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Review IJICEGT

Experimental Energy Analysis of R134a and HC (Propane + Butane) as a Refrigerant in Domestic Refrigerator

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ABSTRACT

This research work presents an experimental and numerical study for identical household refrigerator using hydrocarbon butane/propane mixture as a drop replacement for R134a. GWP of R134a is very high (i.e., 1300) as compared to hydrocarbon butane/propane mixture (i.e., 8). The household refrigerator basically designed to work with R134a. In this study, the cooling performance for both refrigerants was experimentally measured and then compared for suction temperature, temperature after condensing, temperature after cooling with respect to time (in minute). Montreal and Kyoto protocols talk regarding the substances which are responsible for increasing global warming and ozone depletion, i.e., those substances having high value of ODP and GWP must be replaced by new eco-friendly substances. Among the various refrigerants, recently, hydrocarbons are considered as refrigerants due to their low ODP and GWP. The hydrocarbons refrigerants also give better performance as compared to CFC and HFC refrigerants. After experimental comparative analysis, we get, R134a gives better performance as compared to hydrocarbon butane/propane mixture. Hydrocarbon butane/propane mixture cannot be directly used in same system which is designed for R134a. The use of hydrocarbon butane/propane mixture in existing refrigerator required the compressor range. Experimental test has been carried out in moderate climate condition. In this work, derived the equation model, is used which is solved by Energy Equation Software.

Keywords: Domestic refrigerator, GWP, COP, HC (butane/propane), R134a

INTRODUCTION

Recently, in most of the household refrigerators, R134a is used as refrigerant which has zero ozone depletion potential but has high global warming potential. R134a has lower value of GWP as compared to others refrigerants such as R413a, 401a, 401b, 410a, and R407c etc., but it cannot be neglected due to its considerable adverse environment impact. Recently, maximum cooling system uses the R134a as a working substance which has 1300 GWP and zero ODP value. The rapid increase in industrialization and urbanization increases the demand for the refrigerators and the Air conditioners. The use of refrigerants like R134a which are having high GWP is not environment friendly and causes global warming. A directive has been published by European Parliament, which bans such refrigerants. From few decades, global warming continues to increases due to increase in use of refrigerators and air conditioners. Recent work on the various new eco-friendly refrigerants such as R1234yf/R134 (i.e.,

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mixture R513A), R1234ze, R413A and propane/isobutane (R290/R600a), and hydrocarbons etc. refrigerants to replace the R134a in domestic refrigerator. Energy and exergy analysis is very useful to calculate the performance of household refrigerator with different refrigerants [1].

LITERATURE REVIEW

There are various literatures are available on refrigerants and domestic refrigerator. Here, these are few literatures which we observed and reviewed before doing experiment. Yang *et al*. presents the three kinds of tests which were carried out to investigate the performance of low GWP refrigerant R513A as a potential substitute of R134a [2]. According to the experimental results, it can be concluded that the refrigerant mixture R513A (at 80 g charge) can be considered as a direct drop-in replacement of R134a in the household refrigerator without any redesign of the entire Refrigerator technologies are comprehensively analysed and compared. Single and dual evaporator cycles are widely used due to the product cost. The parallel circuit cycle is the most efficient one among dual evaporator cycles and it seems promising for the time being. In order to increase the efficiency of VCC, it is expected that research on advanced VCC such as ejector and two-stage cycles will be continued in the short term. Refrigerator technologies are changing and evolving in response to power and environmental issues. Therefore, if there are other restrictions on the refrigerant or current technology being applied to the refrigerator, NIK technologies can be considered promising. In that case, it is most important to develop magnetic materials that can increase system efficiency, minimize size, and reduce material cost. Aprea *et al*. compared the performance of R134a with R1234yf and conclude that R1234yf is saving more energy and in favour of the improvement of the cooling capacity [3]. The binary mixture refrigerant has the closest behaviour to R134a in terms of temperatures and pressures. Belman-Flores *et al*. was experimentally investigating the performance of domestic refrigerator to replace the 134a by R1234yf and concluded that it cannot directly replace due to higher exergy consumption values [4]. There are some modifications which will be required in design of components of refrigerator to allow refrigerant R1234yf.

Aprea *et al*. compared R134a with R1234yf and studied the energetic performances of R1234yf and its binary mixture with R134a [5]. The binary refrigerant is saving more energy, and in favour of the improvement of the cooling capacity. In addition, the mixture refrigerant has the closest behaviour to R134a in terms of temperatures and pressures. Sanchez *et al*. concluded that R1234yf could be considered as a direct drop-in alternative to R134a with a 10% COP reduction [6]. Mota-Babiloni *et al*. found that R450A can be directly used in system in place of R134a with slightly lower refrigerating capacity and almost same coefficient of performance [7]. To obtain the better energy and exergetic performance of the system, it is advisable that redesigns and optimizes the charge of refrigerant. Mota-Babiloni *et al*. presented a drop-in analysis of internal heat exchanger on the performance of a VCRS system using R1234ze (E) and R450A (R1234ze (E)/R134a, 58/42% weight) for the replacements of R134a [8]. According to their result, R1234ze (E) performs better as compared to other refrigerants. El-Morsi theoretically analysed the performance of various refrigerants such as R290, R600, LPG and R134a, and concluded that R600 performs better among all the refrigerants [9]. Balaji *et al*. [10], on the basis of study, showed that CFCs and HCFCs (R134a) are harmful for ozone layer which protects the earth environment from UV rays [11–15]. Soni *et al*. presents exergetic analysis for comparing the performance of refrigerants in VCRS cycle [16].

On the basis of literature study, use of those refrigerants must be stopped which have high ODP and GWP. According to the Kyoto protocol [17] agreements, those refrigerants which are responsible for increasing global warming must prohibited from being used in cooling systems [18]. According to the Montreal Protocol [19], those refrigerants which are responsible for depleting the ozone layer must be prohibited from being used in cooling systems. Currently, HFC refrigerants are the good leading alternative to CFC and HCFC refrigerants in cooling systems.

WORKING PRINCIPLE OF VAPOUR COMPRESSION SYSTEM

The refrigeration system uses the working fluid known as refrigerant to transfer the heat from low temperature medium to high temperature. Figure 1 shows the schematic diagram of simple VCRS system.

Compressor

It is the key component of a household refrigerator. It raises the pressure of vapour refrigerant up to the condenser pressure.

Condenser

In condenser, vapour refrigerant passes through the numbers of coils and converts back into the liquid to obtain the cooling.

Expansion Device

Expansion device controls the flow of refrigerant throughout the system and reduces the higher condenser pressure to a lower evaporator pressure of liquid refrigerant. Some of the liquid substance vaporises during irreversible expansion process [20–25].

Cooling Component

In cooling component (i.e., evaporator), as liquid refrigerant passes through the evaporator, it starts to absorb the latent heat and cools the space around it.

A fictitious pressure-enthalpy diagram is used for a typical refrigeration cycle as shown in Figure 2. After, condensing, the refrigerant enters into the expansion device where it undergoes an abrupt drop in pressure. Due to this abrupt drop in pressure. adiabatic flash evaporation of some of liquid refrigerant takes place and temperature of this refrigerant mixtures decrease which is lower than the enclosed space whose low temperature is required to be maintained.

Now, this cold liquid-vapour refrigerant mixture passes through the evaporator' coils over which a fan circulates the warm air, and the evaporation of liquid refrigerant takes place due absorption of the heat from this warm air. Simultaneously, the circulating air is cooled and it is supplied to the enclosed space to maintain the desired temperature.

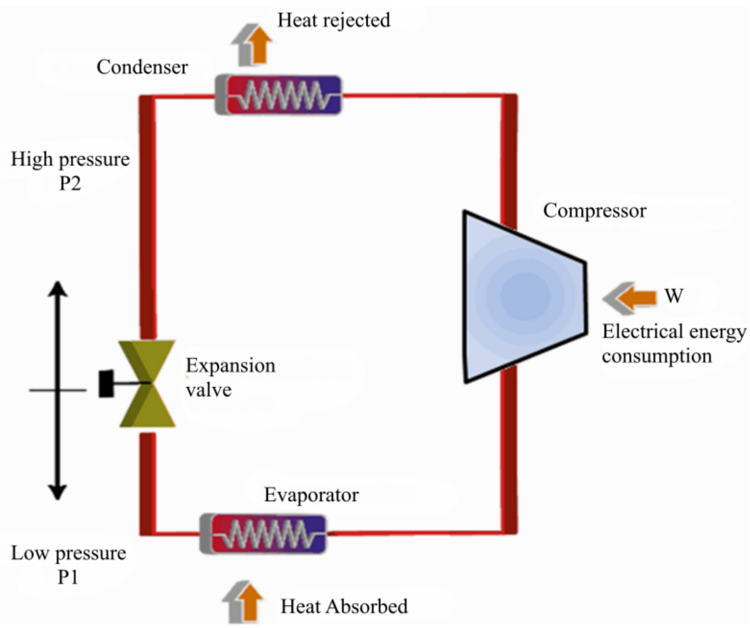

Figure 1. Simple vapour compression refrigeration system.

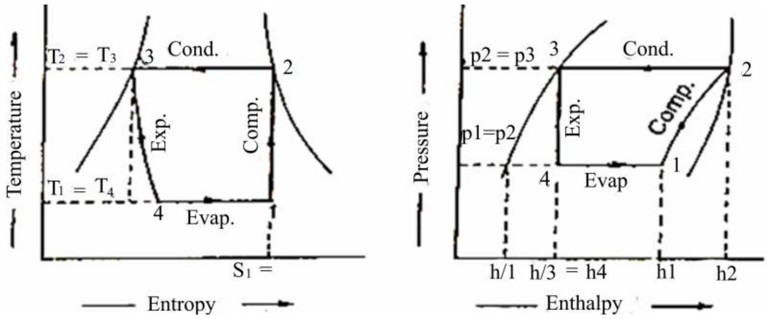

Figure 2. Theoretical vapour compression cycle.

Experimental Set-up

Figure 3 represents the experimental set up of domestic refrigerator. Experimental test has been performed on household Electrolux refrigerator of 165 l capacity. It consists of hermetic sealed reciprocating compressor, wire mesh air cooled compressor, capillary tube and evaporator. To measure the temperature at various points of the household refrigerator, digital thermocouples have been used. To measure the condenser higher pressure and evaporator lower pressure, conventional bourdon tube type pressure gauge has been used. Figure 4 shows the schematic diagram for measuring locations of domestic refrigerator apparatus.

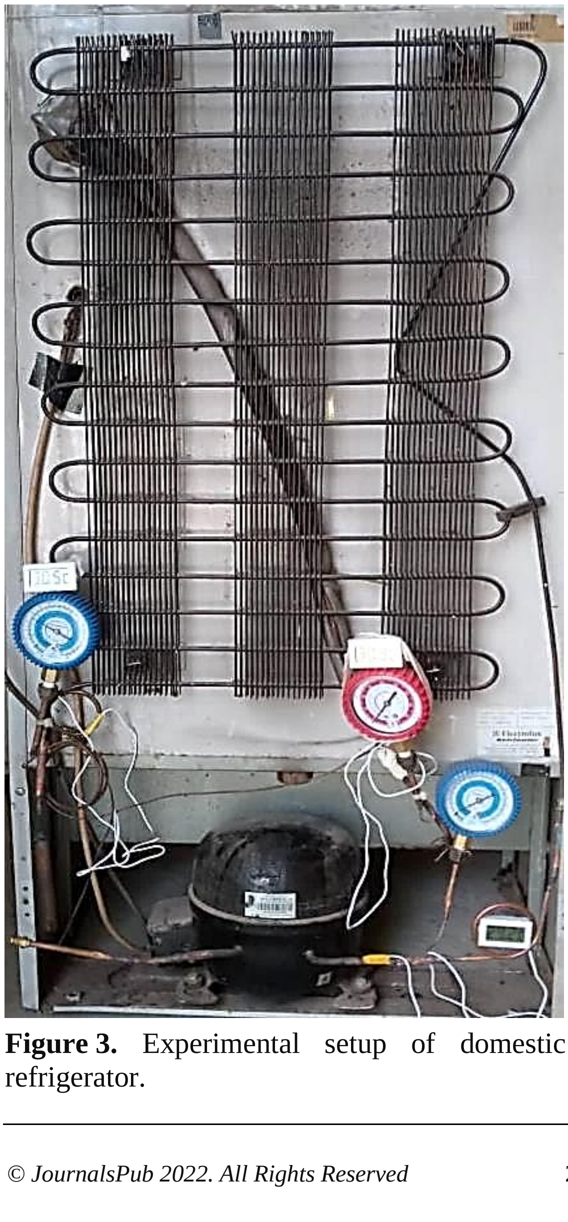

Figure 3. Experimental setup of domestic refrigerator.

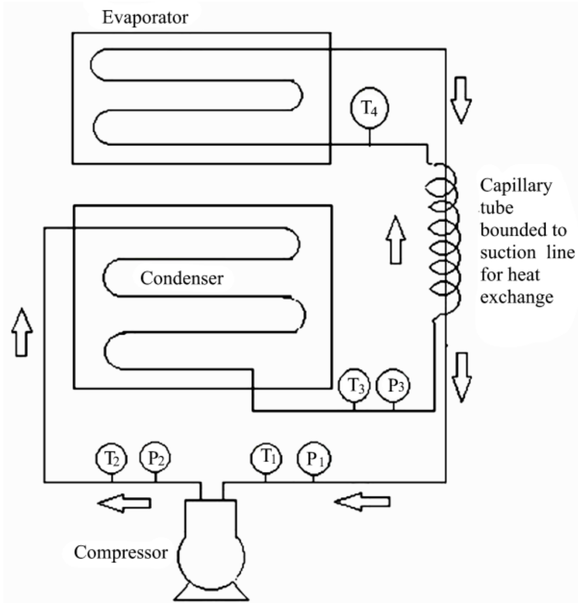

Figure 4. Measuring locations of domestic refrigerator apparatus.

Test Procedure

The household refrigerator was charged with 70 gm of R134a. After completion of the charging process, switch on to start the compressor of this refrigerator. The experiment tests have been started to perform.

RESULT AND DISCUSSION

Table 1 represents the pressure and temperature values measured at different locations of the refrigerator for the hydrocarbon refrigerant when the compressor is stopped and working in steady state condition. Similarly, Table 2 represents for R134a. The Tables 3–6 show the comparative data for R134a and HC (propane + Butane) with respect to different parameters.

Table 1. Pressure and temperature table of HC (Propane + Butane).

Time (min)	Discharge	Suction	After Condensing	Discharge	Section	After Condensing	Cooling
	Pressure	***Pressure***	***Pressure***	***Temperature***	***Temperature***	***Temperature***	***Temperature***
	(P1)	*(P2)*	*(P3)*	*(T1)*	*(T2)*	*(T3)*	*(T4)*
Off Condition	2 (psi)	0 (psi)	2 (psi)	28.9°C	29.2°C	29.5°C	26.5°C
30 (min)	116 (psi)	0 (psi)	102 (psi)	43.3°C	29.0°C	30.5°C	26.3°C
60(min)	118 (psi)	0 (psi)	107 (psi)	53.9°C	31.1°C	31.9°C	26.5°C
90 (min)	119 (psi)	0 (psi)	109 (psi)	57.0°C	31.4°C	32.2°C	26.9°C
120 (min)	120 (psi)	0 (psi)	110 (psi)	59.4°C	31.9°C	32.9°C	27.2°C

Table 2. Pressure and temperature Table of R134a.

Time (min)	Discharge	Suction	After Condensing	Discharge	Section	After Condensing	Cooling
	Pressure	***Pressure***	***Pressure***	***Temperature***	***Temperature***	***Temperature***	***Temperature***
	(P1)	*(P2)*	*(P3)*	*(T1)*	*(T2)*	*(T3)*	*(T4)*
Off Condition	4 (psi)	50 (psi)	59 (psi)	30.9°C	31.2°C	31.2°C	30.9°C
30 (min)	4 (psi)	23 (psi)	220 (psi)	63.9°C	30.2°C	39.7°C	–7.7°C
60 (min)	3 (psi)	24 (psi)	220 (psi)	71.9°C	30.5°C	38.7°C	–9.0°C
90 (min)	3 (psi)	22 (psi)	220 (psi)	74.4°C	30.0°C	37.6°C	–10.0°C
120 (min)	3 (psi)	19 (psi)	220 (psi)	73.8°C	29.5°C	37.1°C	–10.8°C

Table 3. Comparison of R134a and HC (Propane + Butane) by suction temperature vs. time.

Time (min)	**HC Suction temperature (℃)**	**R134a Suction temperature (℃)**
Off Condition	29.2	31.2
30	29.0	30.2
60	31.1	30.5
90	31.4	30.0
120	31.9	29.5

Table 4. Comparison of R134a and HC (Propane + Butane) by discharge temperature vs. time.

Time (min)	**HC Discharge Temperature (℃)**	**R134a Discharge Temperature (℃)**
Off Condition	28.9	30.9
30	43.3	63.9
60	53.9	71.9
90	57.0	74.4
120	59.4	73.8

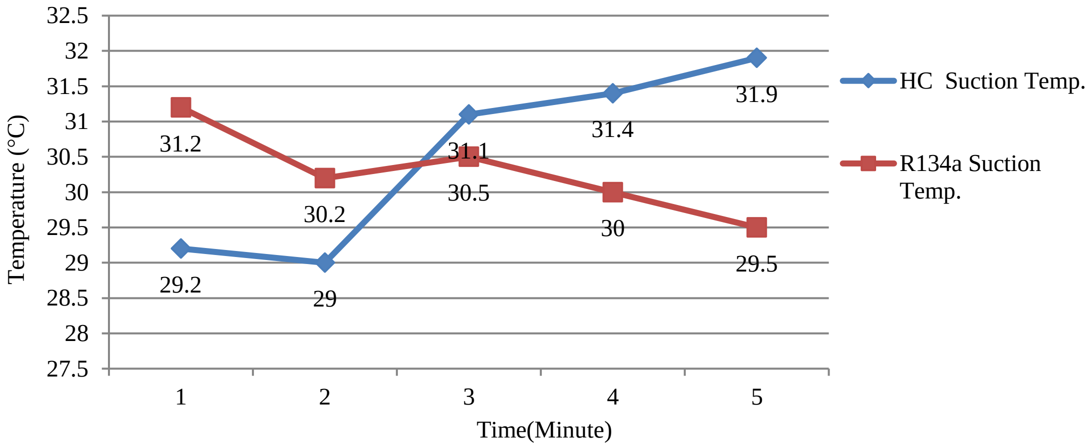

Figure 5. Suction temperature (℃) vs. time (min).

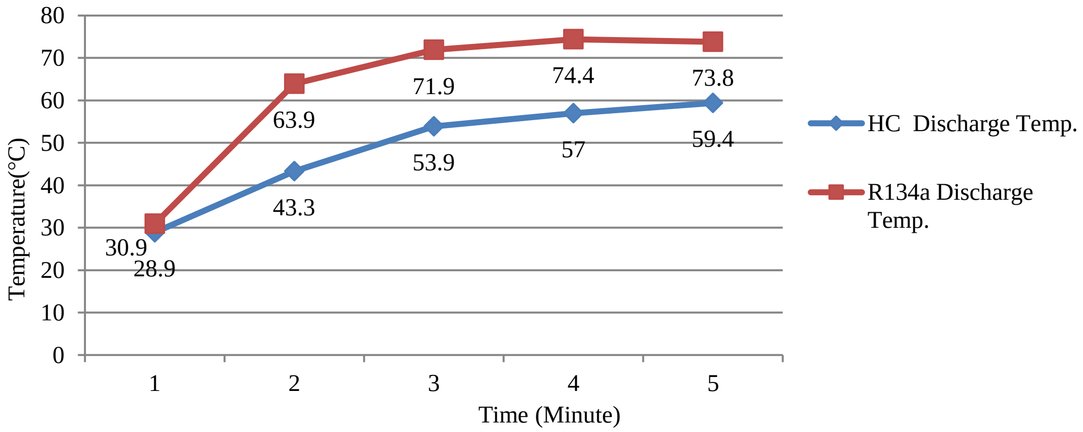

Figure 6. Discharge temperature (in℃) vs. time (min).

Table 5. Comparison of R134a and HC (Propane + Butane) by after condensing temperature vs. time.

Time (min)	HC After Condensing Temperature (℃)	R134a After Condensing Temperature (℃)
Off Condition	29.5	31.2
30	30.5	39.7
60	31.9	38.7
90	32.2	37.6
120	32.9	37.1

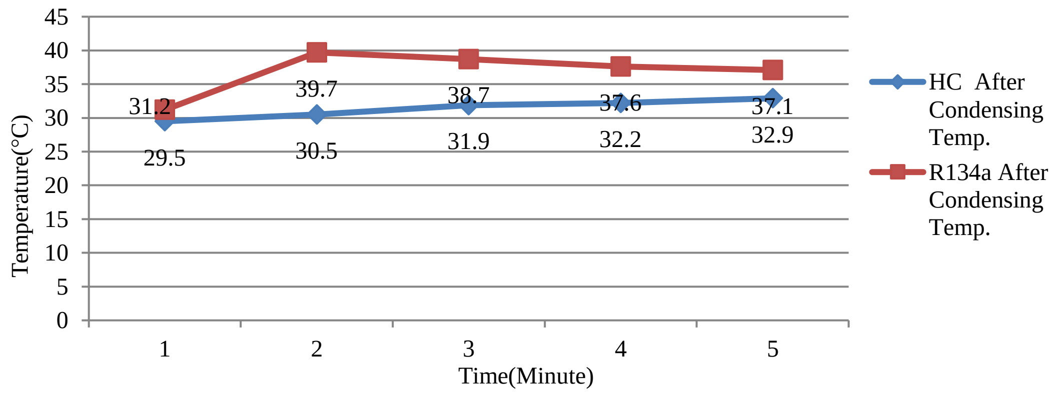

Figure 7. After condensing temperature (in℃) vs. time (min).

Table 6. Comparison of R134a and HC (Propane + Butane) by cooling temperature vs. time.

Time (min)	HC Cooling Temperature (℃)	R134a Cooling Temperature (℃)
Off Condition	26.5	30.9
30	26.3	–7.7
60	26.5	–9.0
90	26.9	–10.0
120	27.2	–10.8

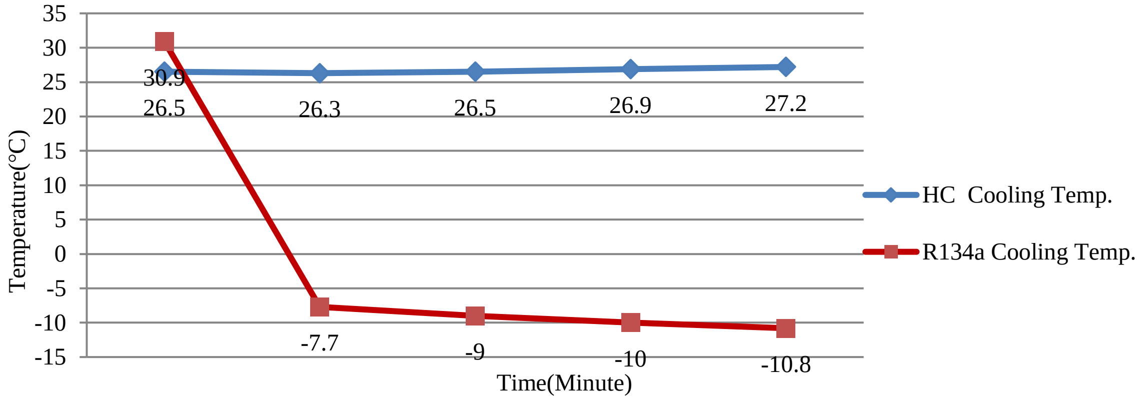

Figure 8. Cooling temperature (in℃) versus time (min).

Experimental test has been performed on a specially modified household refrigerator. This household refrigerator is firstly charged with 70 gm R134a and performed the test. This test has been continued for 15 days and daily taking readings of pressure and temperature at different locations of the system from 9:00 AM to 5:00 PM. After performing all the tests with R134a, the system was refilled with 55 gm of hydrocarbons propane/butane zeotropic blend. At the start, transient test has been carried out to test the system that how much time is required to reach to steady state. In the beginning, temperature rises at a faster rate and then reduces at latter stage.

Figure 5 represents the comparison of R134a and HC (Propane + Butane) for variation of suction temperature in ℃ with respect to time in minutes. For HC refrigerants, the values of suction temperature continue to rise, while for R134a it decreases. Figure 6 show the variation of after discharge temperature with respect to time. Discharge temperature continues to increase with time. The maximum discharge temperature of 73.8℃ for R134a while 59.4℃ for HC refrigerant were obtained. R134a has more condensing temperature as compared to HC (propane + Butane). Figure 7 shows the comparison of R134a and HC (propane + Butane) with the variation of condensing temperature versus time. R134a has higher condensing temperature as compared to HC (propane + Butane). Figure 8 shows the comparison of these two refrigerants by variation of cooling temperature with respect to time. The minimum temperature is obtained as –10.8℃ with charge of 70 gm R134a. R134a has higher values of cooling capacity as compared to HC (propane + Butane).

CONCLUSION

Experimental test was performed on domestic refrigerator with 70 gm of R134a and with 55 gm of HC (Propane + Butane). The energy equation solver software has been used to simulate the mathematical model and compare the performance of R134a and hydrocarbon mixture refrigerant in domestic refrigerator. The performance of refrigerator was predicted for the characteristics of suction temperature (℃), discharge temperature (℃), condensing temperature (℃) and cooling temperature (℃). These characteristics have been evaluated with variation of time in minutes. From this experimental test, it was concluded that hydrocarbon propane/butane mixture refrigerant could not be used as a drop-in replacement for R134a in household refrigerator due to its lower refrigerating capacity. Commercial hydrocarbon propane/butane mixture yields various desirable characteristics but needs a compressor range.

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