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Performance Analysis of domestic refrigerator using HFC134a and HFC134a/HC mixture Refrigerant

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ABSTRACT

An experimental performance comparison study on domestic refrigerator system was conducted and compared with HFC134a and M09 (HFC134a and HC blend (containing 55.2%HC600a and 44.8%HC290 by weight)) mixture refrigerant. The domestic refrigerator system was initially designed to operate with HFC134a. The temperature variation along the evaporator coil was less than 2.7ºC.This shows that temperature glide due to zeotropic nature of the refrigerant does not influence much on the uniformity in evaporator coil temperature. The M09 mixture cools the system 6 minutes faster than the HFC134a due to its better heat transfer characteristics. The reduction in pull down time in the Freezer, chiller, Food, and Crisper compartment of M09 system are 24.34%, 11.11%, 1.91%, and 7.90 % respectively. The energy consumption of M09 system was 2.1%lesser than HFC134a system. The M09 mixture shows 8.69% improvement in COP than HFC134a. The OFF cycle time for the Freezer max Cool airflow position is larger than other positions and hence the system performance will be better than other air flow position. . The overall performance has proved that the above M09 refrigerant mixture could be the best long term alternative to phase out R134a.

Keywords: Mixture Refrigerant; R134a; Hydrocarbon.

1. INTRODUCTION

The refrigerants chlorofluorocarbon (CFCs) and hydro chlorofluorocarbon (HCFCs) both have high ozone depleting potential (ODP) and global warming potential (GWP) and contributes to ozone layer depletion and global warming. As per the Montreal protocol, the developed countries have already phased out CFCs and the developing countries have to be totally phased out it by 2008.

In India, about 80% of the domestic refrigerators use R134a as refrigerant due to its excellent thermodynamic and thermo physical properties. But R134a has high GWP of 1300.the higher GWP due to R134a emissions from domestic refrigerators leads to identifying a long term alternative to meet the requirements of system performance, refrigerant-lubricant interaction, energy efficiency, environmental impacts, safety and service. The test has been conducted as per BIS standards [1].

The consumed energy, compressor power, refrigerant temperature and pressure at the inlet and outlet of the compressor are recorded and analyses as well as the distributions of temperature at various positions in the refrigerator [2].

Already many research works have been done the two (HFC134a & M09) refrigerants. The power consumption of a HFC134a system would be 5-15 % less than CFC12 system [4].

The compressor consumed 3% and 2% less energy than that of HFC134a at 28ºC ambient temperature when isobutene and butane was used as refrigerants respectively. The domestic refrigerator was charged with 140g of HFC134a and 70g of HCs and blends of HCs. This is an indication of better performance of HCs as refrigerants. The final conclusion is that butane and isobutene can be used in the existing refrigerator-freezer without modification of the components [5].

The power consumption of the optimized R134a system was 12.3%higher that of the optimized R290/R600a system. The cooling speed of the optimized R290/R600a system at the incase setting temperature of -15ºC was improved by 28.8% over that of the optimized R134a system because of the slightly higher operating pressure and relatively high heat transfer performance of R290/R600a[8].

Refrigerating capacity of R290/R600a (68/32by wt %) mixture was higher in the range 28.6-87.3% in the lower evaporating temperature and 30.7-41.3%in the higher evaporating temperature than R134a.

Energy Consumption of R290/R600a (68/32by wt %) mixture was higher in the range 6.8-17.4% than R12 and 8.9-20%than R134a.The refrigeration efficiency of the system increase with the increase in condensing and evaporating temperature[9].

60g of HCM consumes about 11.1%lesser energy compared to that of R134a.Pull down time and ON time ratio of the HCM is reduced by about 11.6%and 13.2% respectively [10].

All investigated hydrocarbon mixtures of propane, butane and isobutene can be used as possible alternative refrigerants to R-12 with COP values that are competitive with R-12 values. The 100% propane mixture has the highest COP values among all hydrocarbons tested. The 50% propane mixture is selected to be the most suitable alternative refrigerant to R-12 based on both COP and saturated curve match characteristics [12].

Experiments are designed on a refrigerator manufactured for 105 g R134a charge. The effect of parameters including refrigerant type, refrigerant charge and compressor type are investigated. Total energy destruction of the domestic refrigerator with HFC type compressor for R134a, R600a and R436A are 0.0389, 0.0301, 0.0471, respectively and for R600a and R436A with HC type compressor are 0.0292, 0.0472, respectively[13].

The risk associated with these two appliances was compared and the key for the DR the overall ignition frequency was found to be similar to the empirical observations. The ignition frequency and the overall risk of overpressure and thermal intensity for the DR is about 100 times higher than SAC. The calculated ignition frequency of both DR and SAC is extremely low, being less than one ignition event per million DRs Over a 10-year period or one event per 100 million SACs in 10 years [14].

The proposed replacements are the binary mixtures R-32/R-134a in compositions 20/80%, 30/70%, 40/60% by mass, and the ternary blends R-407B (10wt% R-32, 70wt% R-125, 20wt% R-134a), R-152a/R-125/R-32 (48wt% R-152a, 18wt% R-125, 34wt% R-32), R-410B (45wt% R-32, 55wt% R-125) and R-507A (50wt% R-125, 50wt% R-143a). The refrigeration heat pump cycle examined for 8 refrigerants and for a given GSHPS established to cover the energy demands of a glass office building [15].

A vapor injection refrigeration cycle using mixture R290/R600a was studied. Two different cases related to the choice of reference temperatures were evaluated. Best performance was achieved between 40-50 wt% R290 and expansion ratio of50%.A maximum COP was obtained for a mixture containing 40 wt% of R290. COP of vapor injection refrigeration cycle is 16-32% greater than the one of a vapor compression cycle, depending on the composition of the mixture refrigerant and pressure drop at the cycle upper-stage expansion valve [16].

The literature review brings out the fact that many researchers have studied with different hydrocarbon refrigerant mixtures with HFC134a as alternative to R12 and R134a in domestic refrigerators. The objective of the present study is to explore the possibility of using above mentioned M09 in a 220 liter domestic refrigerator with 32˚C atmosphere temperatures. The influence of ambient temperatures on the performance characteristics of the refrigerator under continuous and cycling running operating mode at different freezer air temperatures and cabin air temperature with 32°C ambient temperature have been studied.

Nomenclature

COP-Coefficient of Performance

GWP-Global Warming Potential

H-Enthalpy-kJ/kg

J-Joule

ODP -Ozone Depleting Potential

P-Pressure (bar)

T-Temperature (ºC)

W-Watt

m_a- mass of air (kg)

C_p- Specific heat of air (kJ/kgK)

ΔT_{Fr}-Temperaturedifference in Freezer compartment (K)

ΔT_{cab}-Temperaturedifference in Cabin compartment (K)

ΔT_{cr}-Temperaturedifference in Crisper compartment (K)

Subscripts

a - Air
e -Evaporator
c - Compressor
Cd - Condenser
Cr - Crisper
Fr - Freezer
Cab - Cabin

2. EXPERIMENTAL

The schematic diagram of domestic refrigerator experimental setup with the total volume of 200 liters is as shown in Fig1. It consists of a refrigerator cabin; the hermetically sealed reciprocating compressor present in the system was lubricated by mineral oil. The evaporator placed in the freezer is a free convection heat exchanger on the other hand the condenser is a free convection finned air cooled type heat exchanger. The temperature and pressure at various points were measured to study the performance of HFC134a and HFC134a/HC mixture. Digital pressure gauge with ±0.25% accuracy was mounted at the inlet and outlet of the compressor coil. Film type PT100 RTD sensors have been used to measure the refrigerant (tube wall) temperature at various points in the system. Seven more temperature sensors are fixed in compartment to measure the air temperature, two in the freezer compartment, four in the food storage compartment and another one in the crisper compartment, which are specified as per BIS standard for testing the Domestic refrigerator performance.

According to BIS standard for testing the domestic refrigerator the temperatures should be maintained as -15°C in the freezer compartment, +0˚C to +7˚Cshould be maintained in the food storage compartment, +8˚C to +14˚C should be maintained in the crisper compartment.

Before charging the system it was evacuated to the extent of 320µm Hg with the help of a double stage vacuum pump. This was done so as to remove the moisture in the system. Suitable drier was also used to absorb any moisture present in the system.

A power meter with accuracy of 0.01kW-h has been used to measure the power consumption of the compressor. To measure the energy consumption a watt hour meter is used. A data logger has also been used to measure the temperature at all point's with an accuracy of 0.25˚C.

2.1. Experimental procedure

Initially, the system was flushed with nitrogen gas to eliminate impurities, moisture and other foreign materials inside the system, which may affect the accuracy of the experimental results. The experiments were conducted according to IS1476 (part1) [1]. To conduct no load pull down test, the door was kept open until temperature inside the refrigerator has reached the steady state condition with ambient temperature (43°C). As per manufacturer's recommendation, 96.34 g of Refrigerant was charged in the both refrigerator for conducting tests. The actual refrigeration capacity and COP of the refrigerator were calculated as per the procedure. The energy consumption of the compressor was measured by energy meters. All the experimental observations were made after attaining the steady state conditions (4h).

The cycling running tests were carried out at 32ºC ambient temperature condition. Hence, in the present study, performance comparison of domestic refrigerator is using

Table - 1: Properties of Refrigerants

Code	**R134a**	**R290**	**R600a**
GWP (100yr)	1300	20	20
ODP	0	0	0
Hazard to life group classification	6	5b	5b
Explosive limits in air % by volume	Non flammable	2.3-7.3	1.8-8.4
Latent heat (kJ/kg)	216.87	423.33	364.25
Critical pressure (mPa)	4.06	4.25	3.64
Critical temperature (ºC)	101.1	96.7	134.7
Boiling point (ºC)@1101.25Kpa	-26.1	-42.07	-11.73
Molecular Weight	102.03	44.8	55.2
Chemical Formula	CH_2FCF_3	C_3H_8 (Propane)	C_4H_{10} (Isobutene)

HFC134a and HFC134a/HC refrigerant mixture. Temperature at different locations were recorded every one minute intervals. Pressure at compressor suction and discharge was measured every one minute intervals. The power consumption of the refrigerator during continuous running tests was measured after attaining the steady state condition at ambient temperature 32°C. The energy consumption per day during cycling running tests was measured after 24 h by using a digital energy meter. The measured values were used to study the performance characteristics of the refrigerator

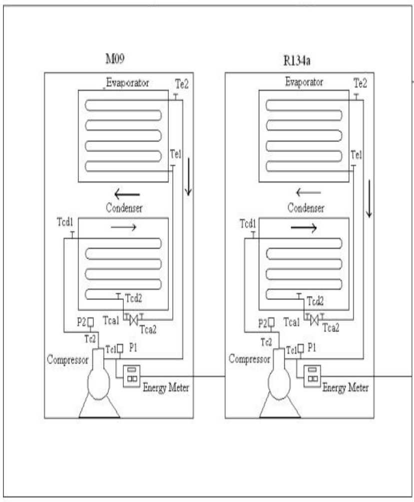

Figure - 1: Schematic diagram of the test unit and apparatus.

3. RESULTS AND DISCUSSION

Experimental results obtained for continuous running test with different compartments air temperature settings at 43ºC ambient temperature are discussed in this section. The various performance parameters obtained from the experimentation are plotted in graphs

3.1. Pull down characteristics

Pull-down time is the time required to reduce the air temperature inside the refrigerator from ambient condition(43°C) to the desired freezer, cabin, and crisper air temperatures of -15°C,4°C,7°Cand 13°C in the freezer, chiller, cabin and crisper respectively , according to IS1476(part1)[1].

About 115min was required to reach the required freezer temperature (-15°C) for M09. It is shown in [Figure 1]. 152min was required to reach the required chiller temperature (4°C) for M09. It is shown in [Figure 2]. 154min was required to reach the required Food temperature (7°C) for M09. It is shown in [Figure 3]. 163min was required to reach the required crisper temperature (13°C) for M09. It is shown in Figure 4.

A reduction in pull down time percentage in the refrigerator Freezer, chiller, Food, Crisper was observed to be about 24.34%, 11.11%, 1.190%, and 7.90 % for M09 system. The Pull down time was reduced, respectively compared to R134a due to its high latent heat of vaporization

Table -2: Compartment Air temperature Reduction Pull down time

Compartment	IS1476 temperature (°C)	R134a	M09	Reduction Pull down time (%)
Freezer	-15	152	115	24.34
Chiller	4	171	152	11.11
Food	7	157	154	1.190
crisper	13	177	163	7.90

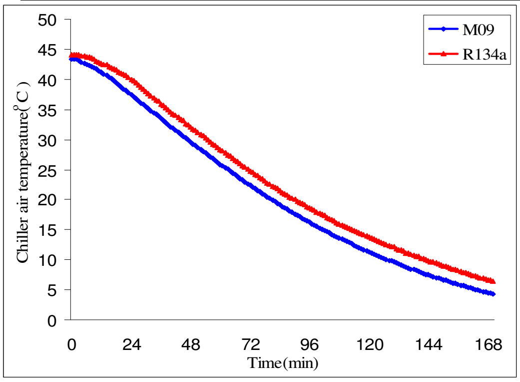

Figure - 1: Freezer compartment comparison (R134aVsM09).

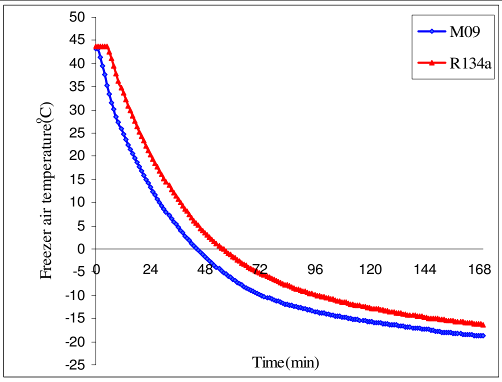

Figure - 2: Chiller compartment comparison (R134aVsM09).

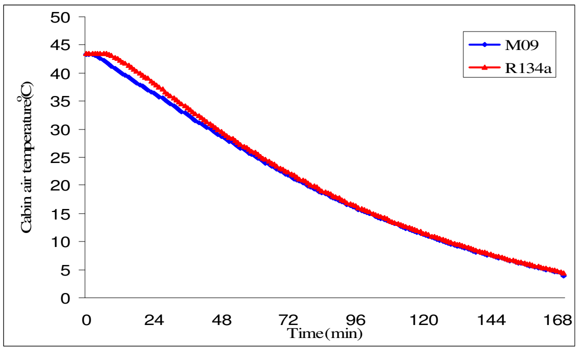

Figure - 3: Cabin compartment comparison (R134a Vs M09).

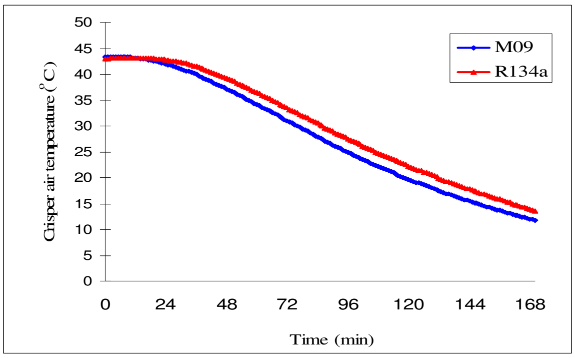

Figure - 4: Crisper compartment comparison (R134a Vs M09).

2. Performance characteristics

The M09 compressor discharge temperature is slightly higher than R134a due to its higher specific heat ratio (Figure 7) and evaporator inlet temperature is lower than R134a due to its high latent heat of vaporization (Figure 5). The M09 mixture system shows 8.69 % improvement in COP than R134a system. It was shown in (Figure 8).

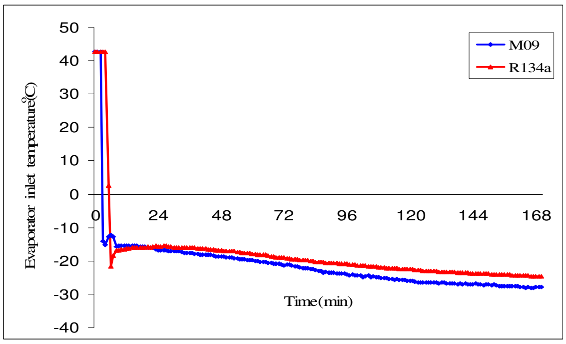

Figure - 5: Variation of evaporator inlet temp vs time at 43°C ambient.

The M09 system energy consumption was 2 to 3% higher than R134a system.ButM09 system pull down time was 30 minutes shorter than R134a system due to its high latent heat of vaporization. During the pull down, M09 system energy consumption was 0.11789kW, R134a system energy consumption was 0.141538kW. It was shown in figure 9.

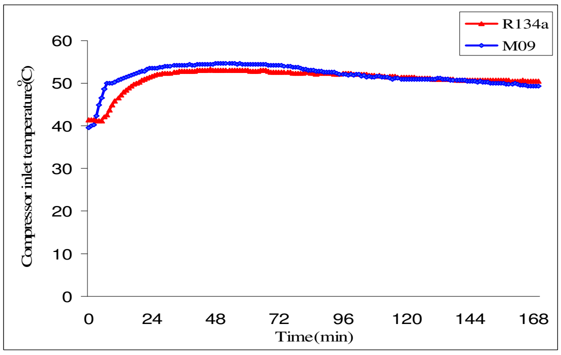

Figure – 6: Variation of compressor inlet temp vs time at 43°C ambient.

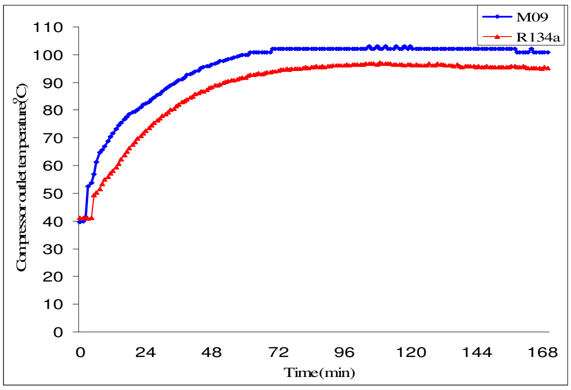

Figure – 7: Variation of compressor outlet temp Vs time AT 43°C ambient.

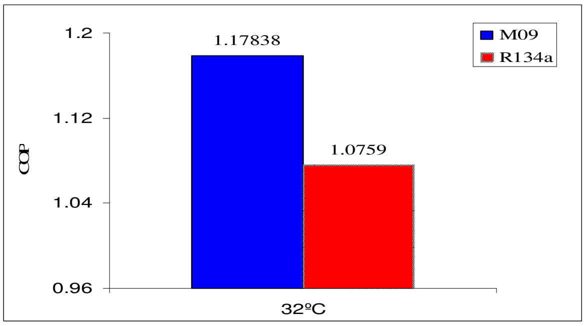

Figure - 8: Comparison of Actual COP.

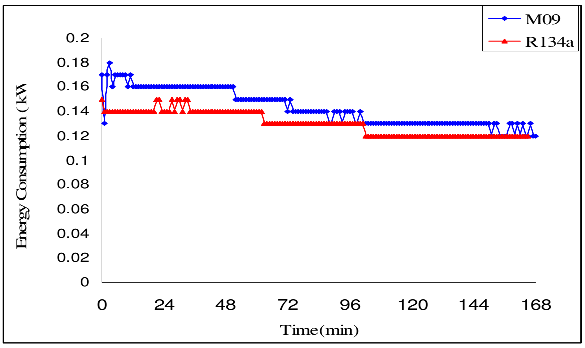

Figure - 9: Comparison of energy consumption.

3. Air flow analysis:

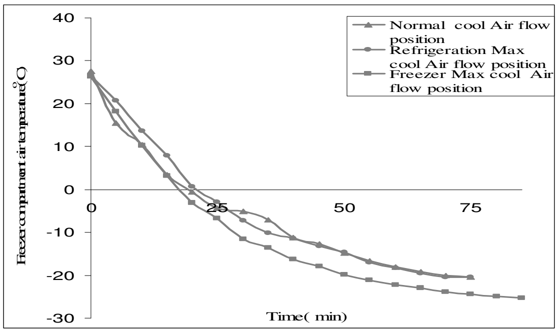

Figure - 10: Comparison of air flow position in freezer compartment.

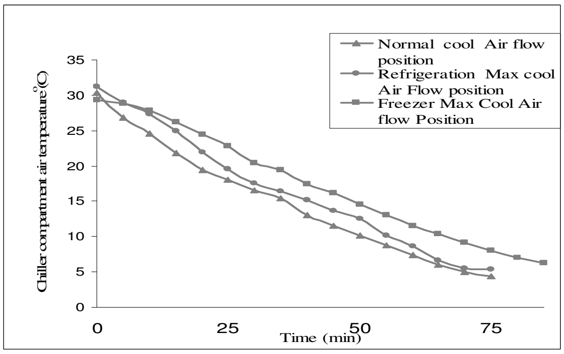

Figure – 11: Comparison of air flow position in chiller compartment.

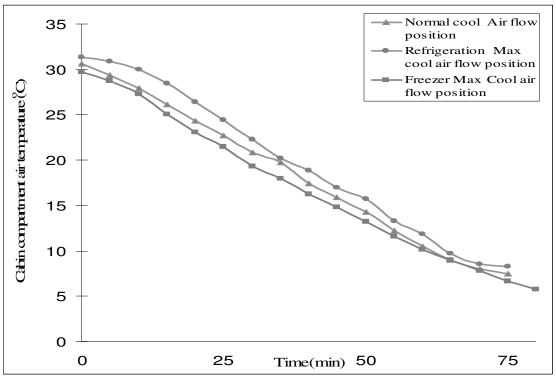

Figure - 12: Comparison of air flow position in cabincompartment.

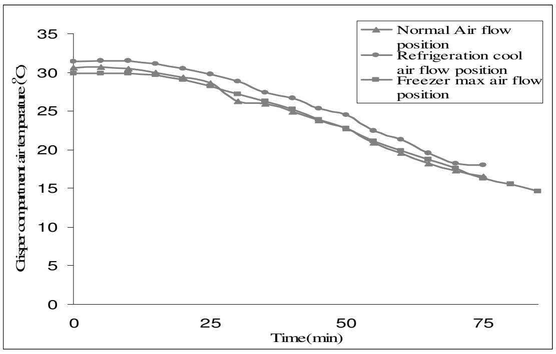

Figure - 13: Comparison of air flow position in crisper compartment.

The comparison of Freezer air temperature with time of air flow position changes for M09 is shown in figure 10. The Freezer Max cool air flow position result is better compared to other damper air cool position. The result showed that freezer compartment air temperature in Freezer max air cool, Refrigeration max air cool, Normal air cool by about -24.4°C -20.4°C and -20.35°C, respectively.

The comparison of Chiller air temperature with time of air flow position changes for M09 is shown in figure 11. The Normal cool air flow position result is better compared to other damper air cool position. The result showed that Chiller compartment air temperature in Freezer max air cool, Refrigeration max air cool, Normal air cool by about 6.4°C 5.4°C and 4.4°C, respectively.

The comparison of Cabin air temperature with time of air flow position changes for M09 is shown in figure 12. The Freezer max cool air flow position result is better compared to other damper air cool position. The result showed that Cabin compartment air temperature in Freezer max air cool, Normal air cool, Refrigeration max air cool by about 5.7°C 7°C, 43°C and 8.24°C respectively.

Table - 3: Comparing R134a with M09 result during ON Cycle.

Temperature (°C)	R134a	M09
Eva in	-27.00	-29.40
Eva out	-20.90	-26.80
Com in	39.30	35.70
Com out	68.80	73.60
Conden in	62.30	65.70
Conden out	45.90	44.50
Capillary out	-7.15	-17.40
Freezer(supply)	-17.40	-16.20
Freezer (centre)	-17.60	-15.20
Chiller	4.46	2.09
Food storage(cabi)	4.57	4.42
Food storage(cab2)	5.33	5.31
Food storage(CAB3)	4.20	5.17
crisper	9.86	12.40
I(Ampere)	0.68	0.70
Per on cycle time(min)	17	12
Per 6 hours on cycle	7(times)	10 (times)
Per 6 hours off cycle	7(times)	10(times)
Refrigeration capacity (kW)	0.38327	0.44993
Comprssor consume power (kW)	0.35294	0.3818
Actual COP	1.0759	1.17838
Energy consumption kWh/day	1.040	1.013

The comparison of Crisper air temperature with time of air flow position changes for M09 is shown in figure 13. The Freezer max cool air flow position result is better compared to other damper air cool position. The result showed that Crisper compartment air temperature in Freezer max air cool, Normal air cool ,Refrigeration max air cool by about 14°C 16°C and 18°C, respectively. The M09 result was compared with R134a and tabulated in table 2.The air flow position comparison was tabulated in table 3.

Table - 4: Air flow position comparison

M09 system	Refrigeration Max Cool air flow position	Normal Cool Air flow position	Freezer Max Cool air flow position
Cut in time	13(min)	12(min)	22(min)
Cut off time	38(min)	45 (min)	56(min)
Evaporator inlet	-30.8°C	-29.8ºC	-33.9°C

4. CONCLUSION

The behavior of M09 refrigerant mixture with mineral oil as the lubricant to the compressor and HFC134a has been experimentally analyzed in a domestic refrigerator and following conclusions are made.

The temperature variation along the evaporator coil was less than 2.7°C.This shows that temperature glide due to zeotropic nature of the refrigerant does not influence much on the uniformity in evaporator coil temperature.

The M09 mixture cools the system 6 minutes faster than the HFC134a due to its better heat transfer characteristics.

The reduction in pull down time in the Freezer, chiller, Food, and Crisper compartment of M09 system are 24.34%, 11.11%, 1.91%, and 7.90 % respectively.

The energy consumption of M09 system was 2.1%lesser than HFC134a system.

The M09 mixture shows 8.69% improvement in COP than HFC134a.

The OFF cycle time for the Freezer max Cool airflow position is larger than other positions and hence the system performance will be better than other air flow position.

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