Effect of internal heat exchanger to the performance of vapor compression cycle using refrigerant R32

H V Sihombing¹, A H Nasution¹, and H Ambarita¹*

¹Sustainable Energy Research Centre, Universitas Sumatera Utara, Jl. Almamater Kampus USU, Medan 20155 Indonesia

*Corresponding Email: himsar@usu.ac.id

Abstract. Vapor compression refrigeration cycle generally is used in the Air-Conditioning (AC) system. In order to increase the energy efficiency, the Coefficient of Performance (COP) of the cycle need to be enhanced. Many innovations can be used, one is to utilize internal heat exchanger (IHX). In this work, the effect of IHX in the vapor compression cycle with refrigerant R32 is investigated and compared with refrigerant R22. The analyses are carried out at temperature evaporation of -5°C, 0°C, and 5°C by using software ASPEN PLUS. The results show that effect of IHX in the cycle with refrigerant R22 increases the COP from 22.78% to 25.61%. On the other hand, in the cycle with refrigerant R32 the COP increases from 33.79% to 36.80%. The average increase for the cycle with refrigerant R22 and refrigerant R32 is 24.14% and 37.04%, respectively. This fact reveals that IHX in the cycle with R32 is more effective that the cycle with refrigerant R22.

1. Introduction
Vapor compression refrigeration cycles are widely used in air-conditioning cycle and also in industrial refrigeration applications. Since, the cycle consumes significant energy, the enhancement of the performance of vapor compression has come under scrutiny. There are many strategies to improve the performance of vapor compression cycle have been found in literatures such as refrigerant replacement, cycle modification, optimum temperature and pressure [1-3], etc. The performance of a single stage vapor compression cycle will down at high heat released and low evaporation temperatures. In general, this can be avoided by employing modification cycle. One of the strategies is to employ inter-cooling in order to decrease the specific volumes and the discharge temperatures, which as a result decreases the power input to the compressor [4].

The performance of a single stage using internal heat exchanger vapor compression cycles have been studied and analyzed by several researchers. Nakagawa et al. [5] and Liopis et al. [6] have studied internal heat exchanger used in CO₂ cooling cycle. Djuanda [7] reported an analysis of the internal heat exchanger in air conditioning cycle used refrigerant R410a. The used internal heat exchanger will increase the COP 9.02 %. Zhenying et al. [8] studied the effect an internal heat exchanger on the transcritical carbon dioxide refrigeration cycle with expander. The results showed that internal heat exchanger increases specific cooling capacity and COP 17%. Wantha [9] investigated the characteristics of tube-in-tube internal heat exchanger for refrigerant R1234yf and R134a. It was shown that the heat transfer coefficient for R 1234yf is lower than R134a by 11-17%. Zhang et al. [10] reported the analysis and optimization a single stage and doubles stage vapor compression cycle with an internal heat...
exchanger. The work showed that double stage compression and the internal heat exchanger have a significant effect on the optimum COP.

The above studies reveal that study on the internal heat exchanger installed in a vapor compression cycle is an interesting topic to be explored. In particular, it shows different effect at different refrigerant. The present work focuses on the investigation performance of single stage vapor compression refrigeration cycle with internal heat exchanger. The effect of the internal heat exchanger will be investigated in different refrigerant. The used refrigerants are R22 and R32. These refrigerants are typically used in the air-conditioning applications. In addition, the refrigerant R32 is a new refrigerant that can be used to replace R22. The objective of this study is to examine the maximum coefficient of performance (COP) of the cycle at several different working pressures. The results are expected to supply the necessary information on development highly efficient vapor compression refrigeration cycle.

2. Solution Method

In the present work, the vapor compression cycle is simulated using Aspen plus commercial software. The studied vapor compression cycle is shown in Figure 1. Aspen plus is a computer-aided code which uses the underlying physical relationships (e.g., material and energy balance a thermodynamics equilibrium, rate equations) to predict process performance (e.g., stream properties, operating conditions, and equilibrium sizes). Process analysis may involve the use of experimental means to predict and validate performance. Then in the simulation process, we need to give the initial process input and flow sheet are required to predict process output.

![Figure 1. Process simulation](image)

The schematic diagram of single-stage using internal heat exchanger vapour compression refrigeration cycle is shown in Figure 2. In the figure, the $p-h$ diagram is also presented. It can be seen that the component of the cycle consists of one compressor, condenser, internal heat exchanger, and evaporator.

![Figure 2. The component and $P-h$ diagrams of the vapor compression cycle](image)
The governing equations of the cycles are developed as follows. The power of compressors ($W_c$) is calculated by
\[ W_c = \dot{m} (h_2 - h_1) \]  
(1)
Here, $\dot{m}$ [kg/s], $h_1$, and $h_2$ is the mass flow rate, enthalpy of the refrigerant at point 1 and 2, respectively. After leaving the compressor, the refrigerant release the heat to the ambient in the condenser. The heat release by the cycle to ambient is given by equation (2) and calculated as follows.
\[ \dot{Q}_c = \dot{m} (h_2 - h_1) \]  
(2)
Where, $h_2$ and $h_3$ is enthalpy of the refrigerant at the inlet and the exit of the condenser, respectively. The heat absorbed by the refrigerant in the evaporator, $\dot{Q}_e$ is given by:
\[ \dot{Q}_e = \dot{m} (h_3 - h_5) \]  
(3)
Here, $h_3$ and $h_5$ is the enthalpy of the refrigerant at the inlet and the exit of the evaporator. Refrigeration effect (ER) of the cycle is calculated by equation (4).
\[ ER = (h_0 - h_5) \]  
(4)
The coefficient of performance of the cycle (COP) is given by
\[ COP = \frac{ER}{W_c} \]  
(5)
The above parameters will be examined in the results.

3. Results and Discussions
The analyses were carried out using ASPEN process simulation software. The flow diagram of the cycle analysed is shown in Figure 3. The figure shows that an internal heat exchanger is installed in the cycle. In this process each individual component is simulated and then connected as a closed loop.

![Figure 3. Flow sheet of refrigeration cycle using internal heat exchanger](image-url)
As mentioned in the previous section, the analysis is divided into two cases, case 1 is the cycle with refrigerant R22 and case 2 is with refrigerant R32. In order to vary the operating conditions, three different conditions have been simulated. The first condition is when the vapor compression cycle is operated at temperature evaporation of -5°C and temperature condensation of 30°C. The second condition is at temperature evaporation of 0°C and temperature condensation of 35°C, and the third condition is at temperature evaporation of 5°C and temperature condensation of 40°C. For all cases and conditions, the cooling load is assumed to be constant at 1000 Ton.

The simulation results will be discussed in three sub section. They are refrigeration effect, compressor power, and coefficient of performance. The results for each sub section are explained in the followings.

3.1. Refrigeration Effect

Figure 4 shows the refrigeration effects of each cycle. In the figure, the refrigeration effect from the evaporator using internal heat exchanger is shown by red line. The refrigeration effect from the evaporator without internal heat exchanger (IHX), known as standard cycle, is shown by blue line.

![Figure 4. Refrigeration effect for Refrigerant R22 and Refrigerant R32](image)

It can be seen that, as expected, the refrigerant effect of the cycle with internal heat exchanger is higher than the standard cycle. This occurs for all conditions. This fact suggests that internal heat exchanger do increase the refrigeration effect of the cycle. The same trend is also shown by the cycle...
with refrigerant R32. The figure will be used to examine the effect of IHX to the cycle with refrigerant R22 in comparison with refrigerant R32. For refrigerant R22, at temperature evaporation of -5°C the RE of the standard cycle and cycle with IHX is 1.481 kJ/kg and 1.633 kJ/kg, respectively. Thus, IHX increases the RE about 10.27%. At evaporation temperature of 0°C and 5°C, the RE increases about 11.46% and 12.95%, respectively. On the other hand, at the similar evaporation temperatures with refrigerant R32, the RE increases about 9.94%, 11.09%, and 12.53%, respectively.

3.2. Compressor Power

Figure 5 shows the compressor power of the cycle for all cases. The compressor power almost constant for all temperature evaporations. The compressor power of the cycle with IHX is relatively lower than the standard one. It can be said that IHX decreases the compressor power. The similar trend is shown for both refrigerants. For refrigerant R22, at temperature evaporation of -5°C, the compressor power of the standard cycle and cycle with IHX is 0.41 kJ/kg and 0.37 kJ/kg, respectively. IHX decreases the compressor power of 10.19%. On the other hand, for refrigerant R32 at the same temperature evaporation, the compressor power of the standard cycle and cycle with IHX is 0.52 kJ/kg and 0.43 kJ/kg, respectively. Here, IHX decreases the compressor power of 17.8%. This fact suggests that IHX works more effective in the cycle with refrigerant R32 in comparison with the cycle with refrigerant R22.

![Figure 5. Compressor power for Refrigerant R22 and Refrigerant R32](image)
3.3. Coefficient of Performance (COP)
Finally, the examination will be carried out using COP. Figure 6 shows the performance of the cycle for all cases. The figure shows that, in general, the COP of the cycle increases with decreasing temperature evaporation. It can be seen that installing IHX will increase COP significantly. For refrigerant R22 the COP of the standard cycle at temperature evaporation of -5°C, 0°C, and 5°C is 3.6, 3.4, and 3.2, respectively. While for the cycle with IHX, the COP at the similar temperature evaporation is 4.42, 4.23, and 4.03, respectively. These facts reveal that IHX increases the COP about 22.78%, 24.02%, and 25.6%, respectively. The average increase of the COP is 24.14%.

![Figure 6. Coefficient of Performances for Refrigerant R22 and Refrigerant R32](image)

| Temperature evaporation [°C] | Refrigerant R22 | Refrigerant R32 |
|-----------------------------|-----------------|-----------------|
| Standard | IXH | Difference | Standard | IXH | Difference |
| -5°C | 3.61 | 4.43 | 22.78% | 4.85 | 6.49 | 33.79% |
| 0°C | 3.41 | 4.23 | 24.02% | 4.63 | 6.51 | 40.54% |
| 5°C | 3.21 | 4.04 | 25.61% | 4.40 | 6.02 | 36.80% |
| Average | 24.14% | Average | 37.04% |
In order to examine the effect of the IXH to the Coefficient of the Performance to the cycle with different refrigerant, the COP for all cases are shown in Table 1. The table shows that the effect of IHX in the cycle with refrigerant R22 increases the COP from 22.78% to 25.61%. On the other hand, in the cycle with refrigerant R32 the COP increases from 33.79% to 36.80%. The average increase for the cycle with refrigerant R22 and refrigerant R32 is 24.14% and 37.04%, respectively. This fact reveals that IHX in the cycle with R32 is more effective that the cycle with refrigerant R22.

4. Conclusions
The effect of the Internal Heat Exchanger in a vapor refrigeration cycle has been investigated numerically. The conclusions of this study are as follows. By installing the Internal Heat Exchanger, both refrigerants show the similar trend. The refrigerant effect increases and the compressor power decreases. As a result, the coefficient of the performance increases. The increasing of the COP in the cycle with refrigerant R32 is higher than refrigerant R22. Thus, IHX is more effective in the cycle with refrigerant R32 than R22.

References
[1] Ambarita H, Nasution AH, and Sihombing HV 2018 IOP Conf. Series: Material Science and Engineering 420 012038.
[2] Ambarita H, Nasution A H, Siahaan N M and Kawai H 2016 Case Studies in Thermal Engineering 8 105-114.
[3] Ambarita H, Nasution DM, Gunawan S and Nasution AH 2017 IOP Conf. Series: Material Science and Engineering 180 012027
[4] Purohit N, Gupta DK, and Dasgupta MS 2015 Energy Procedia 90 171-178.
[5] Llopis, R, Sanz-Kock C, Cabello R, Sánchez D, Torrella E 2016 Applied Thermal Engineering 103 1077-1086
[6] Nakagawa M, Marasigan AR, Matsukawa T 2011 International Journal of Refrigeration 34 1577–1586.
[7] Djuanda D 2018 AIP Conference Proceedings 1984 020008.
[8] Zhang Z, Tian L, Chen Y, and Tong L 2014 Entropy 16 5919-5934.
[9] Wantha C 2019 Applied Thermal Engineering 157 113747.
[10] Zhang Z, Hou Y, and Kulacki FA 2018 Applied Thermal Engineering 140 147-157.
[11] Arora R C 2010 Refrigeration and Air Conditioning, PHI, New Delhi

Acknowledgement
This work is a part of research project funded by Ministry of Research and Higher Education of Republic of Indonesia. The scheme of the research project is “Hibah Desentralisasi PDUPT DRPM” Year of 2019.