World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Research Article)

Check for updates

Study of expansion valve capacity at constant thermal load and 5°C room temperature in refrigerated truck unit

I Gede Bawa Susana [1, *] and I Ketut Perdana Putra [2]

[1] *Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125, Indonesia*

[2] *Department of Electrical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125, Indonesia*

World Journal of Advanced Engineering Technology and Sciences, 2024, 13(02), 429–434

Publication history: Received on 21 October 2024; revised on 30 November 2024; accepted on 02 December 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.2.0600

Abstract

The main role of the expansion valve in a vapor compression refrigeration system is to regulate the mass flow rate of the refrigerant gas, so the study was conducted to evaluate the effect of variations in the expansion valve capacity on the cooling performance of the Truck Refrigerator unit. This is related to the suitability of the temperature of the products transported using the truck refrigerator, which often experiences damage so that the product or goods are rejected in the market. The study showed that the cold reach time to obtain a temperature of 5°C in the refrigerator truck cooling room when using an expansion valve with a larger cooling capacity (3500) occurred faster than an expansion valve with a standard cooling capacity (2000 W). The Coefficient of Performance (COP) that occurred when using an expansion valve with a standard cooling capacity (2000 W) was 3.099. This value is smaller than the expansion valves with a cooling capacity of 1000 W and 3500 W with values of 3.226 and 3.928, respectively. Using an expansion valve with a cooling capacity that is more significant than the standard was found to produce the highest COP. This also means lower power consumption and, of course, lower electricity bills. The work of the compressor in the refrigeration system is very dependent on the COP value.

Keywords: Expansion valve; Thermal load; Coefficient of Performance (COP); Cooling system

1. Introduction

Refrigerator trucks are needed to transport fresh products that require low temperatures, such as meat, fruits, vegetables, and fish. In addition, refrigerator trucks are used to ship chemicals and pharmaceuticals sensitive to temperature. In the Truck Refrigerator unit, a cooling agent called refrigerant is used. The refrigerant circulates in the truck refrigerator unit to absorb heat in the air that is to be conditioned so that the conditions desired by the user are obtained, and heat is released into the free air. This process of heat absorption and release occurs due to the difference in temperature between the air and the refrigerant.

Refrigerant is the most critical component in the refrigeration cycle, as it produces cooling and heating effects on the refrigeration machine. A refrigerant is a working fluid that circulates in the refrigeration cycle. Refrigeration systems are primarily used in transportation equipment, using the vapor compression cycle. Several studies have been conducted on applying vapor compression refrigeration systems for food such as cucumbers, tomatoes, and beer; fishing boats; cold boxes for eggplant; and refrigerators [1, 2, 3]. The heat transfer process in the refrigeration system occurs from low temperature to higher temperature. Heat is absorbed from the space at a low temperature and released to the space at a higher temperature. This process occurs due to the difference in temperature between the refrigerant

* Corresponding author: I Gede Bawa Susana

and the ambient air. The application of the vapor compression cycle of the refrigeration system in transportation equipment is shown in Figure 1 in an ideal cycle state [4].

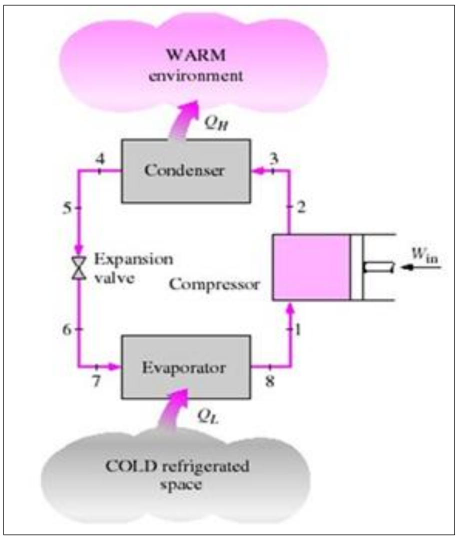

Figure 1 Ideal vapor-compression refrigeration cycle [4]

Vapor compression refrigeration, in principle, uses four main components that are interconnected such as compressor, condenser, evaporator, and expansion valve. This study explicitly discusses the expansion valve. The expansion valve is one of the basic elements of the refrigeration system. It reduces the pressure of the liquid refrigerant and regulates the flow of refrigerant to the evaporator. The expansion valve has a significant role in the vapor compression refrigeration system, namely regulating the mass flow rate of the refrigerant gas related to the evaporator load conditions, reducing the temperature and pressure. In addition, it protects the compressor from liquid buildup by controlling the level of overheating as a function of the expansion valve [5]. The performance of the vapor compression system depends in part on the expansion device. The expansion valve is a small and strong component that is important for controlling the flow of refrigerant and maintaining the right temperature and pressure in the system. It plays an important role in heating, ventilation, and air conditioning (HVAC) systems [6].

An expansion valve is a tool that expands high-pressure and high-temperature refrigerant fluid to a low-pressure and low-temperature state. The expansion valve, as a regulator of the rate and pressure of the refrigerant flow according to the cooling load that the evaporator must serve, is adjusted to the pressure given by the compressor. The expansion valve regulates so that the evaporator can always work so that maximum refrigeration cycle efficiency is obtained or the amount of refrigerant coming out of the expansion valve according to the amount of refrigerant needed by the evaporator so that the refrigerant can evaporate perfectly when it exits the evaporator.

The main role of the expansion valve in a vapor compression refrigeration system is to regulate the mass flow rate of the refrigerant gas so that research is conducted to evaluate the effect of variations in the expansion valve capacity on the cooling performance of the Truck Refrigerator unit. This is related to the suitability of the temperature of the products transported using the truck refrigerator, which often experiences damage so that the product or goods are rejected in the market. Based on this, the cooling system in the Truck Refrigerator unit was redesigned by varying the expansion valve capacity for a constant thermal load and room temperature of 5°C.

2. Material and methods

The study was conducted on one unit of Truck Refrigerator installed on a food transport vehicle with an expansion valve based on a cooling capacity of 2000 W. Testing was conducted for an expansion valve with a standard cooling capacity of 2000 W and variations for cooling capacities of 1400 W and 3500 W. The study was for a constant room temperature of 5°C. The measuring instruments include one unit of manifold gauge set, digital thermometer, digital tachometer, digital scales, and refrigerant 134a (R 134a). The study was conducted to determine the impact of changes in expansion valve capacity if reduced and enlarged from the standard 2000 W. The data collection procedure is carried out as shown in Figure 2. The expansion valve is presented in Figure 3.

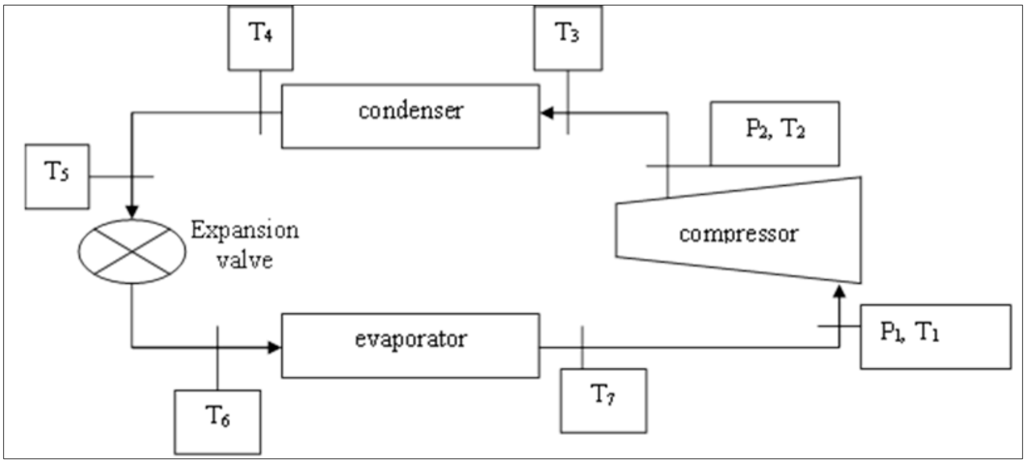

Figure 2 Testing scheme

Figure 3 Expansion valve

The expansion valve regulates the evaporator to always work so that the maximum efficiency of the refrigeration cycle is obtained or the amount of refrigerant coming out of the expansion valve is by the amount of refrigerant needed by the evaporator so that the refrigerant can evaporate perfectly when it exits the evaporator. In this analysis, the actual vapor compression cycle will be used, where in practice the vapor compression cycle deviates from the standard vapor compression. The important differences between the actual vapor compression cycle and the standard vapor compression cycle are as follows.

- There is a decrease in pressure along the condenser and evaporator pipes.
- There is a process of sub-cooling the liquid leaving the condenser before entering the expansion valve.
- Further heating of the vapor leaving the evaporator before entering the compressor.
- There is an increase in entropy during the compression process (non-isentropic compression).
- The expansion process is non-adiabatic.

Although the process in the standard cycle is not the same as the actual cycle process, the process in the standard cycle is needed to facilitate the theoretical analysis of the cycle. The main quantities that apply in the actual vapor compression cycle can be known with the help of the pressure enthalpy diagram. The main quantities in question are compression work, refrigeration effect, and COP [7]. Compression work (Wc), kJ/kg, is the change in enthalpy in processes 1-2, with h_1 being the initial enthalpy of compression (kJ/kg) and h_2 being the final enthalpy of compression (kJ/kg).

$$Wc = h_2 - h_1 \text{ (kJ/kg)} \qquad \text{.......... (1)}$$

The refrigeration effect (q_r), kJ/kg, is the heat transferred in processes 6-7, where h_6 is the initial enthalpy of vaporization (kJ/kg) and h_7 is the final enthalpy of vaporization (kJ/kg).

$$q_r = h_7 - h_6 \text{ (kJ/kg)} \qquad \text{.............. (2)}$$

The COP of an actual vapor compression cycle is the refrigeration effect divided by the compression work as in Equation 3.

$$COP = \frac{q_r}{W_c} = \frac{h_7 - h_6}{h_2 - h_1} \quad \text{………… (3)}$$

3. Results and discussion

The expansion valve variations to achieve a constant cooling temperature of 5ᵒC based on each cooling capacity of 1000 W, 2000 W, and 3500 W affects the cold reach time, compression work, refrigeration effect, refrigerant mass flow rate, and performance coefficient. Expansion valve 1 is based on a cooling capacity of 1000 W, expansion valve 2 is based on a cooling capacity of 2000 W. Expansion valve 3 is based on a cooling capacity of 3500 W. Figure 4 shows the effect of changes in expansion valve capacity from the standard 2000 W for the cold reach time at a cooling temperature of 5ᵒC.

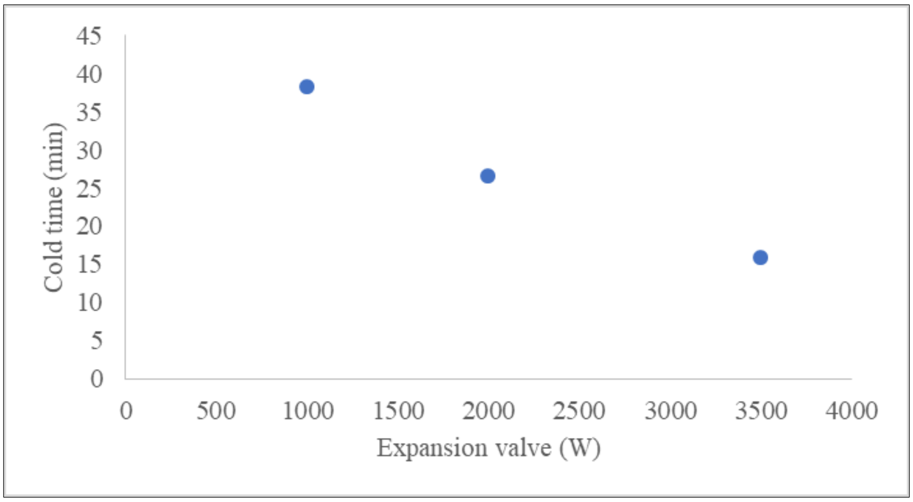

Figure 4 Comparison of expansion valve variations against cold reach time

Based on Figure 4, the cold reach time for the expansion valve with a cooling capacity of 2000 W is 26.56 minutes. The cold reach time for using an expansion valve with a cooling capacity of 3500 W is 15.77 minutes. The reach time for using an expansion valve with a cooling capacity of 1000 W is 38.21 minutes. It was found that using an expansion valve with a cooling capacity greater than using an expansion valve with a standard cooling capacity of 2000 W provides a faster cold reach time. The use of expansion valves with a cooling capacity smaller than those with a standard cooling capacity of 2000 W results in a longer cooling time. The cold reach time is to obtain a temperature of 5ᵒC in the refrigerator truck cooling room. When using an expansion valve with a larger cooling capacity, the cold reach time occurs faster than when using an expansion valve with a smaller cooling capacity. The results of the study are in line with Putra et al. [8] that a larger expansion valve produces a faster temperature drop as an impact of opening the valve earlier, and the evaporator absorbs heat faster due to the larger refrigerant flow when the engine is turned on. An interesting thing found in the study is that the refrigeration effect is not directly proportional to the cold reach time. The refrigeration effect is the amount of heat absorbed per pound (one unit of mass) of refrigerant in the refrigerated space to produce useful cooling [9]. As shown in Figure 5, the refrigeration effect on the use of an expansion valve with a standard cooling capacity is 136.92 kJ/kg.

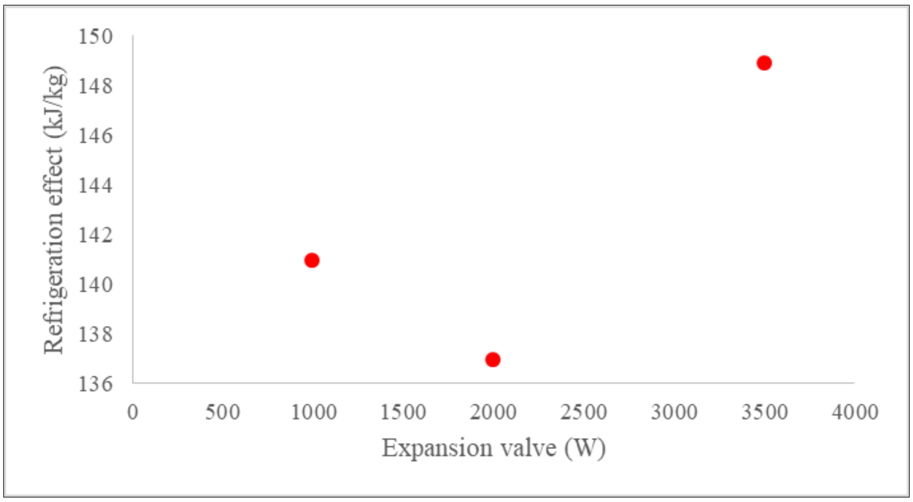

Figure 5 Comparison of expansion valve variations on refrigeration effect

Using expansion valves with smaller and larger cooling capacities than the standard produces a larger refrigeration effect of 140.916 kJ/kg and 148.916 kJ/kg, respectively. The refrigeration effect affects the coefficient of performance in the cooling system. The coefficient of performance (COP) of the use of expansion valves is shown in Figure 6.

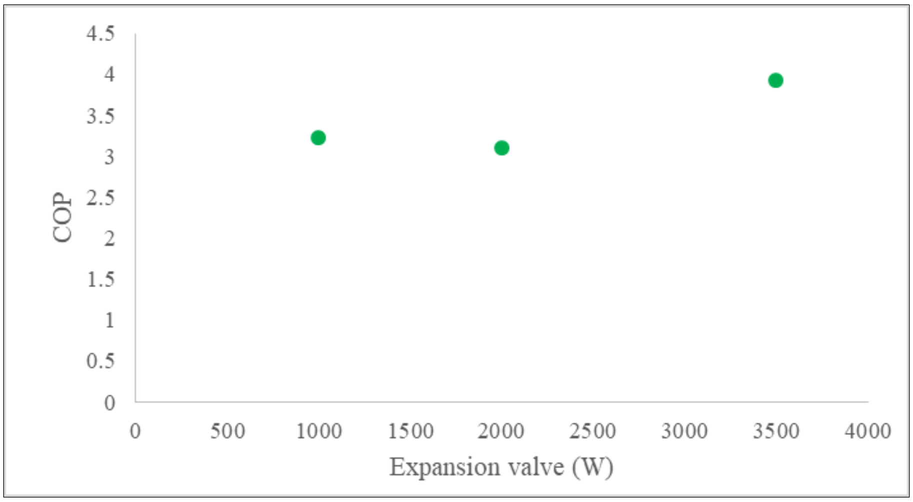

Figure 6 Comparison of expansion valve variations against COP

The COP that occurs when using an expansion valve with a standard cooling capacity (2000 W) is 3.099. This value is smaller than when using an expansion valve with a cooling capacity of 1000 W and 3500 W with values of 3.226 and 3.928, respectively. It was found that using an expansion valve with a cooling capacity greater than the standard resulted in the highest COP. This is related to the greatest heat absorption in the evaporator, which has an impact on the high COP that occurs. Higher COP means greater energy efficiency. The COP of a vapor compression system serves as a measure of compressor efficiency and is used to monitor the operating and maintenance costs of a refrigeration system [10]. The higher the COP value, the lighter the compressor works in an air conditioning system [11]. This also means lower power consumption and, of course, lower electricity bills. The work of the compressor in a refrigeration system is very dependent on the COP value.

4. Conclusion

The use of an expansion valve with a cooling capacity greater than the standard provides a faster cold reach time. The cold reach time on an expansion valve with a cooling capacity of 1000 W is 38.21 minutes, 3500 W is 15.77 minutes, while the standard (2000 W) is 26.56 minutes. The highest coefficient of performance (COP) occurs in an expansion valve with a cooling capacity of 3500 W of 3.928. This condition shows that the expansion valve in the refrigeration system of a truck refrigerator unit is better to use an expansion valve with a cooling capacity greater than the standard.

A COP higher than the standard shows that greater energy efficiency affects the compressor working lighter in an air conditioning system. This means lower power consumption and, of course, lower electricity bills.

Compliance with ethical standards

Acknowledgments

The author also wishes to thank the Department of Mechanical Engineering, University of Mataram, for facilitating the implementation of this research.

Disclosure of conflict of interest

The authors declare no conflict of interest.

References

[1] Buntu TR, Sappu FP, Maluegha BL. Analysis of cooling load of food products using cold box LUCAS NULLE type RCC2 cooling machine. Jurnal Online Poros Teknik Mesin. 2017; 6(1): 20-31.

[2] Al hasbi G, Budiarto U, Amiruddin W. Performance analysis of vapor compression refrigeration system design on 5 GT fishing vessels in the Rembang area. Jurnal Teknik Perkapalan. 2016; 4(4): 768-778.

[3] Al-Ajmi ENRM. (2015). Coefficient of performance enhancement of refrigeration cycles. Int. Journal of Engineering Research and Applications. 2015; 5(3): 117-125.

[4] Çengel YA, Boles MA, Kanoglu M. Thermodynamics: An Engineering Approach. 9th ed., McGraw-Hill. 2019.

[5] Sivaraman N, Vaidyanathan RM, Patel M, Markos M. Performance analysis of refrigerants with various expansion valves in vapour compression refrigeration and air-conditioning system. Materials Today: Proceedings. 2021; 45(2): 2465-2469.

[6] Bopray A, Downer R, Ward K. Understanding expansion valves in HVAC systems. Available online: https://todayshomeowner.com/hvac/guides/what-are-expansion-valves/ (accessed on 1 March 2024).

[7] Borgnakke C, Sonntag RE. Fundamentals of Thermodynamics. 10th. John Wiley & Sons. 2020.

[8] Putra IPGKM, Wijaksana H, Sucipta M. The effect of variation in expansion valve capacity on cooling performance in cold storage machines. Natural Sciences Engineering & Technology Journal. 2023; 3(1): 177-181.

[9] Orr B. What is Net Refrigeration Effect (NRE)? Available online: https://hvacrschool.com/what-is-net-refrigeration-effect-nre/. 2021.

[10] Dapito Jl, Chua AY. Coefficient of Performance Prediction Model for an On-Site Vapor Compression Refrigeration System Using Artificial Neural Network. International Journal of Technology. 2024; 15(3): 505-516.

[11] Solka G, Hidayat N, Andrizal, Lapisa R. Coefficient of Performance (COP) Analysis of Air Conditioning System Trainers at 2970 rpm. Jurnal Teknologi dan Pendidikan Vokasi Indonesia. 2023; 1(1): 51-66.