The optimum temperature of single-stages vapor compression refrigeration cycle for Air-Conditioning unit

H Ambarita¹²*, A. Halim Nasution², S. Ginting³ and H V Sihombing²

¹Sustainable Energy and Biomaterial Centre of Excellent, University of Sumatera Utara, Jl. Almamater Kampus USU, Medan 20155, Indonesia
²Graduate School of Mechanical Engineering, Faculty of Engineering, University of Sumatera Utara, Jl. Almamater Kampus USU, Medan 20155, Indonesia
³Mechanical Engineering Department, University of HKBP Nommensen, Medan

*Email: himsar@usu.ac.id

Abstract. Vapour-compression cycle is the most widely used refrigeration cycles for Air-Conditioning (AC) units. The system consumes a significant amount of the energy. Thus, any modification to improve the energy efficiency is extremely needed. One of the well-known modification is multistage VC cycles. The objective of this study is to search the optimum high pressure based on environmental temperature of air condition. The single-stage cycle is analysed using for three different refrigerants (R32, R22 and R134a.). Pressure was varied based on ambient temperature. The governing equations and the boundary conditions are solved using Aspen Plus software. COP, refrigeration effect (RE), and compressor power as optimum temperature are plotted. The results show that there exists an optimum temperature for optimum cycle.

1. Introduction
The development of science and technology has widely impact with human life. Today’s the use of vapor compression cycle is growing significantly in particular for dense populated cities. Air conditioning necessary systems almost in all places where people congregate, such as residential, companies, schools and work sites. Air conditioning (AC) is a refrigeration system used in order to provide comfort in our living spaces. Considering the growth of economy and living standard, it is estimated that vapor compression cycle will consume huge amount of electricity. A considerable amount of research on vapor refrigeration cycle has been conducted to improve energy efficiencyof vapor compression cycle such as using heat recovery technique, multi stages cycle, etc. [1 – 6].

The present paper focus in the optimum temp temperature vapor compression cycle for efficiency energy. Yunus et al. [7] reported a study on effect of ambient temperature on the performance of air conditioning system. In the study, focus on determining the cabin temperature distribution, energy consumption of the compressor and the coefficient of performance AA Cusing by refrigerant HFC-R134a with three various ambient temperature (30, 35 and 40 °C). Al-Rashed [8] optimized the evaporator temperature on vapor compression refrigeration system. Six common refrigerants are selected for the analyses include R600a (isobutene), R290 (propane), R134a, R22, R410a, and R32. It was shown that an excessive overheat reduces the refrigerant mass flow rate, the evaporator effect and the refrigeration coefficient of performance (COP). Suhemanto et al. [9] reported evaluation and comparison of the steady-state performance parameters of an ACC system employing R1234yf and R134a for different ambient temperature. It was tested at four different compressor speeds, namely 1000, 1500, 2000 and 2500 rpm, and the temperature of the air
streams at the inlets inside duct of 30 °C and varies the outside duct of 30, 35 and 40 °C. Harrington et al. [10] studied refrigerating appliances operate across a range of temperature conditions. In the study was focused to measured energy consumption at four ambient temperature from 10 °C to 40 °C. Khan et al. [11] experimentally investigated the effect of different variable on energy consumption of a household refrigerator. The ambient temperature has varied from 20 to 33 °C. Energy consumption has increases by about 15% to 53 % because the ambient temperature increases. Song and Cao [12] reported the optimal value of medium temperature using by R134a cycle. Baskaran and Mathews [13] reported the thermal analysis of vapor compression refrigerant system. Five common refrigerants analyses include R429A, R430A, R431A and R152a with three varied of temperature (30°C, 40°C and 50°C). It was shown that the effect of varied temperature on compressor pressure.

Those studies show that optimize the vapor compression refrigeration cycle base on ambient temperature. This paper focuses on numerical analysis in the optimum pressure base on ambient temperature of single stage vapor compression refrigeration cycle. The objective is to explore the optimum coefficient of performance (COP) of the system at several different working pressure base on ambient temperature of condenser. In the section of vapor compression cycle processes will be considered for analysis by using the Aspen plus. The results are expected to supply the necessary information on developing high efficient vapor compression refrigeration cycle.

2. Methods
In the present study Aspen plus is used for modelling the system vapour compression cycle is shown in figure 1. Aspen plus is a computer-aided software 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). It is a market-leading process modelling tool for different area of applications like conceptual design, optimization, metal and material, coal power industries and performance monitoring for the specialty chemical.

![Figure 1. Vapor compression cycle system block processing by using Aspen plus software](image-url)
The schematic diagram of single-stage 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 system consists of compressor, condenser, expansion valve, and evaporator. Several assumptions are made. The resistance of the refrigerant flow is negligible. The pressure loss in evaporator and condenser are neglected. The differences of potential energy and kinetic energy of the refrigerant are ignored. The suction and exhaust fluctuations of compressors are neglected.

![Schematic and $p$-$h$ diagrams of the system](image)

**Figure 2.** Schematic and $p$-$h$ diagrams of the system

The governing equations of the systems are developed as follows. The power in the compressor ($\dot{W}_c$) is calculated by

$$\dot{W}_c = \dot{m}_1 (h_2 - h_1)$$

(1)

where $h_1$ and $h_2$ are enthalpy of the refrigerant at the inlet and the exit of first compressor.

The heat release by the system to ambient is given by equation (2).

$$\dot{Q}_c = \dot{m}(h_3 - h_2)$$

(2)

The heat absorbed by the refrigerant in the evaporator, $\dot{Q}_e$ is given by:

$$\dot{Q}_e = \dot{m}(h_1 - h_4)$$

(3)

Refrigeration effect (ER) of the system is calculated by equation (4).

$$ER = (h_1 - h_4)$$

(4)

The coefficient of performance of the system (COP) is given by:

$$COP = \frac{\dot{Q}_e}{\dot{W}}$$

(5)

3. Results and Discussions

The analysis is carried out for refrigerant R32, R22 and R134a. Temperature evaporation is constant at $0^\circ\text{C}$ and operating condition of compressor base are varied on ambient temperature. The cooling load is assumed to be constant at 1000 Ton.
Table 1. Variance operating system vapor compression

| Refrigerant | Temperature Evaporation [°C] | Temperature Condensation [°C] |
|-------------|------------------------------|------------------------------|
| R 32        | 0 30 32 34 36 38 40 42 44 46 48 50 | R22 30 32 34 36 38 40 42 44 46 48 50 |
| R22         | 0 30 32 34 36 38 40 42 44 46 48 50 | R134a 30 32 34 36 38 40 42 44 46 48 50 |

3.1. Refrigerant Effect

The refrigeration effect from in the system was shown in figure 3. In the figure, the refrigeration effect from the evaporator using R32 is shown by red line. The refrigeration effect from the evaporator using R22 is shown by black line. The refrigeration effect from the evaporator using R134a is shown by blue line. The figure shows the same trend for all cases and the highest refrigeration effect is refrigerant R134a. As a result, the refrigeration effect in the system increases with increasing pressure.

![Figure 3. Mass flow rate in the system for case 1 and case 2](image)

3.2. Compressor Power

Figure 4 shows the compressor power of the system for all refrigerants. The figure shows the almost similar trend. Pressure base on ambient temperature is strongly affected on the energy consumption of the refrigerator. The power increases with increasing the pressure. As a note, the temperature evaporation present system is fixed.

As a system the power of the system is calculated by using Aspen plus software. In the figure, the total of the compressor power in the system is shown by red line. The figure shows the point optimum pressure, the compressor power met coefficient of performance. The highest pressure difference in the system is for Refrigerant R32 and followed by Refrigerant R22 and Refrigerant R134a. It can be seen that compressor consumption of refrigerant R134a is higher than refrigerant R22 and Refrigerant R32. Also, the compressor consumption of refrigerant R22 is higher than refrigerant R32.
Figure 4. Compressor power for all refrigerant

3.3. Coefficient of Performance

Figure 5 shows the performance of the system for all cases. The figure shows that, in general, the COP of the system increases with decreasing pressure difference of the system. Pressure base on ambient temperature is strongly affected on the coefficient of performance the refrigerator. As a note, the highest pressure difference in the system is for Refrigerant R32 and followed by Refrigerant R22 and Refrigerant R134a. It can be seen that COP of refrigerant R134a is higher than refrigerant R22 and Refrigerant R32. Also, the COP of refrigerant R22 is higher than refrigerant R32.
4. Conclusions

The optimum temperature operational condition of single-stage vapor compression refrigeration cycle has been investigated. Numerical simulations have been carried out to investigated the optimum pressure base on temperature for refrigerant R32, R22, and R134a for different ambient temperature. The results of the present study are compared with the correlation proposed in the literature. The conclusions of this studies are as follows.

- With the variance temperature compression of three refrigerant gives optimum pressure of each refrigerant.
- There exists a minimum compressor power for an optimum pressure. This fact reveals that there will be exist an optimum performance of the system.
- There exist an ambient temperature affect the performance of system. The COP increased when compressor power decreased.

5. References

[1] Ambarita H 2018 IOP Conference Series: Earth and Environmental Science126 012018
[2] Ambarita H and Sihombing H V 2018 Journal of Physics: Conference Series978 012098
[3] Nasution A H, Sembiring P G and Ambarita H 2018 IOP Conference Series: Materials Science and Engineering308 012027
[4] Pintoro A, Ambarita H, Nur T B and Napitupulu F H 2018 IOP Conference Series: Materials Science and Engineering308 012026
[5] Ambarita H, Nasution D M, Gunawan S and Nasution A H 2017 IOP Conference Series: Materials Science and Engineering180 012027
[6] Ambarita H, Nasution A H, Siahaan N M and Kawai H 2016 Case Studies in Thermal Engineering8 105 – 114
[7] Yunus H M, Nasution H, Aziz A A, Sumeru and Dahlan A A 2016 Applied Mechanics and Materials ISSN: 1662-7482, pp 221-225.
[8] Al-Rashed A A A A 2011 Alexandria Engineering Journal50, 283-290.
[9] Suhemanto M, Hosoc M and Aral M C 2016 AIP Conference Proceedings 1778, 030004
[10] Harrington L, Aye L and Fuller B 2018 Applied Energy 211, 346-357
[11] Khan M I H, Afroz H MM, Rohoman M A, Faruk M and Salim M 2013 International Journal of Energy Engineering vol. 3 pp. 144-150
[12] Song Y and Cao F 2018 Energy Conversion and Management 166, 409-423
[13] Baskaran A and Mathews P K 2012 International Journal of Scientific and Engineering Research Vol.3 ISSN: 2229-5518
[14] Parpas D, Amaris C, Sun J, Tsamos K M, Tassou S A 2017 Energy Procedia 123, 156-163
[15] Arora R C 2010 Refrigeration and Air Conditioning, PHI, New Delhi
[16] Khurmi R. S and Gupta J K 2008 Refrigeration and Air Conditioning, S.Chand & Company Ltd, New Delhi