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Performance Analysis of Vapour Compression Refrigeration Systems Using Hydrofluorocarbon Refrigerants

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Abstract: In this paper, the performances of four ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R125, R134a, R143a and R152a) selected to replace R12 in a vapour compression refrigeration system were investigated experimentally and compared. The performance in term of coefficient of performance (COP), refrigerating capacity (RC), and compressor work (We) were evaluated for the investigated refrigerants at various evaporating and condensing temperatures. The system performance increases as the evaporating temperature increases, but reduces as the condensing temperature increases. The results obtained showed that the investigated refrigerants confirmed that R152a and R134a have approximately the same thermodynamic performances similar to R12 while deviation of R125 and R143a were very large. But the best performance was obtained from the used of R152a in the system. As a result, R152a could be used as a drop-in replacement for R134a in vapour compression refrigeration system. The COP of R152a obtained was higher than those of R12, R125, R134a, R143a. Also, R152a offers the best desirable environmental requirements; zero Ozone Depleting Potential (ODP) and very low Global Warming Potential (GWP).

Key words: Hydro-Fluoro-Carbon, refrigerants, ozone-friendly, performance characteristics, refrigeration system.

1. Introduction

A class of chemical compounds called Chlorofluorocarbon (CFC) refrigerants has been in widespread use since the 1930s in such diverse applications as refrigerants for refrigerating and air-conditioning systems, blowing agents for plastic foams solvents for microelectronic circuitry and dry cleaning sterilants for medical instruments (Bolaji BO, 2005). The linkage of the CFC refrigerants to the destruction of the ozone layer, which has been established recently; is attributable to their exceptional stability because of which they can survive in the atmosphere for decades and ultimately diffusing to the rarefied heights where the stratospheric ozone layer resides (McMullan JT,2002). The inventors of these refrigerants could not have visualized the ravaging effects of the refrigerants on the ozone layer. They intentionally pursued refrigerants with the exceptional stability that was imposed as one of the necessary requirements of the ideal refrigerant they were called upon to invent (Cavallini A, 1996).

The primary requirements of the ideal refrigerant before the discovery of CFC refrigerants were as follow: it should have normal boiling point in the range of -40°C to 0°C; it should be non-toxic; it should be non-flammable; and it should be stable. None of the refrigerants available at that time, including sulphur dioxide, carbon dioxide, ammonia, methyl chloride, and ethyl chloride; could meet any of the requirements. The CFC refrigerants fulfilled all the primary requirements and heralded an unprecedented revolution in the refrigeration and air-conditioning industry (Bhatti, M.S.1999). Today, the litany of the requirements imposed on an ideal refrigerant has increased. The additional primary requirements now include zero Ozone Depletion Potential (ODP) and zero Global Warming Potential (GWP) (Kumar KS, Rajagopal K, 2007 and Park K, Shim Y, Jung D 2009). According to Calm et al. (Calm JM, Wuebbles DJ, Jain AK 1999), the environmental concerns relating to ozone depletion and global warming were not dreamt of when Midgley and associates invented the CFC refrigerants.

A single-fluid Hydrofluorocarbon (HFC) refrigerant, R134a and R152a are the leading replacement for domestic refrigerators. Although the ODP of these are zero, (Table 1).

Table 1.1: Some properties and environmental impacts of selected alternative refrigerants

Refrigerants	Chemical formula	Molecular mass	Boiling point(ºC)	Ozone depletion potential(ODP)	Global warming potential (GWP)
R12	CF_2CL_2	121	-29.8	1	8100
R125	C_2HF_5	120	-48.1	0	2800
R134a	$C_2H_2F_4$	102	-26.1	0	1300
R143a	$C_2H_3F_4$	84	-47.2	0	3800
R152a	$C_2H_4F_2$	66	-24.0	0	140

Sources: ASHRAE, 2001; Bitzer, 2007.

International concern over relatively high global warming potential of R134a has caused some European countries to remove R134a from refrigerator/freezers and abandon it as replacement refrigerant in domestic refrigerator. For this reason, the production and use of R134a will be terminated in the near future (Bolaji, B.O. 2008 and Wongwises S, Chimres N 2005). Therefore, other replacements will be needed that are thermodynamically attractive as R134a. This paper compares the performance of R134a and other two low GWP HFC refrigerants (R32 and R152a) in vapour compression refrigeration system. The performance parameters of the refrigerants were determined by means of theoretical cycle calculation using experimental data.

2. Experimental

2.1 Technical detail of experimental system

The 'UNICOOL' make, vapour compression refrigeration system manufactured by NEELAM ENGG., AGRA helps in understanding basics of a refrigerator. A small heater provided in evaporator simulates heat load. Various measurements like evaporating and condensing pressure and temperature, input to compressor and heater enable the students to calculate power consumption and theoretical and actual COP of the refrigeration system.
The machine consists of following components:

- Hermitically sealed KIRLOSKAR compressor of capacity 1/3 tons which runs on R12 operating between 0 and 55°C
- Air cooled condenser (Free Convection)
- Evaporator with proper insulation and a variable input heater installed inside
- Capillary expansion valve
- Measuring gauges for temperature and pressure at all control points.

2.2 Objective

The vapour compression refrigeration system is an important refrigeration unit of the thermal lab of the department of mechanical engineering of University institute of technology, the constituent college of the Rajiv Gandhi technical university, which controls engineering education in the state of Madhya Pradesh. The vapour compression refrigeration system operates on refrigerant R12 which is most important CFC refrigerant identified for phase out in the country by HFC refrigerant. The system is frequently used for experimentation by graduate and post graduate students of the department. The institute has been one of the few institutes selected for funding for research work under World Bank project TEQIP. A research work was undertaken for finding the most suitable ozone-friendly Hydrofluorocarbon refrigerant for replacing ozone depleting refrigerant R12. In the paper, the performance evaluation of alternative ozone-friendly Hydrofluorocarbon refrigerants in the vapour compression refrigeration system has been done. Then most suitable refrigerant has been selected for replacing harmful refrigerant.

2.3 Replacement

Imminent CFC shortages would threaten the useful life of the appliance of CFC equipment. As the CFC shortages increase, the cost of CFCs will rise, along with the operating costs of the equipment. "Replacement" is the only term and the most effective solution for discontinuing and reducing the CFC emissions from existing appliances. Replacement is the process by which the equipment currently using an ozone depleting refrigerant is made to operate on a non ozone depleting refrigerant, without major effects on the performance of the equipment and without significant modifications or changes for the equipment, ensuring that existing equipment operates until the end of it's economic life. It has been proved by various case studied that retrofitting is economically viable in small scale refrigeration equipment than in large capacity systems.

2.4 Theoretical Analysis and Methodology

A vapour compression refrigeration system is widely used refrigeration method for both domestic and commercial refrigerators. It uses circulating liquid refrigerant as a medium which absorbs heat from the space to be cooled and subsequently rejects that heat elsewhere. Four non-ozone depleting HFC refrigerants (R125, R134a,R143a and R152a) were selected from methane and ethane derivatives and their performances in vapour compression refrigeration system were investigated. The p-h diagram shown in Fig.1 is frequently used in the analysis of vapour compression refrigeration cycle. The Vapour compression refrigeration system is developed to investigate the effect of the evaporating and condensing temperature on the following performance parameters of the of vapour compression refrigeration system: the refrigerating capacity (RC), the compressor work input ($\dot{W}_c$), the coefficient of performance(COP).The required data for the models are:
Specifying the nature of the refrigerant by fixing the physical and thermodynamic properties obtained from ASHRAE (2001).
Fixing the evaporator and condenser temperatures.
Fixing the refrigerant mass flow rate in (kg/s).

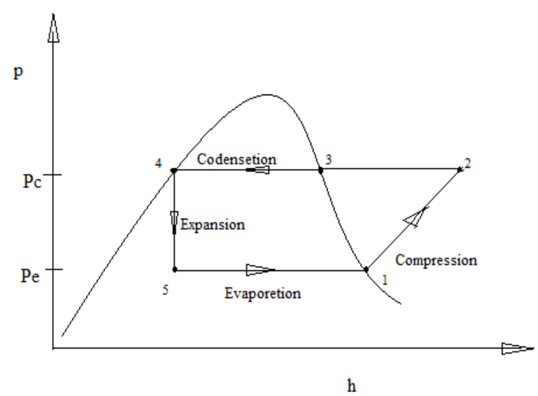

Fig 1: Vapour compression refrigeration cycle on p-h diagram
The p-h diagram is frequently used in the analysis of vapour compression refrigeration cycle and usually consists of the four processes.

Process 1-2 is the compression.
Process 2-4 is the Condensation.
Process 4-5 is the expansion.
Process 5-1 is the evaporation.

3. Methodology

$pv^k = c$
Where
V = Volume

C = Constant
K= Polytropic index

$$p_1 v_1^{k} = p_2 v_2^{k}$$

$$\left(\frac{v_2}{v_1}\right)^{k} = \frac{p_1}{p_2}$$

$$\left(\frac{v_2}{v_1}\right) = \left(\frac{p_1}{p_2}\right)^{\frac{1}{k}}$$

From the ideal gas equation

$$PV=RT$$

$$V= \frac{RT}{P}$$

$$V_1 = \frac{RT_1}{P_1} \text{ and } V_2 = \frac{RT_2}{P_2} \qquad (4)$$

Substituting for V_1 and V_2 in equation (3)

$$\frac{RT_2P_1}{RT_1P_2} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{k}}$$

$$\frac{P_1T_2}{P_2T_1} = \frac{P_1^{\frac{1}{K}}}{P_2^{\frac{1}{K}}}$$

$$\frac{T_2}{T_1} = \frac{P_2\left(P_1^{\frac{1}{K}}\right)}{P_1\left(P_2^{\frac{1}{K}}\right)}$$

$$\frac{T_2}{T_1} = \frac{P_2\left(P_2^{\frac{-1}{K}}\right)}{P_1\left(P_1^{\frac{-1}{K}}\right)}$$

$$\frac{T_2}{T_1} = \frac{P_2^{\left(1-\frac{1}{K}\right)}}{P_1^{\left(1-\frac{1}{K}\right)}}$$

Therefore

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{K-\frac{1}{K}}$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}$$

The polytrophic index (k) is evaluated at T1

$$k = \frac{C_P}{C_V}$$

T1 and T2 are the suction and discharge temperatures.
P1 and P2 are the evaporating and condensing pressures.
C_p = Specific heat capacity at constant pressure.
C_v = Specific heat capacity at constant volume.

The model will estimated at following data :
The compressor discharge T2 and the different enthalpies involved in the cycle.
The compressor work input,

$$W_c = m_r(h_2 - h_1)$$

The heat rejected in the condenser,

$$Q_c = m_r(h_2 - h_1)$$

4. Results and Discussions

4.1 Results

The selected Hydro-fluorocarbon (HFC) refrigerants were evaluated at different condensing and evaporating temperature and the results are as shown below:
Table 4.1 and 4.2: Thermodynamic properties of refrigerants at condensing temperature 40ºC

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	9.5882	-20	1.5070	60	104.44	31.4	3.3261
R125	20.0790	-20	3.3755	58	68.09	20.76	3.2798
R134a	10.1660	-20	1.3273	60	130.14	40.08	3.2470
R143a	18.3140	-20	3.1535	65	111.87	18.03	6.2047
R152a	9.0927	-20	1.2068	80	221.59	50.49	4.3888

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	9.5882	-10	2.1878	57	109.07	25.7	4.2440
R125	20.0790	-10	4.8272	60	73.25	13.96	5.2471
R134a	10.1660	-10	2.0060	58	136.25	33.41	4.0781
R143a	18.3140	-10	4.4823	56	117.5	18.58	6.3240
R152a	9.0927	-10	1.8152	74	228.8	42.87	5.3370

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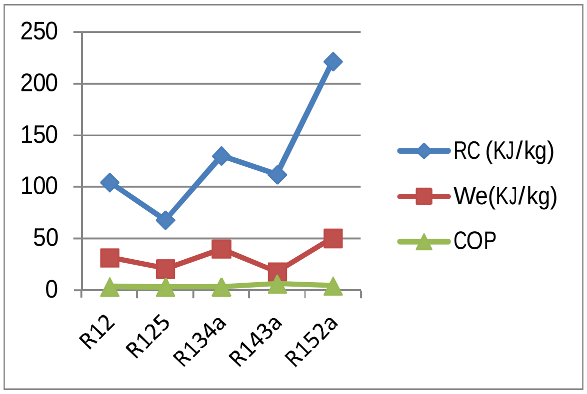

Figure 4.1: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -20 °C and T_c of 40°C.

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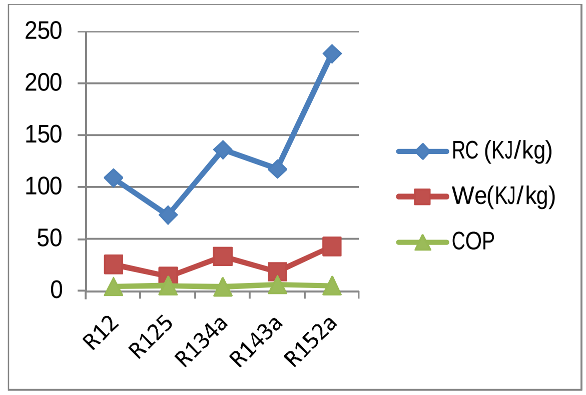

Figure 4.2: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -10 °C and T_c of 40°C.

Table 4.3 and 4.4: Thermodynamic properties of refrigerants at condensing temperature 30ºC

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	7.4365	-20	1.5070	48	114.61	27.97	4.0976
R125	15.6800	-20	3.3755	46	82.84	24.03	3.4474
R134a	7.7020	-20	1.3273	48	144.83	36.14	4.0075
R143a	14.3400	-20	3.1535	58	129.35	23.4	5.5278
R152a	6.8982	-20	1.2068	64	240.14	48	5.0000

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	7.4365	-10	2.1878	44	119.25	22.04	5.4106
R125	5.6800	-10	4.8272	47	88.00	18.83	4.6734
R134a	7.7020	-10	2.0060	46	150.94	29.26	5.1586
R143a	4.3400	-10	4.4823	56	135.38	17.37	7.7939
R152a	6.8982	-10	1.8152	58	247.34	38.9	6.3500

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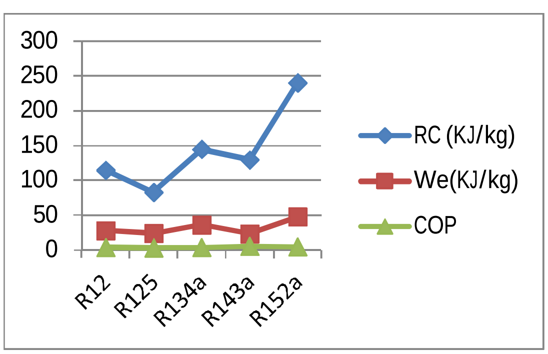

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Figure 4.3: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -20 °C and T_c of 30°C

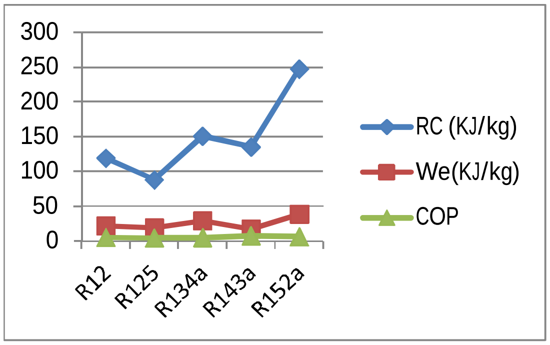

Figure 4.4: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -10 ºC and T_c of 30ºC

Table 4.5 and 4.6: Thermodynamic properties of refrigerants at condensing temperature 20ºC

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	5.6642	-20	1.5070	34	124.51	23.16	5.3821
R125	12.0500	-20	3.3755	34	96.72	22.88	4.0502
R134a	5.7171	-20	1.3273	36	159.08	31.1	5.1151
R143a	11.0520	-20	3.1535	42	145.89	25.67	5.6832
R152a	5.1291	-20	1.2068	48	258.17	39.33	6.5642

Refrigerants	Pe (bar)	Te (ºC)	Pe(bar)	T2 (ºC)	RC (KJ/kg)	We(KJ/kg)	COP
R12	5.6642	-10	2.1878	31	129.15	17.02	7.588
R125	12.0500	-10	4.8272	34	101.88	18.51	5.838
R134a	5.7171	-10	2.0060	32	165.19	23.12	7.145
R143a	11.0520	-10	4.4823	40	157.52	19.6	7.7306
R152a	5.1291	-10	1.8152	40	266.38	30.13	8.8410

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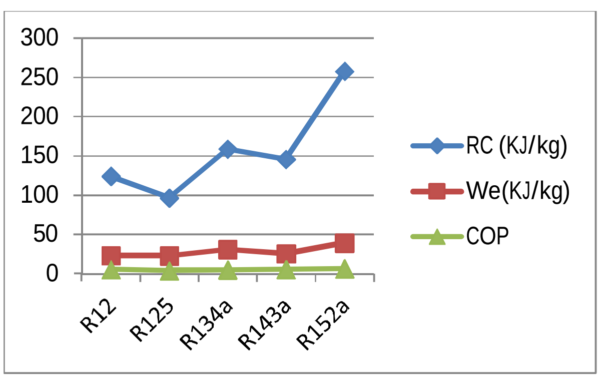

Figure 4.5: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -20 ºC and T_c of 20ºC.

4.2 Discussion

Figure 4.1 to 4.6 show the refrigerating capacity of the selected HFC refrigerants and that of R12. The RC increases as the evaporating temperature increases and also

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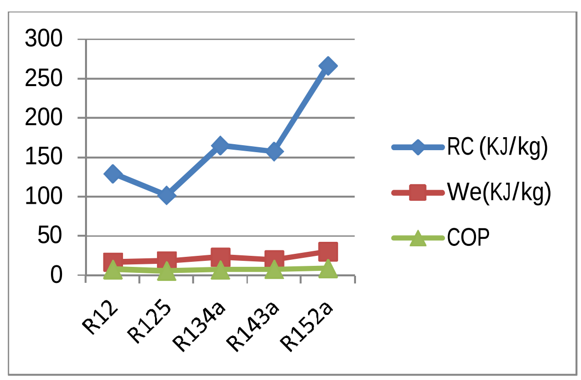

Figure 4.6: The compressor work, refrigerating capacity and coefficient of performance of the refrigerants at T_e of -10 ºC and T_c of 20º.

increases as the condensing temperature reduces. R134a, R152a and R143a have a higher refrigerating capacity than that of R12 for the three condensing temperatures considered, while that of R125 is much lower and the cooling effect of a vapour compression refrigeration system is evaluated by its refrigerating capacity.

Figure 4.1 to 4.6 show the effect of evaporating temperatures on the compressor loads for the three condensing temperatures (40, 30 and 20°C) for R12 and its potential alternative HFC refrigerants in a vapour compression refrigeration system. As shown in these figures, the compressor work increases as the evaporating temperature reduces and increases as condensing temperature increases.
Figure 4.1 to 4.6 show the variation of coefficient of performance (COP) with varying evaporating temperature for three condensing temperatures (40, 30 and 20°C) for R12and its four HFC refrigerants in a vapour compression refrigeration system. As shown in these figures, COP increases as the evaporating temperature increases and it reduces as the condensing temperature increase. Similar trends and variations were obtained for COP of the potential alternative HFC refrigerants for all the cases studied.R134a andR152a shows a slightly lower and .higher COP with average value of 3.9% an 13.2% and that of R12. An average value of 34% lower and 35.2% higher were obtained for R125 and R143a. At a lower evaporating and condensing temperature, the COP ofR143a reduces.
Based on these results, R152a and R134a are better R12alternatives than R125 and R143a because they have higher refrigerating capacity (RC) and coefficient of performance (COP) which are required in a vapour compression refrigeration system, but R134a which is the current leading alternative for R12 in all domestic applications has a relatively high global warming potential (GWP) and has hindered its general acceptance as the ideal alternative refrigerant (Table 1.1). Therefore R152a with lower GWP is recommended for comprehensive evaluation.

5. CONCLUSION AND RECOMMENDATION

R12 that is commonly used as working fluid in vapour compression refrigeration system all over the world is being phased out due to their environmental hazard of ozone depletion. In this research work, the performance of four HFC refrigerants (R125, R134a, R143a and R152a) regarded as R12 alternative in vapour compression refrigeration system were investigated using simulation model. The model was developed to predict the performance of the selected refrigerants based on their coefficient of performance (COP), refrigerating capacity (RC) and the compressor work.
The result obtained showed that R152a and R134a have physical properties and thermodynamic performance similar to R12. R152 has higher coefficient of performance (COP), higher refrigerating capacity than R12, while R134a has a slightly lower COP and higher refrigerating capacity than R12. Due to the high global warming potential (GWP) of R134a, R152 will be preferred as working fluid in vapour compression refrigeration system.

REFERENCES

Bhatti, M.S. (1999). A historical look of clorofluorocarbon refrigerants. ASHRAE Transactions, part 1, 1999.pp.1186-1206

Bolaji, B.O. (2005). CFC refrigerants and stratospheric ozone: past, present and future, In: Environment sustainability and conservation in Nigera, Okoko, E, and Adekunle, V.A.J. (Eds.); Book of reading of Environment conservation and Research Team, chap. 37, pp. 231-239.

Bolaji, B.O. (2008). Investigating the performence of some environment-friendly refrigersants as alternative to R12 in vapour compression refrigeratrion system. PhD. Thesis in the Department of Mechanical Engineering, Federal University of technology, Akure, Nigeria, pp. 150.

Cavallini A, Working fluids for mechanical refrigeration. *International Journal of Refrigeration* 19 (1996) 485-496.

Kumar KS, Rajagopal K, Computational and experimental investigation of low ODP and low GWP HCFC-123 and HC-290 refrigerant mixture alternative to R12, *Energy Conversion and Management* 48 (2007) 3053-3062.

McMullan JT, Refrigeration and the environment issues and strategies for the future, *International Journal of Refrigeration* 25 (2002) 89-99.

Park K, Shim Y, Jung D, Experimental performance of R432A to replace R22 in residential air-conditioners and heat pumps, *Applied Thermal Engineering* 29 (2009) 597-600.

Wongwises S, Chimres N, Experimental study of hydrocarbon mixtures to replace HFC134a in a domestic refrigerator. *Energy Conversion and Management* 46 (2005) 85-100.