

Performance Enhancement of the Refrigeration System by Adding Capacitor and Replacing Refrigerant- Experimental Study

Mohammad Harun-Or-Rashid, Mohammad Ishtiak Ashraf, Md. Shayel Khan



Abstract: Manufacturing process and performance analysis of a non-frost refrigeration system are presented in this paper. Main objectives of this research were to suggest better refrigerant as well as propose a technique for further reduction of the power consumption of the system. Performance of the refrigeration system was evaluated for Tetra-fluoro-ethane and Isobutene refrigerant. From the experiment, it is found that, coefficient of performance of the system with Isobutene is better than the coefficient of performance with Tetra-fluoro-ethane. Not only that, Tetra-fluoro-ethane is higher global warming refrigerant than Isobutene. In addition, in this paper, it is shown that, if capacitor is added to the electric circuit then power consumption of the system is dramatically decreased. To reduce the power consumption of the system, capacitors of different micro-farad were added and optimum one was selected through experiment. Maximum coefficient of performance was found for Isobutene with 10 μ F capacitor. In case of Isobutene, 47.736% energy was saved. Hence, it is proposed to add a capacitor to the circuit and use Isobutene rather than Tetra-fluoro-ethane as refrigerant for better performance of the system.

Keywords: Capacitor, Coefficient of Performance, Isobutene, Non-Frost Refrigeration System, Reactive Power, Tetra-Fluoro-Ethane

I. INTRODUCTION

Refrigerators are found in almost every home in the modern world. In this system, refrigerant takes heat from the cooling chamber and releases heat to the atmosphere. The household refrigeration system works on vapor compression cycle where there are four basic processes: isentropic compression in a compressor, constant pressure heat rejection in a condenser, throttling in an expansion device and constant pressure heat absorption in an evaporator. In the present study, experimental setup was developed. To ensure the reliability of the experimental setup as well as to get

acceptable data several papers in related field have been studied. M. Abuzar Qureshi et al. [1] investigated coefficient of performance (COP) using Tetra-fluoro-ethane (R134a) and Isobutene (R600a) refrigerant in domestic refrigerator at steady state condition. G. Maruthi Prasad Yadav [2] carried out experiment on vapor compression refrigeration system with liquid line and suction line heat exchanger by using R134a and R404a refrigerants. They concluded that by increasing the length of the heat exchanger, performance of the refrigerator can be increased. Panda et al. [3] made inquires on performance of refrigerant in refrigeration system. He concluded that, R600a could be an alternate of R22 and R134a. Ramesh P. Sah et al. [4] examined a vapor compression refrigeration system with different refrigerants (R134a, R152a, R290 and R32). They found that, R290 has the lowest pressure ratio and highest cooling capacity. On the other hand, R32 has the highest discharge temperature. K. Nagalakshmi [5] investigated the design and performance of refrigeration system by using R12 and R134a refrigerants and concluded that COP of R12 was little greater than R134a. Conversely, Sarthak et al. [6] showed that, R152a and R290 refrigerants have approximately same performance as R134a. Raja Kumar Gond et al. [7] evaluated the performance of vapor compression refrigeration system using various refrigerants alternative of R134a. Rasti et al. [8] carried out experiment on domestic refrigerator and freezer using R600a and R436a refrigerant to replace R134a. They showed that, R600a and R436a can be considered as a convenient alternative of R134a. Mujahid Sheikh [9] conducted the comparative analysis of energy efficiency ratio and electric power consumption of domestic refrigerator using R134a and R600a at constant evaporator temperature [10]. They found that, energy efficiency ratio of R600a is higher than R134a [11]. From the previous research works it was found that, COP of the refrigeration system can be improved by replacing various refrigerants [12]. But there is lack of work on further improvement of COP. Therefore, main motivation of this research was not only to suggest the better refrigerant but also to propose a technique for further reduction of the power consumption [13]. In the present study, performance of the refrigeration system with R134a and R600a refrigerants were evaluated through experiment [14]. It was found that, if R134a is replaced by R600a and capacitor is not installed then coefficient of performance is increased by 8.1135% [15]. On the other hand, if 10 μ F capacitor is used then COP is increased by 18.917% compared to R134a [16]. Furthermore, from experiment, it was found that, with R600a refrigerant and capacitor, power consumption of the refrigeration system was reduced by 47.436%.

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II. DESCRIPTION OF THE EXPERIMENTAL SETUP

For carrying out this research work, experimental setup was designed and constructed according to Fig. 1. But in the

present study, condenser is made of copper tube and attached to the inner surface of the body. Therefore, there is no

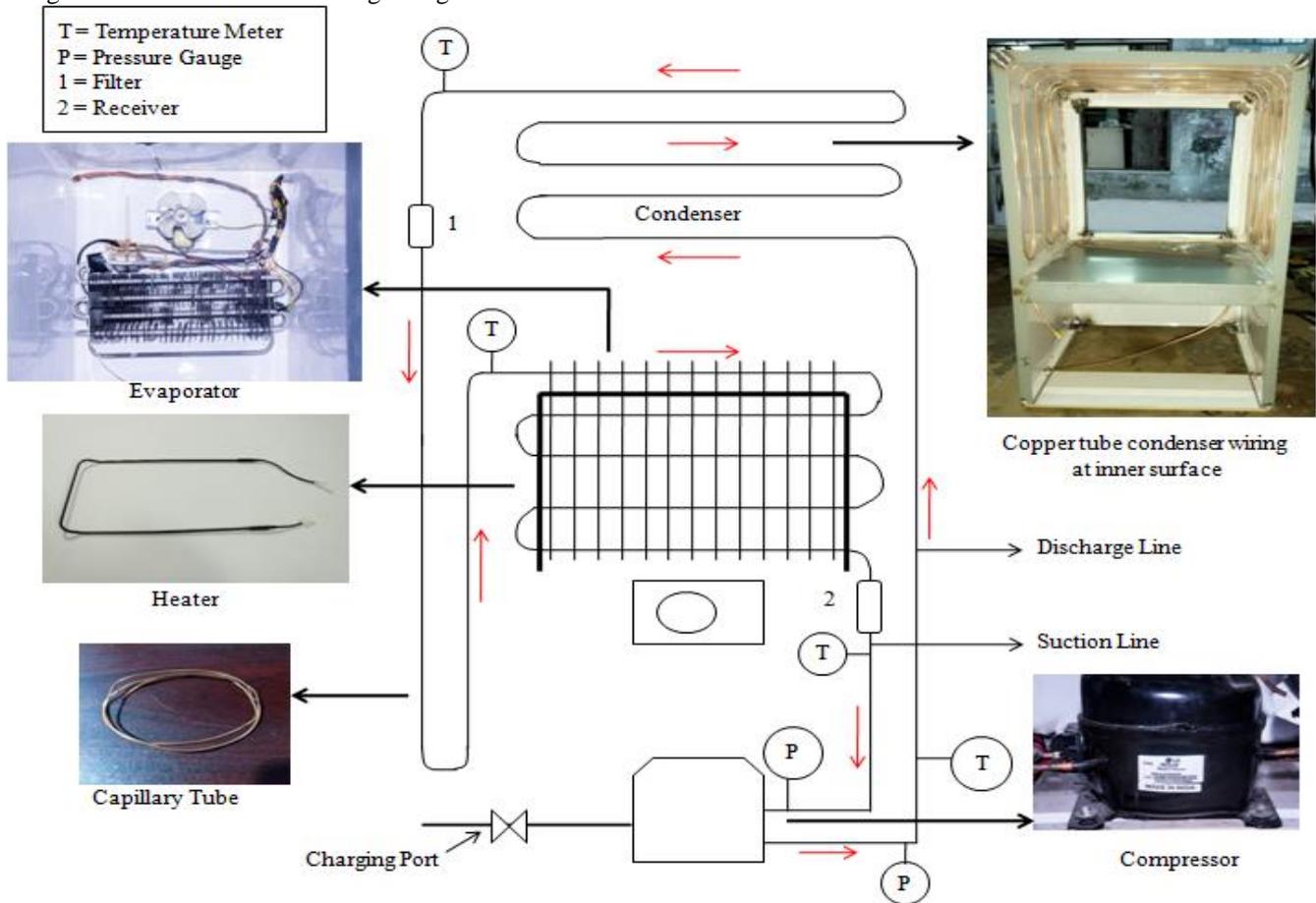


Fig. 1. Schematic of the experimental setup

possibility of fouling. Furthermore, thermal conductivity of copper tube is 5 times higher than the fin type iron condenser of commercial refrigerator [17]. Space between the evaporator chamber and outer chamber is filled with high thermal resistance material, PU foam. Fig 2 is showing the back side of the experimental setup [18]. Six digital thermometers are connected to the desired points to measure the temperature. The digital temperature meters are showing the temperatures of particular points [19]. The time interval between updating results of temperature meter was 10 sec. Two pressure gauges are installed to the suction and discharge line of the compressor by flaring [20]. The evaporator is made of aluminium [21]. It has 5 rows and contains 203 small plate fins. There is a receiver at the outlet of the evaporator and a moisture filter at the outlet of the condenser. The filter is used to filter the bad particles which are existed inside the tubes and in the refrigerant [22]. The receiver is attached to the outlet of the evaporator to resist the liquid refrigerant to go to the compressor. Because it can damages the piston of the compressor [23]. The heart of the non-frost refrigerator is the timer motor which controls the run time of compressor and heater. In this research, the timer motor gave 8 hours power to the compressor and 15 minutes to the heater. The heater was controlled by the defrost thermostat, which allowed the heater to run only when good amount of frost was formed. As the compressor runs most of time, it heated up quickly. To protect it from overheating an

overload protector is added with the circuit. In overheated enough, the overload protector cuts the circuit and wait for some time to cool down the

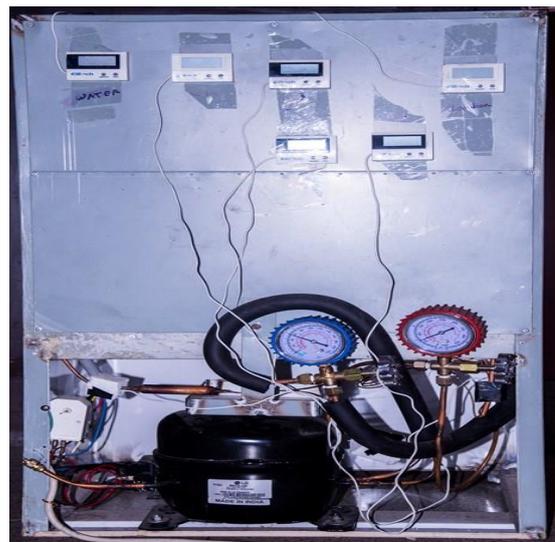


Fig. 2. Back View of the Experimental Setup

compressor, and then restart the compressor again. Common, starting and running are the three ports of compressor. The starting and the running ports are connected to the positive temperature coefficient (PTC) relay. In the PTC relay capacitors were installed parallelly. To measure the voltage and ampere, clamp type multi-meter was connected in parallel and series respectively, with the compressor. The capacitor was connected with the compressor in parallel connection. After carrying out the leak test, refrigerant was

Table 1 Specification of the experimental setup

Specimen	Description
Sheet metal	28 gauge color sheet metal. Thickness 0.00012mm
Insulation	0.05 m thick insulation of PU foam.
Condenser tube	Material Copper
	Diameter 0.003 m
	Length 11.4 m
Evaporator tube	Material Aluminium
	Diameter 0061 m
	Length 5.436 m
	Number of fin 203
Capillary tube	Diameter 0.0008 m
	Length 2.4384 m
Compressor	Hermetic sealed, 1/8 hp, LG Model-MA53LJGG
Evaporator fan	1.2 watts Air velocity 0.78 m/s
Heater	200 watts rod type heater
Capacitor	2.5µF, 3.5µF, 5µF, 6µF, 8.5µF, 10µF and 12.5µF
Gas charge	R134a: 0.110 kg
	R600a: 0.125 kg
Evaporator chamber volume	61.47 liters

charged in the refrigeration system and experiment was conducted. Several times power consumption was tested using capacitor of different values. Specification of the experimental setup is presented in Table 1.

In the present study, compressor power was estimated by eq. (1).

$$P_p = V \times I \times \cos(\phi) \tag{1}$$

Here, P_p is the power, V is the applied voltage and I is the current. The term $\cos(\phi)$ is the power factor and its value is 0.82. On the other hand, compressor work done was calculated by eq. (2).

$$W_c = \dot{m} (h_2 - h_1) \tag{2}$$

Here, W_c , \dot{m} , h_1 , h_2 are compressor work done, mass flow rate, enthalpy at entrance and exit of the compressor respectively. The amount of heat absorbed by the refrigerant is called the refrigerating effect and it is estimated by the eq. (3).

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

Here, R_{effect} is the refrigerating effect, h_4 is the enthalpy of the refrigerant at the entrance of the evaporator. COP, the ratio of the refrigerating effect and the compressor work done, was calculated by the eq. (4).

$$COP = \frac{R_{effect}}{W_c} \tag{4}$$

The part of power which is directly utilized by the load without storing is known as active power. On the other hand,

the part of the power which is stored in the elements of any electric circuit qualifies as reactive power. To improve the power factor a capacitor is added in the circuit. This capacitor acts as a reactive current generator and provides required reactive power to the compressor. It reduces the total current drawn from the distribution system and subsequently increases the system capacity.

III. RESULT AND DISCUSSION

The experiment was conducted for 8 hours long to observe the performance of the refrigeration system. The temperature, pressure, voltage and electric current were measured to investigate the power consumption and COP.

Inlet and outlet temperature differences of condenser at different time are presented in Table 2. Here, heat transfers from the condenser to the atmosphere through natural convection process. It is found that temperature drop of R600a is less than the temperature drop of R134a. This is because of the nature of the refrigerants and inlet temperature of R134a refrigerant is higher than the temperature of R600a.

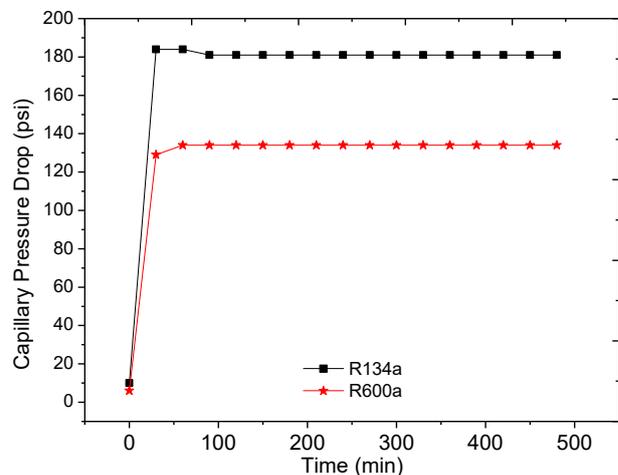


Fig. 3. Capillary pressure drop versus time

Table 2 Experiment data of condenser and evaporator chamber

Time (min.)	Inlet and outlet temperature difference of condenser (°C)		Evaporator chamber temperature (°C)	
	R134a	R600a	R134a	R600a
0	1.1	5.7	28.6	31.8
30	16.8	11.6	-0.4	9.8
60	21.2	12.3	-1.1	9.6
90	23.6	12.2	-1.9	9.3
120	24.2	12.3	-2.1	8.9
150	24.4	12.3	-2.4	8.7
180	24.3	12.7	-2.6	8.4
210	24.1	12.9	-2.1	8.1
240	24.2	13	-2.9	7.9
270	23.9	12.6	-2.9	7.4
300	24	12.5	-3	7
330	24.2	12.2	-3	6.5
360	23.9	12.5	-3	6.2
390	23.7	12.4	-3.1	5.8
420	23.8	12.3	-3.1	5.5
450	24.2	12.5	-3.1	5.2
480	23.7	12.4	-3.1	5.1

Fig. 3 shows the pressure drop in capillary tube for both refrigerants with respect to time. As refrigerant flows through the capillary tube, pressure drops due to friction of tube wall and bend. Consequently, temperature drops and velocity of flow increases. In the present study, it is found that, in case of R134a refrigerant, pressure drop is higher than the pressure drop for R600a. This is because R134a is denser than R600a refrigerant. After 480 minutes inlet and outlet temperature of R134a refrigerant was 43.1 °C and -20.7 °C respectively. On the other hand, in case of R600a, after 480 minutes inlet and outlet temperature was 35.6 °C and -7.5 °C respectively.

Temperatures of the evaporator chamber at different time are also presented in Table 2. Temperature of the evaporator chamber is lower for R134a refrigerant. This is because of the density and viscosity of R134a is higher than R600a. During flow of refrigerant through the capillary tube, pressure drops, and consequently, temperature also drops. Since, the density and viscosity of R134a is higher than the density and viscosity of R600a, therefore, more frictional loss was occurred and lower temperature was found for R134a. Hence, in case of evaporator, the inlet temperature of R134a refrigerant is lower than the inlet temperature of R600a. As a result, R134a absorbed more heat from the evaporator chamber. In case of R134a, more temperature was dropped and more frost was formed than R600a. Conversely, heater power consumption depends upon the amount of frost has formed. Therefore, refrigeration system with R134a refrigerant, consumes more power than the refrigeration system with R600a refrigerant. Heater is controlled by the defrost thermostat. Heater turns off automatically after frost melts down. Compression ratio depends upon the density and viscosity of the fluid. If density and viscosity of a fluid is found higher, then, the compression ratio of that fluid will be higher. Since the density and viscosity of R134a refrigerant are higher than the density and viscosity of R600a, therefore, the compression ratio is also higher for R134a than R600a.

In the present study, compressor work done is found higher for R134a refrigerant. It depends upon the properties of the refrigerant. For more viscous and denser refrigerant, compressor needs to do more work. It also varies with the flow of current and the voltage of the electricity. Therefore, if flow of current or voltage fluctuates then compressor work done also fluctuates. Fig. 4 shows the mass flow rate of the refrigerant (R134a, R600a) with respect to time. Mass flow rate of R134a refrigerant is found higher. Mass flow rate greatly depends upon the compressor work done. As compressor work done is higher for R134a refrigerant, therefore, mass flow rate is also higher. It fluctuates because of the fluctuation of the compressor work done. Refrigerant effect means the quantity of heat is absorbed from the refrigerated space to produce useful cooling. Refrigerant effect is found almost same for both refrigerants. COP is the ratio of refrigerant effect and compressor work done. Fig. 5 shows the coefficient of performance of R134a and R600a refrigerant with respect to time. COP of the system is higher for R600a than R134a because compressor work done of R600a is less than R134a. Hence, it is better to replace R134a refrigerant by R600a. Fig. 6 to Fig. 7 is showing the power consumption of the

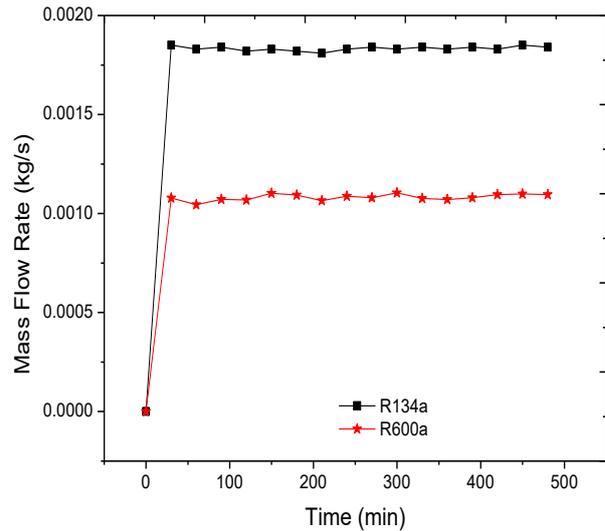


Fig. 4. Mass flow rate versus time

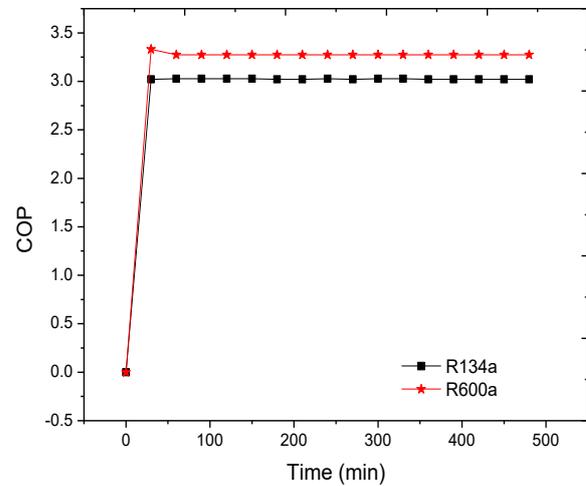


Fig. 5. COP versus time (without capacitor)

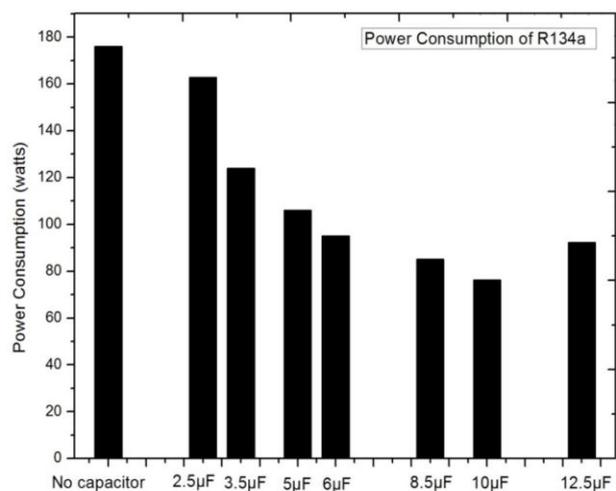


Fig. 6. Clustered column representation of power consumption for R134a

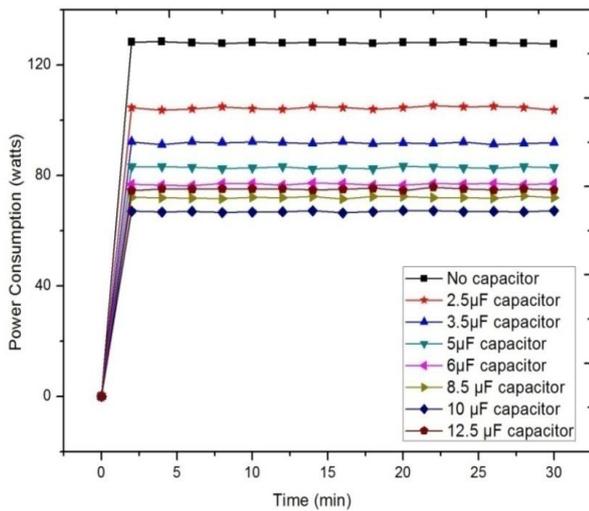


Fig. 7. Power consumption versus time for R600a refrigerant

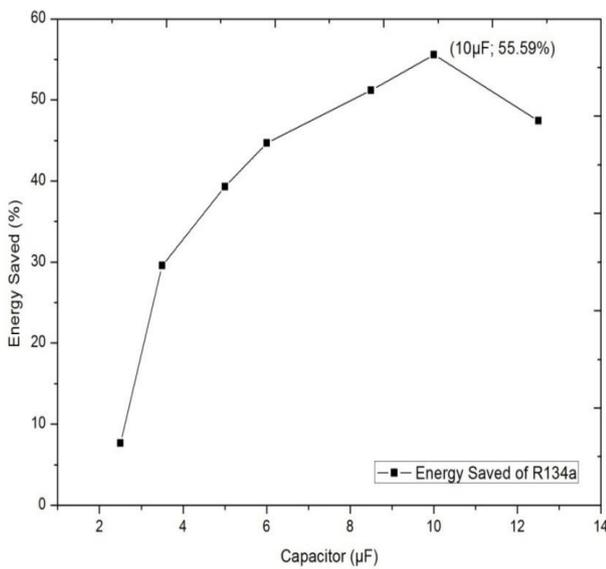


Fig. 8. Various capacitors versus Energy saved for R134a

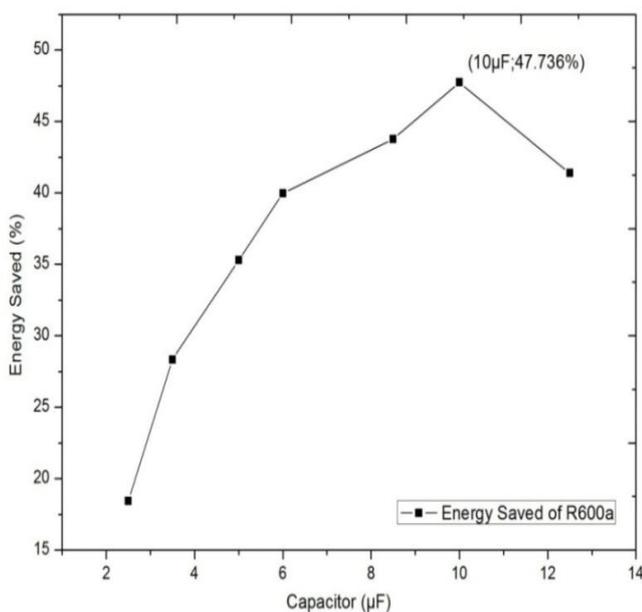


Fig. 9. Various capacitors versus Energy saved for R600a

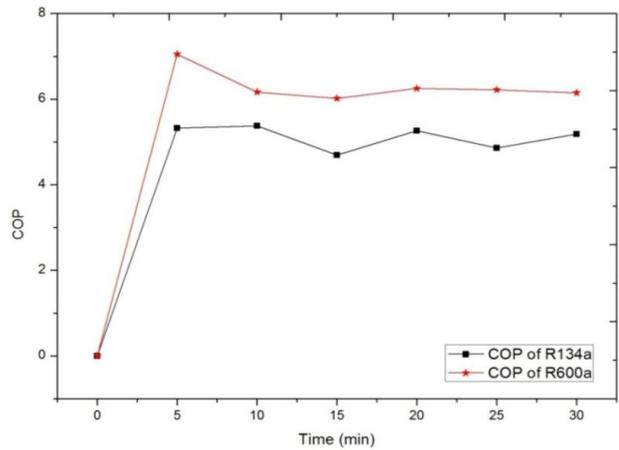


Fig.10. COP for 10µF capacitor

refrigeration system for R134a and R600a refrigerant with respect to time, respectively. While running without capacitor, power consumption by the compressor was found highest. This is because of the reactive power (non-working magnetized power) of the main power supply was dominating at that time. As the capacitor was installed, the reactive power loss of the main supply line was reduced by supplying reactive power from the capacitor and corrected the power factor. Therefore, as soon as the capacitor was used less power consumption was found. In this research, 2.5µF, 3.5µF, 5µF, 6µF, 8.5µF, 10µF and 12.5µF capacitor was investigated. From experiment it was found that, 10µF capacitor was the optimum choice to minimize of the power consumption. Because for 10µF capacitor power factor became 1. It means that, there was no supply of reactive power from the main supply line. As the 12.5µF capacitor was added, the power consumption started to rise again because the reactive power supply was increasing. Since the lowest power consumption is found for 10µF capacitor, therefore, in the present study, it is selected. Fig. 8 and Fig. 9 are showing energy saved by different capacitors for R134a and R600a refrigerant respectively. Form experimental data it was found that, if compared with no capacitor condition, then 55.59% and 47.736% energy were saved for R134a and R600a respectively. While using 10µF capacitor, the reactive power of the main power supply line was reduced and power consumption was minimized. Fig. 10 shows the COP of the system for a 10µF capacitor. Since the compressor work done for R600a is lower than R134a therefore, COP of the system with R600a is higher than COP with R134a. In the present research, average value of COP was taken to compare the performance of two refrigerants. While capacitor was not attached to the electric circuit, then for R600a system COP was 8.1135% higher than the COP for R134a. On the other hand, if 10µF capacitor is added to the circuit then for R600a system COP becomes 18.917% higher than the COP for R134a.

IV. CONCLUSION

In the present study, a non-frost refrigerator was developed and experiment was conducted with R134a and R600a refrigerant.

In case of no capacitor condition, the power consumption was found lower for R600a than R134a. Therefore, in this condition, if R134a is replaced by R600a then COP of the system is increased. For further decreased of the power consumption a 10 μ F capacitor was selected through experiment. While 10 μ F capacitor was used then 66.90958 watts and 76.23895 watts power consumption was found for R600a and R134a respectively. Finally it was found that, COP of the system was higher by 8.1135% with R600a refrigerant while there was no capacitor in the circuit and 18.917% while 10 μ F capacitor was installed; compared to the COP of the system with R134a refrigerant. Therefore, it is recommended to replace R134a by R600a; use an appropriate capacitor to increase the coefficient of performance of the refrigeration system.

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