Comparative Study of Eco-friendly Refrigerants in a Lower Capacity Air-Conditioning System

B. Hadya, P. Usha Sri and Suresh Akella

Abstract—In this paper, the possibility of using R32 and R290 refrigerants in a vapour compression refrigeration system were studied and compared theoretically with R22. Refrigerant 22 is a Hydro Chlorofluorocarbon (HCFCs) group Refrigerant, having Ozone Depletion Potential of 0.05 and Global Warming potential 1700 which causes more environmental impact, world community has decided to replace these. The environmental friendly refrigerant like Hydrocarbon refrigerants (HCs) and Hydro fluorocarbon (HFCs) have emerged as Zero Ozone Depletion Potential and low Global warming Potential. To phase-out HCFCs the overall evaluation in terms of Energy Efficiency, safety, Economic aspects is studied for favorable performance for lower capacity i.e.1 TR air conditioning systems. The operating temperatures for Evaporator at -15°C and condensing temperatures at 30°C and 40°C were considered for theoretical performance comparison. With compare to R22, The Coefficient of performance for R290 and R32 is closely matches for higher condensing temperature. At higher ambient (condensing) temperature, R290 gives better COP than that HCFC-22 per TR. Pressure ratio indicates the size of compressor and condenser, R32 pressure ratio is 25% high, R290 pressure ratio is 14 % more with compare to R22. Per Ton Refrigeration R32 requires very high Power (hp) because the pressure ratio is very high. As compare to the environmental impact, R32 has zero ODP and 220 GWP, R290 have zero ODP and 3 GWP. R32 requires robust condenser and R290 (Propane) as a refrigerant has two disadvantages, One is fire risky and second is size of the compressor should be bigger than while using of R22 of the assigned refrigeration machine.

Keywords— Alternate refrigerants, Hydrocarbon, Hydro chlorofluorocarbon, Vapour compression system, Hydro Fluorocarbon, Performance characteristics.

I. INTRODUCTION

Refrigerant Phase-out and retrofit is a highly complicated problem which requires effective knowledge of different science and engineering fields. The last seven decades, the CFCs and HCFCs have been used in the field of refrigeration and air conditioning due to their favourable characteristics. The use of refrigerant has got more significance and HCFCs -22 is one of the important refrigerants in air conditioning all over the world [1]. The major disadvantage of R22 is ozone layer depletion and global warming effect, which causes lot of ill health and diseases for living and non living things. As per the agreement of Montreal and Kyoto protocol 1987 all CFC’S and HCFC’S must be phased out both in developed and developing countries. As per ASHRAE standard 34 all HCFC should be phased out by 2030 [2,4].The Govt. of India, The Ministry of Environment and Forest (MoEF), emphasizing and giving indications on Environmental Impact Assessment (EIA). The Ministry has issued the Environmental Impact Assessment Notification, 2006, which makes environmental clearance mandatory for the development activities to identify, examine, assess and evaluate the likely and probable impacts of a proposed project (alternate refrigerants) on the environment and, thereby, to work out remedial action plans to minimize adverse impact on the environment. Usage of natural refrigerants for Air conditioning system may be a best option for effective utilization for eco-friendly atmosphere.

II. LITERATURE REVIEW

The science and practice of creating a controlled climate in indoor spaces is called air conditioning. Refrigerant is a heat carrying medium which during the cycle. To search for alternative to refrigerant( HCFCs group) 22 A comprehensive literature study has been carried out for retrofit to existing vapour compression refrigeration system for various alternate refrigerants for both empirical and simulated results are studied [4], the basic performance and environmental parameters are Ozone layer: Molina and Rowlands (1974) has been expanded into a comprehensive and very complex theory emphasis about 200 reactions that CFCs are significantly destroyed by UV radiation in the stratosphere. in the year 1987 Hoffman predicted 3 % global ozone depletion with contact of CFCs emissions of 700 thousand tone /year [4,5].

Montreal Protocol: the United Nations environment programme conference held in Montreal in September 1987 the decision taken to phase out depleting substances (ODS) within a fixed time period is known as Montreal Protocol. Some of the feature of MP is as follows. Developed

Haday Boda is with the University Colleges of Engineering, Osmania University, Hyderabad, Andhra Pradesh, INDIA. (Phone: 09440349195, fax: 04027097250; e-mail: hadya.ou@gmail.com).
P. Usha Sri was with the University Colleges of Engineering, Osmania University, Hyderabad, Andhra Pradesh, INDIA. (e-mail: emaithushari@yahoo.com).
Suresh Akella was with Sreyas Institute of Engineering & Technology, affiliated to J.N.T.U. Hyderabad, A.P., INDIA.(e-mail: s4akella@gmail.com).
countries will phase out CFCs by 1996. Developing countries will phase out CFCs by 2010 with freeze in 1999 and gradual reduction thereafter. Developed countries will phase out HCFCs by 2030 while developing countries have been provided a grace period of ten years i.e. phase out by 2040. Global warming is another serious issue. Some naturally occurring substances mainly cause this but CFCs have very large global warming potential. [6,7].

III. GLOBAL WARMING

The global warming issue was addressed by the third conference of parties to the United Nations framework convention on climate change (UNFCCC) in December 1997 held at Kyoto. This is known as Kyoto protocol (KP). According to this, the developed countries of KP should reduce their average greenhouse gas emissions in aggregate by 5.2% below the 1990 levels within a period of 2008-2012. Developing countries do not have any obligation under KP. In the year 1988 International Panel on Climate Change (IPCC) was established for scientific intergovernmental body to evaluate the risk of climate change caused by human activity. The IPCC provides the general accepted value for GWP, which changed slightly between 1996 and 2001. The IPCC has predicted an average global rise in temperature of 1.4°C to 5.8°C between 1990 and 2100.

3.2 Phase out schedule

<table>
<thead>
<tr>
<th>HCFC</th>
<th>Phase out Schedule %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>100</td>
</tr>
<tr>
<td>2004</td>
<td>65</td>
</tr>
<tr>
<td>2010</td>
<td>35</td>
</tr>
<tr>
<td>2015</td>
<td>10</td>
</tr>
<tr>
<td>2020</td>
<td>5</td>
</tr>
<tr>
<td>2030</td>
<td>0</td>
</tr>
</tbody>
</table>

From the table I, the phase-out of HCFCs uses a cap or limit, based on ozone depletion (ODP) unit concept. The base of the cap is determined via the following formula: 1989 CFC production X ODP X 2.8% + 1989 HCFC production X ODP = Total ODP weighted cap. Fig.1 and 2 shows, the levels of ozone depletion potential (ODP) and Global warming potential (GWP). The refrigerant used in earlier days were either toxic, flammable, leakage of refrigerant caused panic and poisoning when these occurred at night time. The refrigeration industry needs a new refrigerant if they ever expected to get anywhere.

IV. WORKING PRINCIPLE

The simple Vapour Compression Refrigeration cycle is shown in Fig.3. It consists of following four essential parts 1. Compressor, 2. Condenser, 3. Expansion Valve, and 4. Evaporator.
Compressor compresses the vapour refrigerant to the condenser with high pressure and temperature, in the condenser condensation takes place by rejecting heat with cooling medium either water or air as a cooling medium the phase transfer takes place from vapour refrigerant to liquid refrigerant and enters into the Expansion Valve, the function of the expansion valve is to reduce the pressure from high condenser pressure to low evaporator pressure by throttling process, finally the liquid refrigerant enters in the Evaporator where cooling effect is produced by absorbing heat from the cooling space and only pure vapour enters into the compressor.

### 4.1 Theoretical Cycle Analysis

The P-h diagram (Moeller diagram) shown in fig.4 is frequently used in the analysis of Vapour Compression Refrigeration cycle, the significant performance characteristics are Compressor work (\(W_c\)), Refrigeration Effect (\(Q_E\)) and Coefficient of Performance (COP). Process 1 to 2 is compression, 2 to 3 Condensation (Heat Rejection), 3 to 4 Expansion process (Throttling) and 4 to 1 Evaporation process (Heat absorption), the system performance is calculated as follows:

\[
\text{COP} = \frac{Q_E}{W_c} \quad (1)
\]

\[
W_c = m_r (h_2 - h_1) \quad (2)
\]

\[
Q_E = m_r (h_4 - h_1) \quad (3)
\]

\[
\text{Pressure ratio} (Pr) = \frac{P_c}{P_e} \quad (4)
\]

\[
\text{Power Required Per TR} = \frac{3.5}{\text{COP}} \text{kW} \quad (5)
\]

Where,

\(h_1\) and \(h_2\) are Enthalpies of Refrigerant at the inlet and outlet of compressor (kJ/kg).

\(h_3\) and \(h_4\) are Enthalpies of Refrigerant at the inlet and outlet of expansion valve (kJ).

The evaporator pressure (\(P_E\)) should be positive and as near atmospheric as possible. If it is too low, it would result in large volume of the suction vapour. If it is too high, there exit overall high pressure in the system, which results for stronger equipment and higher cost.

### V. PERFORMANCE COMPARISON

Table II shows the theoretical comparison of refrigerant and their properties like molecular weight, chemical formula, Normal boiling point, Critical Temperature and Critical Pressures. R32 the critical temperature is very low, if the refrigeration cycle is operated near the critical temperature COP reduces, hence the refrigeration critical temperatures should be large.

The performance parameters for selected refrigerants, In the Reversed Rankine Cycle the evaporator temperature is assumed to enter at -15°C (saturated vapour) and Condenser temperature is assumed as 30°C and 40°C, And their performance is compared. From fig.5 to fig.7 shows the performance characteristics for different operating pressures and temperatures, as shown in fig.5 for the ambient conditions if the condenser temperature at 40°C COP for R290 very high and R32 COP is closely matches to HCFC22.

Normal Boiling Point is an important property of refrigerant since many other properties are related to it. Normal Boiling Point of the refrigerant should be low so that the refrigerant can be used at low evaporator temperatures. Critical Temperature and Pressure plays an important role in refrigeration cycle.

**Table II: Refrigerants and their Properties**

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>HCFC-R22</th>
<th>HFC-R32</th>
<th>HC-R290(Propane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression ratio (Pr) at Tc 30°C and Te -15°C</td>
<td>4.03</td>
<td>3.95</td>
<td>3.7</td>
</tr>
<tr>
<td>Compression ratio (Pr) at Tc 40°C and Te -15°C</td>
<td>4.06</td>
<td>5.08</td>
<td>4.64</td>
</tr>
<tr>
<td>COP at Tc 30°C and Te -15°C</td>
<td>5.01</td>
<td>3.826</td>
<td>4.58</td>
</tr>
<tr>
<td>COP at Tc 40°C and Te -15°C</td>
<td>3.387</td>
<td>3.8</td>
<td>3.785</td>
</tr>
<tr>
<td>Power consumption In hp per TR</td>
<td>1.011</td>
<td>2.29</td>
<td>1.031</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>86.48</td>
<td>52.042</td>
<td>44.1</td>
</tr>
<tr>
<td>Chemical formula</td>
<td>CHClF₂</td>
<td>CH₂F₂</td>
<td>C₃H₈</td>
</tr>
<tr>
<td>NBP°C</td>
<td>-40.9</td>
<td>-51.71</td>
<td>-42.07</td>
</tr>
<tr>
<td>Critical Temp.°C</td>
<td>96</td>
<td>78.41</td>
<td>96.8</td>
</tr>
<tr>
<td>Critical pressure(bar)</td>
<td>49.74</td>
<td>58.3</td>
<td>42.54</td>
</tr>
</tbody>
</table>
The temperature above which vapour cannot be condensed is called critical temperature. Critical temperature should be well above condensing temperature. If the critical temperature of a refrigerant is too near the desired condensing temperature, the excessive power consumption results. The critical pressure should be low so as to give low condensing pressure.

Fig. 6 shows the pressure ratio, Fig. 7 shows the power consumption per TR., for different condensing temperatures.

VI. CONCLUSION

The Coefficient of performance of R290 is nearly matches with R22 with low power consumption, R32 have lower molecular weights, The relative performance of a refrigerant is directly related to molecular weights as well, the lower molecular weight would have low mass flow rate, higher latent heat. R32 pressure ratio is 25% high, R290 pressure ratio is 14% more with compare to R22. R32 Consumes very high power per TR. The advantage of R32 is very low flammability with compare to (HCs) R290. Hydrocarbons refrigerants have zero ODP and very small GWP. As they have Potential of better performance, they are being used in many countries now days. The only limitation with Hydrocarbon refrigerants is they are flammable; hence the safety issues must be addressed in terms of Manufacturing, handling, storage and servicing. The HFCs are transitional compounds substitutes with low ODP, but, these will also have to be replaces. The hydrogen atom causes hydrolysis and also having GWP, hence these are also uncertain candidates in near future. To prevent the environmental damage and to reduce the harmful effects the refrigeration industry must shift towards the natural refrigerants.

ACKNOWLEDGEMENT

This Part of work has been carried out under O.U/D.S.T-PURSE Programme, Scheme no A-38. And TUCUMSEH Products Company, Balanagar, Hyderabad, India.

REFERENCES

[6] PhD. Theses of Dr. Azizuddin on Alternate Refrigerants for Air Conditioning.
[9] Refrigeration and Air Conditioning Book by C.P ARORA and DOMKUNDWER.
[10] Andersson Johansson, MCS*, Per Lundqvist, PHD, Ass.Prof. "Replacement of R22 in existing Installations: Experiences from the Swedish Phase out" Royal institute of technology, Department of Energy Technology, S-100 44 Stockholm, SWEDEN.