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(RESEARCH ARTICLE)

Changes in freezing temperature, energy consumption, exergy loss and efficiency, and cooling coefficient of R22 and R404a refrigerants over experimental time

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Abstract

This article is to study the working efficiency of air freezing systems using R22 and R404a refrigerants. The main objective is to determine the loss, exergy efficiency and cooling coefficient (COP) of the freezing refrigeration system using R22 and R404a refrigerants. Theoretically, find the law of change in freezing time, energy consumption for the freezing refrigeration system using R22 and R404a refrigerants, machine running at without load (do not leave ingredients in the freezer when the air temperature in the freezer reaches -45°C), with load (when the product core temperature reaches -18°C) by direct and indirect fluid supply methods and find appropriate fluid supply methods for the system's R22 and R404a of refrigerants two-level compression freezer, at the same time analyze exergy and find the suitable freezing mode for the refrigeration system in freezing conditions at temperatures from -30°C to -45°C, wind speed of 6 m/s.

Keywords*:* R22; R404a; Freezing temperature; Energy consumption; Exergy; Cooling coefficient

1. Introduction

Refrigeration technology has been around for hundreds of years and is widely used in many different technical fields: in the food processing and preservation industry, chemical industry, wine and beer industry, biology, automatic measurement, low temperature drying techniques, construction, oil industry, material manufacturing, tools, machine design and manufacturing, seed treatment, medicine, sports, and the life. Today, the refrigeration industry has rapidly developing using for many different purposes. Its scope is increasingly expanding and play a necessary role and indispensable engineering industry in life and technology of all countries. Freezing temperature, energy consumption, exergy loss and performance, cooling coefficient of R22 and R404a refrigerants play a decisive role in the quality of frozen products. When the temperature drops, it will inhibit the activity of enzymes in the food itself and microorganisms, reducing the vital activities of cells, thereby slowing down or stopping the transformation processes that cause damaged and rotten. If the reduce of 10°C happen, the biochemical reaction rate decreases by 1/2 to 1/3. In addition, microorganisms stop working in the range of (-10 ÷ Tkt)°C. Molds can withstand cold better than about (-15 ÷ -12)°C, and the water is at least 15% liquid [1]. However, when the temperature of some foods is lower to (-22 ÷ -16)°C, the 14% and 86% water in the food has crystallized, microorganisms die and stop functioning. Currently there are two cooling methods: direct and indirect cooling. In indirect freezing, use natural or forced convection cold air (convective heat transfer) to lower the temperature of the freezing environment to -40°C to -45°C to freeze the product. If the freezing is slow, the air convections naturally, while when the freezing is quick (like IQF), the air is forced by convection. In addition, we can also use a mixture of salt water or other refrigerant, but it must be friendly to the environment, food, and people [1,2]. In direct freezing, usually using contact freezers, the product is placed in trays and sandwiched between freezing shaking plates, inside the hollow shaking plates there is refrigerant flowing through, and the evaporation temperature is -45°C to -50°C. The cooling method is mainly by conduction, and the cooling speed is relatively fast. In addition, the direct freezing method can also use liquid nitrogen as a refrigerant with a very low

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evaporation temperature of -196°C, fast freezing speed, lasting only (5-10) minutes, and low cost. The composition is very high, so it is not used for common foods but for high-end products with high economic value.

Currently there is no publication on freezing temperature, energy consumption, exergy loss and efficiency, and cooling coefficient of R22 and R404a refrigerants according to experimental time. Therefore, this article focuses on solving this unmentioned problem.

2. Study objects and methods

The research method for analysis is theoretical method combined with experiment. The theory application of energy methods and exergy analysis to calculate the cooling coefficient (COP), loss and exergy efficiency of a two-level freezing system using R22, R404a refrigerants. Applying theory on energy methods and exergy analysis combined with experiments to determine freezing time, energy consumed in the freezing process, exergy loss and efficiency, and cooling coefficient of the system Two-level freezing using refrigerants R22, R404a using direct and indirect fluid supply methods. Engineering Equation Solver (EES) software is used to analyze enthalpy and entropy parameters at the specific points of the cycle when the air temperature in the freezer [3,4].

3. Results and discussion

3.1. Change in freezing temperature of refrigerants R22 and R404a according to experimental freezing time

The direct fluid supply method has a shorter time than the indirect fluid supply method in both loaded and unloaded machine modes for two refrigerants (R22 and R404a). Therefore, the comparison of freezing time of R22 with R404a under loaded and unloaded machine conditions using the direct fluid supply method was performed in this study.

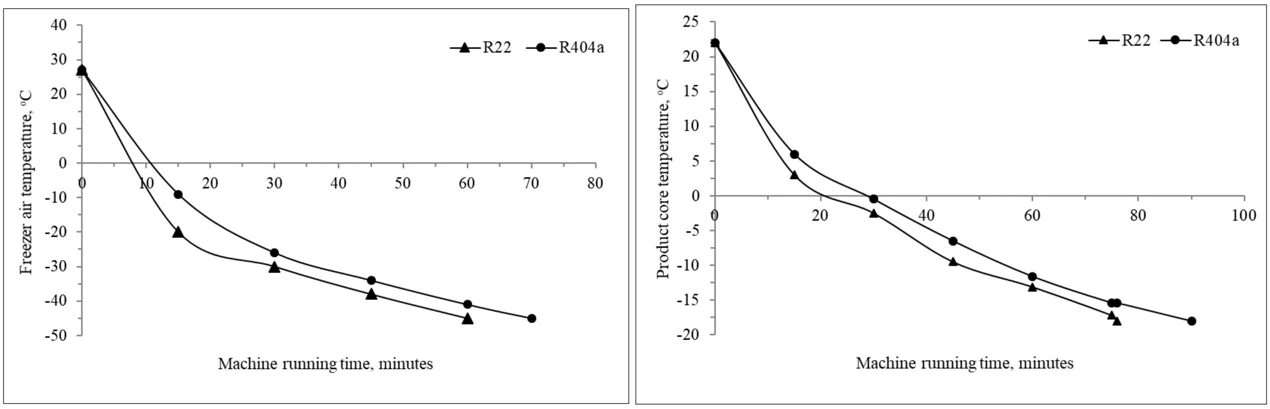


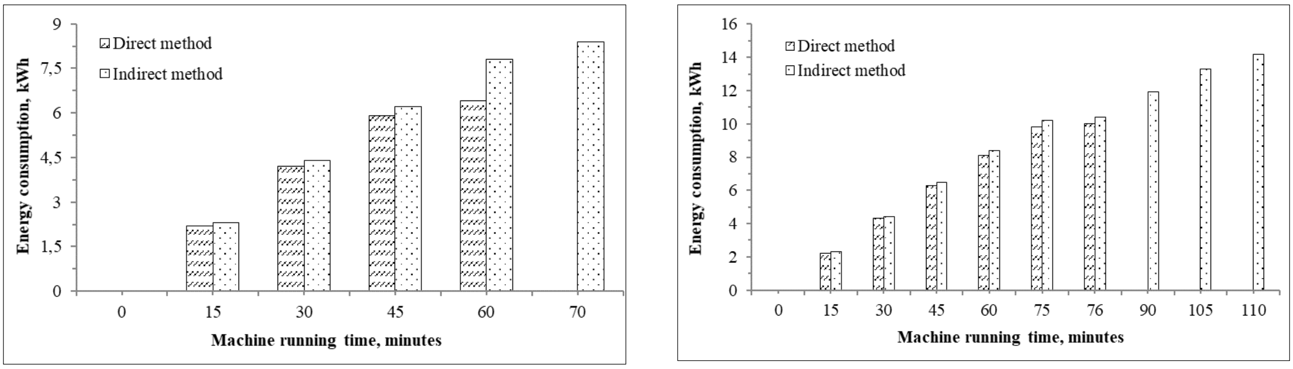
Figure 1 Change in temperature according to freezing time of R22 and R404a machines running without load and load

Air temperature change in the freezer of refrigerants R22 and R404a according to machine running time (Figure 1). Let the air temperature in the freezer reach -45°C with R22 refrigerant in 60 minutes and R404a in 70 minutes. Freezing time using R404a is 10 minutes longer than R22, corresponding to an increase of 14.2%. The change in product core temperature of the refrigeration system using R22 and R404a refrigerants according to the time the machine runs under load shows that for the product core temperature to reach -18°C, the machine run time is 76 minutes with R22 refrigerant and 90 minutes with R404a refrigerant. Freezing time using R404a is 14 minutes longer than R22, corresponding to an increase of 15.5%. Refrigeration systems using R404a refrigerant run without load and load about 14.8% longer than R22 refrigerant. The direct fluid supply method gives better results in terms of time and performance for using R22 and R404a refrigerants.

3.2. Change energy consumption

3.2.1. Change the energy consumption of the refrigeration system using R22 refrigerant

The change in energy consumption over running time of the refrigeration system using R22 refrigerant, with the machine running at idle according to direct and indirect fluid supply methods shows that, over running time, the energy consumed is consumption increases, at the same time, the energy consumption of the indirect fluid supply method is higher than that of the direct fluid supply method (the direct method).



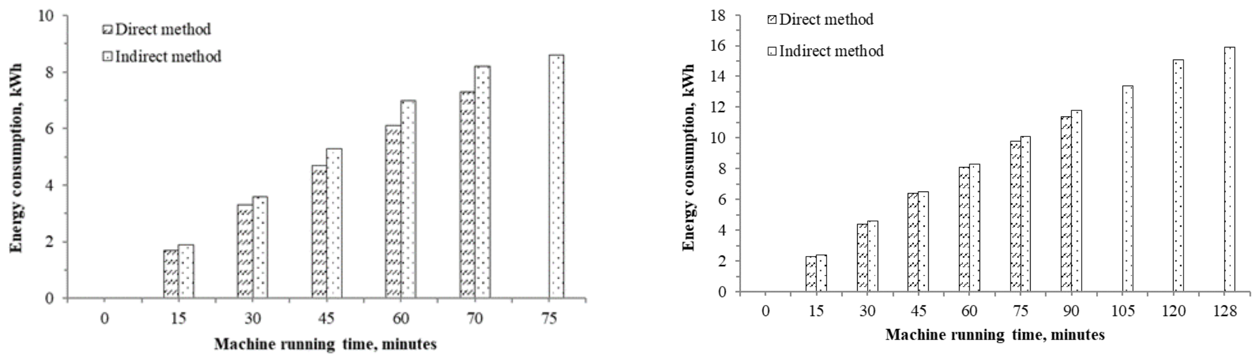
(a) (b)

Figure 2 Energy consumption over time of R22 and machine running: a) without load; b) load

At the same time, the indirect fluid supply is 6.2 kWh, while the direct fluid supply is 5,9kWh when the machine runs for 45 minutes. For the air temperature in the freezer to reach -45^oC, the indirect fluid supply method (the indirect method) uses up 8.4 kWh, the direct method uses up 6.4 kWh. The indirect method consumed 2 kWh energy, it is more than the direct method, corresponding to an increase of 23.8%. The change in energy consumption over time running the machine with load is shown in Figure 2. The law of change is similar to a machine running at idle. The indirect fluid delivery method consumed energy higher than the direct method. At the same time, the machine runs for 76 minutes, the indirect fluid supply is 10.3 kWh, the direct fluid supply is 10 kWh. In order for the frozen product temperature to reach -18^oC, the energy consumed by the direct R22 liquid supply method is 10 kWh, and the indirect liquid supply is 14.2 kWh. The energy cost consumed for the indirect fluid supply method is 4.2 kWh more than the direct method, corresponding to an increase rate of 29.5%.

3.3. Change the energy consumption of the refrigeration system with R404a refrigerant

The change in energy consumption over the running time of the refrigeration system using R404a refrigerant was similar to R22 when the machine running without load according to both methods. At the same time, the energy consumption of the indirect method is higher than that of the direct method. Specifically, the indirect method need 7.3 kWh, and the direct fluid supply is 8.1 kWh when the machine runs for 70 minutes.



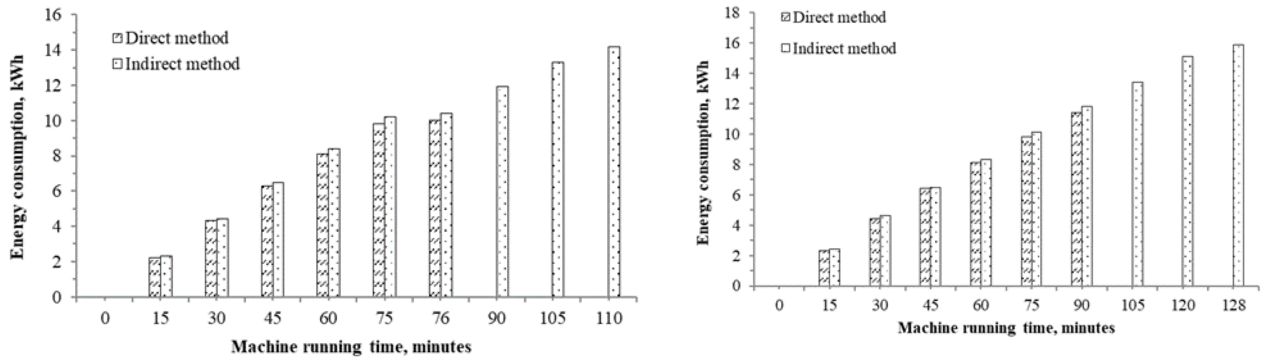
(a) (b)

Figure 3 Energy consumption over time of R404a: a) machine without load; b) machine with load

For the air temperature in the freezer to reach -45^oC, the indirect fluid supply method consumes 9.8 kWh, and the direct fluid supply consumes 7.3 kWh. The energy consumed for the indirect fluid supply method is 2.5 kWh more than the direct fluid supply method, corresponding to an increase of 25.5%. The change in energy consumption over the time the machine runs under load according to the direct and indirect fluid supply methods Figure 3. For the frozen product temperature to reach -18^oC, the energy consumed for the direct liquid supply method is 11.5 kWh, and the indirect liquid supply is 15.9 kWh. The energy consumed for the indirect fluid supply method is 4.4 kWh more than the direct method, corresponding to an increase rate of 27.6%.

3.4. Comparing the energy consumption of R22 and R404a refrigerants

The energy consumption of direct method was less than the indirect method for both loaded and unloaded modes using R22 and R404a refrigerants. Therefore, it is necessary to study comparing energy consumption using R22 with R404a to directly method to machines running without load and load, change in air temperature of a freezer using R22 and R404a refrigerants according to the time the machine with load.



(a) (b)

Figure 4 Energy is consumed over time using R22 and R404a and the machine without load

For the air temperature in the freezer to reach -45^{o}C, the energy consumed using R22 refrigerant is 6.4 kWh, R404a is 7.3 kWh. The energy consumed using R404a is 1.3 kWh more than R22, corresponding to an increase of 12.3%. The energy consumption change of the refrigeration system using R22 and R404a refrigerants according to the time the machine runs under load is shown (Figure 4). For the product core temperature to reach -18^{o}C, the energy consumed using R22 refrigerant is 10 kWh, R404a is 11.45 kWh. The energy consumed using R404a is 1.45 kWh more than R22, corresponding to an increase of 12.6%. The refrigeration system uses R404a refrigerant. Energy consumption increased from 12.3 to 12.6% for the machine running without load and with load, compared to R22 refrigerant. R404a refrigerant replaces R22 refrigerant when operating the direct fluid supply system. Its energy consumption increases from 12.3 to 12.6%. Considering the replacement purpose and current requirements, it is acceptable.

3.5. Variation of exergy loss and efficiency, cooling coefficient (COP)

Based on experiments and pictures below. Exergy loss and efficiency, cooling coefficient (COP) of the refrigeration system using R22 and R404a refrigerants for direct and indirect fluid supply working under load in freezing modes with air temperature in the refrigerator freezing: -30^{o}C, -35^{o}C, -40^{o}C, -45^{o}C through experiment and calculation results are as follows [5].

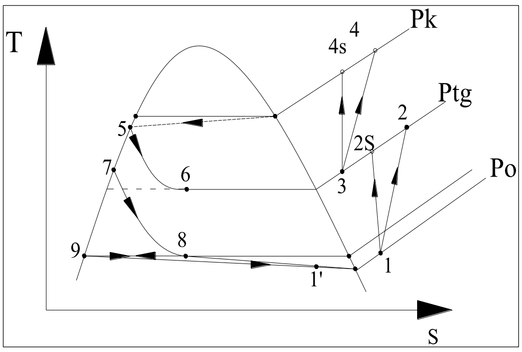


Figure 5 Actual working cycle of the refrigerant

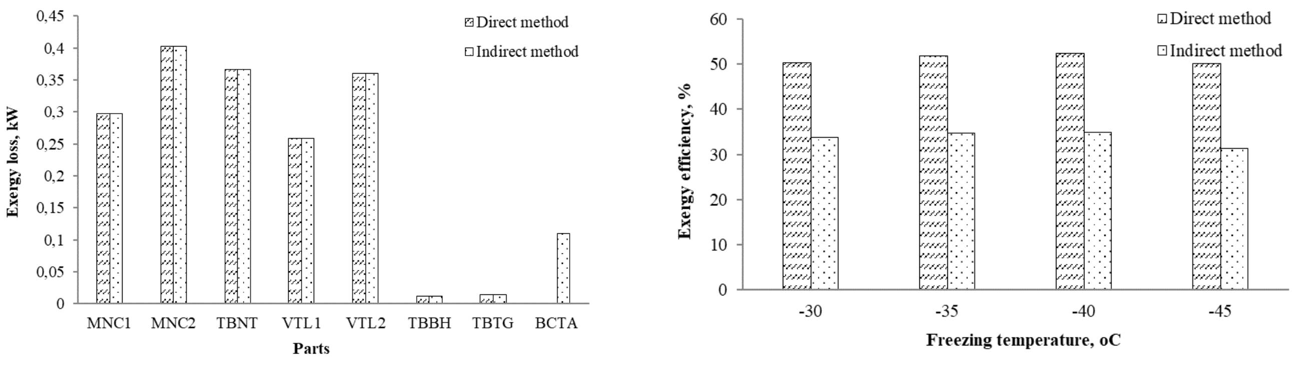
3.6. The refrigeration system with R22 refrigerant

From experimental results, measuring the working parameters of the refrigeration system in terms of pressure and temperature based on the software "Engineering Equation Solver (EES) can determine the enthalpy and entropy parameters at special points of the cycle." when the air temperature in the freezer is: -30^{o}C, -35^{o}C, -40^{o}C, -45^{o}C has been tested. From the experimental results, calculate the loss, exergy efficiency and COP of the refrigeration system to obtain the following calculation results.

Table 1 Exergy loss of laboratory equipment using MCL R22 for direct fluid supply, kW

Order	Parameters	Air temperature in the cabinet, ^oC			
		- 30	- 35	- 40	- 45
1	Level 1 compressor: MNC1	0,29	0,29	0,31	0,32
2	Level 2 compressor: MNC2	0,37	0,37	0,35	0,35
3	Condensing equipment: TBNT	1,25	1,19	1,15	1,14
4	Throttle valve 1: VTL1	0,1	0,09	0,1	0,11
5	Throttle valve 2: VTL2	0,13	0,14	0,15	0,17
6	Evaporator: TBBH	0,85	0,8	0,79	0,79
7	Intermediate equipment: TBTG	0,308	0,272	0,154	0,0606

According to freezing temperature, the exergy loss of stage 1 and stage 2 compressors does not change much. At the same freezing temperature, the exergy loss of the stage 2 (high stage) compressor is much than that of the stage 1 (low stage) compressor. The results are similar to the previous notices [6,7]. Specifically, at -35^oC, the exergy loss of MNC1 is 0.29 kW, while that of MNC2 is 0.37 kW, an increase of 0.08 kW. Corresponding increase of 21.6% compared to level 1 compressor. The reason is that the volume flow of level 2 compressor is more than that of low level compressor. The experimental parameters showed m2 = 0.072 kg/s and m1 = 0.054 kg/s. The exergy loss of the expansion valves increases as the freezing temperature decreases (Table 1). As in VTL2, at a temperature of -35^oC, the exergy loss through the throttle valve is 0.13 kW. At -45^oC, the exergy loss through the throttle increases to 0.17 kW. The reason is that the air temperature in the freezer decreases, causing the temperature and evaporation pressure to decrease. During the throttling process, the enthalpy does not change, so when the evaporation temperature decreases. After the throttling process, the entropy increased to be resson for the exergy loss increase through the throttle valve. At the same freezing temperature, the exergy loss of expansion valve 2 is more than that of expansion valve 1. For example, at a temperature of -40^oC, the exergy loss through expansion valve 1 is 0.10 kW. But through throttle 2nd is 0.15 kW. The reason is that the rate increase in entropy through expansion valve 2 is higher than that through expansion valve 1, even though the mass flow of refrigerant through expansion valve 2 is higher than expansion valve 1. Exergy loss of condenser decreases when freezing temperature decreases. At a temperature of -30^oC, the exergy loss through the condenser is 1.13 kW. But at -40^oC, it dropped to 1.03 kW. The reason is that when the freezing temperature decreases, the mass flow of refrigerant through the condenser decreases. The variation of exergy efficiency is shown in Figure 6.



(a) (b)

Figure 6 Exergy loss and efficiency of R-22

At temperatures -30^oC and -45^oC, the lowest exergy efficiency was 50.32% and 50.17%, respectively. The highest exergy efficiency at freezing temperature -40^oC was 52.49%, and at -35^oC, the efficiency was 51.75%, which was lower 0.74%, compered to at -40^oC. The above research results are also consistent with the fact that seafood processing enterprises export the air temperature in freezers at about -35^oC to -40^oC. The variation of refrigeration coefficient is shown in

Figure 6, showing that the refrigeration coefficient COP decreases when the freezing temperature decreases. At a temperature of -30°C, the cooling coefficient is 2.17. At -45°C, the cooling coefficient reduced to 1.76. The reason is that when the freezing temperature decreases, the specific refrigeration capacity decreases, the compression ratio of the compressor increases, leading to a decrease in the volumetric efficiency of the machine, and at the same time, the evaporation temperature decreases, leading to the specific volume of the refrigerant. The suction into the compressor decreases, causing the mass flow rate of the machine to decrease. Therefore, when the freezing temperature decreases, the cooling capacity of the machine decreases, leading to a decrease in the cooling coefficient. However, at -30°C, the highest cooling coefficient is 2.17, but the exergy efficiency is only 50.32%, is smaller than at freezing temperatures -35°C (51.7%) and -40°C (52.49%). While the cooling coefficient decreases, corresponding to freezing temperatures -35°C and -40°C with COP of 2.03 and 1.93. The thing exhibited that the cooling coefficient COP does not indicate the working efficiency of the refrigeration system at maximum exergy efficiency. The exergy efficiency at freezing -45°C got 50.17% lower than freezing at -35°C and -40°C. Although the lower the freezing temperature, the shorter the freezing time will limit the loss of product quality after the freezing process. But a operation costs are high due to increased energy consumption (Figure 7).

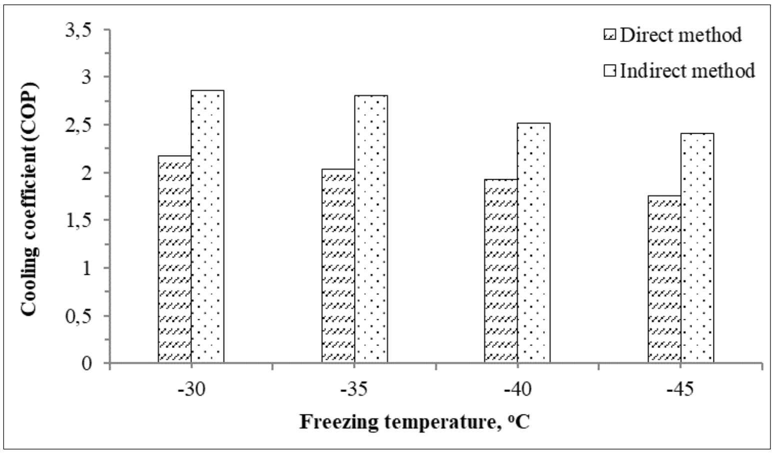


Figure 7 Cooling coefficient according to freezing temperature R-22

The above research results are also consistent with the conclusions of Dincer and Cengel (2001) [8] is that exergy analysis overcomes the disadvantages of the 1st and 2nd laws of thermodynamics and is a powerful tool for analyzing both the quantity and quality of energy use as well as Yumrutas and Kunduz (2002) [9] stated that the exergy analysis method is a powerful tool in the design, optimization and performance evaluation of refrigeration cycles. Freezing has not much difference at about 1.14 kW.

3.7. The refrigeration system uses R404a refrigerant

Similarly, the enthalpy and entropy parameters at specific points in the cycle when the air temperature in the freezer at -30°C, -35°C, -40°C, and -45°C can be determined experimentally.

Table 2 Exergy loss of equipment in the refrigeration system using R404a refrigerant for direct fluid supply, kW

STT	Parameter	Air temperature in the cabinet, °C			
		-30	-35	-40	-45
	Level 1 compressor: MNC1	0,31	0,31	0,31	0,32
	Level 2 compressor: MNC2	0,4	0,41	0,41	0,4
	Condenser: TBNT	1,09	1,01	1,03	1,01
	Throttle valve 1: VTL1	0,21	0,22	0,24	0,24
	Throttle valve 2: VTL2	0,29	0,31	0,33	0,31
	Evaporator: TBBH	1,07	0,96	0,87	0,87
	Intermediate device: TBTG	0,398	0,362	0,325	0,318

Variation of exergy loss of equipment in the refrigeration system exhibited that the loss is the largest at the condenser, followed by at the evaporator (Figure 8). Therefore, the rule is the same as the R22 refrigerant.

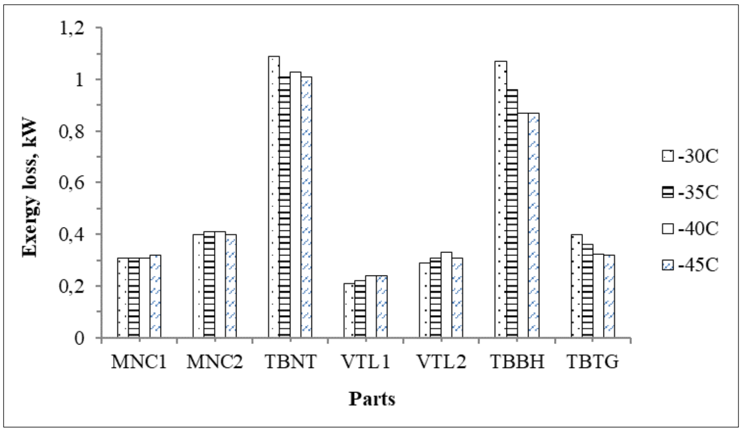


Figure 8 Exergy loss and performance of refrigeration system according to R-404a

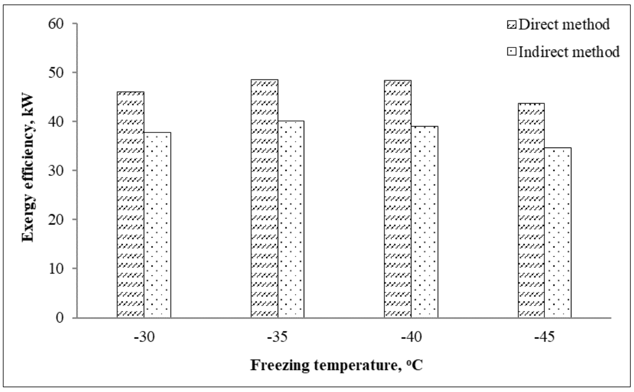


Figure 9 Exergy performance of refrigeration system according to R-404a freezing temperature

The change in exergy efficiency showed that the lowest exergy efficiency is 43.7% at -45°C (Figure 9). The exergy of other refrigerants is also previous noticed by Jatinder and Jagdev Singh (2017) [10]. The highest exergy efficiency at freezing temperatures -35°C and -40°C were 48.6% and 48.4%, respectively. The above study results are consistent with the fact that when processing exported seafood, the air temperature in the freezer is about -35°C to -40°C at enterprises.

3.8. Comparison between the yield of exergy and COP

Table 3 Exergy efficiency, cooling coefficient of MCL R22 and R404a for direct method

Refrigerant	**Parameter**	**Air temperature in the cabinet, °C**			
		-30	-35	-40	-45
R22	Exergy performance, %	50,32	51,75	52,49	50,17
	Cooling coefficient of the cycle (COP)	2,17	2,03	1,93	1,76
R404a	Exergy performance, %	46,0	48,6	48,4	43,7
	Cooling coefficient of the cycle (COP)	1,78	1,66	1,55	1,43

The above research results show that the exergy efficiency of the refrigeration system running the direct fluid supply method is higher than the indirect fluid supply method for both R22 and R404a refrigerants. Therefore, it is necessary to compare the exergy performance of refrigeration systems running the direct fluid supply method of R22 and R404a refrigerants.

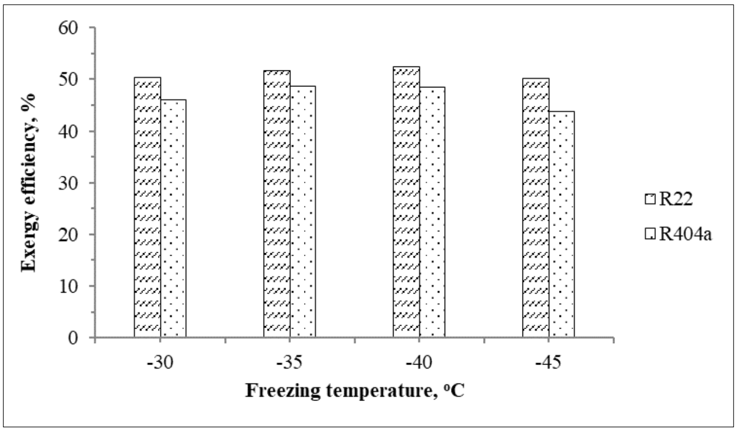


Figure 10 Exergy efficiency of refrigeration system according to temperature and refrigerant (R22 and R404a)

The results shown that the exergy efficiency of R22 refrigerant is higher than R404a at all temperature levels. The freezing temperature in freezers at businesses usually operates from -35°C to -40°C. At freezing temperature -35°C, the exergy efficiency of refrigerant R22 is 51.75%, that of R404a is 48.6%. The exergy efficiency of R22 refrigerant is 3.15% greater than R404a. At -40°C, the exergy efficiency of refrigerant R22 is 52.49%, that of R404a is 48.4% (Figure 10 and Table 3). The exergy efficiency of R22 refrigerant is 4.09% greater than R404a. Thus, the exergy efficiency of R22 refrigerant is about 3.15% to 4.09% higher than R404a at the freezing temperature commonly used in export seafood processing enterprises. Based on the above calculation, when using refrigerant R22 or R404a, you should use the direct method for the air freezing system. The temperature range of -35°C to -40°C delivers the best performance. With R22, the performance is 3.15% to 4.09% better than R404a, with this result when replacing R404a on the same system is acceptable.

4. Conclusions

The direct method is more effective than the indirect method. R22 refrigerant can cool faster than R404a. The energy consumption and exergy loss of R22 are lower than that of R404a refrigerant. The exergy and cooling efficiency of R22 is higher than that of R404a for direct and indirect methods. However, R22 destroys the ozone layer, causing a greenhouse effect, so it needs to be replaced. Refrigerant Gas R404A is an HFC mixture of R125, R143A and R134A and is used in low and medium temperature refrigerators such as supermarket freezers. Refrigerant gas SSB R404A is the most optimal gas trusted by the world's leading equipment and compressor manufacturers.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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