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Comparative Analysis of Performance of Three Ozone-Friends HFC Refrigerants in a Vapour Compression Refrigerator

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Abstract: In this paper, the performances of three ozone-friendly Hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) in a vapour compression refrigeration system were investigated experimentally and compared. The results obtained showed that R32 yielded undesirable characteristics, such as high pressure and low Coefficient of Performance (COP). Comparison among the investigated refrigerants confirmed that R152a and R134a have approximately the same performance, 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 R134a and R32 by 2.5% and 14.7% respectively. 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 [1]. 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 [2]. 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 [3].

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 [4]. 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) [5-6]. According to Calm et al. [7], 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, is the leading replacement for domestic refrigerators. Although the ODP of R134a is zero, the GWP is relatively high (Table 1). 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 [8-9]. 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 Theoretical Analysis

Three non-ozone depleting HFC refrigerants (R32, R152a and R134a) 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. In the refrigeration system, the representative performance characteristics are compressor power (W_c, kW), refrigerating effect (Q_e, kW) and Coefficient of Performance (COP).

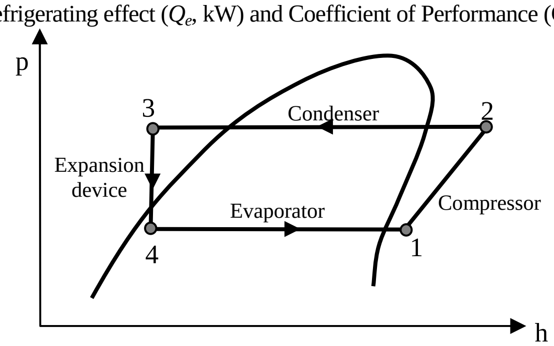

Figure 1. Vapour compression refrigeration system on p-h diagram.

Table 1. Some properties and environmental impact of selected alternative refrigerants [13-15].

Refrigerants	Chemical formula[13]	Molecular weight[14]	Boiling point (°C)[14]	Ozone Depletion Potential (ODP)[15]	Global Warming Potential (GWP)[15]
R32	CH_2F_2	52	-51.7	0	650
R134a	$C_2H_2F_4$	102	-26.1	0	1300
R152a	$C_2H_4F_2$	66	-24.0	0	140

Fig. 2 shows a schematic diagram of a vapour compression refrigerator, which consists essentially of a hermetic reciprocating compressor, an evaporator, a condenser and a capillary tube. These components are connected by pipelines in which a refrigerant with suitable thermodynamic properties circulates.

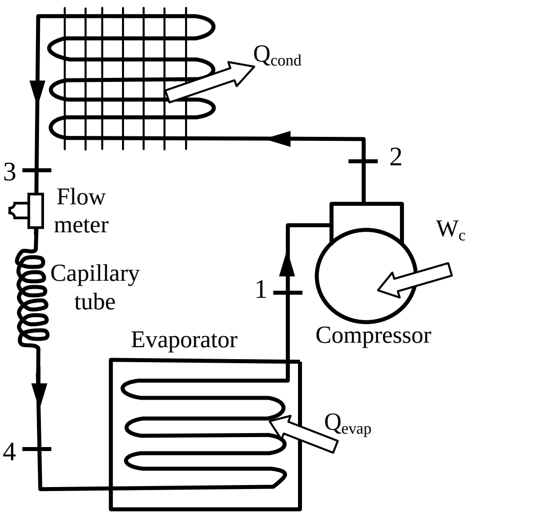

Figure 2. Schematic diagram of a vapour compression refrigerator.

(ii) Compressor

The isentropic work input to compressor (W_{cs}, kJ/s) is expressed as:

$W_{cs} = m_r(h_2 - h_1)$ (2)

where h_2 is the enthalpy of refrigerant at the outlet of compressor (kJ/kg).

The actual compressor work (W_c, kJ/s) is given as

$W_c = W_{cs}/\eta_s$ (3)

where η_s is the isentropic efficiency.

(iii) Condenser

The heat rejected by the condenser (Q_{cond}, kJ/s) to the atmosphere is given as

$Q_{cond} = m_r(h_2 - h_3)$ (4)

where h_3 is the enthalpy of refrigerant at the outlet of condenser (kJ/kg).

(iv) Capillary Tube

In the capillary tube the enthalpy remains constant (isenthalpy process), therefore,

$h_3 = h_4$ (5)

From the first law of thermodynamic point of view, the measure of performance of the refrigeration cycle is the coefficient of performance (COP) and is the refrigerating effect produced per unit of work required [11]. It is expressed as:

$\mathrm{COP} = Q_{evap}/W_c$ (6)

The volumetric cooling capacity (VCC, kJ/m^3) is the refrigerating effect per unit volume flow rate at the inlet to the compressor. It is expressed as [12]:

$Q_{evap}/(m_r V_s)$ (7)

where V_s is the specific volume at inlet to the compressor (m^3/kg).

Compressor pressure ratio (P_r) is given as:

$P_r = P_{dis}/P_{suc}$ (8)

where, P_{dis} = refrigerant vapour pressure at the compressor discharge (kN/m^2); and P_{suc} = refrigerant vapour pressure at the compressor suction (kN/m^2).

2.2 Experimental Setup

The schematic diagram of the vapour compression refrigeration system is shown in Fig. 2. The system was instrumented with two pressure gauges with accuracy of ±0.5 kPa at the inlet and outlet of the compressor for measuring the suction and discharge pressures. The temperature of the refrigerant at four different points as indicated in Fig. 2 was measured with copper-constantan thermocouples with accuracy of ±0.1°C. The energy consumption of the refrigeration system was measured with energy meter with accuracy of ± 0.2 kWh. The mass flow rate of the refrigerant was measured using a flow meter with ±0.01 kg/h accuracy installed in the liquid line between the condenser and the capillary tube. Service ports were installed at the inlet of expansion device and compressor for charging and recovering the refrigerant. The evacuation of moisture in the system was also carried out through the service port.

The system was charged with the help of charging system and evacuated with help of vacuum pump to remove the moisture. After charging each refrigerant, data were collected at different evaporator temperatures and the following performance parameters were obtained using Eqs. (1) to (8): refrigerating effect (Q_{evap}), compressor work input (W_c), condenser heat load (Q_{cond}), Coefficient of Performance (COP), Volumetric Cooling Capacity (VCC) and pressure ratio (P_r).

3. Results and Discussions

The results of performance comparison of the investigated refrigerants (R32, R152a and R134a) in the vapour compression refrigeration system are shown in Figs. 3 to 9. Fig. 3 shows the variation of discharge temperature as a function of the evaporator temperature for the investigated refrigerants. As shown in this figure, R32 has a significantly higher discharge temperature than the other refrigerants. R152a has the lowest discharge temperature. The advantage of a lower discharge temperature is that there will be less strain on the compressor and hence a longer compressor life. In addition the oil is less likely to break down.

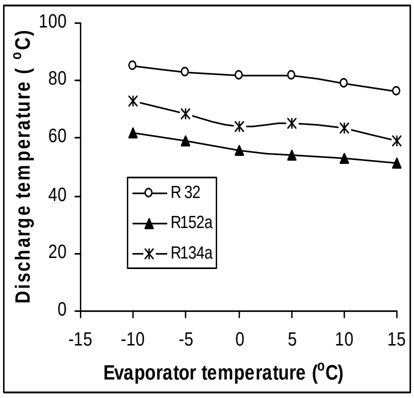

Figure 3. Variation of discharge temperature with varying evaporator temperature for R32, R152a and R134a.

Fig. 4 illustrates the variation of the saturation pressure as a function of the evaporator temperature for the three refrigerants. As shown in the figure, R152a has the lowest pressure with mean pressure of 7.0% lower than that of R134a and R32 has the highest pressure with mean pressure of 37.2% higher than that of R134a. The pressure of R152a was very close to that of R134a. Refrigerant with low pressure is desirable in the system because the higher the pressure the weightier must be the equipment parts and accessories.

Fig. 5 shows the variation of pressure ratio with varying evaporator temperature for R32, R152a and R134a. The figure shows that pressure ratio decreases with increase in evaporator temperature. The trends are similar for the three refrigerants. As shown in the figure, pressure ratios of R32 are higher than those of R152a and R134a. Average pressure ratios for R32 and R152a were 25.8% higher and 2.6% lower than that of R134a, respectively. Therefore, heavy compressor and higher compressor work are required for R32, while the same compressor is usable for both R134a and R152a.

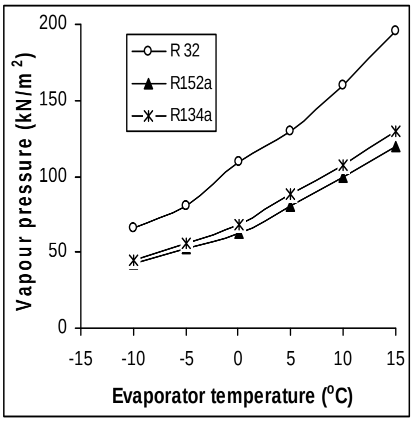

Figure 4. Variation of vapour pressure with varying evaporator temperature for R32, R152a and R134a.

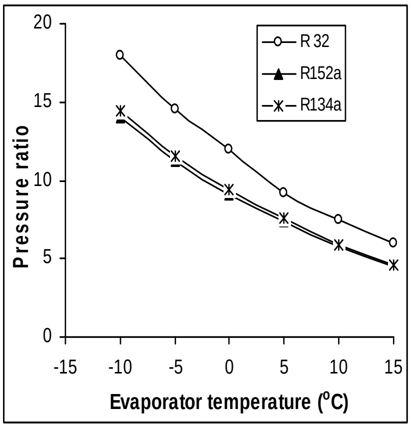

Figure 5. Variation of pressure ratio with varying evaporator temperature for R32, R152a and R134a.

The variations of the condenser heat load against evaporator temperature are presented in Fig. 6 for the three refrigerants. As shown in the figure, the condenser heat load increases as the evaporator temperature increases. Also, in this figure, R152a has the lowest heat load. The changes of compressor input power with evaporator temperature are illustrated in Fig. 7, which reveals that the compressor input power increases as the evaporator temperature increases. The average compressor input power for R32 was 34.5% higher than that of R134a, while the power input for R152a was 9.5% lower than that of R134a.

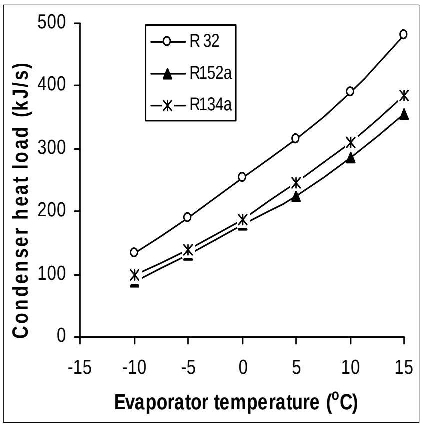

Figure 6. Variation of condenser heat load with varying evaporator temperature for R32, R152a and R134a.

Fig. 8 shows the variation of Volumetric Cooling Capacity (VCC) with varying evaporator temperature for the three refrigerants. The figure shows that the VCC increases with increase in evaporator temperature. This is due to the increase in cooling effect and decrease in specific volume, which means that the higher the VCC the smaller is the size of compressor required. The VCC obtained for R152a was 3.5% higher than that of R134a, while that of R32 was 25.2% lower than that of R134a. Therefore, bigger size of compressor is required for R32. The VCC for R152a is quite close to that of R134a. Fig. 9 shows the variation of Coefficient of Performance (COP) with varying evaporator temperature for the three refrigerants. As shown in this figure, the COP increases as evaporator temperature increases. R152a has the highest COP with average value of 2.6% higher than that of R134a and R32 has the lowest COP with average value of 15.5% lower than that of R134a.

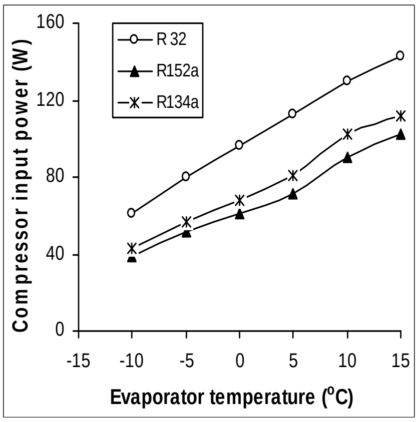

Figure 7. Variation of compressor input power with varying evaporator temperature for R32, R152a and R134a.

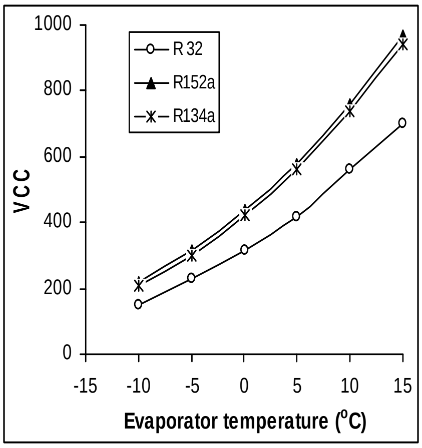

Figure 8. Variation of volumetric cooling capacity (VCC) with varying evaporator temperature for R32, R152a and R134a.

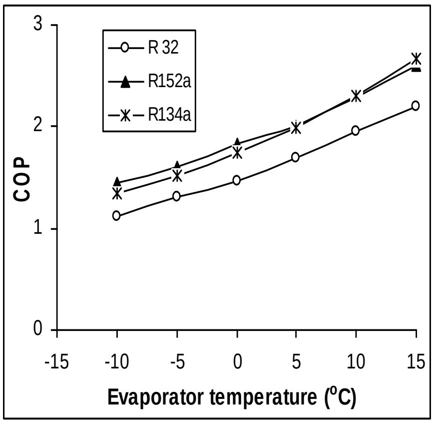

Figure 9. Variation of coefficient of performance (COP) with varying evaporator temperature for R32, R152a and R134a.

4. Conclusion

In this paper the performances of three ozone-friendly, Hydrofluorocarbon (HFC) refrigerants (R32, R152a and R134a) in a vapour compression refrigeration system were investigated experimentally and compared. Based on the investigation results, the following conclusions are drawn:

(i) Out of the three refrigerants investigated, R152a offers the best desirable environmental requirements; it has zero Ozone Depletion Potential (ODP) and very low Global Warming Potential (GWP).

(ii) R32 yields undesirable characteristics, such as high operating temperature and pressure, low Volumetric Cooling Capacity (VCC) and low Coefficient of Performance (COP).

(iii) The vapour pressures of R152a and R134a are nearly the same, but vapour pressure of R32 is higher than that of R134a by 37.2%.

(iv) The mean pressure ratios of R152a and R32 are 2.6% lower and 25.8% higher than that of R134a respectively, therefore, heavy compressor is required for using R32.

(v) The condenser heat load of R152a is close to that of R134a.

(vi) The VCC of R32 is lower than that of R134a by 25.2%. However, that of R152a is nearly the same with R134a over the considered range of operating conditions.

(vii) The average COP of R152a is higher than those of R134a and R32 by 2.6 and 17.6%, respectively.

(vii) R152a refrigerant has approximately the same performance with R134a, therefore, R152a is considered as a good drop-in substitute for R134a in vapour compression refrigeration system. The best performance was obtained from the use of R152a in the system.

References

[1] Bolaji BO, CFC refrigerants and stratospheric ozone: past, present and future, *Book of Readings of Environment Conservation and Research Team* 37 (2005) 231-239.

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

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

[4] Bhatti MS, A historical look at chlorofluorocarbon refrigerants, *ASHRAE Transactions* 1 (1999) 1186-1206.

[5] 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.

[6] 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.

[7] Calm JM, Wuebbles DJ, Jain AK, Impacts on global ozone and climate from use and emission of 2,2-dichloro1,1,1-trifluoroethane (HCFC-123) *Journal of Climatic Change*, 42 (1999) 439-474.

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

[9] Bolaji BO, *Investigating the performance of some environment-friendly refrigerants as alternative to R12 in vapour compression refrigeration system*, PhD Thesis in the Department of Mechanical Engineering, Federal University of Technology Akure, Nigeria (2008).

[10] Bolaji BO, Effects of sub-cooling on performance of R12 alternative in a domestic refrigerator, *Thammasat International Journal of Science and Technology* 13 (2010) 12-19.

[11] Dossat RJ, Horan TJ, *Principles of Refrigeration*, Prentice-Hall International Inc. New Jersey, USA (2002) 454 pp.

[12] Fatouh M, El Kafafy M, Assessment of propane/ commercial butane mixtures as possible alternatives to R134a in domestic refrigerators. *Energy Conversion and Management* 47 (2006) 2644-2658.

[13] Zhou X, Lian Z, Li Z, Yao Y, Experimental study on HFC-125 critical heat pump, *Applied Thermal Engineering* 27 (2009) 988-993.

[14] ASHRAE, *Thermophysical Properties of Refrigerants Chapter 20*, ASHRAE Fundamental, Inc. Atlanta 20 (2001) 1-67.

[15] Bitzer, *Refrigerant Report*, Bitzer International, 13th Edition, 71065 Sindelfingen, Germany, http://www.bitzer.de Accessed on June 24, 2007.