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A STUDY ON PERFORMANCE ENHANCEMENT OF REFRIGERATORS USING ECONOMIZERS

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ABSTRACT

Many studies have been conducted to overcome the deterioration of COP (coefficient of performance) that occurs from lowering the evaporating temperature of a cascade cycle to extremely low temperatures. This study applied economizers to low stage and high stage cycles to enhance the performance of theR134a-R404a cascade cycle. Cycle analysis was performed to examine changes in cycle performance with condensing temperature, evaporating temperature, cascade temperature difference and economizer ratio. Numerical analysis revealed a 13% improvement in both cooling capacity and COP from applying an economizer to the low stage cycle. The optimal temperature difference of the cascade heat exchanger was approximately 6°C.

Keywords: refrigerators, cascade cycle, R134a-R404a, intermediate temperature, COP, capacity

INTRODUCTION

Saving energy has become an important issue in economic development and with increasing worldwide population. High-efficiency refrigeration cycles are commonly used in housing and industrial refrigerators, and many studies have been conducted to improve their efficiency.

Refrigerated warehouses must operate at -30~-50°C for proper storage of fish and meat. To maintain such low temperatures, low-temperature refrigeration systems are necessary. One such device is the cascade cooling cycle, which uses two-stage, or three-stage compression cycles or two cycles. However, there are certain constraints in obtaining low temperatures with multi-stage cycle devices involving a single refrigerant. Attempting to lower the evaporating temperature will lead to an excessively large compression ratio, which in turn causes a drop in compression efficiency and COP, which is the performance coefficient of cascade refrigeration cycles. The low temperature range of -30~-50°C can best be achieved through a cascade refrigeration cycle which uses a cascade heat exchanger to exchange heat between low temperature cycles involving R23 and R744 refrigerants, with high temperature cycles involving R22, R717 and R290 refrigerants [1].

Studies on refrigerators used in extremely low temperature applications have focused on performance enhancement through cascades, and the improvement of refrigeration performance through renewable energy. Numerous studies have been carried out on enhancing COP by making structural changes to the cycles.

COP and optimum temperature also vary with refrigerant characteristics. Among the many studies on refrigerant characteristics, R290 and R600a were used by Yan *et al*. [2], CO_2-propylene by Dubey *et al.* [3], and R134-CO_2 by Carlos *et al*. [4].

In addition to refrigerant characteristics, refrigerators have been extensively studied for the purpose of COP enhancement. For instance, Chen et al. [5] used engine waste heat to study calories in relation to external temperature. Enhancing the COP of cascade cycles was investigated through the use of subsystems consisting of pumps by Xu *et al.* [6], absorbers by Cimsit *et al*. [7], geothermal energy by Li *et al.* [8], and solar energy by Lv *et al.* [9]. These studies concentrated on retrieving energy from external sources to improve performance.

Other methods of COP enhancement involve flash tanks and economizers. Xu *et al*. [10] applied flash tanks to the standard cycle of the R32 refrigerant and observed changes in COP and EER. Vaisman *et al.* [11] applied economizers and looked at the effects of different refrigerants on COP.

In spite of the above, cascade cycles with economizers have yet to be extensively studied. Against this backdrop, this study applied economizers to low stage and high stage cycles to improve the operating performance and cycle efficiency of the R134a-R404a cascade cycle. EES [12] was employed for cycle analysis, and the effects of economizers on COP and cooling capacity were reviewed.

ANALYSIS METHOD AND CONDITIONS

Heat rejection rate with respect to the PTC heater fin pitch

To increase COP at extremely low temperatures, economizers were attached to the high stage (HC) and low stage cycles (LC), and cycle analysis was performed for each case. The refrigerant was R134a for HC and R404a

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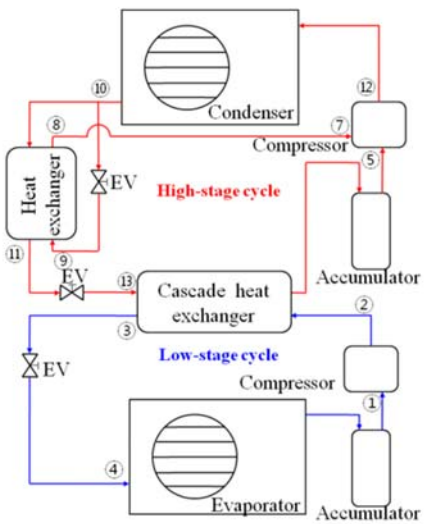
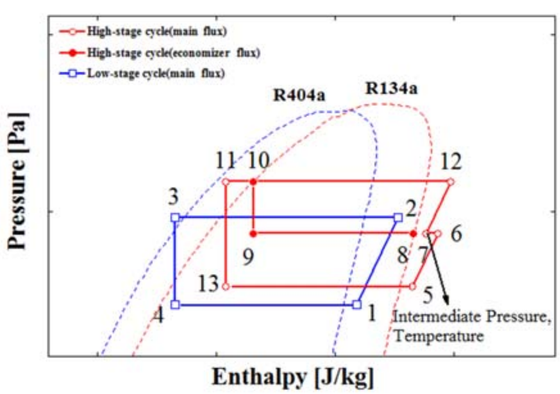
for LC. Figures 1 and 2 show the cycle schematic and P-h diagram with the economizer system applied to HC and LC. In the cascade cycle, the cascade heat exchanger acts as the evaporator for HC and condenser for LC. The economizer system allows part of the condensed refrigerant to flow to the supporting expansion valve for heat exchange, thereby increasing super cooling. Moreover, compression load is reduced by the mixing of the refrigerant in the middle of the compressor. Table-1 presents the conditions for analysis. The standard conditions are a condensing temperature of 20ºC, an evaporating temperature of -30ºC, and a cascade temperature difference of 6ºC. The economizer ratio and intermediate temperature were assumed to be 10% and 5ºC respectively. Cycle changes were observed under various analysis conditions.

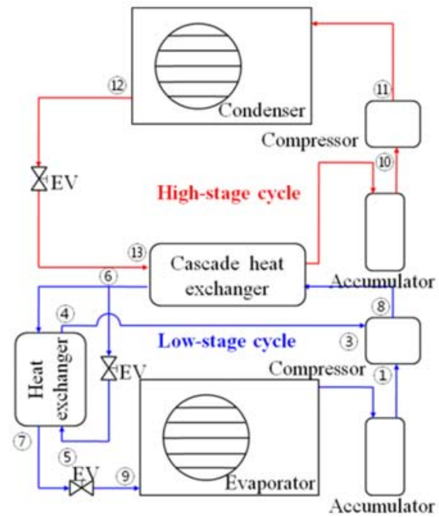


(a) Cycle schematic.

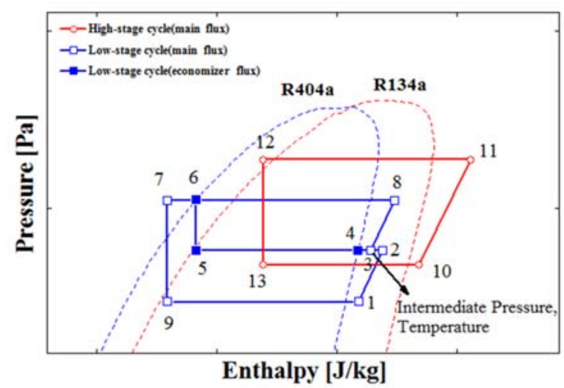


(b) P-h diagram

Figure-1. Cascade cycle schematic and P-h diagram for HC with economizer.



(a) Cycle schematic.



(b) P-h diagram

Figure-2. Cascade cycle schematic and P-h diagram for LC with economizer.

Table-1. Cycle analysis conditions.

Parameters	Range
Condensing temperature	15ºC ~ 25ºC
Evaporating temperature	-35ºC ~ -25ºC
Temperature difference in a cascade heat exchanger	5ºC ~ 9ºC
Economizer injection ratio	0% ~ 20%

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RESULTS AND DISCUSSIONS

Variations of COP and cooling capacity with condensing temperature

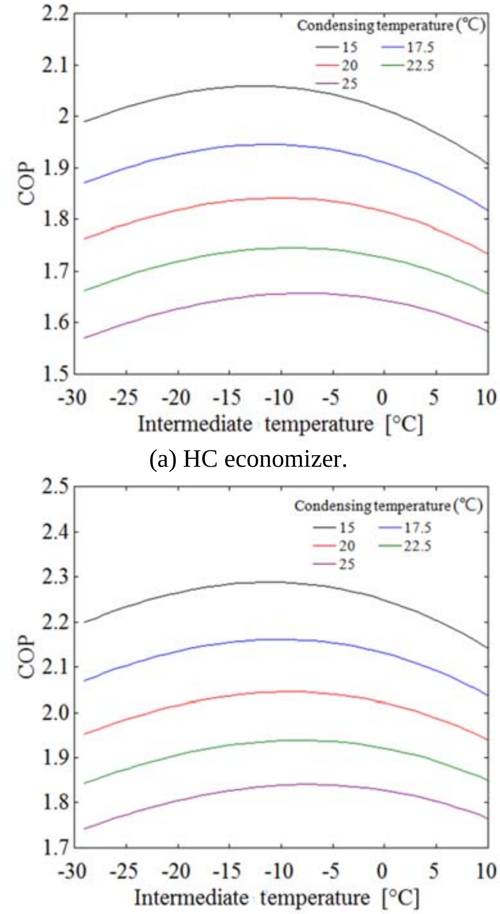
Using R134a-R404a as the refrigerant, cycle analysis was carried out with the high stage and low stage cycles of the binary cascade refrigeration system while each was attached with an economizer. COP was analysed while varying the condensing temperature from 15 to 25°C. Figure-3 shows the variation of COP with intermediate temperature for the HC and LC economizers. For both cases, the intermediate temperature is highest at maximum COP. For the HC economizer shown in Figure-3(a), the optimum intermediate temperature drops from -8°C to -13°C when the condensing temperature decreases from 25°C to 15°C. For the LC economizer showed in Figure-3(b), the optimum intermediate temperature drops from -7°C to -11°C for the same decrease in condensing temperature. From the two cases, we can see that optimum intermediate temperature drops with condensing temperature.

Figure-4 shows the variations of cooling capacity and COP with condensing temperature. Here, the intermediate temperature is assumed to be 5°C. When the economizer is applied to HC, cooling capacity is hardly affected, even as the condensing temperature decreases by 10°C, but COP improves by approximately 0.35. When the economizer is applied to LC, a 10°C decrease in condensing temperature has no influence on cooling capacity, but improves COP by 0.4. This shows that cooling capacity is hardly affected by condensing temperature, but COP improves by 22% with a 10°C drop. Low condensing temperature in cascade cycles equipped with economizers is expected to contribute to COP enhancement.

COP is higher by 0.25 for the LC economizer than the HC economizer. Thus, cycle efficiency is better when the economizer is attached on the LC side.

Variations of COP and cooling capacity with evaporating temperature

With the aforementioned experimental conditions, COP was analysed while varying the evaporating temperature from -35 to 25°C. Figure-4 shows the variation of evaporating temperature and COP with intermediate temperature. For the HC economizer shown in Figure-4(a), the optimum intermediate temperature rises from -13°C to -8°C when the evaporating temperature increases from -35°C to -25°C. For the LC economizer showed in Figure-4(b), the optimum intermediate temperature rises from -12°C to -7 °C for the same increase in evaporating temperature. From the two cases, we can see that optimum intermediate temperature rises with evaporating temperature. COP improves by approximately 29%.



(a) HC economizer.

(b) LC economizer

Figure-3. Variations of cascade cycle COP with intermediate temperature.

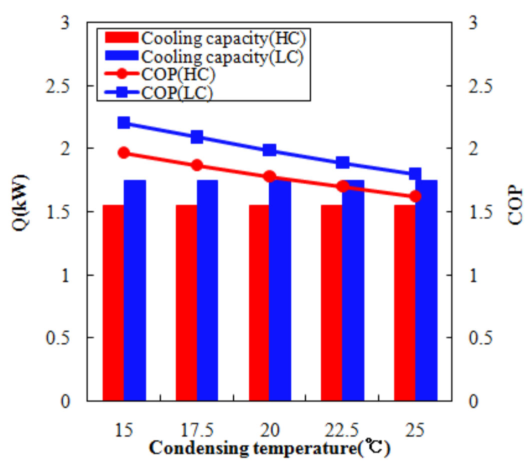


Figure-4. Variations of cooling capacity and COP with condensing temperature.

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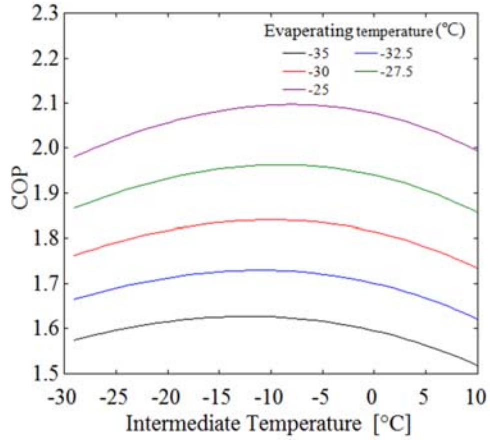
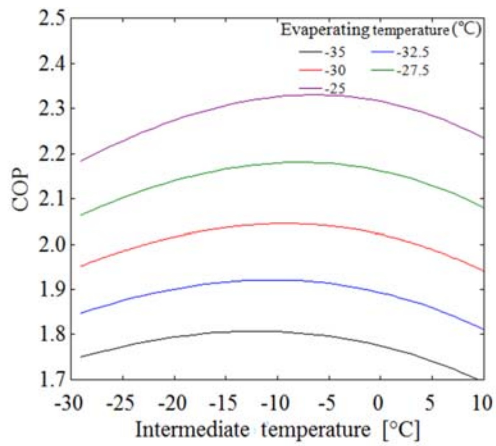


(a) HC economizer.



(b) LC economizer.

Figure-5. Evaporating temperature and COP with intermediate temperature.

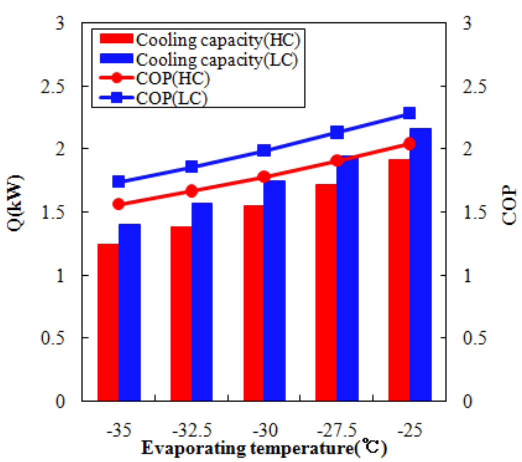


Figure-6. Cooling capacity and COP with evaporating temperature.

Figure-4 shows the variations of cooling capacity and COP with evaporating temperature. Here, the intermediate temperature is also assumed to be 5ºC. When the economizer is applied to HC, cooling capacity increases by 0.76kW and COP by 0.54, as evaporating temperature rises by 10ºC. When the economizer is applied to LC, cooling capacity increases by 0.67kW and COP by 0.48 for the same increase in evaporating temperature. A 10ºC rise in evaporating temperature translates to a 49% and 31% increase in cooling capacity and COP, respectively.

Variations of COP and cooling capacity with cascade heat exchanger temperature

Figure-7 shows the variation of COP with different cascade heat exchanger temperatures. As the temperature difference of each cascade heat exchanger rises, COP decreases. The optimum intermediate temperature is the temperature at which maximum efficiency is achieved. As shown in Figure-7(a), when the temperature difference of the cascade heat exchanger drops from 9ºC to 5ºC, the optimum intermediate temperature rises from -11ºC to -10ºC. Also, COP increases from 1.72 to 1.89. In Figure-7(b), as the temperature difference of the cascade heat exchanger falls from 9ºC to 5ºC, the optimum intermediate from -11ºC to -9ºC. Accordingly, COP increases from 1.91 to 2.09. For both cases, a decrease in the temperature difference of the cascade heat exchanger leads to an increase in optimum intermediate temperature and COP, by 1~2ºC and 10% respectively.

Figure-8 shows the variation of cooling capacity and COP with different cascade heat exchanger temperatures when the intermediate temperature is 5ºC. For the HC economizer, when the temperature difference decreases by 4ºC, the cooling capacity and COP increase by 0.07 kW and 0.19 respectively. For the LC economizer, the same decrease in temperature difference results in an increase in cooling capacity and COP by 0.06kW and 0.17 respectively. These results show that the temperature difference of the cascade heat exchanger hardly affects temperature increases

Cooling capacity, but improves COP by approximately 10%. COP improves with smaller temperature differences in the cascade heat exchanger. However, the smaller the temperature difference, the larger the size of the heat exchanger.

Variations of COP and cooling capacity with economizer ratio

Changes in COP were examined while varying the economizer ratio from 0% to 12% at 3% increments. Figure-9 presents the variation of COP with economizer ratio and the intermediate temperature. As shown in Figure-9(a), when the economizer ratio varies from 0% to

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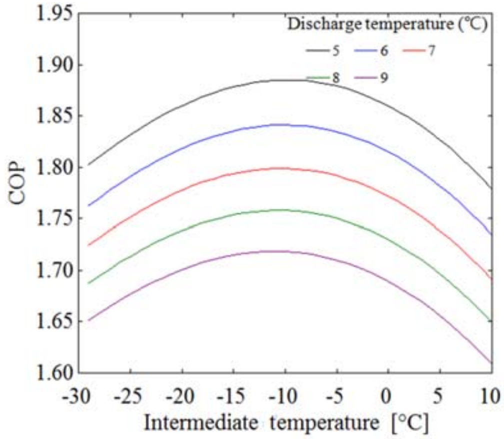
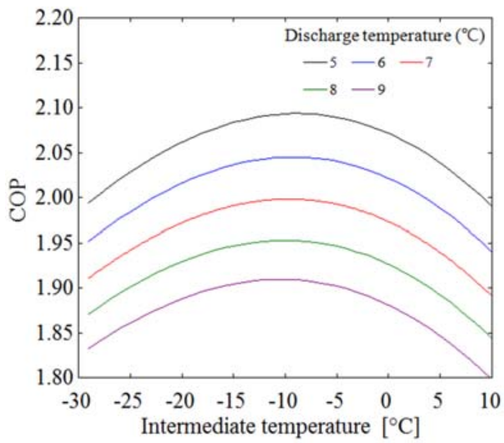
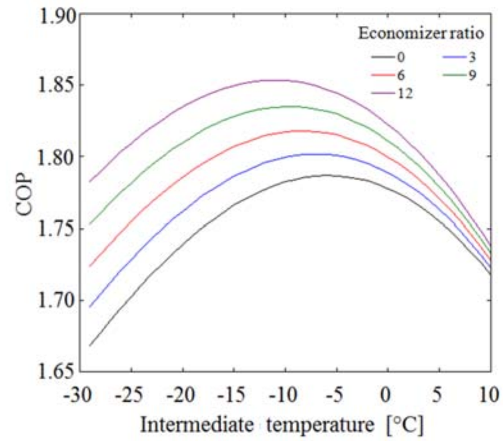


(a) HC economizer.

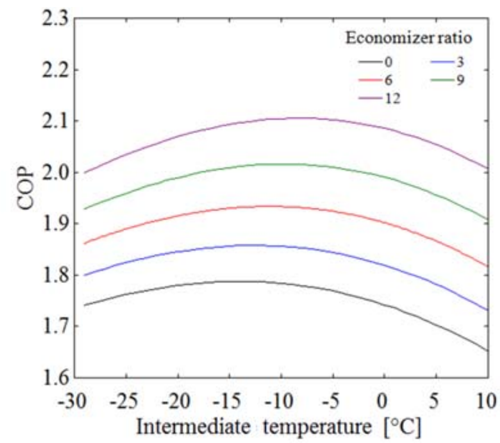


(b) LC economizer.

Figure-7. Variations of COP with different cascade heat exchanger temperature and the intermediate temperature.



(a) HC economizer.



(b) LC economizer.

Figure-9. Variations of COP with economizer ratio and the intermediate temperature.

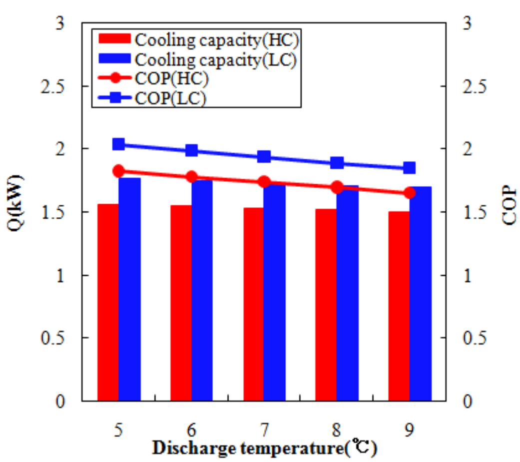


Figure-8. Cooling capacity and COP with discharge temperature in the cascade heat exchanger.

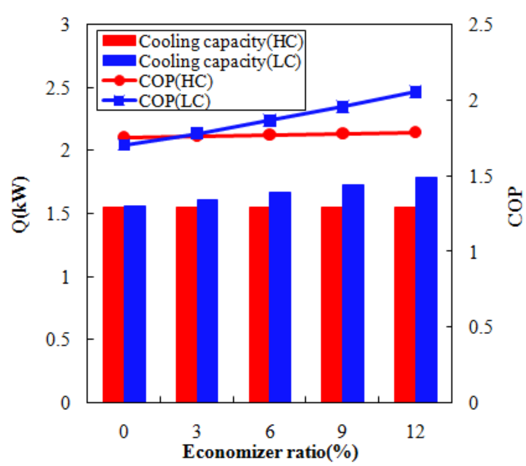


Figure-10. Variations of cooling capacity and COP with economizer ratio.

12%, the optimum intermediate temperature decreases from -6°C to -11°C. During this time, COP increases from 1.79 to 1.85. In Figure-9(b), when the economizer ratio varies from 0% to 12%, the optimum intermediate temperature increases from -14°C to -9°C. COP also improves from 1.79 to 2.1.

Increasing the economizer ratio lowers the optimum intermediate temperature for the HC economizer, but raises the temperature for the LC economizer. COP improves for both cases.

Figure-10 shows the variation of cooling capacity and COP with economizer ratio when the intermediate temperature is 5°C. For the HC economizer, increasing the economizer ratio from 0% to12% has almost no effect on cooling capacity but improves COP by 0.03. For the LC economizer, increasing the economizer ratio from 0% to 12% leads to a higher cooling capacity and COP, by 0.23 kW and 0.35 respectively. The cooling capacity and COP of the HC economizer are hardly affected by economizer ratio. On the other hand, increasing the economizer ratio from 0% to 12% improves the cooling capacity and COP of the LC economizer by 15% and 21% respectively. Thus, it is more effective to apply the economizer to LC rather than HC.

CONCLUSIONS

To improve the performance of refrigeration cycles at extremely low temperatures, this study applied an economizer system to a cascade refrigeration system having R134a-R404aas refrigerants and carried out cycle analysis. The following conclusions were derived.

a) The increase in cooling capacity and COP is insignificant when the economizer is applied to HC. However, applying the economizer to LC improves both cooling capacity and COP by approximately 13% under standard conditions. Thus, it is more efficient to apply the economizer to LC than HC.
b) A decrease in condensing temperature hardly affects cooling capacity but leads to a higher COP. An increase in evaporating temperature results in higher cooling capacity as well as COP.
c) Efficiency improves with smaller temperature differences in the cascade heat exchanger. However, the smaller the temperature difference, the larger the size of the heat exchanger.
d) Economizer ratio had no significant effect in the HC economizer, but improved the efficiency of the LC economizer by up to 21%.

Further experiments needs to be performed with the economizer system applied to cascade refrigeration cycles.

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REFERENCES

[1] Getu H.M., Bansal P.K. 2008. Thermodynamic analysis of an R744-R717 cascade refrigeration system. International Journal of Refrigeration. 31:45-54.

[2] Yan G., Hu H., Yu J. 2015. Performance evaluation on an internal auto-cascade refrigeration cycle with mixture refrigerant R290/R600a. Applied Thermal Engineering. 75: 994-1000.

[3] Dubey A. M., Kumar S., Agrawal G. D. 2014. Thermodynamic analysis of a transcritical CO2/propylene (R744–R1270) cascade system for cooling and heating applications. Energy Conversion and Management. 86: 774-783.

[4] Carlos, S. K., Rodrigo, L., Daniel, S., Ramon, C., Enrique, T. 2014. Experimental evaluation of a R134a/CO2 cascade refrigeration plant. Applied Thermal Engineering 73: 41-50.

[5] Yue C., Han D., Pu W., Weifeng He. 2015. Energetic analysis of a novel vehicle power and cooling/heating cogeneration energy system using cascade cycles. Energy. 82: 242-255.

[6] Xu Y., Chen F. S., Wang Q., Han X., Li D., Chen G. 2015. A novel low-temperature absorption-compression cascade refrigeration system. Applied Thermal Engineering. 75: 504-512.

[7] Cimsit C., Ozturk I. T. 2012. Analysis of compression absorption cascade refrigeration cycles. Applied Thermal Engineering. 40: 311-317.

[8] Li T., Zhu J., Zhang W. 2012. Cascade utilization of low temperature geothermal water in oilfield combined power generation, gathering heat tracing and oil recovery. Applied Thermal Engineering. 40: 27-35.

[9] Lv X., Yan G., Yu J. 2015. Solar-assisted auto-cascade heat pumpcycle with zeotropic mixture R32/R290 for small water heaters. Renewable Energy. 76: 167-172.

 ISSN 1819-6608

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[10] Shuxue X., Guoyuan M., Qi L., Zhongliang L. 2013. Experiment study of an enhanced vapor injection refrigeration / heat pump system using R32. International Journal of Thermal Sciences. 68: 103-109.

[11] Vaisman I. B. 2000. Economizer Cycle in Air Conditioning Systems with Rotary Vane Compressors. International Refrigeration and Air Conditioning Conference. Paper 522.

[12] EES, 2012, F-chart Software LLC., V9.100-3D.