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Enhancement of the Overall Performance of Vapor Compression Refrigeration System (VCRS) using Environmentally Friendly Refrigerant and Jumping Capacitors – Experimental Study

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ABSTRACT: In this study, the performance of the enhanced vapour compression refrigeration system was investigated. Proposing a better refrigerant and suggesting a technique to minimize the power consumption are the main objectives of this study. Tetra-fluoro-ethane and Isobutene refrigerants were used and the performance of the system was evaluated. From the experiment, a better coefficient of performance was found with Isobutene as compared to Tetra-fluoro-ethane. In addition, Isobutene has less impact on global warming. Furthermore, in this study, the power consumption of the compressor is significantly reduced by adding capacitors to the electric circuit. During the experiment, different micro-farad capacitors were added in order to decrease the power consumption of the system and the optimum one selected. Maximum coefficient of performance was obtained using 10μF capacitor with Isobutene refrigerant, resulting in energy saving of 62.5%. Thus, the performance of the system can be improved by using Isobutene refrigerant instead of Tetra-fluoro-ethane refrigerant and adding a capacitor to the electric circuit.

Keywords: Refrigeration, Power Consumption, Coefficient of Performance, Capacitor.

I. INTRODUCTION

Refrigeration systems are utilized in variety of everyday situations. In the modern world, these systems can be found in almost every building and house [1]. In this system, refrigeration takes place when heat is conveyed from the evaporator cabinet to the ambient by the refrigerant [2]. Each vapor compression refrigeration system attains its work by four basic processes: isentropic compression in the compressor, constant pressure heat rejection in the condenser, throttling in an expansion valve, and constant pressure heat addition in the evaporator.

In the current paper, experimental apparatus was developed and fabricated. Several papers in related field have been studied to ensure the authentication of the current study. Abuzar and Bhatt (2014) carried out the investigation of the coefficient of performance of the household refrigerator using Tetra-fluoro-ethane (R134a) and Isobutene (R600a) refrigerants [3]. They found that systems with R600a refrigerant deliver greater COP than systems with R134a. Mahmood *et al*., (2018) analyzed the performance of the refrigeration system utilizing R134a and R600a refrigerants, but obtained different result than the previous study. They found that the COP of R600a is less than the COP of R134a [4]. However, this reduction is acceptable as R600a has zero potential for ozone layer depletion.

Austin (2016); Boorneni and Satyanarayana (2014) carried out a comparative study of the performance of R134a and R600a refrigerants in vapour compression refrigeration (VCR) system. Results from their comparison and review show that the system charged with R600a performs better than the system charged with R134a [5, 6].

Sisat *et al*., (2018) analyzed the performance of the VCR system using refrigerant mixture of R134a/R600a rather than R134a. Both Barathiraja *et al*., (2017); Saibhargav *et al*., (2019) investigated refrigeration system using refrigerant mixture of (R290/R600a) instead of R134a [7, 8, 9]. They found that using these refrigerant mixtures has decreased the power consumption and improved the performance of the system. Gill and Singh (2017) carried out an experimental analysis of R134a/LPG refrigerant mixture as a replacement of R134a in a VCRS. They concluded that the refrigeration capacity and COP of the system are 10.6% and 15.2%, respectively, higher for R134a/LPG than those obtained with R134a [10].

Panda *et al*., (2016) enhanced the performance of the vapor compression refrigeration system. It was concluded that R600a can be used instead of R22 and R134a [11]. Sah *et al*., (2014) investigated a refrigeration system using several refrigerants (R134a, R152a, R290 and R32). It was concluded that the maximum cooling capacity and minimum pressure ratio can be achieved with R290 refrigerant [12]. Hence, the maximum temperature has been obtained with R32 refrigerant in the discharge line. Nagalakshmi and Marurhiprasad (2014) analyzed the performance of the VCR system by utilizing R134a and R12 refrigerant [13]. Results showed that the coefficient of performance (COP) of R134a was slightly smaller than R12. On the other hand, Thakar *et al.,* (2017) illustrated that both refrigerants R152a and R290 have almost same performance as R134a [14].

Gond *et al*., (2016) carried out the evaluation of the performance of a refrigeration system utilizing several refrigerants instead of R134a [15]. Rasti *et al*., (2011); Hastak and Kshirsagar (2017) analyzed the performance of a household VCR system using R600a and R436a refrigerants rather than R134a. It was found that both R436a and R600a refrigerants could be a long-term alternative to R134a [16, 17].

In addition, Bolaji (2014) investigated the performance of R152a and R600a refrigerants as an alternative to R134a in a refrigeration system. Results showed that R152a performed better than the other two refrigerants as it has the highest refrigeration effect and COP [18].

Sheikh and Qureshi (2015) carried out a comparative study of a refrigeration system using R600a and R134a refrigerants. It was discovered that energy efficiency ratio is higher for R600a than for R134a [19].

Sabari and Prasanthi (2017) carried out the improvement in COP of domestic refrigerator with wrinkle shaped condenser using R134a and R600a as refrigerants. Results showed that the wrinkle shaped condenser with pitch angle 90° has given the highest COP among all observations [20].

In previous studies, the performance of the refrigeration system was improved by replacing various refrigerants. However, the lack of further improvement of the COP is noticeable. Thus, main contribution of the current study was not only to propose a better refrigerant but to suggest a technique to reduce the power consumption as well. For that, motor capacitor CBB60 450V with four different types (5μF, 8μF, 10μF, 12μF) are used. Both refrigerants, R134a and R600a, have been utilized and compared in the current study so as to show which one makes the system consume less power and give higher COP. The reason behind using these two refrigerants is that these to refrigerants are widely available and cheep in the region where the current research made in.

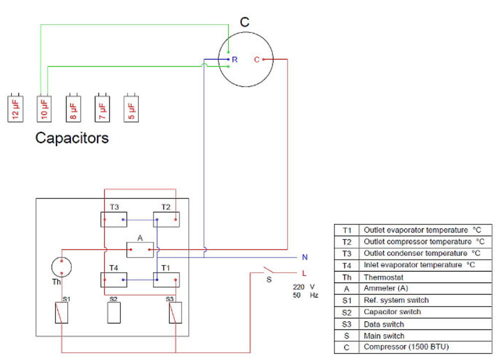

Fig. 1. Electrical circuit of the current system.

However, R134a is causing ozone layer depletion and contributes more in global warming phenomena when compared to R600a. The electrical circuit of the current system is presented in Fig. 1.

II. DESCRIPTION OF EXPERIMENTAL SETUP

The experimental setup was designed and manufactured. The layout of the system is shown in Fig. 2 and the manufactured machine is shown in Fig. 3. The condenser is made of copper tube as the copper tube has a high thermal conductivity. Low thermal conductivity material, PU foam, is used to fill the gap between the evaporator chamber and the external chamber.

To measure the temperature, four digital thermometers are located in certain points. In order to measure the pressure, two pressure gauges are installed, one to the section line of the compressor and the other to the discharge line of the compressor. The evaporator is made of aluminum. A filter has been installed at the outlet of the condenser so as to filter the refrigerant from bad particles. To protect the compressor from overheating, an overload protector is added to the circuit which cuts the circuit when the compressor overheated. Compressor has three ports, common, starting and running. The positive temperature coefficient (PTC) relay is connected to both starting and running ports. The capacitor and the compressor were connected in parallel. Clamp type multi-meter was connected in parallel and series with the compressor so as to measure the voltage and amperage. The system was checked for any leakage, and then the refrigerant was charged into the system and experimentation was carried out.

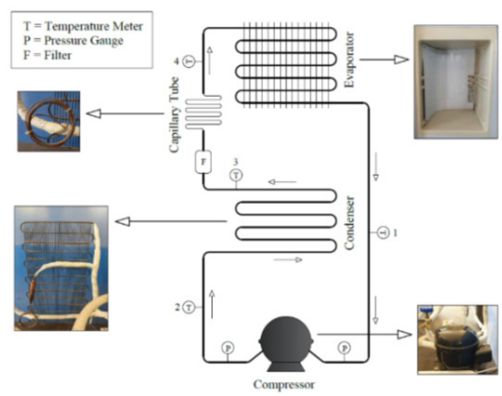

Fig. 2. System design layout.

Fig. 3. Electrical circuit of the current system.

In the current study, the work done by the compressor (Pc) was calculated by Eqn. (1).

$$P_c = V \times I \times \cos(\emptyset) \quad (1)$$

Where, V is applied voltage, I is current, and cos (Ø) is the power factor with value of 0.82. The clamp type multi-meter is used to measure the voltage and the current. Furthermore, mass flow rate (m) was estimated by Eqn. (2)

$$m^{\cdot} = Pc/(h_2 - h_1) \quad (2)$$

where, h_1 and h_2 are enthalpies at compressor entrance and exit, respectively. The refrigeration effect (R_{effect}) was calculated by Eqn. (3)

$$R_{effect} = \dot{m}(h_1 - h_4) \quad (3)$$

The coefficient of the performance (COP) of the refrigeration system was calculated by Eqn. (4)

$$COP = R_{effect}/Pc \quad (4)$$

III. RESULTS AND DISCUSSION

The experiment was conducted and the performance of the system was observed for 180 minutes. Properties of the manufactured system were measured to investigate the power consumption and COP.

The experimental data were presented in Table 1, and the results are listed in Table 2. From the data measured during the experiment, it can be noticed that the temperature drop at the condenser is higher for R134a as compared to R600a. Also, the pressure drop at the capillary tube is higher for R134a than for R600a. This occurs because R134a is denser and has greater viscosity than R600a.

In this research, 5µF, 8µF, 10µF, 12µF capacitors were investigated. Fig. 4 shows the power consumption for R134a and R600a refrigerants with and without the use of capacitor. During the operation, when no capacitor was utilized, the system recorded the highest power consumption. The reason behind that is the reactive power of the main power supply. Once the capacitor was installed, the reactive power was supplied by the capacitor and reduced the reactive power loss of the main supply line dramatically. By installing capacitors, the system recorded the lowest power consumption for 10µF capacitor using R600a refrigerant. Therefore, 10µF capacitor was found to be the optimum choice and it is selected for the current study. On the other hand, when 12µF capacitor was installed, the power consumption started to increase because the supply of the reactive power started to rise again. Furthermore, R134a consumes more power than R600a. This is due to the properties of the refrigerants. For example, as R134a is denser and has more viscosity, the compressor needs to do more work.

Table 1: Experimental data of the current study.

Properties	Without capacitor		Capacitor 5µF		Capacitor 8µF		Capacitor 10µF		Capacitor 12µF	
	R134a	R600a	R134a	R600a	R134a	R600a	R134a	R600a	R134a	R600a
Outlet evaporator temp. T1 (°C)	-7	-12	-18	-12	-17	-12	-16	-8	-12	6
Inlet condenser temp. T2 (°C)	65	49	63	49	65	50	71	56	70	67
Outlet condenser temp. T3 (°C)	15	16	11	20	12	14	12	12	20	11
Inlet evaporator temp. T4 (°C)	-9	-14	-23	-19	-22	-15	-22	-10	-20	0
Ambient temp. T5 (°C)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Low pressure P1 (bar)	1.09	0.965	1.2	0.965	1.21	0.965	1.21	0.965	1.33	0.965
High pressure P2 (bar)	6.013	4.81	11.8	5.1	12.01	4.75	12.3	5.3	12.8	11.0325
Current I (amp)	0.8	0.73	0.5	0.4	0.5	0.33	0.5	0.3	0.6	0.5

Table 2: Results of the current study.

Properties	Without capacitor		Capacitor 5µF		Capacitor 8µF		Capacitor 10µF		Capacitor 12µF	
	R134a	R600a	R134a	R600a	R134a	R600a	R134a	R600a	R134a	R600a
Compressor work (KW)	0.1443	0.1316	0.0902	0.0721	0.0902	0.0595	0.0902	0.0541	0.1082	0.0902
Mass flowrate (Kg/s)	0.0024	0.0014	0.0017	0.00083	0.00158	0.00064	0.00145	0.00058	0.00189	0.00093
Refrigeration effect (KW)	0.1460	0.4172	0.2893	0.2436	0.2690	0.1932	0.2517	0.18566	0.3113	0.2966
COP	2.88	3.17	3.207	3.38	2.98	3.247	2.79	3.43	2.877	3.288

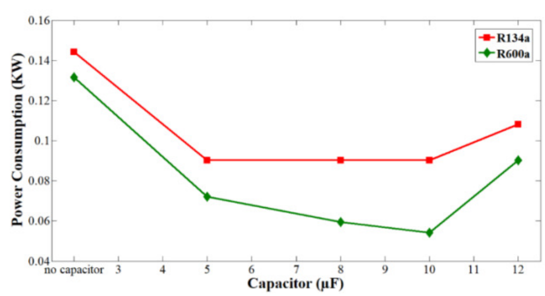

Fig. 4. Power consumption versus capacitor.

Fig. 5 shows the mass flowrate of both refrigerants (R134a and R600a) at different capacitor. It is found that mass flowrate of R134a is higher. This is because mass flowrate highly depends on the work done by the compressor. As long as the work done by the compressor is higher for R134a, the mass flow rate is higher as well.

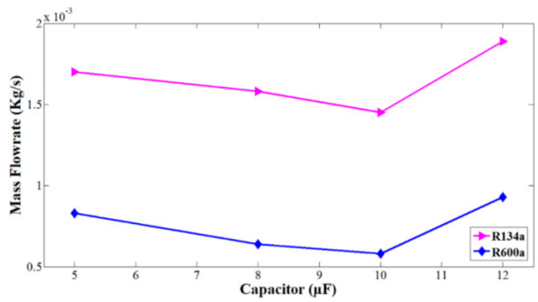

Fig. 5. Mass flowrate versus capacitor.

Fig. 6 illustrates the energy saved by each capacitor for R134a and R600a refrigerant. When compared with no capacitor condition, it was found that R600a refrigerant in combination with 10µF capacitor reduced energy consumption by 62.5%, which is the highest amount of energy that can be saved in this study. This is because while using 10µF capacitor, the power consumption was decreased as the reactive power was reduced.

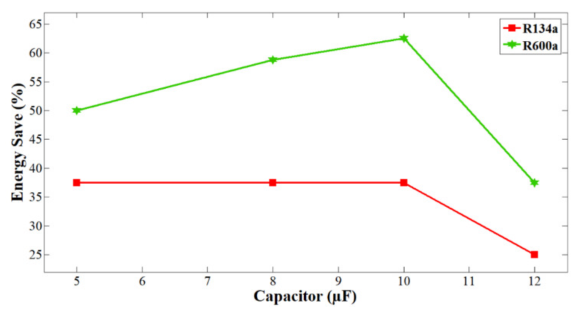

Fig. 6. Energy save versus capacitor.

COP is the ratio of refrigeration effect to the work done by the compressor. Fig. 7 shows the COP of R134a and R600a refrigerants at each capacitor. It can be seen that COP of the system with R600a is higher than the COP of R134a refrigerant. This is because the compressor is required to do less work when R600a is used as compared to the work required of the compressor when R134a is used. Therefore, R600a refrigerant is a recommended alternative to R134a refrigerant

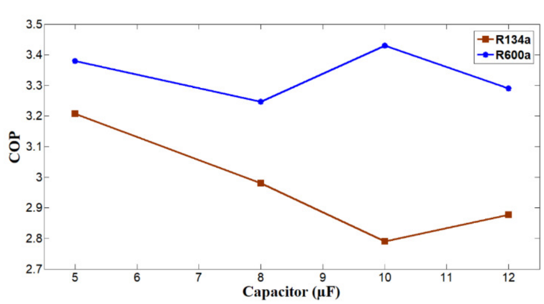

Fig. 7. Coefficient of performance vs capacitor.

Fig. 8 illustrates the performance improvement ratio by each capacitor. From the experimental data, when performance of R600a is compared with R134a for each capacitor, the performance of the system can be improved by up to 18.6% while using R600a refrigerant and 10µF capacitor.

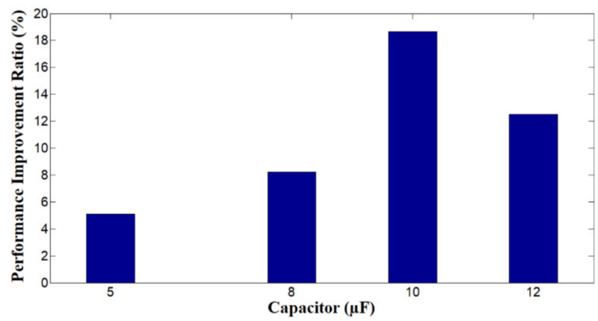

Fig. 8. Performance improvement ratio versus Capacitor.

IV. CONCLUSION

The VCR system was fabricated and experiment was conducted. The system was charged with R134a and R600a refrigerant. For further improvement, various capacitors have been installed in the electrical circuit of the system. The coefficient of performance and energy saving of the system was investigated.

– In case of no capacitor, up to 8.8% of energy can be saved and 9.14% of performance can be improved when using R600a instead of R134a, respectively.

– For further reduction in power consumption and performance improvement of the system, four capacitors have been installed and investigated.

– When compared with no capacitor condition, up to 62.5% of energy can be saved while using R600 refrigerant and 10µF capacitor.

Therefore, 10µF capacitor with R600a refrigerant are recommended.

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