Study of Performance of Binary Mixture of R134a and R161 as a Substitution of R134a in a Domestic Refrigerator

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***Abstract*— In this paper, a detailed study of hydrocarbon refrigerants R134a and R161 is performed. The mixture after the theoretical study at specified temperature range in a domestic refrigerator is proposed as an alternative refrigerant to R134a. Study is performed by considering domestic refrigerator and its working conditions. The temperature range was set between -5°C and 50°C with 5°C sub cooling and 10°C compressor inlet superheating. The composition was selected such that the performance should not vary but the global warming potential must be lowered. The main objective of this study is to replace the existing refrigerant without modification in the existing design. So, this study compares the performance, economical and environmental aspects of existing R134a and mixture of R134a/R161.**

Keywords—COP, Refrigerant, GWP, ODP, Montreal protocol and Kyoto ptrotocol.

I. Introduction

As we see the brief history of refrigerants, no refrigerant has made its firm position in the industry of refrigerant. The history starts with ether and now hydrocarbons are used. The major concern about the hydrocarbons is their flammability, global warming potential and ozone depletion potential. According to Montreal and Kyoto protocol the use of halons, chloroflourocarbons was banned serially.(John T. McMullan). And now the objective is to phase out the HCFCs also. So in order to achieve this objective there is a need of finding out the alternatives. R134a is a good alternative for the existing refrigerants as it is having 0 ODP. But the GWP value is very high (Wongwise et. al). So though the refrigerant is performing well with systems running on VCC it is lacking in full filling environmental requirements.

In recent years, the study was performed for proposing the alternate refrigerants by using number of refrigerants like R290a, R600a, HFO1234yf, R152a, R161 etc. For example S. J. Sekhar et. al (2005) studied the performance of HFC134a/HC600a/HC290 mixture as a substitution for R12. Sad Jarall (2012) performed experiments by using HFO1234yf as a drop in substitute for existing R134a in a rotary compressor operated refrigeration system. And concluded with the results that states HFO1234yf has lower COP, refrigeration capacity but gives higher evaporation and convection heat transfer coefficients than R134a. A. S. Dalkilic et. al. (2010) compared the performances of various alternative refrigerants in a vapour compression refrigeration system. Results showed that HC290/HC600a (40/60 by wt.%) and HC290/HC1270 (20/80 by wt.%) are found to be the most suitable alternatives among the tested refrigerants for R12 and R22 respectively. Jianyong Chen et. al. (2008) proposed a new refrigeration cycle for residential air conditioning system using R32/R134a mixture. Results showed that (30/70 by wt.%) combination can be a strong replacement for R22. M. Wu et. al. (2014) studied the performance of refrigeration system by directly replacing R134a by R161. Results showed that the COP is more in case of R161 when the evaporator temperature is lower and it come closer to COP of R134a when the evaporation temperature rises. Recently, Prof. Zhao Yang et. al. (2015) experiments on flammability of R161 showed that the flammability range of this refrigerant can be reduced combining it with flame suppression inhibitors like

R227ea, R1234ze (E). As flammability of R161 is a major concern in the replacement the last mentioned study contributes much more in this concern. In this paper the mixture of R134a and R161 is studied as a replacement for the R134a in domestic refrigeration system. Its thermodynamic properties and cycle performances are investigated theoretically.

II. THEORY

A. Introduction to the refrigerant mixture and its composition

Before proposing the new binary refrigerant mixture the operating of the domestic refrigerator needs an overlook. A domestic refrigerator generally operates in the moderate working temperature limits. -10°C to 5°C evaporation temperature and 45°C to 60°C condenser temperature. The compressor discharge temperature is obviously more than the condenser temperature. Considering capacity of the refrigerator and sealing provided to the cabin moderate cooling rate is required. So, not much change is required in the case of heat dissipation rate and evaporation rate in the case of new refrigerant. The refrigerant should be environment friendly in case it is leaked from the system. The new mixture is selected to full fill the following requirements:

1. Its GWP should be less than that of R134a
2. Specific refrigeration capacity should be more
3. It should be compatible with existing system without any modifications in the system.
4. The use of the new refrigerant should be economical.

By considering these requirements as objectives this study was performed. Both refrigerants were first examined at different combinations by weight. REFPROP 9.0 routines were used for calculating the refrigerant properties at these different combinations. A simulation program in NETBEANS by using JAVA was constructed for calculation of the cycle performance at various compositions. The simulations of cycle performances for different refrigerant combinations were performed to find out the optimum combination. While calculating the cycle performances following basic assumptions were considered : 1. there are no pressure losses in the system, 2. there are no leakages in the system, 3. overall efficiency of compressor is predefined i. e. 0.51 (Xiao Hong Han et. al. 2012), 4. lubricating oil used and its oil circulation rate is same for both the refrigerants. All the calculations used to obtain the results were taken from the book (Refrigeration and air conditioning third edition by C. P. Arora). After calculating the performance parameters at various combinations finally at the combination of HFC-134a and HFC-161 (60/40 by wt.%) was considered for further study and it was referred as MR1. The results of performance of different combinations were plotted in table 1 and basic thermo-physical properties were listed in table 2. From table 1, it can be observed that at 60/40 (by weight %) combination of these two gases the COP was similar to that of R134a but the specific refrigeration effect was increased by 37% and volumetric refrigeration capacity by 32.6%. The GWP value if we calculate on weight basis comes down to 785 which is far lower than the existing refrigerants GWP value. Further the COP goes on increasing with increasing percentage of R161. But it will not be feasible to use R161 directly as it is inflammable and its lower flammability limit is 3.92% (Prof. Zhao Yang et. al. 2015). So there is a need of mixing it with some moderate amount of R134a.

B. Theoretical cycle performance of MR1 and R134a

The condenser and evaporator temperatures were considered to be constant firstly and then they were varied and different temperature combinations and results were studied. Initially the evaporator temperature was assumed to be -5°C. And the condenser temperature was assumed to be 50°C. subcooling of 5°C at condenser exit and superheating of 10°C at compressor inlet was considered. In later case evaporator temperatures were varied from -10°C to 0°C and similarly condenser temperatures from 45°C -55°C. Each evaporator temperature was matched with every condenser temperature and the results are discussed in the next section. Cycle performances using simulation were checked for both the refrigerants and then compared.

III. RESULT AND DISCUSSIONS

After simulating the cycle performance at specified temperature of evaporator and condenser the obtained results are plotted in Table 3. From the results it was observed that the COP of the cycle increases with increase in evaporator temperature for same condenser temperature. And COP of MR1 is very close to R134a at different operating conditions. Specific and volumetric refrigeration effect also increases with increase in evaporator temperature. The specific refrigeration effect and volumetric refrigeration effect of MR1 were 37% and 32.6 % respectively more than that of R134a. The discharge temperature slightly decreases with increase in evaporator temperature. And it was more than that of R134a in each case. Pressure ratio also follows the same behavior like discharge temperature and goes on decreasing with increase in evaporator temperature. But it was lower in case of MR1 than R134a. So, all the results and discussions clears the picture that R134a can be replaced directly by MR1 in case of domestic refrigerator.

Fig. 1 to Fig. 6 shows the results of comparison between the two refrigerants. Fig. 1 is the comparison of R134a and MR1 on a temperature versus saturation pressure graph. It can be observed that saturation pressure of MR1 at given temperature is more than that of R134a. The pressure of MR1 at lowest temperature is 1.43 times that of R134a and this changes to 1.24 times at highest temperature. Fig. 2 shows the COP variation with evaporator temperature. Results show that COP of both refrigerants do not vary from each other except in one or two cases. Fig. 3 is a comparison of specific refrigeration capacity at different evaporation temperatures. The refrigeration effect is about 1.46 times more than that of R134a. Fig. 4 compares the specific work consumption of compressor for both refrigerants. From fig. 5 it can be observed that the use of MR1 gives higher compressor discharge temperature in each working temperature range. And fig. 6 shows that the pressure ratio of MR1 is slightly lower than that of R134a.

A. Abbreviations and Acronyms

COP - Coefficient of performance
GWP - Global warming potential
ODP - Ozone depletion potential
Re - Specific refrigeration effect
Wc - Compressor work
Rev - Volumetric refrigeration effect
PR - Pressure ratio
mr - mass flow rate of refrigerant
Tdis - compressor discharge temperature
Pe - evaporator pressure
Pc - condenser pressure

B. Equations

Compressor work (Wc) = h2 - h1 (1)
Refrigeration effect (Re) = h1 - h5 (2)
COP = Re / Wc (3)
Refrigerant mass flow rate (mr) = (TR x 3.51 / Re) (4)
Power = mr x Wc (5)
Volumetric refrigeration capacity (Rev) = Re / vs (6)
Pressure Ratio (PR) = P2 / P1 (7)

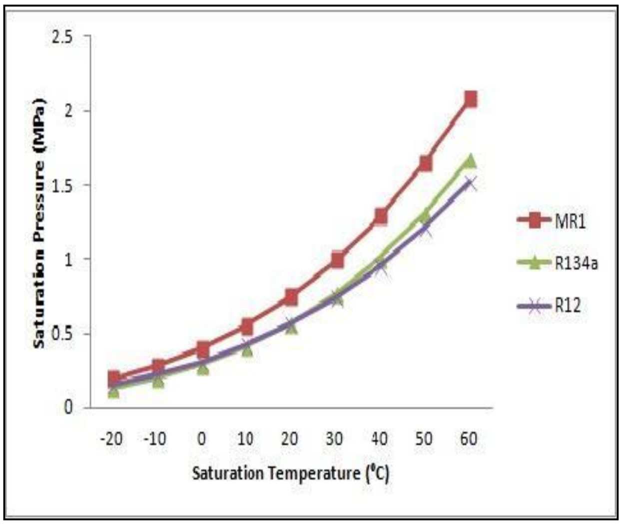

Figure 1 : Saturation pressure vs saturation temperature

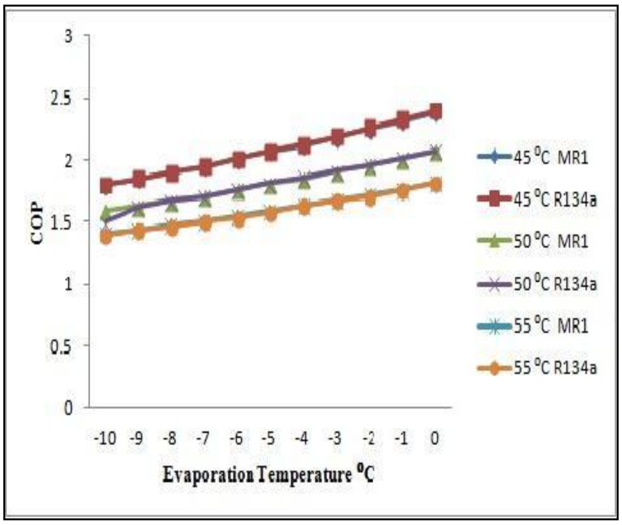

Figure 2 : COP vs evaporation temperatures

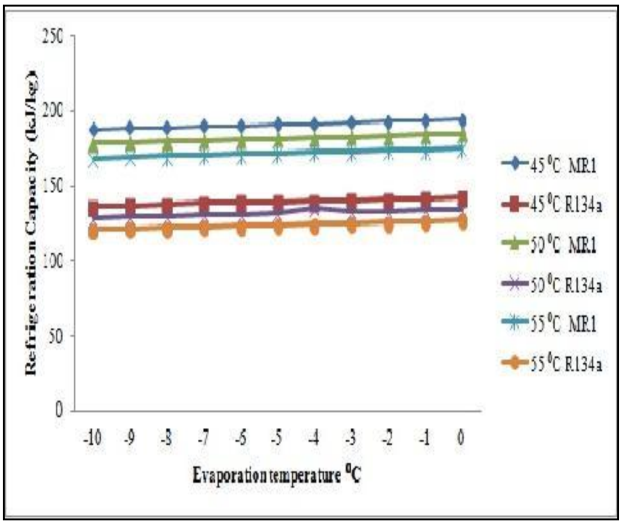

Figure 3 : Refrigeration effect vs evaporation temperature

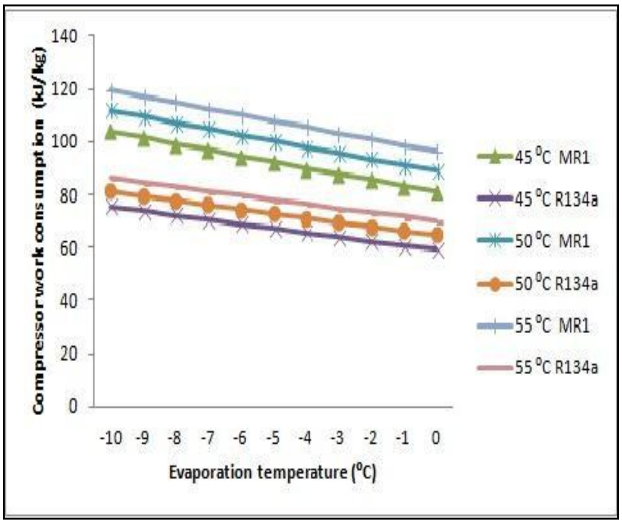

Figure 4: Compressor work vs evaporation temperature

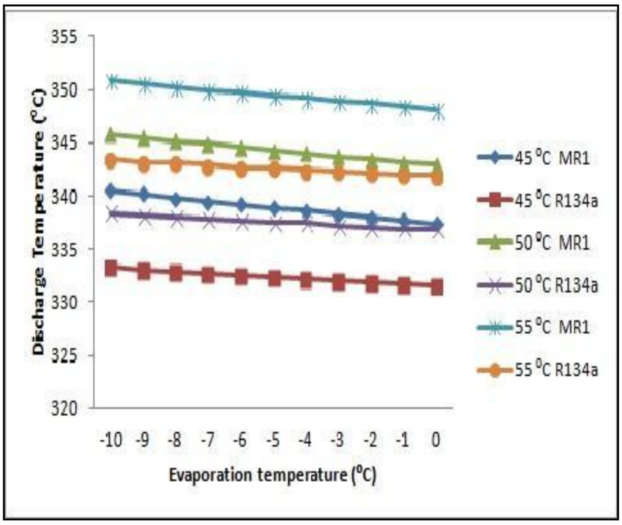

Figure 5 : Discharge temperature vs evaporator temperature

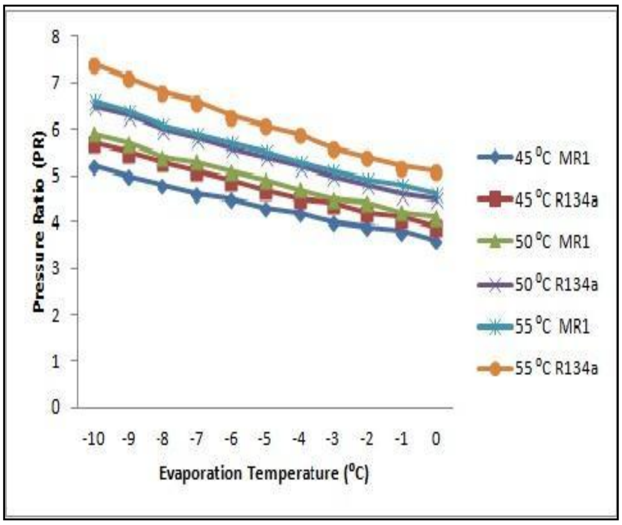

Figure 6 : Pressure ratio vs evaporator temperature

IV. CONCLUSION

In this paper a new substitute in the form of MR1 is proposed for substitution in domestic refrigerator in place of R134a. A mixture of HFC-134a and HFC-161 (60/40 by wt.%) was selected and the theoretical performances were checked by simulation. After studying the results it was observed that MR1 and R134a were having identical COP at each temperature combination. At same COP the specific and volumetric refrigeration effect were 37% and 32.6 % respectively more than that of R134a. Moreover the discharge temperature is more than R134a by 2.01%. Also the pressure ratio the pressure ratio is reduced by 10.2%. As per the environmental performance is concerned there is a considerable drop in GWP value. Thus overall the substitution of MR1 is most preferable as it is system compatible, environmentally sound and also gives superior performance than existing one. This study is purely theoretical and need further practical validation.

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TABLE 1 : CYCLE PERFORMANCES OF REFRIGERANT MIXTURE AT DIFFERENT COMPOSITIONS

R134a	R161	Wc	Re	COP	P	Tdis	Pe	Pc	PR	Rev
1	0	72.8	132.0	1.81	1.9	337.5	0.24	1.31	5.4	1585.6
0.9	0.1	80.0	142.8	1.78	1.9	339.8	0.27	1.43	5.2	1732.3
0.8	0.2	86.8	154.8	1.78	1.9	341.6	0.29	1.53	5.1	1874.5
0.7	0.3	93.4	167.8	1.79	1.9	343.0	0.31	1.60	5.0	2000.4
0.6	0.4	100.2	181.6	1.81	1.9	344.3	0.33	1.64	4.9	2103.9
0.5	0.5	107.2	195.9	1.82	1.9	345.5	0.34	1.68	4.8	2184.3
0.4	0.6	116.7	208.6	1.78	1.9	350.6	0.35	1.70	4.8	2222.2
0.3	0.7	122.1	225.9	1.85	1.8	347.8	0.36	1.71	4.7	2289.4
0.2	0.8	129.7	241.4	1.88	1.8	348.9	0.36	1.72	4.7	2322.8
0.1	0.9	137.5	257.0	1.86	1.8	350.0	0.36	1.72	4.7	2347.4
0	1	145.4	272.9	1.87	1.8	351.1	0.36	1.72	4.6	2366.1

TABLE 2 : THERMO-PHYSICAL PROPERTIES OF R134a , MR1 and R12

Property (Unit)	R12	R161	R134a	MR1
Molecular mass	120.93	48.1	102.03	80.45
Normal boiling point temperature (°C)	-29.8	-36.0	-26.07	-30.04
Critical temperature (°C)	112.0	102.2	101.06	101.51
Critical pressure (MPa)	4.14	4.70	4.06	4.31
ODP	0.82	0	0	0
GWP	8100	12	1300	785

TABLE 3 : THEORETICAL DATA AT DIFFERENT TEMPERATURES

Refrigerant	Tc	Te	COP	Re	Wc	Rev	Tdis	PR	Pe	Pc
MR1	45	-10	1.8	187.7	104.1	1826.8	340.5	5.2	0.19	1.46
	50	-10	1.59	178.3	112	1735.2	345.8	5.9	0.33	1.64
	55	-10	1.41	168.7	119.6	1641.9	350.9	6.6	0.39	1.85
	45	-5	2.07	191	92.4	2212.9	338.9	4.3	0.19	1.46
	50	-5	1.81	181.6	100.2	2103.9	344.3	4.9	0.33	1.64
	55	-5	1.59	172	107.8	1992.8	349.5	5.5	0.39	1.85
	45	0	2.38	194.2	81.3	2662.5	337.4	3.6	0.19	1.46
	50	0	2.07	184.8	89	2533.4	342.9	4.1	0.33	1.64
	55	0	1.81	175.2	96.5	2402.0	348.1	4.6	0.39	1.85
R134a	45	-10	1.8	136.5	75.6	1362.9	333.3	5.7	0.19	1.15
	50	-10	1.5	129	81.3	1288.1	338.4	6.5	0.24	1.31
	55	-10	1.39	121.3	86.7	1211.9	343.4	7.4	0.29	1.48
	45	-5	2.07	139.2	67.3	1675.6	332.4	4.7	0.19	1.15
	50	-5	1.81	132.0	72.8	1585.6	337.5	5.4	0.24	1.31
	55	-5	1.58	124.3	78.2	1493.9	342.6	6.1	0.29	1.48
	45	0	2.4	142.4	59.3	2044.6	331.6	3.9	0.19	1.15
	50	0	2.07	134.9	64.8	1936.9	336.8	4.5	0.24	1.31
	55	0	1.81	127.3	70.2	1827.5	341.9	5.1	0.29	1.48