Experimental Analysis of Using R-600a Refrigerant in Undercounter Chiller Applications

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Abstract. This research was conducted to analyze the use of R-600a in undercounter applications. The use of R-600a refrigerant is an effort to save energy and reduce the Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). Testing was carried out at an ambient temperature of 24°C and temperature storage setup was 0 °C. Testing was carried out using a load of 33.245 kg of cabbage. The results of this research showed that the energy consumption of the under-counter chiller decreased by 6%. The decrease in electrical energy consumption is due to the refrigerant pressure on the suction and discharge side of the compressor when using R-600a refrigerant is lower than R-134a, but it makes COP decrease by 2%. R-600a can be recommended for under-counter chillers because R-600a is an environmentally friendly hydrocarbon, has low ODP and GWP values, and is energy efficient.

Keywords: COP, Energy Consumption, Refrigerant, R-600a, Undercounter Chiller

1 Introduction

Until now, the development of refrigeration systems is still being carried out to get better performance and energy savings. The performance of the refrigeration system is expressed in terms of the coefficient of performance (COP). The large COP shows that the refrigeration system is getting more efficient and good performance (Rasta et al., 2018, Hidayati et al., 2023). In addition to COP, there are several things that affect the development of refrigeration systems, that is energy savings, refrigerants with low Ozone Depletion Potential (ODP), and low Global Warming Potential (GWP) (Ragavendiran, et al., 2024; Sigar, et al., 2017).

One of the refrigeration systems that is widely used in commercial kitchens is the undercounter chiller. Undercounter chiller is a refrigerator designed like a kitchen countertop. Undercounter chiller serves to cool vegetables, fruits, and beverages. The working temperature of the under-counter chiller is 0°C - 10°C. The Undercounter chiller operates on the principle of a vapor compression system. This vapor compression system activates the refrigerant by compressing it to a higher pressure and temperature in the compressor after producing a cooling effect. The compressed refrigerant transfers its heat to the exhaust and is condensed into a liquid form. This

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liquid refrigerant is then throttled into a low-pressure and low-temperature vapor to produce a cooling effect during evaporation (Kase et al., 2020; Wang, 2001). Undercounter chillers mostly use R-134a, where this refrigerant has a GWP value of 1300 (Mclinden et al., 2017). To maintain environmental safety, in the future, the use of R134a will soon be banned. Table 1 shows the main properties of some refrigerants that have low GWP values as alternative refrigerants (Zhang et al., 2019).

Table 1. Main properties of refrigerants

Property	R134a	R290	R600	R600a	R1270
Critical point (°C)	101	97	152	135	91
Critical pressure (kPa)	4059	4251	3796	3629	4555
P_s at at 0°C (kPa)	293	474	103	151	564
P_s at at 40°C (kPa)	1017	1629	378	531	1688
Latent heat at 0°C (kJ/kg)	199	375	385	342	308
Latent heat at 40°C (kJ/kg)	163	307	345	312	303
ODP	0	0	0	0	0
GWP_{100}	1300	3	3	3	3
ASHRAE safety level	A1	A3	A3	A3	A3

Research to develop environmentally friendly and energy-efficient refrigeration machines has been conducted by several researchers, such as that conducted by Yu, who used a mixture of R-290 and R-600a refrigerants. with a refrigerant mass ratio of 65% + 35% (HC1), 50% + 50% (HC2) and 100% R600a (HC3) with R134a refrigerant obtained results, namely the highest COP when the system uses a mixture of 65% R-290 + 35% R-600a refrigerant and the most efficient is when the system uses 100% R-600a refrigerant (Yu & Teng, 2014).

A study on a car air conditioner using refrigerant R-134a and R-600a was conducted by charging at 8 psig, varying the speed of the evaporator fan blower, and taking data every 10 minutes to get the highest COP results in a car air conditioning system using refrigerant R-134a with speed 3 while the most efficient is a car air conditioning system using refrigerant R-600a with blower speed in position 1(Aziz et al., 2020).

A refrigeration system was tested by Sigar using refrigerants R-290, R-600a, and R-234yf. The data collection was carried out at an evaporation temperature of -10°C, a condensation temperature of 42°C, and a subcooling temperature of 6 °C. The highest and most efficient COP results were obtained when the system used R600a refrigerant (Sigar et al., 2017). This research was conducted to determine the performance and energy saving of an undercounter chiller with a storage capacity of 350 liters using R-600a refrigerant.

2 Methodology

Undercounter chiller testing was conducted using R-134a and R-600a. The load in this study was 40 cabbages weighing 33.245 kg. Temperature storage was 0 °C. Testing was carried out at ambient temperature and room temperature of 24°C. The filling of the refrigerant for both refrigerants was based on the same evaporator temperature, which was 10 °C. This study aims to obtain the COP and electricity consumption for 24 hours. After obtaining the refrigerant pressure and temperature, data processing is carried out by taking the average temperature and pressure of the refrigerant every 1 hour for 24 hours. Furthermore, the data is processed using the Coolpack application. The specifications of this under-counter chiller are as follows:

Table 2. Undercounter chiller specifications

Indicator	Value
Model	BGT-15C
Cooling capacity	0.806 Kw
Refrigerant	R-134a
Refrigerant mass	350 gr
Power	350 Watt
Voltage	220 Volt
Frequency	50 Hz
Capacity	350 Lt

The setup of pressure, temperature and electrical energy measuring instruments is shown in Figure 1, setup of cabbage and temperature sensor is shown in Figure 2.

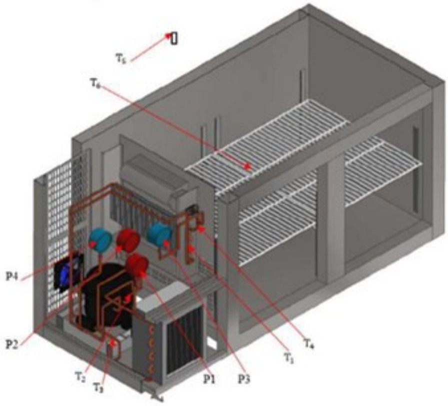

Figure 1. Measuring instruments setup

Where:
P_1 = refrigerant pressure at the evaporator outlet
P_2 = refrigerant pressure at the compressor outlet
P_3 = refrigerant pressure at the condenser outlet
P_4 = refrigerant pressure at the evaporator inlet
T_1 = refrigerant temperature at the evaporator outlet
T_2 = refrigerant temperature at the compressor outlet
T_3 = refrigerant temperature at the condenser outlet
T_4 = refrigerant temperature at the evaporator inlet
T_5 = ambient temperature

T_6 = room temperature

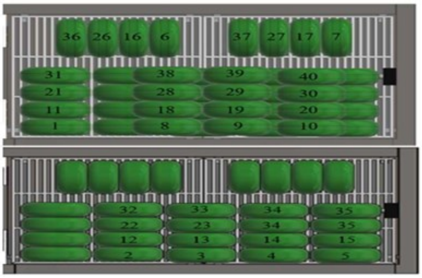

Figure 2. Setup of cabbage and temperature sensor

This Arduino data logger can measure temperature, voltage, electric current, electrical frequency, electrical energy, power, and power factor. By connecting the power input cable from the undercounter chiller to the contact box on the data logger, the Arduino will read and send the data to Microsoft Excel using PLX DAQ.

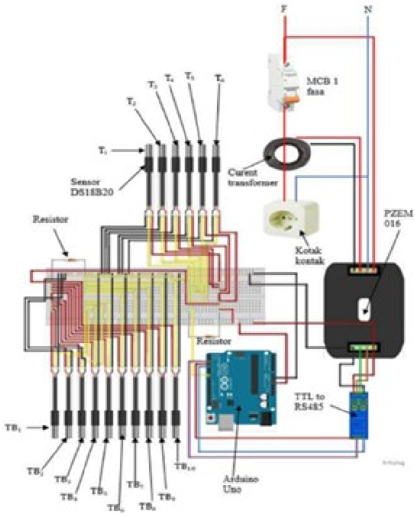

Figure 3. Temperature and electrical energy data logger using Arduino Uno

3 Result and Discussion

To obtain the performance and energy use of the under-counter chiller when using R-134a and R-600a, the comparative tests were performed. Figure 4 shows the time required to reach the under-counter chiller room temperature, from 24ºC to 0ºC. It takes 135 minutes to reach the when using R-134a with an average temperature decrease of

0.9°C. When using R-600a, it takes 235 minutes with an average temperature decrease of 0.5°C. This proves that R-134a at the same load and ambient temperature, is faster to reach the room temperature of under-counter chiller than R-600a.

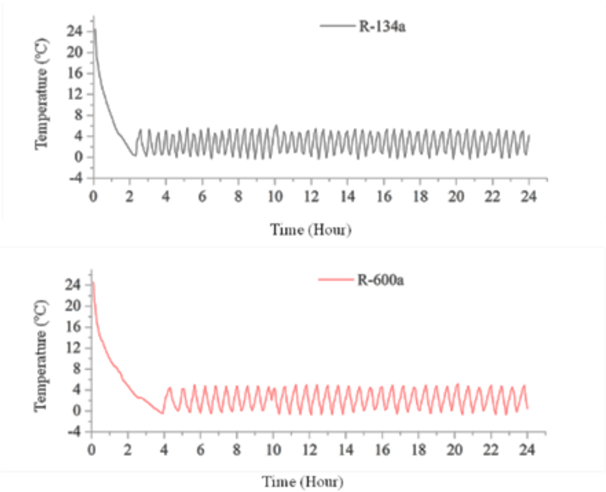

Figure 4. Time vs under-counter chiller room temperature

Figure 5 below shows the relationship between refrigerant temperature and time. The compressor inlet temperature (T_1) when using R-134a refrigerant is lower than R-600a. The average compressor inlet refrigerant temperature is 0.9°C and 1.3°C for R-134a and R-600a respectively. From the compressor inlet temperature, the difference can be seen during hours 1 to 3, where the compressor inlet temperature when using R-134a refrigerant is lower than R-600a. At hours 4 to 24, there is little difference and temperature stability begins to be achieved. It can be said that with increasing time, the cooling load in the chiller room decreases and makes the compressor inlet temperature stable.

The compressor outlet temperature (T_2) when using R-134a refrigerant is higher than R-600a, with an average of 53°C and 44.6°C respectively. To reach room temperature of 0°C, R-134 takes 135 minutes, shown in the figure that the compressor outlet temperature increases from hour 1 to 2. While in R-600a, it takes 235 minutes, it appears that the temperature increases from hour 1 to 4. The longer the compressor is on, the compressor outlet temperature will increase. The condenser outlet temperature (T_3) when using R-134a is higher than R-600a, because the higher the compressor outlet temperature (T_2), the higher the condenser outlet temperature. The average condenser outlet temperatures for R-134a and R-600a are 29.4°C and 28.1°C, respectively.

The evaporator inlet temperature (T_4) when using R-134a is lower than R-600a, because the higher the compressor outlet temperature (T_2), the lower the evaporator inlet temperature, so R-134a reaches room temperature faster. If the refrigerant temperature out of the compressor (T_2) is stable, then the refrigerant temperature in the evaporator (T_4) will be stable as well. The average evaporator inlet temperature for R-134a and R-600a is -8.2°C and -3.4°C respectively.

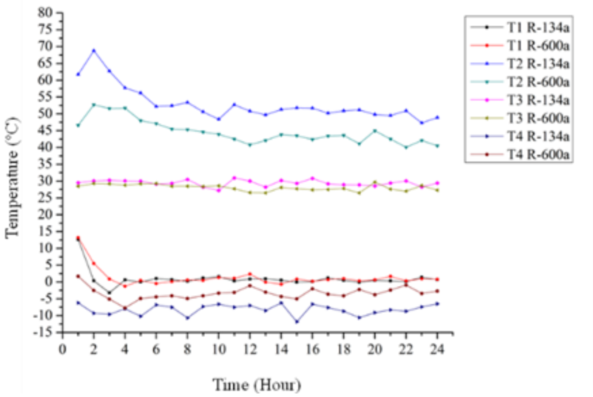

Figure 5. Time vs refrigerant temperature

In the under-counter chiller test using R-134a and R-600a, the refrigerant pressure at the outlet side of the evaporator (P_1) and the outlet side of the compressor (P_2) continues to decrease as time increases, and the cooling load in the under-counter chiller room decreases, as shown in Figure 6.

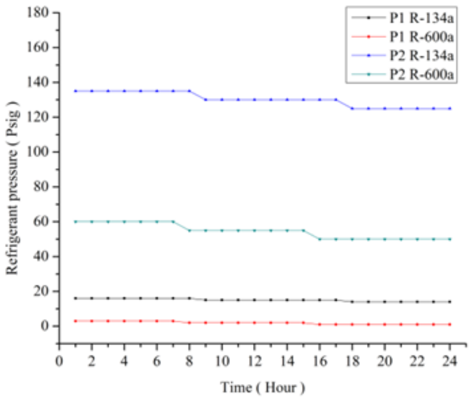

Figure 6. Time vs refrigerant pressure

The evaporator outlet pressure when testing using R-134a decreased from 16 Psig, 15 Psig, and 14 Psig, while when using R-600a, the refrigerant pressure decreased from 3 Psig, 2 Psig, and 1 Psig. For the compressor outlet pressure when using R-134a refrigerant, it decreased from 135 Psig, 130 Psig, and 125 Psig, while in R-600a, the refrigerant pressure decreased from 60 Psig, 55 Psig, and 50 Psig. The decrease in refrigerant pressure on the evaporator outlet is due to the decrease of the evaporator outlet temperature which indicates that the cooling load is decreasing. The decrease in refrigerant pressure on the outlet of the evaporator causes a decrease in the compressor outlet pressure and temperature.

Figure 7 explains that the evaporator temperature when using R-134a is lower than R-600a. The evaporator temperature starts to approach the same value at hour 18 (R-134a) and hour 16 (R-600a), which is -10.35°C and -10.06°C if rounded up it is still in the same evaporator temperature range, which is -10°C. Figure 8 shows that R-134a has a lower refrigeration effect than R-600a. The average refrigeration effect of R-134a and R-600a is 160.09 kJ/kg and 293.88 kJ/kg. Refrigerant enthalpy range R-134a and R-600a are 140 - 560 kJ/kg and 50 - 850 kJ/kg. This causes the value of the refrigeration effect when using refrigerant R-600a higher because the enthalpy range is higher than refrigerant R-134a. The refrigeration effect decreased during the first 2 hours when using R-134a, and then the refrigeration effect began to constant. Whereas when using R-600a the refrigeration effect decreases during the first 3 hours and then becomes constant.

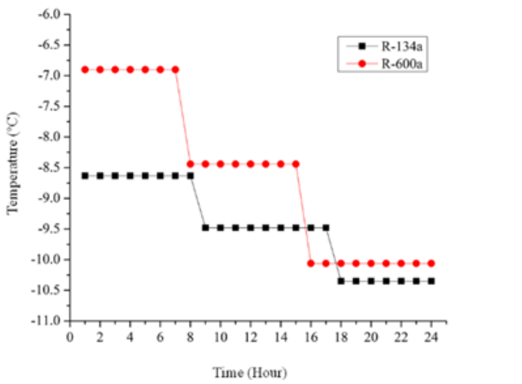

Figure 7. Time vs evaporator temperature

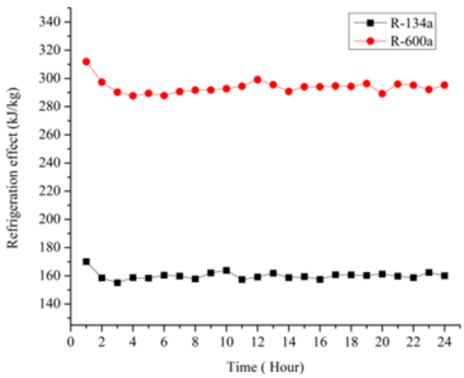

Figure 8. Time vs refrigeration effect

Figure 9 explains that when using R-134a, the compression work increases for 2 hours, as it takes 135 minutes or 2 hours and 15 minutes to reach 0°C. After that, the work of compression starts to decrease and fluctuates with a range between 29 kJ/kg to 32 kJ/kg. When testing using R-600a, the work of compression continues to increase for 235 minutes or 3 hours 55 minutes, until it reaches 0°C. Furthermore, the work of compression decreases and fluctuates with a range between 52 kJ/kg to 64 kJ/kg. R-600a produces higher compressor work than R-134a, because R-600a has a higher range of enthalpy values.

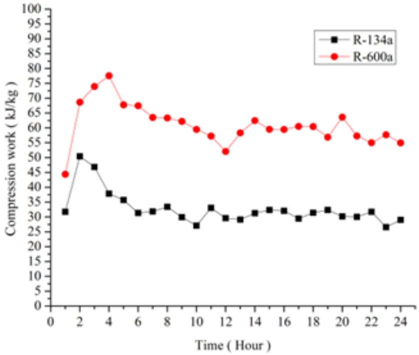

Figure 9. Time vs compression work

Figure 10 explains the COP generated when using R-134a and R-600a are 5.01 and 4.89 respectively. It can be said that the replacement of R-134a to R-600a reduces the COP value by 2%. The decrease in COP is caused because when using R-600a, the compressor works longer so that the temperature of the refrigerant exits the compressor, and the compression work increases. COP will increase if the refrigeration effect is high and the compression work is low.

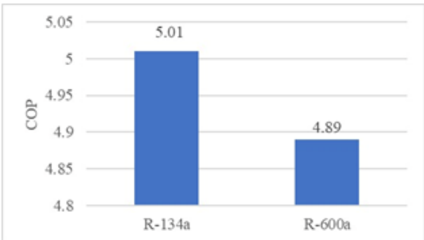

Figure 10. Time vs compression work

Figure 11 describes the use of electrical power during the test. When using R-134a the total number of compressor starts is 51 times with a time of 11 hours 42 minutes, so the compressor turns off for 12 hours 18 minutes. Meanwhile, when using R-600a, the compressor worked 35 times for 13 hours, so the compressor died for 11 hours. The average electrical power of the under-counter chiller when using R-134a and R-600a is 387 watts and 317.3 watts respectively. The replacement of R-134a to R-600a has decreased the use of electric power by 18%. Electric power drops because the refrigerant pressure in the compressor and out of the compressor is lower when testing using R-600a refrigerant. The average electrical power increases because the compressor turns off and on a large amount, and when the compressor starts the starting current is high, so the electrical power increases.

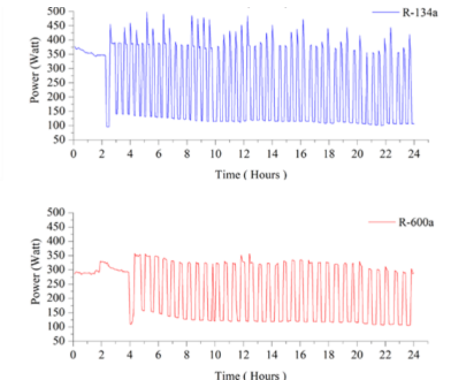

Figure 11. Time vs power

Figure 12 describes the electrical energy consumption when the under-counter chiller is operating. The electrical energy consumption when using R-134a and R-600a is 5938 Wh and 5560 Wh respectively. After refrigerant replacement, the electrical energy consumption decreased by 6%. The decrease in electrical energy consumption is due to the decrease in electrical power in the under-counter chiller machine. The decreased electrical power is attributed to the use of less refrigerant and the number of working compressors using R-600a is less than R-134a, resulting in lower electrical power. If the compressor turns off and on frequently, the electrical energy consumption will increase because the starting current when the engine starts is high.

Figure 12. Electrical energy consumption

4 Conclusion

The electrical energy consumption of the under-counter chiller after being replaced from R-134a to R-600a makes the electrical energy decrease by 6%. The decrease in electrical energy consumption is due to the refrigerant pressure on the suction and discharge side of the compressor when using R-600a refrigerant is lower than R-134a, but it makes COP decrease by 2%. R-600a can be recommended for under-counter chillers, because R-600a is a hydrocarbon that is environmentally friendly, low ODP and GWP values, and is energy efficient.

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