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An Experimental Study of Alternative Refrigerants

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Abstract – Man has been using refrigeration in his everyday life since ancient times for a variety of purposes. The major changes which have taken place in this field over time include primarily trends in the way cooling conditions are created. After beginning using natural ice and sailing across a range of substances, including ammonia, hydrocarbons, etc., the usage of CFCs and HCFCs has now finally reached the stage. The usage of CFCs and HCFCs however leads to the imminent risks of global warming and ozone depletion. To date, a quantity of study has been carried out to complete the abolition of the usage of these CFCs and HCFCs on both the research and social fronts. Recently, the use of coolant mixtures is an effective way of identifying alternatives for the threatening coolant. R134a was recommended as an alternative coolant for R12, on the advent of the Montreal Protocol. In mineral oil R134a is not miscible. It is advised to use polyol ester (POE) synthetic oils. HC refrigerants, on the other side, have flammable properties and safety requirements that restrict the use in domestic equipment of pure HC refrigerants. Due to the above, it will be crucial for the cooling and air-conditioning industry to convert current R134a coolers into environmentally sound refrigerants. We also experimented with alternate refrigerants in this study.

Keywords – Refrigerants, R134a, Taguchi Approach;

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INTRODUCTION

Refrigeration is described as the mechanism by which a temperature below the surroundings may be achieved and maintained, with the purpose of cooling a product or space to the desired temperature. The protection of perishable food items by store them at low temperatures was one of the most significant applications for Refrigeration. Refrigeration systems are still widely used to provide people with warm relief through air conditioning. The air conditioning is the treatment of air in order, as requested by occupants, process or goods in space, to concurrently monitor its temperature, its moisture quality, smoothness, odor and circulation. The issue of cooling and air conditioning comes from human diet and comfort, and its source goes back decades.

"Refrigerant is the heat transfer fluid used in a refrigeration system which absorbs heat from low temperature and pressure areas during evaporation and releases heat at a higher temperature and pressure during condensation."

LITERATURE REVIEW

Vali Shaika et al. (2017) They said that in order to comply with requirements of Kyoto and Montreal protocols it is necessary to use renewable, environmental safe refrigerants in the development of alternative refrigerants. The environmentally friendly hydrocarbon coolers are inflammable in design and should thus be stopped for healthy purposes by their failure from the device. Refrigerants such as R290, R1270, R600a, R600, R32, R134a and R152a have been theoretically studied as substitutes of R12, R22, and R134a. Thermal fluids R134a.

Mota-Babiloni et al. (2015) They report that EU regulations No.517/2014 phase out refrigerants widely used in cooling and air conditioning systems such as R134a, R404A and R410A as their ODP and GWP values are large as a result of prolonged usage. HFCs are compound R32, R125 R152 and R134a, and compound HFOs are compounded R1234yf. A serious environmental concern has been the greenhouse effect that causes world warming. In order to correct these problems, The

Kyoto Protocol provides a framework for the relief of hydrofluorocarbons (HFCs).

Lontsi et al. (2016) studied the cumulative impact of refrigeration injection/compression cycles suggested for frost formation and cooling. During the device output the cold processing temperature and the effect of temperature on the atmosphere was studied with R290, R152a and R134a as refrigerants.

M. A. Sattar et. al. (2007), The efficiency of the cooler with R600a, R600 and the R290/R600a/R600 blend of ternary refrigerant with the R134a were investigated and contrasted. The impacts on COP, cooling influence, piston energy and the heat-reject ratio have been studied from the evaporator and condenser temperatures. The results suggest that when R600a and R600 were used as cooling agents at the room temperature of 28°C, the compressor consumed 3% and 2% less energy than R134a. The compressor ability, COP and mixture of hydrocarbons prove that hydrocarbons in the home cooler can be used as refrigerants. The COP and other experimental findings indicate that HC is used in the domestic cooling industry as a coolant.

OBJECTIVES

1) To investigate the effects of the various process parameters on use of alternative refrigerants.

2) To develop a comprehensive performance model for refrigeration process.

3) To validate the refrigeration model

METHODOLOGY

In the present work experiments were carried out using Taguchi method-based Design of Experiments (DOE) by considering 4 factors at 3 levels. Although, Taguchi method-based design of experiments was the best well recommended procedure for optimization of the process parameters influencing the system performance, full factorial experiments were also conducted to verify the optimized results obtained by the design of experiments

RESULT AND DISCUSSION

COMPRESSOR TEMPERATURE CONSUMPTION, REFRIGERATION EFFECT AND ACTUAL COP TEST FINDINGS

Performance assessments were conducted in accordance with the procedure discussed in chapter 4 at the 320C atmospheric temperature, varying capillary lengths and separate coolant charges at 3 different temperatures (20C, 50C and 80C). The results are seen in Tables 1 to 5. The lowest energy use is 6,3 m, the optimum capillary size is 5,4 m and the best capillary range is 3,3 m for mixing -1, mixture-2, mixing-3, mixing-4 and mix-5. The precision tests are then calculated in order to perform mix-1, 3.3m, 5.4m, 6.3m, 7.2m capillary longitude, and mix-2, and 5 m, on 3.3m, 5.4m and 6.3m capillary length.

Mixing-1 indicates greater energy usage and mixing-5 shows minimum energy consumption for the five alternate mixtures. It is attributed to a raise in the R134a quality of a mixture that reduces the real amount that the energy intake is lowered. The cooling impact has increased as the HC mixture has a more latent heat vaporization than R134a, since the content of the ternary mixture HC has been increased.

Table 1 Blend-1 experimental findings

Refrigerant	Charge in grams	Lcap	Calorimeter Temperature in ºC	Power in watts	Refrigerationeffect in watts	COP
Mixture-1	96	3.3	2	206	245	1.19
			5	210	290	1.38
			8	213	340	1.6
		4.5	2	199	243	1.22
			5	202	283	1.4
			8	205	335	1.63
		5.4	2	187	236	1.26
			5	191	277	1.45
			8	193	329	1.7
		6.3	2	178	232	1.3
			5	180	274	1.52
			8	183	329	1.8
		7.2	2	187	213	1.14
			2	187	213	1.14
			5	191	264	1.38
			8	194	318	1.64
	106	3.3	2	198	271	1.37
			5	201	313	1.55
			8	204	378	1.85
		4.5	2	186	261	1.4
			5	188	299	1.59
			8	192	364	1.9
		5.4	2	181	255	1.41
			5	184	295	1.6
			8	186	356	1.91
		6.3	2	176	250	1.42
			5	178	289	1.62
			8	180	348	1.93
		7.2	2	178	233	1.31
			5	181	268	1.48
			8	185	330	1.78
	116	3.3	2	212	257	1.21
			5	215	305	1.42
			8	218	365	1.67
		4.5	2	203	250	1.23
			5	206	297	1.44
			8	210	357	1.7
		5.4	2	195	252	1.29
			5	197	298	1.5
			8	200	350	1.75
		6.3	2	183	240	1.31
			5	186	283	1.52
			8	188	340	1.81
		7.2	2	193	226	1.17
			5	196	263	1.34
			8	201	322	1.6

Table 2 Experimental results of mixture-2

Refrigerant	Charge in grams	Lcap in meters	Calorimeter Temperature	Power in watts	Refrigeration effect inwatts	COP
Mixture-2	103	3.3	2	199	241	1.21
			5	203	282	1.39
			8	206	340	1.65
		5.4	2	181	230	1.27
			5	184	272	1.48
			8	187	326	1.74
		6.3	2	188	224	1.19
			5	191	262	1.37
			8	195	314	1.61
	113	3.3	2	192	267	1.39
			5	195	304	1.56
			8	199	374	1.88
		5.4	2	170	247	1.45
			5	172	286	1.66
			8	175	343	1.96
		6.3	2	179	242	1.35
			5	182	277	1.52
			8	185	338	1.83
	123	3.3	2	202	248	1.23
			5	206	293	1.42
			8	210	354	1.69
		5.4	2	177	239	1.35
			5	180	277	1.54
			8	183	331	1.81
		6.3	2	191	193	1.01
			5	193	264	1.37
			8	197	320	1.62

Table 3 Experimental results of mixture-3

Refrigerant	Chargein grams	Lcapin meters	Calorimeter Temperature in ^0C	Powerin watts	Refrigerationeffect in watts	COP
Mixture-3	110	3.3	2	192	234	1.22
			5	196	276	1.41
			8	199	336	1.69
		5.4	2	170	224	1.32
			5	172	263	1.53
			8	175	318	1.82
		6.3	2	177	214	1.21
			5	180	252	1.4
			8	184	306	1.66
	120	3.3	2	185	263	1.42
			5	187	295	1.58
			8	190	361	1.9
		5.4	2	163	241	1.48
			5	166	279	1.68
			8	168	334	1.99
		6.3	2	166	229	1.38
			5	170	262	1.54
			8	173	321	1.86
	130	3.3	2	200	250	1.25
			5	203	294	1.45
			8	207	353	1.71
		5.4	2	173	227	1.31
			5	176	269	1.53
			8	179	328	1.83
		6.3	2	179	222	1.24
			5	182	260	1.43
			8	186	313	1.68

Table 4 Experimental results of mixture-4

Refrigerant	Chargein grams	Lcap in meters	Calorimeter Temperaturein ^0C	Powerin watts	Refrigerationeffect in watts	COP
Mixture-4	119	3.3	2	187	224	1.2
			5	189	261	1.38
			8	193	318	1.65
		5.4	2	165	213	1.29
			5	168	252	1.5
			8	171	301	1.76
		6.3	2	173	206	1.19
			5	176	239	1.36
			8	180	292	1.62
	129	3.3	2	179	247	1.38
			5	181	282	1.56
			8	184	343	1.86
		5.4	2	160	229	1.43
			5	163	267	1.64
			8	165	319	1.93
		6.3	2	164	223	1.36
			5	167	256	1.53
			8	170	312	1.84
	139	3.3	2	193	234	1.21
			5	196	274	1.4
			8	200	330	1.65
		5.4	2	168	218	1.3
			5	170	258	1.52
			8	174	313	1.8
		6.3	2	177	212	1.2
			5	181	250	1.38
			8	184	299	1.63

Table 5 Experimental results of mixture-5

Refrigerant	Chargein grams	Lcap in meters	Calorimeter Temperaturein ^0C	Powerin watts	Refrigerationeffect in watts	COP
Mixture-5	129	3.3	2	179	213	1.19
			5	182	246	1.35
			8	185	303	1.64
		5.4	2	163	207	1.27
			5	165	241	1.46
			8	168	291	1.73
		6.3	2	169	198	1.17
			5	172	225	1.31
			8	177	283	1.6
	139	3.3	2	173	236	1.36
			5	175	266	1.52
			8	179	326	1.82
		5.4	2	158	220	1.39
			5	160	253	1.59
			8	163	306	1.89
		6.3	2	162	214	1.32
			5	164	248	1.51
			8	168	303	1.8
	149	3.3	2	186	223	1.2
			5	189	259	1.37
			8	193	315	1.63
		5.4	2	165	203	1.23
			5	168	227	1.35
			8	171	285	1.67
		6.3	2	174	197	1.13
			5	177	219	1.24
			8	181	272	1.5

Compressor strength and cooling impact are determined from the real COP. Both trials have been replicated and comparison findings have been collected on average. Figures 1 to 6 showed average strength and COPs of various capillaries and varying calories in various mixtures.

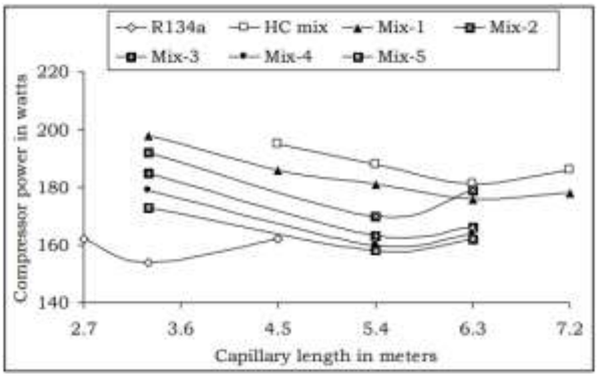

Figure 1 Power variation for the chosen alternative coldants at 20C calorimeter temperature with capillary lengths

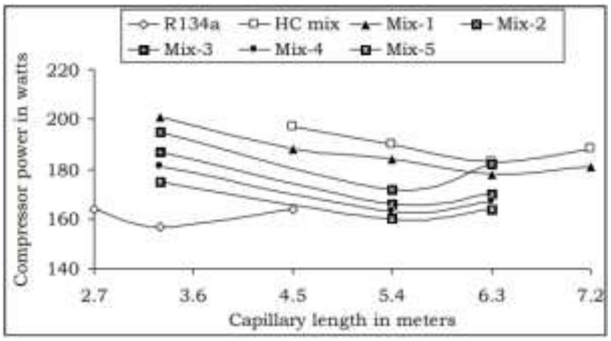

Figure 2 Change of power to capillary length at 50C calorimeter temperature for the alternate refrigerants chosen.

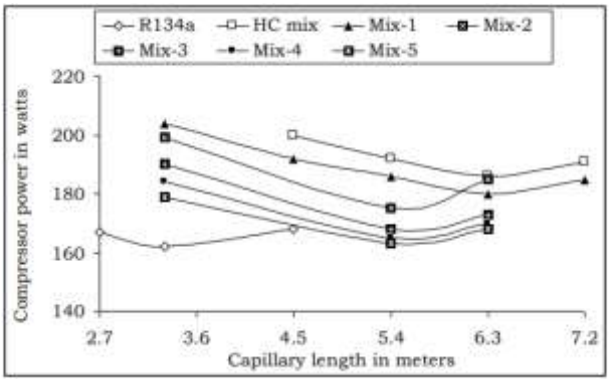

Figure 3 Power variation for the chosen alternative refrigerants at 80C calorimeter temperature with capillary duration

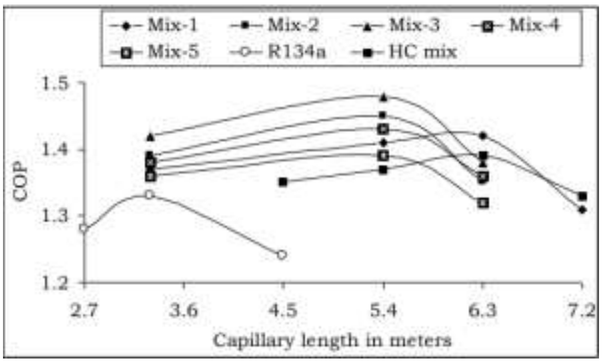

Figure 4 Variability of COP with the capillary distances in 20C calorimeter temperature for select alternate refrigerants

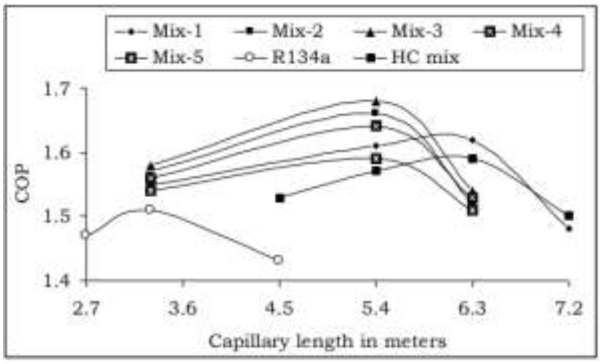

Figure 5 Variation of COP with capillary duration at the 50C calorimeter temperature for the chosen alternative coolants.

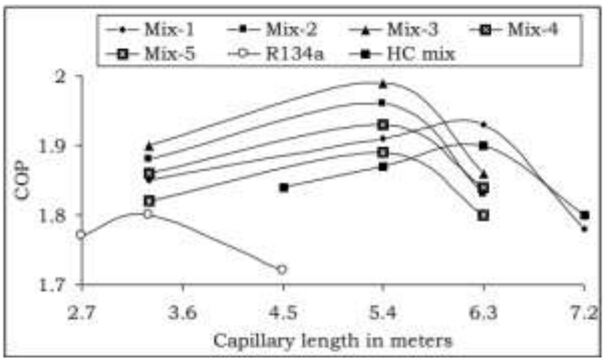

Figure 6 Variable COP for the chosen substitute refrigerant with capillary lengths at 80C calorimeter temperature

The energy demand of the compressor is reduced from mixture-1 to blend-5, as the amount of R134a is increased inside the ternary mixture from Figures 1 to 3. The large particular volume of the HC mixture produces maximum energy intake. Tables 3 to 7 have shown that the influence of cooling decreases by 1 to 5, as latent vapor heat decreases in the ternary blend with declining amount of HC.

The intensity and latent heat of the vaporization of R134a is smaller than the HC blend. For the considered ternary mixtures, specific volumes and latent vaporization heat are greater than R134a and less than the HC mixture. In Figures 1 to 6, the proportion of R134a rises (from blend-1 to blend-5), and COP increases from the blend-1 to blend-3, so COP begins to decrease from the mixture-3, and then from blend-5 to the mixture-3. The reduction in the cooling impact is smaller than the decrease in the compressor energy from mixture1 to mixture3. Later, the reduction in compressor capacity dominates for the mixture-4 and the mixture-5 in cooling impact and thereby reduces COP. Under the working state of the test system as seen in table 7.6 there are unique quantities of the five alternate mixtures.

Table 6 Change in variable volumes for the refrigerants chosen

Refrigerant	R134a	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	HC mix
Specific Volume m3/kg	0.154	0.293	0.273	0.252	0.233	0.214	0.306

TAGUCHI METHOD BASED DESIGN OF EXPERIMENTS (DOE)

The variables and stages of an experiment are systematically designed in typical special, partial factorial (OA) arrangements to identify optimal designs to increase knowledge of the efficiency of the method. It mostly utilizes and simplifies traditional mathematical instruments by defining the collection of sequence guidelines to lay down and analyze effects for the lowest number of experiments.

7.3.1 Factors and its Levels

Table 7 Factors and its levels

Factor	Level 1	Level 2	Level 3
Length of Capillary(m)	3.3	5.4	6.3
Mixture	Mixture-1	Mixture-3	Mixture-5
Refrigerant Charge	m1	m2	m3
Temperature of Calorimeter(0C)	2	5	8

The names of the combinations are as follows.

Mixture-1: “5%R134a/47.5%R600a/47.5%R290”

Mixture-3: “25%R134a/37.5%R600a/37.5%R290”

Mixture-5: “45%R134a/27.5%R600a/27.5%R290”

The equivalent charging volume is measured for each mixture to R134a and is tabled in Table 8. The corresponding load quantity is determined by m2; the m1 and m3 quantities are 10g lower than and higher than those of the m2.

Table 8 Investigated refrigerant load mass for the mixtures

Mixture	Mass of Refrigerant Charge in grams		
	m1	m2	m3
Mixture-1	96	106	116
Mixture-3	110	120	130
Mixture-5	129	139	149

Table 9 Design for Orthogonal array L18 Experimental

Factor	A	B	C	D
Experiment Run	Capillary Length	Mixture	Charge	Calorimeter Temperature
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	2
5	2	2	2	3
6	2	3	3	1
7	3	1	2	1
8	3	2	3	2
9	3	3	1	3
10	1	1	3	3
11	1	2	1	1
12	1	3	2	2
13	2	1	2	3
14	2	2	3	1
15	2	3	1	2
16	3	1	3	2
17	3	2	1	3
18	3	3	2	1

Table 10 S/N value for COP Mean value

Exp.Run	INPUT PARAMETERS				RESPONSE		Mean Value	S/N ratio
	Lcap M	Mixture	Charge grams	Temp. of calorimeter °C	COP			
1	3.3	mix1	m1	2	1.18	1.20	1.19	1.5109
2	3.3	mix3	m2	5	1.56	1.60	1.58	3.973
3	3.3	mix5	m3	8	1.62	1.64	1.63	4.2375
4	5.4	mix1	m1	5	1.44	1.46	1.45	3.227
5	5.4	mix3	m2	8	1.98	2.0	1.99	5.977
6	5.4	mix5	m3	2	1.21	1.25	1.23	1.798
7	6.3	mix1	m2	2	1.41	1.43	1.42	3.0456
8	6.3	mix3	m3	5	1.43	1.43	1.43	3.107
9	6.3	mix5	m1	8	1.58	1.62	1.6	4.082
10	3.3	mix1	m3	8	1.66	1.68	1.67	4.454
11	3.3	mix3	m1	2	1.20	1.24	1.22	1.727
12	3.3	mix5	m2	5	1.51	1.51	1.52	3.636
13	5.4	mix1	m2	8	1.90	1.92	1.91	5.62
14	5.4	mix3	m3	2	1.31	1.31	1.31	2.345
15	5.4	mix5	m1	5	1.45	1.47	1.46	3.287
16	6.3	mix1	m3	5	1.51	1.53	1.52	3.637
17	6.3	mix3	m1	8	1.64	1.68	1.66	4.402
18	6.3	mix5	m2	2	1.31	1.33	1.32	2.411

Table 11 Main effects of the process parameters for mean

Process Parameter	Level	Mean			
		Lcap	Mixture	Charge	Temp. of calorimeter
	L1	1.468	1.526	1.43	1.281
Averagevalue	L2	1.558	1.531	1.623	1.493
	L3	1.491	1.46	1.465	1.743
Main	L2 - L1	0.09	0.005	0.193	0.212
effects	L3 -L2	-0.067	-0.071	-0.158	0.25

Table 12 Key results of the S/N ratio method parameters

Process Parameter	Level	S/N Ratio			
		Lcap	Mixture	Charge	Temp. of calorimeter
	L1	3.2564	3.5824	3.0393	2.1395
Averagevalue	L2	3.709	3.5885	4.1104	3.4778
	L3	3.447	3.2419	3.2630	4.7954
Main	L2 - L1	0.4526	0.0061	1.0711	1.3383
effects	L3 -L2	-0.262	-0.3466	-0.8474	1.3176

Table 13 Response table for means

Level	Lcap	Mixture	Charge	Temp. of calorimeter
1	1.468	1.526	1.43	1.281
2	1.558	1.531	1.623	1.493
3	1.491	1.46	1.465	1.743
Delta	0.09	0.071	0.193	0.462
Rank	3	4	2	1

Lacap (5.4m), mixture3, mass2, calorimeter temperature (80C) dependent on mean is the best setting.

Table 14 Signal to noise response table

Level	Lcap	Mixture	Charge	Temp. of calorimeter
1	3.2564	3.5824	3.0393	2.1395
2	3.709	3.5885	4.1104	3.4778
3	3.447	3.2419	3.2630	4.7954
Delta	0.4526	0.3466	1.0711	2.6559
Rank	3	4	2	1

Ideally set, the temperatures are dependent on Lcap (5.4 m), mixture 3, mass2, calorimeter temperature (80C).

CONCLUSION

The aim of the present study is on developing an eco-friendly refrigerant alternative to R134a that meets the Montreal Protocol, the Kyoto Protocol and the inflammability factors. The ternary mixture of R134a seems to be an appropriate long-range solution for R134a which requires minimal modification in fixed refrigerators with regard to the ecological cooling blend, without an ODP, low GWP and high energy efficiency. A theoretical study for better mixture efficiency is performed using REFPROP 6.0 tools by adjusting the composition of R134a and the optimal mixture composition. The testing was carried out with the R134a and HC mixtures in a vision cooler, using five chosen alternate mixtures to verify the supremacy of the current mixture

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