Comparative Analysis of R-134a and Zeotropic Blend by using Vapour Compression Refrigeration Test Rig

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ABSTRACT

Tetrafluoroethane is used in industrial, domestic and various refrigeration system. R-134a has zero ozone depletion potential and very good chemical and thermodynamic properties, but it has 1300 global warming potential which is high and consumes more power because the environmental impact of global warming has become a challenge to the refrigeration and other industry. Global warming is the increase in the Earth's surface temperature caused by increased emission of greenhouse gases into the atmosphere. There is a need to search the alternatives of R134a. The property software (NIST REFPROP SOFTWARE) uses for performance analysis of new zeotropic blend mixture. It will found to improve the COP of the system 5.2 to 5.6 and GWP.

Keywords--- GIG, GWP, HFC

I. INTRODUCTION

Vapour compression cycle is an improved type of air refrigeration system in which a satisfactory working substance, termed as refrigerant, is used. The refrigerant used, does not leave the system, but is flows throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the mixture which is used for circulating it around the cold chamber and in condensing; it gives out its latent heat to the flowing water of the cooler. In our country, more than 75% of the domestic refrigerator utilizes HFC R-134a as refrigerant, due to its excellent thermodynamic and thermo physical properties. But, HFC R-134a has a high global warming potential of 1300. The HFC refrigerants are considered as one of the six target greenhouse gases under the Kyoto protocol of united nations framework convention on climate change (UNFCCC) In 1997 [1, 2]. The Kyoto protocol was approved by worldwide called for the reduction in emission of greenhouse gas including HFC refrigerants. Fluorine atoms in HFC R-134a is responsible for the major environmental impact (GWP) with serious implementations for the future development of the refrigeration system based industries. Usage of R-134a consumes more power, up to 10-15% [3]. The C.O.P. of the system was also found to be 3% less than the system with R-12 refrigerant [4]. Hydrocarbon refrigerants also have the problem of flammability [5]. In the process of searching for new alternatives, since no single component refrigerant found, hence refrigerant blends as the alternative was recommended, because by mixing two or more than two refrigerants a new working fluid with the desired properties and characteristic can be developed.

1) Theory Of Refrigeration System (Water Cooler) :

Water cooler with water condenser is device shown in fig.1 which absorbs heat form refrigerated space to a temperature of 3 to 40c and water to be cool down. This cycle based on vapour compression refrigeration cycle has four main processes are as:

a) Compression: The low pressure vapour is drawn from the evaporator during the suction stroke of the compressor. The pressure and temperature increase during compression stroke until vapour temperature is more than the temperature of condenser cooling medium.

b) Condensation: When the high pressure refrigerant vapour enters the condenser heat supplies from the condenser to cooling medium. Thus permits the vaporized refrigerant to return to a liquid state.

c) Expansion: After condenser the liquid refrigerant is stored in the liquid receiver until required. From the receiver, the pressure is reduced while it passes through an expansion valve.

d) Vaporization: In the expansion valve the low pressure refrigerant vapour after expansion enters the evaporator or refrigerated space where a considerable mass of heat is absorbed by it and refrigeration is furnished.
II. EXPERIMENTAL SETUP

Figure No.2 shows a vapour compression refrigeration test rig where performance analysis has performed on water cooler by water condenser and Figure No.3 shows the t-s & p-h diagrams of cycle.

Vapour compression refrigeration test rig has following main component are:
- Compressor (Hermetically sealed KCJ444HAG, 250-50 HZ compressor).
- Condenser (water condenser).
- Expansion valve or thermostat valve.
- Evaporator.
- And other components are:
  - Rotameter, Receiver, Pressure gauge, RTD, Voltmeter, Ammeter, Energy meter.

III. PROCEDURE

Firstly of all charge Vapour Compression Refrigeration System (V.C.R.S.) of water cooler with R-134a refrigerant and run the water cooler after 3 hour when the steady state has come take an experimental reading of R-134a given below in the table:

Table: 1 operating condition

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Condition</th>
<th>Pressure (bar) P</th>
<th>Temp.(°C) T</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compressor Inlet</td>
<td>1.9</td>
<td>28.5</td>
</tr>
<tr>
<td>2</td>
<td>Compressor Outlet</td>
<td>18.4</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>Expansion Inlet</td>
<td>18.4</td>
<td>36.4</td>
</tr>
</tbody>
</table>

Where
- \( h_1 \) = specific Enthalpy at the inlet of compres
- \( h_2 \) = specific Enthalpy at the outlet of compressor.
- \( h_3 \) = specific Enthalpy at the outlet of condenser.
- \( V_{g1} \) = specific volume of vapour refrigerant at compressor inlet.
- COP = coefficient of performance.

For R-134a

Take the thermodynamic refrigerant property at all point of VCRS cycle of water cooler by P-H refrigerant chart on operating condition.

Table: 2 Thermo physical property of R-134a

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Condition</th>
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<th>Temp.(°C) T</th>
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<td>18.4</td>
<td>36.4</td>
</tr>
</tbody>
</table>

\( h_1 = 435 \text{ KJ/Kg} \)
\( h_2 = 470 \text{ KJ/Kg} \)
\( h_3 = 250 \text{ KJ/Kg} \)
Actual COP = \( \frac{(h_1-h_3)}{(h_2-h_1)} \)
Actual COP = \( \frac{(435-250)}{(470-435)} \)
Actual COP = 5.2
Compressor work input (KJ/Kg) = \( (h_2-h_1) \)
Compressor work input (KJ/Kg) = 470-435
Compressor work input (KJ/Kg) = 35
R-407x is a non-ozone depleting blend of three HFC refrigerants (R-32, R-125, and R-134a) and was designed to match thermodynamic refrigerant property and possible replacement of R-134a.

The iteration has to be performed on different ratio of R-407x.

### a) Initial Iteration

Mixture ratio of R-407x (By weight ratio 40% R-134a, 30%, R-125, 30% R-32 For 1Kg) and compares the operating condition of water cooler using R-134a by property software (NIST REFPROP 6.01 SOFTWARE). Take a thermodynamic refrigerant property at different point of VCRS cycle of water cooler by P-H refrigerant chart drawn by property software (NIST REFPROP 6.01 SOFTWARE).

**Table: 3 Thermo physical property of mixture ratio of R-407x by weight ratio 40% R-134a, 30% R-125, 30% R-32 for 1Kg**

<table>
<thead>
<tr>
<th>R-134a</th>
<th>R-125</th>
<th>R-32</th>
<th>Vg1</th>
<th>h1</th>
<th>h0</th>
<th>RE=h3-h0</th>
<th>VRc=Vg1/RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>30</td>
<td>30</td>
<td>0.039</td>
<td>46.5</td>
<td>250</td>
<td>215</td>
<td>5426.6</td>
</tr>
</tbody>
</table>

Volumetric refrigerant capacity = 5426.6 KJ/m3

The Volumetric refrigerant capacity of Mixture ratio of R-407x (By weight ratio 40% R-134a, 30%, R-125, 30% R-32 For 1Kg) which is not near the Volumetric refrigerant capacity of R-134a (6643 KJ/m3). this mixture ratio is not used in water cooler as a possible substitute for R-134a. then again iteration has performed on different ratio of R-407x.

The numbers of iteration were taken between initial and final iteration.

### b) Final Iteration

Mixture ratio of R-407x (By weight ratio 88% R-134a, 5%, R-125, 7% R-32 For 1Kg) and compares the operating condition of water cooler using R-134a by property software (NIST REFPROP 6.01 SOFTWARE). Take a thermodynamic refrigerant property at different point of VCRS cycle of water cooler by P-H refrigerant chart drawn by property software (NIST REFPROP 6.01 SOFTWARE).

**Table: 4 Thermo physical property of mixture ratio of R-407x (By weight ratio 88% R-134a, 5%, R-125, 7% R-32 for 1Kg)**

<table>
<thead>
<tr>
<th>R-134a</th>
<th>R-125</th>
<th>R-32</th>
<th>Vg1</th>
<th>h1</th>
<th>h0</th>
<th>RE=h3-h0</th>
<th>VRc=Vg1/RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>5</td>
<td>7</td>
<td>0.0260</td>
<td>425</td>
<td>25</td>
<td>17</td>
<td>6517</td>
</tr>
</tbody>
</table>

Volumetric refrigerant capacity = 6517.8 KJ/m3

The Volumetric refrigerant capacity of Mixture ratio of R-407x (By weight ratio 88% R-134a, 5%, R-125, 7% R-32 For 1Kg) which is near the Volumetric refrigerant capacity of R-134a (6643 KJ/m3). this mixture ratio is used in water cooler as a possible substitute for R-134a. Mixture ratio of R407 is 88% R-134a, 5%, R-125, 7% R-32 in their weight per Kg and we named this new mixture is R-407-x.

### c) For R-407-x

The iteration has to be performed on different ratio of R-407x. Here we use mixture ratio of R407 (By weight ratio 88% R-134a, 5%, R-125, 7% R-32 For 1Kg) and compares the operating condition of water cooler using R-134a by property software (NIST REFPROP 6.01 SOFTWARE). Take a thermodynamic refrigerant property of R407-x at different point of VCRS cycle of water cooler by P-H refrigerant chart drawn by property software (NIST REFPROP 6.01 SOFTWARE).

**Table: 5 Thermo physical property of R-407-x**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Pressure (bar)</th>
<th>Temp. (°C)</th>
<th>Enthalpy (kJ/kg)</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.9</td>
<td>28.5</td>
<td>425</td>
<td>Superheated</td>
</tr>
<tr>
<td>2</td>
<td>18.4</td>
<td>90</td>
<td>455</td>
<td>Superheated</td>
</tr>
<tr>
<td>3</td>
<td>18.4</td>
<td>36.4</td>
<td>255</td>
<td>Sub-cooled</td>
</tr>
</tbody>
</table>

Volumetric refrigerant capacity (V.R.C.) = \( V_g1/RE \) = 0.0260824 m³/Kg

Compressor work input (KJ/Kg) = \( (h_2-h_1) \)

Compressor work input (KJ/Kg) = 455-425

Compressor work input (KJ/Kg) = 30

Refrigerating effect = \( h_1-h_3 \)

Refrigerating effect = 425-255

Refrigerating effect = 170 KJ/Kg

Volumetric refrigerant capacity (v.r.c.) = \( V_g1/RE \) Refrigerating effect

Volumetric refrigerant capacity (v.r.c.) = 0.0260824 / 170

Volumetric refrigerant capacity (v.r.c.) = 6517.8 KJ/m³

ACTUAL COP = \( (h_1-h_3)/(h_2-h_1) \)

ACTUAL COP = 425-255 / (455-425)

ACTUAL COP = 5.6

**IV. RESULT AND DISCUSSION**

The result shown in table No. 4.1 provide valid support in favour of R407-x and best alternate for R-134a.
Table No: 6 Compressions of R-134a and R407-x

<table>
<thead>
<tr>
<th>Comparison</th>
<th>R-134a</th>
<th>R-407-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>COP</td>
<td>5.28</td>
<td>5.866</td>
</tr>
<tr>
<td>Compressor work input(KJ/Kg)</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>Volumetric refrigerant capacity (KJ/m³)</td>
<td>6643</td>
<td>6517.8</td>
</tr>
<tr>
<td>Miscibility with oil</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Specific volume(m³/Kg)</td>
<td>0.02784</td>
<td>0.0260824</td>
</tr>
<tr>
<td>Irreversibility</td>
<td>more</td>
<td>less</td>
</tr>
</tbody>
</table>

**a) Coefficient of performance**

The coefficient of performance (C.O.P.) of a refrigeration cycle is the major criterion for selecting a new refrigerant as a substitute. COP is the ratio of heat extraction capacity in the evaporator to their compressor work. Graph no. 1 shows the cop of R407-x is higher than R-134a, which means that R407-x is greater heat absorption capacity to their compressor work input. R407-x, is the better possible substitute for R-134a.

**b) Global warning potential**

Global warming potential (GWP) is prime criterion in the selection of refrigerant. GWP is measure the how much amount heat traps in the atmosphere by refrigerant. Global warming has several bad effects on environment like melting of glacier, rise in sea water level. GWP of R 134a, R-32, and R-125 are 1300, 675, and 2800 respectively which shows in the graph no 2. Graph no 4.3 shows the comparison of R-134a and R407-x of their GWP. GWP of R407-x is less than R-134a which means that R407-x is the better possible substitute for R-134a.

**c) Volumetric refrigerant capacity**

Graph plotted between the volumetric refrigerant capacity of R-134a and R407-x. Graph no 4.4 shows that volumetric refrigeration capacity of R407-x is very near to R-134a which means that R407-x is used in the compressor without change in size of the compressor.

**d) Specific Volume**

Specific volume shows refrigerant consume space or volume per unit mass. Data for graph is taken form REFPROP property software. Graph plotted between the specific volume and refrigerants. Graph no 4.5 shows that refrigerant R407-x consumes less specific volume. It means that one Kg of R407-x required less volume and size of the compressor has reduced. For this result R407-x is suitable for working range of compressor and better substitute for R134a.
Graph No: 4 Comparison of Specific Volume of Refrigerants

**e) Variation of enthalpy with temperature**

Enthalpy is a good heat extracting capacity of refrigerant. Data for graph is taken from REFPROP software at given pressure and temperature condition. Enthalpy versus temperature graph is plotted for R134a and R407-x which shows that heat extracting capacity. Graph no 4.6 shows at evaporator point enthalpy of R407-x is higher than R-134a which means R407-x is better refrigerant than R-134a.

**f) Entropy variation between refrigerant**

Data for graph is taken from REFPROP refrigerant software at given pressure and temperature reading. Entropy vs. temperature graph is plotted for R-134a and R407-x which shows that entropy of R407-x is less as compared to R-134a at all point of water cooler. This means that the disorderness of refrigerant is minimum and irreversibility is less in R407-x. It means that R407-x is better substitute for R-134a.

**g) Compressor energy input**

Compressor energy consumption is the important criterion for refrigerant. Graph no 3 shows that R407-x consumes less energy than R-134a. R407-x saves 14.28% energy, which means that R407-x is the better substitute for R-134a.

**V. CONCLUSION**

In this study, VCRS of water cooler is used for the performance analysis of alternative new refrigerants substitute for R-134a. Considering the comparison of performance of coefficients (COP) of the water cooler has improved 5.2 to 5.6 which ensure better performance, R-407-x consume less power in the compressor which
ensure that this is energy saving refrigerant, irreversibility is less present in R-407-x because R-134a consume more power input. The specific volume of the R-407-x refrigerant is less than R-134a which means that the size of the compressor has reduced. GWP is reduces as compared to power consumption. Ozone depleting potential of mixture is zero since it does not contain any ozone depleting element like chlorine.

The result proved that R-407-x is the best environment-friendly, energy efficient and promising ‘drop-in’ substitute (without modification in the existing refrigeration system) for R-134a in VCRS of water cooler.

REFERENCES