DMP] with water, ethanol or methanol could be new working fluids for absorption heat pumps or absorption refrigerators. He *et al*. [10] measured thermodynamic properties of [MMIM][DMP] + water/ethanol/methanol and the values suggested these working pairs were suitable for absorption heat pumps. Preisinger *et al*. [11] used AspenPlus to model and compare a SEARS with the working pairs water/[MMIM][DMP], water/[EMIM][DMP], and water/lithium bromide separately. The simulations showed the maximum COP values of water/[EMIM][DMP] and water/LiBr were both more than 0.75. Abumandour *et al*. [12] experimented thermodynamic properties of water/[DMIM][$MeSO_4$] and water/[EMIM][$MeSO_4$]. They applied their experimental data into an absorption heat transformer and found that IL had higher COP while low level temperature below 40 °C and high level temperature over 150 °C. Dong *et al*. [13] simulated a SEARS with water/[DMIM][DMP] as working pairs. The results suggested that the COP of water/[DMIM][DMP] was very close to water/LiBr. Gorakshnath *et al*. [14] performed COP and ECOP of SEARS with water/ [EMISE]. The results indicated that [EMISE] has higher COP than water/NH_3 but lower than water/LiBr. Gorakshnath *et al*. [15] analyzed a SEARS used IL mixed different kind of refrigerants as working fluids. They found the highest COP could reach 0.9, which given by water/[EMIM][BF4]. Moreno *et al*. [16] evaluated 900 IL and eight refrigerants over 7200 system in absorption refrigeration cycles. The results demonstrated that water was an excellent refrigerant when applicable temperature above 0 °C. They also demonstrated selection of IL and suitable refrigerant was crucial to system performance.

However, considering of all the advantages SEARS has, optimizing the cycles of system to enhancing COP is another vital issue. Lots of researchers had validate that hybrid absorption refrigeration system with extra compressor would enhance cooling performance. Ventas *et al.* [17] presented a numerical model of SEARS, which used ammonia-lithium nitrate solution as the working pair, with a compressor located between the evaporator and the absorber. The results showed that the hybrid system has lower operating temperature and higher COP than before. Boer *et al.* [18] added two compressors separately between the evaporator and the absorber in a double effect absorption cycle, which used organic working fluids. Turns out the new cycle had wider working temperature range. Chen *et al.* [19] designed compressor assisted double effect absorption refrigeration system with one compressor between a high temperature generator and a low temperature generator, and one between the evaporator and the absorber. They simulated the thermal performance of the system and each component when compression ratio and heat source temperature changed. In some conditions, COP increased when compression ratio increased. Liu *et al.* [20] and Sun *et al.* [21] both chose R1234yf/ionic liquid as working pairs to analyzed single-effect and one compressor assisted absorption refrigeration system. Their results suggested the increasing cooling performance because of the auxiliary compressor.

To explore better cooling performance and IL-water working pair of SEARS in this article, four kind of IL-water were selected as working pairs: water/[BMIM][DBP], water/[MMIM][DMP], water/[EMIM][DMP], and water/[EMIM][AC] for the NRTL equation parameters they had. According to the research has been reported, these IL-water avoid shortcomings that traditional working pairs have. Furthermore, a SEARS model with two assisted compressors was established in consideration of steady refrigeration process. Using MATLAB to simulated effects and thermal performances when temperature of components changed.

Thermodynamic properties of ionic liquids

The thermodynamic properties of IL are calculated based on the equation of state. Pressure of solution [kPa] can be solved by using activity coefficient method of vapor-liquid equilibrium in binary system. Assuming the Poynting factor as 1 when the pressure of IL is not too high and the temperature [K] is not too low. According to the non-volatility of IL, the vapor phase is pure water vapor. So the simplified formula of pressure:

$$P = \gamma_1 x_1 P_1^s \tag{1}$$

where x is the mole fraction of corresponding component and P_1^s – the saturation pressure of pure water, which calculated from three-parameter Antoine formula:

$$P^s = \mathrm{e}^{A-B/(T+C)} \tag{2}$$

where A, B, and C are constant parameters in tab. 1 [22].

Table1. Parameters for eq. (1)

A	B	C
16.28837	3816.4	–46.13

The γ_1 is the activity coefficient of components in liquid phase, which can be calculated by non-random two-phase NRTL model:

$$\ln\gamma_1 = x_2^2\left[\tau_{21}\left(\frac{G_{21}}{x_1 + x_2 G_{21}}\right)^2 + \frac{\tau_{12}G_{12}}{(x_2 + x_1 G_{12})^2}\right] \tag{3}$$

$$\ln\gamma_2 = x_1^2\left[\tau_{12}\left(\frac{G_{12}}{x_2 + x_1 G_{12}}\right)^2 + \frac{\tau_{21}G_{21}}{(x_1 + x_2 G_{21})^2}\right] \tag{4}$$

$$\tau_{12} = \Delta g_1,\ \tau_{21} = \Delta g_2 \tag{5}$$

$$G_{12} = \mathrm{e}^{-\alpha\tau_{12}}, G_{21} = \mathrm{e}^{-\alpha\tau_{21}} \tag{6}$$

where α is a non-random number of NRTL model and Δg – the an energy parameter between two different components [23, 24]:

$$\Delta g_i = a_i + b_i T + c_i T^2, \quad i = 1,2 \tag{7}$$

where τ also has another expression when the temperature has a wide range [13, 25]:

$$\tau_{ij} = a_i + \frac{b_i}{T} \tag{8}$$

All the parameters of a, b, and c are given in tab. 2.

The specific enthalpy of IL [kJkmol^{-1}] is a function of temperature [K] and mole fraction in eqs. (9) and (10), except the solution of [MMIM][DMP]/water was given [10]:

$$H = H_{298} + \int_{298}^{T} C_p \mathrm{d}T \tag{9}$$

$$H_{298} = H_{298}^E + x_2 \int_{273}^{298} C_{p\cdot[BMM][DBP]}\mathrm{d}T + x_1 \int_{273}^{298} C_{p\cdot H_2O}\mathrm{d}T \tag{10}$$

where $C_{p\cdot[\mathrm{BMIM}][\mathrm{DBP}]}$ and $C_{p\cdot\mathrm{H_2O}}$ are specific heat capacity [kJkg^{-1}K^{-1}] of pure IL and pure water, respectively:

$$C_p = C_{p0} + aT \tag{11}$$

$$C_{p,0} = \sum_{i=0}^{4} A_i x_2{}^i \tag{12}$$

$$a = \sum_{i=0}^{4} B_i x_2{}^i \tag{13}$$

Table 2. Parameters for eqs. (5)-(8)

	i	*a*	*b*	*c*	*α*
[BMIM][DBP](2) + H_2O(1)	1	619851.5248	–3460.915794	4.063200037	0.01093453
	2	5345901.949	–25759.71866	32.85411818	
[EMIM][DMP](2) + H_2O(1)	1	–404950	2183.6	–2.810	0.6004
	2	–7589.1	10.215	–0.0356	
[EMIM][AC](2) + H_2O(1)	1	21.8989	–6138.5058	0	0.7925
	2	–0.3057	–515.1714	0	
[MMIM][DMP](2) + H_2O(1)	1	1.73	177.6	0	0.279
	2	–2.907	–484.6	0	

Table 3 present values for parameters of eqs. (12) and (13).

Table 3. Parameters for eqs. (12) and (13)

[BMIM][DBP](2) + H_2O(1)	A_0	A_1	A_2	A_3	A_4
	0.951507	–5.75141	7.223013	7.520699	–9.78902
	B0	B1	B2	B3	B4
	0.009566	–0.0089	0. 010082	–0. 0388	0.032237
[EMIM][DMP](2) + H_2O(1)	A_0	A_1	A_2	A_3	A_4
	–843. 0997	–20571. 8268	13885. 3913	31381.8543	–26642.5299
	B_0	B_1	B_2	B_3	B_4
	14. 7825	26. 3706	53. 2389	–207. 8705	127. 5218
[EMIM][AC](2) + H_2O(1)	A_0	A_1	A_2	A_3	A_4
	–7. 4849	67. 2513	–210. 0186	266.2418	–117.1237
	B_0	B_1	B_2	B_3	B_4
	0.0404	–0.2805	0.8332	–1.0237	0.4396

The $H^E{}_{298}$ [kJkmol^{-1}] is the excess enthalpy of solution at T = 298 K:

$$H_{298}^E = x_1 x_2 \sum_{i=1}^{4} A_i (1-2x_2)^{i-1} \tag{14}$$

The values of parameter A_i are given in tab. 4.

Table 4. Parameters for eq. (14)

	A_1	A_2	A_3	A_4
[BMIM][DBP](2) + H_2O(1)	–23106.17	7127.68	–979.07	0
[EMIM][AC](2) + H_2O(1)	–13180.2036	–10195.5617	–9439.8398	0
[EMIM][DMP](2) + H_2O(1)	–23379	–11000	–7910	–9016.6

Description and modelling of system

Figure 1 depicts the principle of the SEAR system with assist compressors. The whole system consists of refrigeration and absorption cycles. Solution heated by heat source in generator (gen) to produce high temperature and high pressure refrigerant vapor, which flows into condenser (con), and cooled to liquid by cooling water. The liquid continue runs through valve – 2 becoming low temperature and pressure water, which is evaporated under low pressure in evaporator (eva) to absorb heat of chilled water and realize refrigeration. Another way, the remaining solution from generator called strong solution (SS). The SS flows through heat exchanger (HEX), where it exchanges heat with weak solution (WS), and then flows into absorber (abs). The SS in absorber mixes refrigerant vapor and becomes WS again, then pumped into generator to completes the cycle.

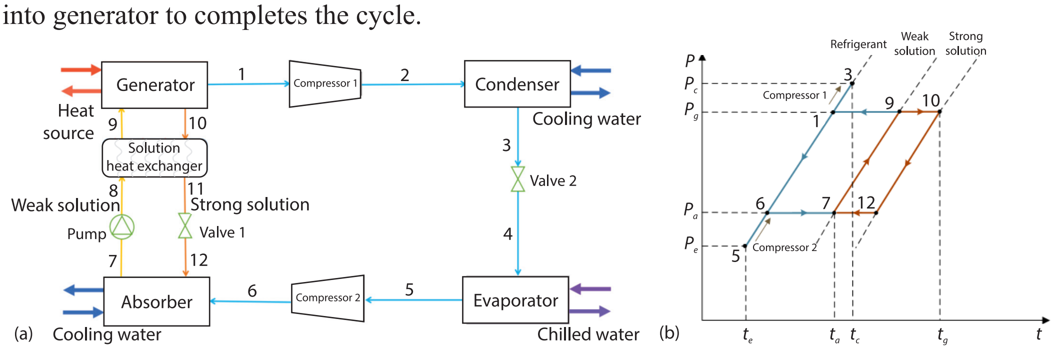

Figure 1. The SEARS with assist compressors; (a) schematic diagram and (b) PT diagram

In this paper, a compressor with CR1 is inserted between generator and condenser, and a compressor with CR2 is inserted between evaporator and absorber. As shown in the PT diagram in fig. 1(b), the concentration difference between the weak and strong solutions has a significant effect on the cycle performance. Compressors have great impact on the concentration difference.

In order to simulate the system, the following assumptions are made in the present study [26]:
– the whole system is in a stable state and the working fluids of each component are in a balanced and saturated state,
– the drop of pressure and losses of energy should be ignored during whole cycle,
– the work of the pump is neglected,
– all valves are isentropic,
– the HEX is an ideal HEX and its heat transfer efficiency is set to 0. 75,
– the P_{gen} (the pressure of generator) is equal to P_{con} and P_{eva} is equal to P_{abs} when the compressors do not work (CR1 = CR2 = 1), and
– the isentropic compression efficiencies η are both 0.7.

Based on these assumptions, the whole system and each component should satisfy the conservation of mass and energy in eqs. (15)-(28).

Generator:

$$\dot{m}_8 = \dot{m}_9 + \dot{m}_1 \tag{15}$$

$$\dot{m}_8 \omega_{WS} = \dot{m}_9 \omega_{SS} \tag{16}$$

$$Q_{gen} = \dot{m}_9 h_9 + \dot{m}_1 h_1 - \dot{m}_8 h_8 \tag{17}$$

$$f = \frac{\dot{m}_8}{\dot{m}_1} = \frac{\omega_{SS}}{\omega_{SS} - \omega_{WS}} \tag{18}$$

$$P_{gen} = \frac{P_{con}}{CR1} \tag{19}$$

where ω is mass fraction, $\dot{m}$ – the mass-flow, and f – the circulation ratio, which is important for SEARS.

Condenser:

$$Q_{con} = \dot{m}_1 (h_2 - h_3) \tag{20}$$

$$P_{con} = P^s (t_{con}) \tag{21}$$

Evaporator:

$$Q_{eva} = \dot{m}_1 (h_5 - h_3) \tag{22}$$

$$P_{eva} = P^s (t_{eva}) \tag{23}$$

Absorboer:

$$Q_{abs} = \dot{m}_9 h_{10} + \dot{m}_1 h_6 - \dot{m}_8 h_7 \tag{24}$$

$$P_{abs} = P_{eva} CR2 \tag{25}$$

Heat exchanger:

$$Q_{HEX} = \dot{m}_8 (h_8 - h_7) = \dot{m}_9 (h_9 - h_{10}) \tag{26}$$

Compressors:

$$W_1 = \frac{\dot{m}_1 (h_2 - h_1)}{\eta} \tag{27}$$

$$W_2 = \frac{\dot{m}_1 (h_6 - h_5)}{\eta} \tag{28}$$

where $\dot{m}_1 = 1$ kg/s and t of each component is initial condition that are given parameters. The mole fraction of solution is calculated by eqs. (1) based on the pressure and temperature that already known, then the corresponding enthalpy of ionic solution is obtained. Two performance indicators are selected to evaluate the effect of the system. They are COP founded on the first law of thermodynamics and ECOP based on the second law:

$$COP = \frac{Q_{eva}}{Q_{gen} + W_1 + W_2} \tag{29}$$

$$ECOP = \frac{Q_{eva}\left(\dfrac{T_0}{T_{eva}} - 1\right)}{Q_{gen}\left(1 - \dfrac{T_0}{T_h}\right) + W_1 + W_2} \tag{30}$$

where $T_0 = 298.15$ K, $T_h = T_{gen} + 10$ K.

The performance of SEARS with [EMIM][DMP]/water or [MMIM][DMP]/water as working pairs were simulated by Zhang [23] and Dong *et al*. [13], respectively. Each literature selected different conditions of system temperature and NRTL models. The [BMIM][DBP] and [EMIM][AC] only had thermal properties from [24, 25]. Comparisons with results in these literature are shown in tabs. 5 and 6. It was observed from these tables that the deviation is reasonable and the model showed reliability for simulation.

Table 5. The COP results from [23]/[13] and this work for water [EMIM][DMP] and water/[MMIM][DMP]

Working pair	t_{eva} [°C]	t_{abs} [°C]	t_{con} [°C]	t_{gen} [°C]	*COP* [23]	*COP* in this work	σ_{in} [%]
[EMIM][DMP](2) + H_2O(1)	10	30	40	80	0. 829	0. 8269	–0. 25%
[MMIM][DMP](2) + H_2O(1)	5	35	40	84. 5	0. 721	0. 737	2. 17%

Table 6. Thermal properties results from [24] and this work for water/[BMIM][DBP]; results from [25] and this work for water/[EMIM][AC]

[BMIM][DBP](2) + H_2O(1)	x_1	*T*	Calculation [24]	Calculation in this work	σ_{in} [%]
P	0.3188	402.15	68.38	68.39	–0.01
C_p	0.1983	298.15	2.5076	2.5073	–0.01
HE	0.2014	298.15	–4457.14	–4457.14	0
[EMIM][AC](2) + H_2O(1)	x_1	*T*	Cal in [Zhou]	Cal in this work	σ_{in} [%]
P	0.3007	347.25	14.18	14.18	0
C_p	0.5834	312.85	2.067	2.0679	–0.04%
HE	0.4015	298.15	–3782.818	–3737.8507	1.19%

Simulation results and discussion

Effect of pressure ratios on performance of the system

Figure 2 showed the effects of two compressors on the performance of SEARS. It was seen from fig. 2(a) that the COP of each IL-based SEARS increased as the CR2 rises from 1.0 to 2.0 when the CR1 keeps constant.

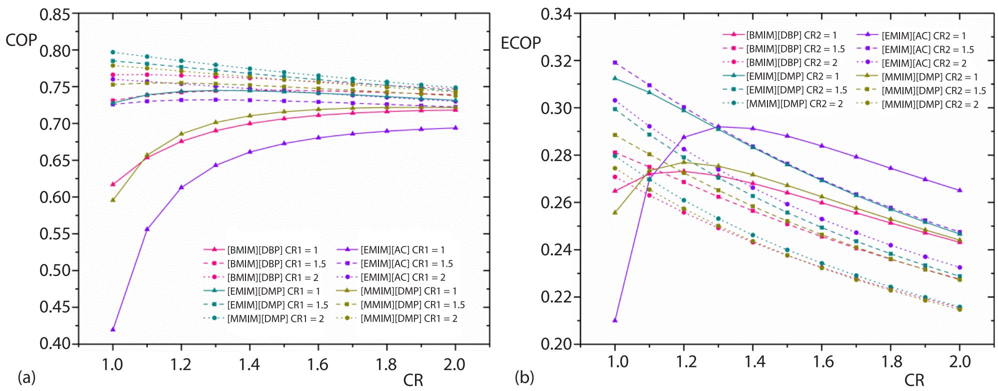

Figure 2. Effect of the compressor ratio (CR1, CR2) on the system; (a) COP and (b) ECOP, where t_{gen} = 75 °C, t_{eva} = 5 °C, t_{abs} = 35 °C, and t_{con} = 35 °C

The compressors-assisted SEARS with [EMIM][DMP]/H_2O as working pairs has the maximum value of COP about 0.8 at CR2 = 2. The [EMIM][AC]/H_2O-baed SEARS shows the largest increment of COP above 80% compared with the non-compressors system.

As shown in figs. 2(a) and 2(b), at the higher smaller value of CR2, the COP and ECOP both present downward trends with the increase of CR1.

This can be attributed to the fact that the consumed power of the compressors increased significantly while the absorbed heat in the SEARS generator decreases slowly, resulting in the increase of input energy and exergy while the cooling capacity output keeps constant, consequently the COP and ECOP descend.

From fig. 2(b), the ECOP of SEARS with [BMIM][DBP]/H_2O, [EMIM][AC]/H_2O [MMIM][DMP]/H_2O as working pairs increased first and then decreased with the increase of CR1 when CR2 = 1. Thus the peak points could be obtained at certain values of CR1. In addition, for all the working pairs, the increase of CR2 has negative effect on the exergetic efficiency of the system.

The aforementioned outcomes proved that assisted compressors has great potential of improving the performance of SEARS. According to the comparative studies of the four IL-based working fluids, [EMIM][DMP]/H_2O has better energy and exergy efficiencies, so it was selected to evaluate the effects of generator temperature and evaporator temperature on the system performance.

Effect of generator temperature on performance of the system

It was seen from fig. 3 that, as the tgen rised, COP and ECOP increased first and then began to decline, reaching their peak values of 0.74 and 0.31, respectively.

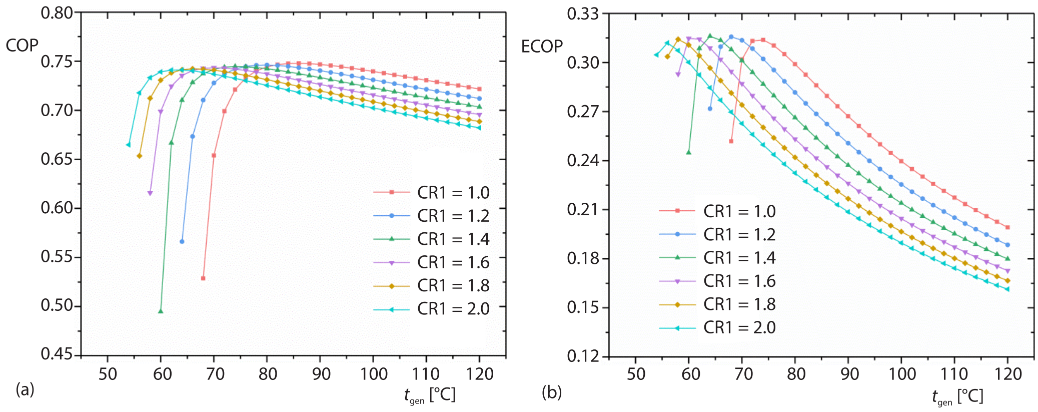

Figure 3. Effects of tgen and pr1on the system; (a) COP and (b) ECOP, where t_{eva} = 5 °C, t_{abs} = t_{con}= 35 °C, and CR2 = 1

Every curve had almost the same trend with the change of CR1. The difference was that the larger the CR1, the lower the generator temperature was required to achieved the same COP. In the condition that CR1 = 1, the peak value of COP emerged at t_{gen} = 85 °C compared that t_{gen} = 65 °C was need to achieve the same level of COP.

The reason is the compressor 1 assists the generator to work, and higher CR1 means lower temperature of the generator needed to balance the pressure of the condenser. Therefore, the higher CR1, the lower grade heat source the system can use even though the increase of

CR1 did not increase the COP value of system. The effects on ECOP as shown in fig. 3(b), the curves had the same trends like COP in fig. 3(a).

Figure 4(a) presented the trend of COP curves was soared and then declined from the peak when tgen increased, which was similar to the effects of CR1. The difference was when CR2 increased, not only the t_{gen} of peak point decreased, but also the value of maximum COP grew. When CR2 = 1, the system had a peak value of COP at t_{gen} = 85 °C. The value was constantly enhanced with the increase of CR2. Furthermore, the system could get an 11% increase with a 25 °C decrease in temperature of generator when CR2 doubled. This trend suggested that the increase of CR2 can improve the performance of the system and take advantage of lower grade heat sources than compressor 1. The ECOP shown in fig. 4(b) still had the same trend with COP.

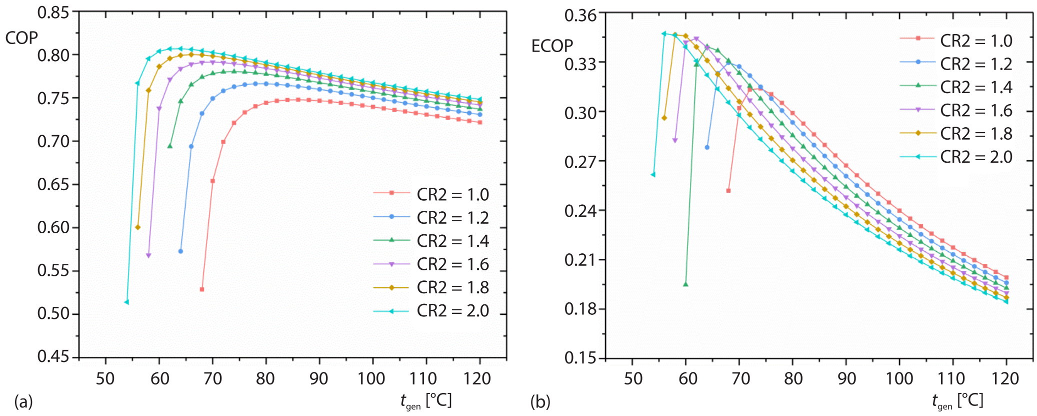

Figure 4. Effects of t_{gen} and CR2 on the system; (a) COP and (b) ECOP, where t_{eva} = 5 °C, t_{abs} = t_{con} = 35 °C, CR1 = 1

Figure 5(a) showed the effects of CR1 on system performance with various evaporator temperatures. Because the variety of data was not obvious not obvious at higher tgen, so the lower t_{gen} was selected lower to described the change clearly. It was seen from the figure that when CR1 was the same, the bigger CR1, the smaller increase of COP caused by teva rising. When t_{eva} = 5 °C, the value of COP firstly increased with the increase of CR1. However, with increasing t_{eva}, the growth of COP caused by the growth of CR1 decreased. When t_{eva} > 9 °C,

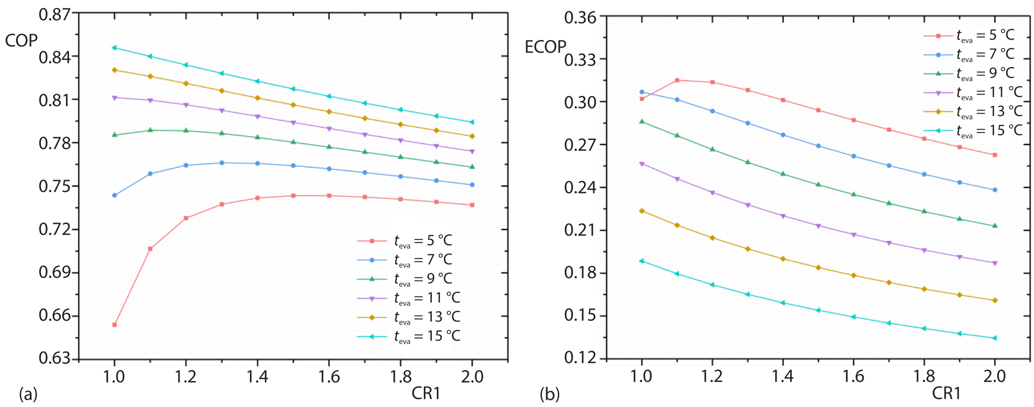

Figure 5. Effects of t_{eva} and CR1 on the system; (a) COP and (b) ECOP, where t_{gen} = 70 °C, t_{abs} = t_{con} = 35 °C, CR2 = 1

the curves of COP declined with the increase of CR1. This due to increase of CR1 will increase ω_{ss} and W_1, and the increase of t_{eva} will decrease ω_{ws}. Both increase will make f drop. When the system started with low t_{eva} and CR1, namely the value of f is large, which makes it drop dramatically with the increase of t_{eva} and CR1. However, the bigger t_{eva}, the smaller decrease of f, as well as the decrease of Q_{gen}. While the power of compressor increases constantly. Therefore, the performance of the system will decline when the increase of power of compressor negatives the decrease of Q_{gen}. Changes of ECOP was shown in fig. 5(b), which could be explained with the same reason.

Conclusions

This article presented an explicit model of a new hybrid SEARS with four kinds of IL-water as working pairs to studied thermal performance of the system when temperature of components and compression ratios changed. The major results were summarized.

- Every kind of IL had different responses to temperature change of each component because of their various NRTL model parameters. The selection of suitable working fluids should based on the system conditions although all four kinds of IL had the maximum COP around 0.7. All in all, system with [EMIM][DMP] as absorbent had the best and the most stable performance when temperature changed.
- The system with IL as working fluids had significant lower tgen than that of traditional working pairs, namely, IL could utilized lower grade heat source. In same condition, the increase of CR1 could further reduce tgen by around 20 °C. The increase of CR2 not only could reduce t_{gen}, but also could enhance COP around 9%.
- There was not an absolute optimal pressure ratio of each compressor for the hybrid system. Assisted-compressors improved the system performance through changing the pressures in circulation loops. However consistent increase of pr did not mean consistent enhance of COP. Increasing CR increased the power consumption of system and decrease ECOP at the same time.
- When CR2 was low, the increase of CR1 increased COP of system. When CR2 was high, the increase of COP decreased with growth of CR1. Therefore, COP decreased after the initial increase. The increase of CR2 improved system performance no matter CR1 was low or high. Namely, installing assisted-compressors was a good choice for SEARS. Moreover, when the system temperature stayed constant, the effects of increasing CR2 on enhancing system performance was better than that of increasing CR1.

Nomenclature

$a,b,c/A,B,C$ – parameters for EOS
C_p – specific heat capacity, [kJkg^{-1}K^{-1}]
f – circulation ratio
H – specific enthalpy, [kJkmol^{-1}]
Q – heat flow, [kW]
$\dot{m}$ – mass-flow rate, [kgs^{-1}]
P – pressure, [kPa]
T – temperature, [K]
t – temperature, [°C]
x – mole fraction
W – power, [kW]

Greek symbols

α – parameter of NRTL model
γ – activity coefficient
η – compression efficiencies
ω – mass fraction

Acronyms

abs – absorber
[BMIM][DBP] – 1-butyl-3-methylimidazolium dibutylphosphate
con – condenser
[EMIM][AC] – 1-ethyl-3-methylimidazolium acetate
[EMIM][DMP] –1-ethyl-3-methylimidazolium dimethylphosphate
ECOP – exergetic efficiency
eva – evaporator
gen – generator

HEX – heat exchanger
IL – ionic liquids
[MMIM][DMP] – 1,3-dimethylimidazolium dimethylphosphate
NRTL – non-random two-liquid
CR – compression ratio
SS – strong solution
SEARS – single-effect absorption refrigeration system
WS – weak solution

Superscript

s – saturation

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