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EXPERIMENTAL STUDY OF ALTERNATIVE REFRIGERANTS TO REPLACE R134a IN A DOMESTIC REFRIGERATOR

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Abstract

This paper explores an experimental investigation of an alternative eco-friendly refrigerant for R134a with a better Coefficient Of Performance (COP), reduced Global Warming Potential (GWP) and Ozone Depletion Potential(ODP). This investigation has been accessed using a hydrocarbon refrigerant mixture composing of R32/R600a/R290 in the ratio of 70:5:25 by weight. The performance characteristics of the domestic refrigerator were predicted using continuous running tests under different ambient temperatures and cyclic running (On/Off) tests at the fixed temperatures i.e., evaporation temperature (-5˚C) and condensation temperature (30˚C). The obtained results showed that the hydrocarbon mixture has lower values of energy consumption; pull down time and ON time ratio also higher Coefficient of Performance (COP). Thus, the performance of the alternate refrigerant derives the better choice than R134a.

Keywords**:** Domestic refrigerator, Alternative refrigerant, R32, R600a, R290, R134a

1. Introduction

Recently, The Ozone Depleting Potential (ODP) and Global Warming potential(GWP) have become the most important criteria in the development of new refrigerants apart from the refrigerant CFCs and HCFCs, both of which have high ODP and GWP due to their contribution to ozone layer depletion and global warming(Dalkilic et al,2010). Results from researchers show that the ozone layer is being depleted due to the presence of chlorine in the stratosphere. The general consensus for the cause of this that CFCs and HCFCs are large class of chlorine containing chemicals, which migrate to react with ozone. This leads to the strict prohibition of

CFCs. The R134a was the first chlorine-free refrigerant discovered (Bolaji,2010). R134a is used nowadays as the working fluid in domestic refrigerators. But it was found that the R134a increasing significantly to the world's greenhouse warming problem. This caused scientists to investigate more environmentally friendly refrigerants than HFC refrigerants for the protection of the environment such as hydrocarbon mixtures as working fluid in refrigeration and air-conditioning systems. The possibility of using hydrocarbon mixtures as working fluid to replace R134a in domestic refrigerators has been evaluated through the simulation analysis. This simulation concludes that the hydrocarbon refrigerants offer desirable environmental requirements i.e., zero ODP and approximately zero GWP (Fatouh et al ,2006). A hydrocarbon blend of difluoromethane (R32), propane (R290) and iso-butane (R600a) is recommended to avoid the stratospheric ozone depletion. The presence of R600a in the mixture is miscible with both mineral oil and synthetic lubricants (Mohanraj et al,2009).The hydrocarbon mixture (R290 and R600a) in the ratio 45.2:54.8 by weight is investigated in the domestic refrigerator in which the COP is improved upto 3.6% and also reduce the indirect global warming due to its higher energy efficiency (Mohanraj et al,2009). The propane/iso-butane mixture at 0.6 mass fraction used as the refrigerant has a 3-4% higher energy efficiency and faster cooling rate. (He et al,2014).The energy analysis using Taguchi method indicates that the charge amount required was 50g which brings economic advantages and also reduces the risk of flammability of the hydrocarbon refrigerant. The amount of total energy destruction in optimum condition is 45.05% of the base refrigerator one (Joybari et al,2013). Researches on R290 and R290/R600a for substituting R134a in a large capacity chest freezer were done. This work concluded that the data of power consumption of R290 is lower by 26.7% and its charging amount is lesser than that of R134a.The COP of R290 is lower by about 4.7% than that of R600a, so that the working fluid R290/R600a in an appropriate proportion can improve the energy conversion effect. Further, this hydrocarbon mixture has an elevated effect on energy conservation when a specialized compressor is designed (Wongwises et al,2005).

In the present work, the problem of R134a is identified from environmental site and the alternative refrigerants are selected. Then, their mass flow ratio are mixed and a better refrigerant is chosen with better mixing ratio. Thereby, the COP of the alternate refrigerant and R134a are compared. Hence, the the main objective is to select an alternate refrigerant with an increased Coefficient Of Performance(COP) and to reduce Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) hydrocarbon mixture R32/R600a/R290 in the ratio of 70:5:25 by weight.

2. Experimental Methodology

The first step is to study the alternative refrigerant to replace R134a in a domestic refrigerator. The details of the experiment setup is shown in Table-1

Table 1 Details of Experimental Set-up

SI NO	Description	Dimension/Range
1	Refrigerator Capacity	200 litres
2	Capillary Tube	0.031mm φ
3	Compound Gauge	-30-220psi
4	Pressure guage	0-300 psi
5	Vaccum Pump	-30PSIG
6	R32/R600a/R290	100gm

The R134a domestic refrigerator setup consist of a hermatically sealed compressor ,natural convection air cooled condenser having a cooling capacity level of 5.67KW/hr, an evaporator and copper capillary tube whose schematic diagram and photographic view of the experimental set up is given in the fig 1 and fig 2.Sensor is attached at the inlet and outlet of compressor, condenser and evaporator. Pressure gauge is attached at the compressor inlet and outlet. Compound gauge is fitted at the condenser outlet. Evacuation of moisture takes place with the help of service port service port .Vaccum pump is used for evacuation and through the charging system refrigerant was filled in the refrigeration system. Properties of R32/R600a/R290 refrigerant from ASHRAE handbook are given in the Table 2.

Table 2 Properties of R32/R600a/R290

Refrigerant	R32	R600a	R290
Safety level	A1	A1	A1
Boiling point	-52^0C	-11^0C	-41^0C
T_{con}	78.1^0C	137.7^0C	66^0C
P_{cond}	5.78 bar	3.78 bar	3.62bar
ODP	0	0	0
GWP	715	-20	-20
COP	2.11	1.99	2.01

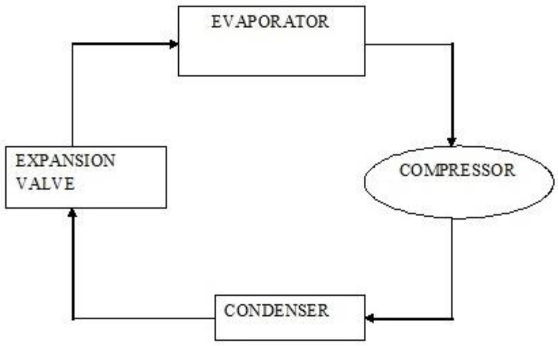

Figure 1 Schematic diagram of the Experimental setup

Figure 2 Photographic View of the Experimental setup

2.1 Experimental Procedure

• As a first step, R-134a is used as a working fluid at room temperature of 32^0C. Pressure and temperature in the inlet and outlet of the compressor, condenser pressure and temperature, evaporator outlet temperature are monitored in every one hour. The Compound pressure gauge and temperature sensors are mounted on the both ends of the compressor and condenser to measure the pressure and temperature of the refrigerant respectively. Finally COP and Mass flow rate is evaluated for the working fluid R134a.

• Then working fluid is released to the ambient and it can be fully evacuated by using vaccum pump running for three hours.

• R32/R600a/R290's are mixed in the proportions of 70%/5%/25% used as refrigerant in the refrigerator.

• The Same procedures are repeated to calculate the COP and Mass flow rate for those mixtures of gases.

3. RESULTS AND DISCUSSION

The assumptions used in the R134a domestic refrigerator are

- Steady state condition.
- No pressure drop through the pipe line in the refrigerator.
- No sub cooling and super heating takes place.
- No heat losess and no heat gain from or to the system.

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Experimental results for COP and Mass flow rate are determined using REFPROP software are shown in Table 3. The various equations used for calculating the parameters under the study are given below

Coefficient of Performance (COP), Mass flow rate, cooling capacity is calculated using some given values.

COP is ratio between Refrigeration effect and work done.

Refrigeration effect = h_1-$h_{4,}$

h_1 is compressor side enthalpy.

h_4 –expansion enthalpy.

$$\text{Work done} = (h_2 - h_1)$$

h_2 – compressor enthalpy.

$$COP = (h_1 - h_4) / (h_2 - h_1)$$

Mass flow rate is ratio between cooling capacity and refrigeration effect.

$$\text{Capacity} = \text{mass flow rate} * (h_{fg})$$

Capacity = 5.67 kW.

h_{fg} – is vapour enthalpy.

Super-heated vapour refrigerant at compressor enthalpy exit (h_2)

$$h_2 = h_1 + (h_{2,is} - h_1) / (\eta_{is,com})$$

Where,

$\eta_{is, com}$ is the isentropic compressor efficiency.

$h_{2\ is}$ the superheated vapour enthalpy at compressor exit.

Table 3. COP and Mass flow rate of (R32/R600a/R290) using Refprop Software

Refrigerants	Mixing ratios	COP	Mass flow rate (kg/s)
R32/R600a/R290	45/5/50	1.90	0.0303
R32/R600a/R290	35/9/56	2.01	0.0286
R32/R600a/R290	30/10/60	1.91	0.0299
R32/R600a/R290	60/5/35	2.01	0.0217
R32/R600a/R290	50/6/44	1.98	0.0203
R32/R600a/R290	65/4/21	2.03	0.0213
R32/R600a/R290	70/5/25	2.21	0.0311
R32/R600a/R290	45/10/45	2.07	0.0295
R32/R600a/R290	50/5/45	1.33	0.0219
R32/R600a/R290	44/6/64	1.93	0.0301
R32/R600a/R290	30/6/64	2.08	0.0233
R32/R600a/R290	72/8/20	1.73	0.0212
R32/R600a/R290	63/7/30	2.04	0.0242
R32/R600a/R290	20/7/73	2.02	0.0227

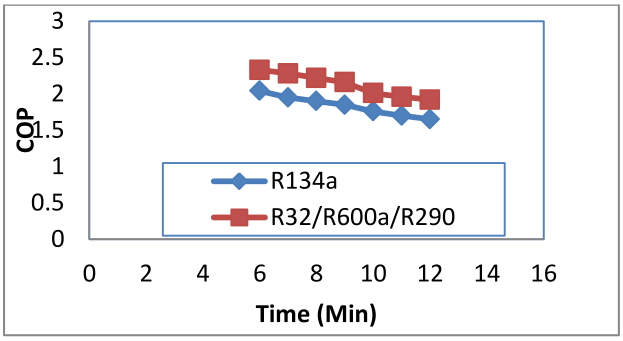

Figure 3 Time vs COP in Half loading condition

Figure 3 shows that the variation of Cop with time in half loading ON condition The pressure and temperature at the suction and discharge of the compressor and that of condenser are measured under half loading condition by switching the refrigerator on. COP decreases with increases in time due to suction pressure and temperature decreases in the compressor i.e, work done in the compressor decrease..R32/R600a/R290 refrigerant mixture has high COP compared with R134a.

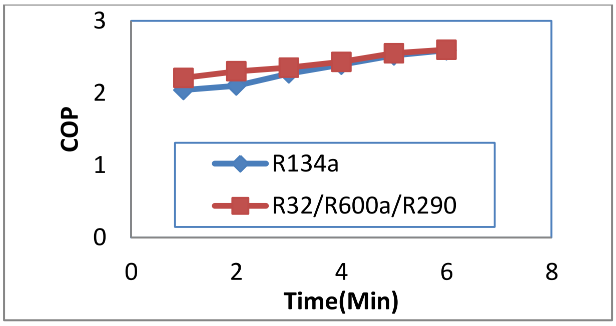

Figure 4 Time vs COP in full loading condition.

Figure 4 shows that the Variation of COP with time in Full loading condition. The pressure and temperature at the suction and discharge of the compressor and that of condenser are measured under loading condition by switching the refrigerator on. COP increases with increase in time due suction pressure and temperature increases in the compressor i.e,work done in the compressor increases.

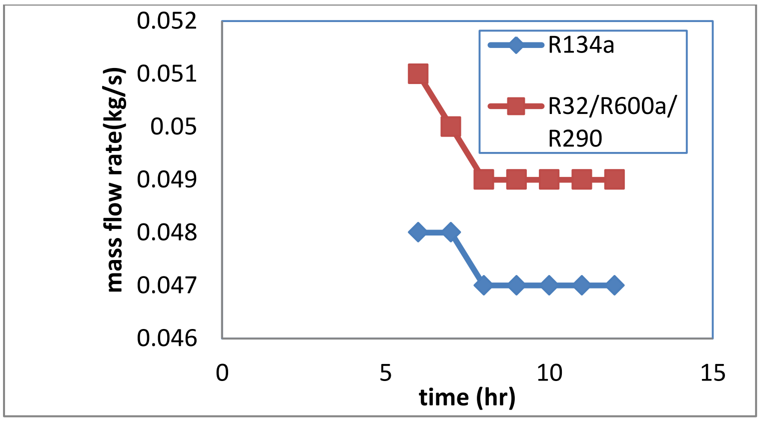

Figure 5Time vs COP loading ON condition

The mass flow rate of the R134a refrigerant measured at different time intervals by switching the refrigerator on. Figure 5 shows that the Variation of mass flow rate with time. Mass flow rate decreases with increases in time, after that it remains constant. Initially Refrigerant takes more time to flow through the compressor.

4. CONCLUSION

The problem of R134a refrigerant is identified from the environmental site. An alternative refrigerant is chosen with better COP and is compared with R134a. The mass flow rate and COP of the chosen refrigerant is calculated and is compared with R134a.

- Mass concentration ratio is (70/5/25) mixer time that COP and Mass flow rate calculated.
- Condensation temperature is fixed (33 C) and evaporator temperature is also fixed (-5 C) that time calculated COP and Mass flow rate.
- R134a at unloading ON condition time, the COP and mass flow rate were lower than (R32/R600a/R290).
- Using (R32/R600a/R290) at loading ON condition time, the COP and mass flow rate values are higher than R134a.
- (R32/R600a/R290) is starting cooling process lower than R134a.
- Mixing refrigerants GWP (global warming potential) is lower than R134a.

Nomenclature

c specific heat (kJ/kg k)

C- Clearance ratio

COP coefficient of performance

h specific enthalpy (kJ/kg)

m mass flow rate (kg/s)

n specific heat ratio

N compressor speed (rpm)

P power (kW)

Q heat transfer rate (kW)

T - Temperature (^{o}C)

T_{cond} condenser temperature(^{o}C)

P_{cond} condenser pressure(bar)

R134a 1,1,1,1 tetraflouroethane

R32 difluoro methane

R600a isobutene

R290 propane

ODP ozone depletion potential

GWP global warming potential

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