Performance Comparison of R22 refrigerant with Alternative Hydrocarbon Refrigerants

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Abstract- A theoretical performance study on vapour compression refrigeration system is done in this study. Hydrocarbon refrigerants such as R290, R600a, R1270 as well as their blend mixtures in various ratios are considered as a drop in candidate for R22. Analysis is done considering the condensing temperature constant at 50°C and varying evaporator temperature from -10 to 10°C. Theoretical results shows that the alternative refrigerants investigated have a slightly lower COP as compared to R22 but much higher refrigerating effect. Blend mixtures shows higher tendency for replacement of R22. The parameters such as refrigerating effect, work done by compressor and COP are investigated at non-superheating/subcooling state as well as superheating and subcooling state.

Keywords: Refrigeration, propane, isobutene, propylene, R22, Hydrocarbon mixture, Alternative refrigerants

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>h</td>
<td>enthalpy kJ/kg</td>
</tr>
<tr>
<td>T</td>
<td>temperature,°C or K</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
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<tr>
<td>ODP</td>
<td>Ozone Depletion Potential</td>
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<tr>
<td>RE</td>
<td>refrigerating effect, kJ/kg</td>
</tr>
<tr>
<td>COP</td>
<td>coefficient of performance</td>
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<tr>
<td>W</td>
<td>isentropic compressor work</td>
</tr>
<tr>
<td>P</td>
<td>pressure, MPa</td>
</tr>
<tr>
<td>S</td>
<td>entropy, kJ/kgK</td>
</tr>
<tr>
<td>HCFCs</td>
<td>hydro chlorofluorocarbon</td>
</tr>
<tr>
<td>HCs</td>
<td>hydrocarbons</td>
</tr>
<tr>
<td>CFCs</td>
<td>chlorofluorocarbons</td>
</tr>
<tr>
<td>HFCs</td>
<td>Hydro fluorocarbons</td>
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<tr>
<td>(C_p)</td>
<td>specific heat , kJ/kg K</td>
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</tbody>
</table>

Subscripts

cod or cond: Condenser

evap or evp: Evaporator

1: evaporator superheat

2: compressor superheat

3: condenser saturated liquid

4: evaporator saturated mixture

I. INTRODUCTION

Due to the excellent thermodynamic and chemical stability the Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) are most widely used in the refrigeration and air conditioning application. Regulation of European Parliament and Council, 29 June 2000 on substances depleting ozone layer states that no manufacturer or importer may place on the market or use HCFCs after 31 December 2009. Because of the international regulation the non-ozone depleting hydrofluorocarbons (HFCs) have been extensively used in most of the refrigeration and air conditioning system.

Nowadays another problem has created a huge trouble in world that is global warming. Due to this effect, the temperature of the world is increasing to such an extent that controlling of such refrigerants is an important issue. The refrigerant which contains atleast one fluorine atoms is more prone to global warming potential. In order to solve this issue the Kyoto protocol was proposed which classified HFCs as one of the greenhouse warming gases. In the future the refrigerants which have zero ozone depletion potential (ODP) value and low global warming potential (GWP) value will retain its existence for a long run in refrigeration and air conditioning field.

One of the best ways to tackle such situation is to use the natural hydrocarbon refrigerants (HCs). Hydrocarbons have zero ODP and very low GWP values. In addition to these properties the hydrocarbon refrigerants also have preferable specifications like non toxicity, higher performance, high miscibility with mineral oil and good accordance with the existing system. In spite of these advantages the HCs were prohibited due to their high flammability concern. At the present stage this trend is somewhat relaxed due to environmental concern of HFCs, HCFCs, CFCs. Therefore, some of the flammable refrigerants have been applied to certain applications.

Many investigations have been done in the research of substitute of CFC 22 and HFC 134a. Calm [1] presented review on generation of refrigerants. The CFCs and HCFCs belong to third generation of refrigerants while HCs belongs to fourth generations of refrigerants as per the literature. Park and Jung [2] presented an experimental study on performance of hydrocarbon refrigerants and their mixtures as a drop in replacement of HCFC22 or R22. The results showed that coefficient of performance (COP) of the hydrocarbon mixtures was up to 5.7% higher than that of HCFC22 and propane.
(HC290) showed 11.5% reduction in capacity. The amount of charge was reduced up to 55% as compared to HCFC22. Rocca and Panno [3] presented an experimental performance on a vapour compression refrigeration system tested with R22 and then with three new HFC fluids R417A, R422A and R422D. The performances of the new fluids were not efficient as when using R22. Park and Jung [4] also studied the thermodynamic performance of R170/R290 mixture on a heat pump bench tester in an attempt to substitute R22. Test results showed that with the use of this mixture the COP increased as the composition of R170 increased. The mixture of R170/R290 at 4%/96% composition showed the similar capacity and COP as that of R22. Wongwises et al. [5] presented an experimental study on the application of hydrocarbon mixtures to replace HFC134a in automobile air conditioners. The results showed that all the hydrocarbon refrigerant mixture yield higher COP than HFC134a. But the mixture of HC290/HC600/HC600a in the ratio of (50/40/10 by wt.%) was found to be suitable than other mixtures for replacement of HFC134a. Cabello et al. [6] presented an experimental evaluation on a single stage vapour compression plant using three different refrigerants R134a, R407C and R22. The analysis showed that at high compression ratios the COP of R22 was lower than the refrigerant R407C. Purkayastha and Bansal [8] measured the performance of R290 and R22 in a heat pump of 15kW capacity and found that the COP of R290 is 18% higher than that of R22 with decrease in heating capacity of 15%. The refrigerant mass of R290 was half that of R22. Jung et al. [9] conducted a series of tests with 14 refrigerant mixtures to replace R22 for air-conditioning application and found that the performance of some zeotropic mixtures was better than that of R22.

In this study, a vapour-compression refrigeration system for hydrocarbon refrigerant and the binary mixture is used for the best performance. This study mainly focuses on theoretical investigation of vapour-compression refrigeration cycle. The refrigerants used in this study such as R290, R600a, R1270 and binary mixtures such as R290/R600a (50/50), R290/R600a (40/60), R1270/R290 (50/50), R1270/R290 (80/20) are used as working fluid as a drop in replacement of R22 and R134a.

### II. CALCULATION PROCEDURE

For the ease of calculation some assumptions are to be made. Those are as follows:

1) Efficiency of compressor is not considered.
2) Compression is isentropic.
3) No pressures drop in the condenser as well as evaporator.
4) Isenthalpic expansion in the expansion valve.
5) Heat losses from all the parts are neglected.

Isentropic compression work of compression (W\text{comp}) is given by:

\[ W_{\text{comp}} = h_2 - h_1 \]

The refrigerating effect (RE) is calculated as:

\[ \text{RE} = h_1 - h_4 \]

Coefficient of performance is given by:

\[ \text{COP} = \text{RE} / W_{\text{comp}} \]

### III. RESULTS AND DISCUSSION:

#### Table 1: Operation of various refrigerants on VCR at T\text{cond}=50^\circ\text{C} and T\text{evap}=-10^\circ\text{C}

<table>
<thead>
<tr>
<th>Refrigerants (by wt.%)</th>
<th>W\text{comp} (kJ/kg)</th>
<th>RE (kJ/kg)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R22</td>
<td>43.34</td>
<td>137.95</td>
<td>3.18</td>
</tr>
<tr>
<td>R134a</td>
<td>39.344</td>
<td>121.14</td>
<td>3.08</td>
</tr>
<tr>
<td>R290</td>
<td>75.14</td>
<td>225.86</td>
<td>3.18</td>
</tr>
<tr>
<td>R600a</td>
<td>69.256</td>
<td>218.88</td>
<td>3.16</td>
</tr>
<tr>
<td>R1270</td>
<td>77.08</td>
<td>226.75</td>
<td>2.94</td>
</tr>
<tr>
<td>R290/R600a (50/50)</td>
<td>76.24</td>
<td>227.51</td>
<td>2.983</td>
</tr>
</tbody>
</table>

#### Fig1. Traditional VCR cycle used in analysis a) non-superheating/subcooling b) superheating/subcooling case

The parameters such as refrigerating effect (RE), work done by compressor (W\text{comp}) and coefficient of performance (COP) are investigated for various evaporating temperature ranging from -10 to 10\^\circ\text{C} and constant condensation temperature of 50\^\circ\text{C}.
1. Refrigerating effect:
   a) R22 vs. alternative refrigerants
      
      ![Graph showing refrigerating effect of R22 vs. alternative refrigerants]
      
      From Fig. 2, it can be seen that the refrigerating effect of all the refrigerants increases with the increase in the evaporation temperature. R1270 has the highest refrigerating effect and except R1270/R290 (50/50) all the refrigerants show increased refrigerating effect than R22. The R290/R600a (40/60) refrigerant shows similar capacity as that of R22.

   b) R22 vs. hydrocarbon mixture
      
      ![Graph showing refrigerating effect of R22 vs. hydrocarbon mixture]
      
      From Fig. 2, it can be seen that the refrigerating effect of all the refrigerants increases with the increase in the evaporation temperature. R1270 has the highest refrigerating effect and except R1270/R290 (50/50) all the refrigerants show increased refrigerating effect than R22. The R290/R600a (40/60) refrigerant shows similar capacity as that of R22.

2) Work done by compressor:
   a) R22 vs. alternative refrigerants
      
      ![Graph showing work done by compressor vs. evaporation temperature]
      
      From the Fig. 3 it can be seen that the work done by compression decreases as the evaporation temperature increases. All the tested refrigerants have much higher isentropic work values as compared with R22.

   b) R22 vs. hydrocarbon refrigerants
      
      ![Graph showing COP vs. evaporation temperature]
      
      From the Fig. 4 it can be seen that the pure hydrocarbon has slightly lower COP than R22 and hydrocarbon mixture also have lower COP than R22.

Case 2: Superheating/Subcooling by 5°C each
4) **Refrigerating effect:**
   a) R22 vs. alternative refrigerants
   ![Fig.5. Refrigerating effect vs. evaporating temperature](image)
   The refrigerating effect increases as the evaporation temperature increases from -10°C to 10°C and constant condensation temperature 50°C highest occurs for R1270.

5) **Coefficient of performance (COP):**
   a) R22 vs. alternative refrigerants
   ![Fig.6 COP vs. evaporating temperature](image)
   The coefficient of performance increases as the evaporation temperature increases from -10°C to 10°C and constant condensation temperature 50°C. Lowest occurs for R1270 and other alternative refrigerants have slightly higher values that R22.

IV. **COMPARISON: CASE 1 Vs. CASE 2**

6) **Refrigerating effect:**
   a) R22 and R290
   ![Fig.7. Refrigerating effect (a, b) vs. evaporation temperature](image)
   Fig. 7 a and b shows that the refrigerating effect of the superheating and subcooling state is much greater than non-superheating and subcooling state as the evaporation temperature increases from 10°C to 10°C and condensing temperature of 50°C. From this figure it follows that for the higher performance of the system the system should be operated under superheating and subcooling state.

7) **Coefficient of performance (COP):**
   a) R22 vs. R290
   ![Fig.8 COP vs. evaporation temperature](image)
From the Fig. 8 it can be seen that the COP of the superheating and subcooling case is higher than the non-superheating/subcooling case for evaporating temperatures increasing from -10°C to 10°C and condensing temperature of 50°C.

The thermo-physical, restrictions related to safety, environmental impact, and associated legislation are the most significant factors in choosing a new refrigerant. Low viscosity of liquid and vapour phases, high latent heat, high thermal conductivities of liquid and vapour phases, high latent heat, and small temperature glide are the desired thermo-physical properties of refrigerant mixtures in the literature. As a result of analysis in this study the HC290/HC1270 (20/80 by wt%) instead of R22 seems to be the best alternative refrigerant in terms of the factors in choosing a new refrigerant.

V. SUMMARY
In this study, an ideal vapour-compression refrigeration system is considered for performance comparison of R22 with the alternative hydrocarbon refrigerants and their mixtures. The main parameters of systems such as refrigerating effect (RE), work done by compressor (W\text{comp}) and coefficient of performance (COP) are tested for constant condensing temperature and increasing evaporator temperature. The refrigerating effect and coefficient of performance increases with the increase in the evaporation temperature while the work done by compressor decreases with the increase in evaporation temperature. The environmental impact ozone depletion potential (ODP) and global warming potential (GWP) of refrigerants was also considered while selecting the proper refrigerant. Analysis was also carried out under superheating/subcooling state and the results showed that the value of parameters is much higher as compared to non-superheating/subcooling state. After doing the analysis the results showed that HC290/HC1270 (20/80 by wt.%) and R1270 is the most suitable alternative refrigerant among refrigerants tested for R22.

REFERENCES