Evaluation for Replacement of R22 as R161 in the Vapour Compression Cycle through Aspen Plus Software

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ABSTRACT

As per the scientific study of environmental pollution extensively, there is a significant need to phase out R22 earlier than that prescribed by Montreal protocol. Any alternative to R22 has to possess all desirable properties of refrigerants like thermodynamic efficiency, non-flammable and non-toxic, thermal and chemical stability, compatibility and low cost. There are other concerns such as Ozone Depletion Potential (ODP) & Global Warming Potential (GWP) of a refrigerant. The R161 is a zero ODP and low GWP refrigerant with excellent thermo physical properties and was neglected with contention that flammable fluids are not safe to be used as refrigerants. With the technological development, refrigeration industry has started working on flammable refrigerants. In this paper theoretical performance study on an ideal vapour compression refrigeration system with refrigerant R161 and R22 was done for a range of evaporating temperature ranging between -15°C to 10°C and constant condensation temperature of 55°C. Environmental properties, thermo-physical properties and chemical properties of R161 and R22 are compared. Theoretical results showed that R161 is more energy efficient than R22. The discharge temperatures are lower than that of R22. Thus the study is an attempt to suggest an eco-friendly alternative refrigerant to R22. It gives better graphical interface with direct access because the refrigerant R161 can be an excellent replacement for refrigerant R22 for medium temperature applications. In this paper theoretical cycle performance of both the refrigerants for the evaporator temperature range of -15°C to 10°C shows that R161 is a promising alternative refrigerant to R22. COP values are higher and discharge temperature is lower for R161 compared to R22. COP value with R161 can be improved by designing a refrigeration system especially for R161.

Keywords: COP - Coefficient of Performance, GWP - Global Warming Potential, ODP - Ozone Depletion Potential, R - Refrigerant

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INTRODUCTION

R161, a hydro fluoro carbon, (ethyl fluoride) is chlorine free and has been neglected due to its flammability, but expected improvement in performance of a refrigeration system using this refrigerant makes it attractive. Very little work has been reported in the literature. At international level, some research on R161 has been reported in China. Some researchers have worked on system performance with mixtures of R-161 and other refrigerants. Most of the research on R161 has been carried out in China. In India, very little, that too theoretical work has been reported. No experimental work has been reported yet. From literature review one can say, this is the time to develop a small scale refrigeration system for R161 and to test its performance. Yongmei Xuan et. Al. [11] suggested ternary mixture of HFC-161, HFC-125 and R143a as an alternative refrigerant to R502. Xuan et al [12] used ternary mixture of R161/R125/R134a (10/45/45% by weight) as drop-in for R404A in refrigeration application and found COP was nearly equivalent to R404A. Han et al [2] used ternary non-zeotrope mixture of R32/R125/R161 as an alternative to R407C and found that refrigeration capacity as well as coefficient of performance was superior to R407C. Guo (2009) compared the properties of R161 and R290 as a replacement to R22 and it was found that R161 posses excellent properties than R290 in the field of R22 replacement. Padalkar et.al. [8] in his simulation work for
5.27kW air conditioner split unit, observed that R161 has higher energy efficient, comparable cooling capacity, lower discharge temperature, lower power consumption and smaller refrigerant charge than R22 refrigeration system. Xiao-hong Han et al [12] have experimented refrigerant R161 as an alternative refrigerant to R410A in a small scale refrigeration system. Results of this experimentation show that R161 is a promising alternative refrigerant to R410A for small scale refrigeration system, which supply a valuable reference for the development of actual system of R161. Yingwen Wu et al have investigated the feasibility of R161 in comparison with R22 and R290, in residential air-conditioner. He studied the performance of 3.5kW residential air-conditioner, theoretically as well as experimentally. Results showed that R161 has better thermodynamics performance than R290. Peng Li et. al. analysed experimentally heat transfer and pressure drop characteristics of R161 in a horizontal smooth tube and observed that the evaporation heat transfer coefficient of R161 is about 10% to 25% higher than that of R22 when vapour quality exceeds 0.4. Most of the research on R161 has been carried out in China. In India, very little, that too theoretical work has been reported. No experimental work has been reported yet at national level.

II. CURRENT THEORY & PRACTICE– NUMERICAL APPROACH:

With increasing recognition of environment protection, a great deal of attention has been devoted to the negative environmental effect of CFCs and HCFCs refrigerant. Based on scientific findings, regulatory requirements and market pressure, the governing selection criteria for the new alternative refrigerants are changing. New long term alternative refrigerant should have not only zero ODP but it should have low GWP value – initially 150 or less with old requirements of suitability, safety, and material compatibility. At the same time it should have short (but not too short) atmospheric life. Most important, new alternative must offer high efficiency to reduce indirect contribution to the greenhouse effect. In refrigeration and air-conditioning industries, R22 is the most widely used refrigerant as far as possible. Complying with Montreal Protocol, R22 is being phased out in developed and developing countries. In recent years, R134a refrigerant has been recommended and applied in actual equipment to replace R22 by most researchers and refrigerant manufacturers. However, R134a has high global warming potential (GWP=1300). Therefore, R134a can be a long term alternative and can only be used as one of transitional candidates. Recently, the natural refrigerant R290 have been recommended as one of the refrigerant alternative. Thus, as on date, R290 and R161 are the two refrigerants for evaluation as a replacement to R22. Now we have sufficient information to build a real circuit. By taking the components shown below and connecting those with tubing and adding refrigerant first remove all air and moisture a real cooling system can be built.

By using fans to circulate air over the evaporator (the air will be cooled), and condenser (the air will be heated), switch on the compressor and we have a refrigeration machine. Sounds simple, but careful design and specification of components is needed. The control valve is a key component. Usually named as "Expansion Valve" this device regulates the superheat at the outlet of the evaporator. The temperature sensor at the outlet of the evaporator is connected to the valve to provide feedback on the adjustment of the valve. Most valves work automatically by means of a diaphragm, and are termed Thermostatic Valves, whilst other types are electronic.

It is really quite simple in principle. The properties of the Refrigerant or Working Fluid are known to a high level of accuracy and by measuring the pressure and temperature at points 1, 2, 3, 4 the P-h diagram can be established. In practice only two pressure measurements 2 and 3 are required. Instrumentation and computer techniques are now available which allow fast diagnostics of almost any system.

III. CALCULATION METHOD

For Cycle analysis the following Parameters of Vapour compression cycle are used.

1) **Pressure ratio is calculated by using**

\[
\text{Pressure ratio} = \frac{P_{\text{Cond}}}{P_{\text{evap}}}
\]

2) **Compressor work is calculated by using**

\[
W_c = \frac{\gamma}{\gamma - 1} P_1 V_1 \left\{ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right\}
\]

3) **Refrigerating effect is calculated by using**

\[
R.E = h_4 - h_1
\]

4) **Volumetric refrigeration Capacity is calculated by using**

\[
V.R.C = \rho_1 \times V.c
\]

5) **Coefficient of Performance is calculated by using**

\[
C.O.P = \frac{R.E}{P}
\]
IV. RESULTS DISCUSSIONS WITH GRAPHS

IV.1 Pressure Ratio Vs Evaporating Temp.

Above graph shows that pressure ratio decreases with increase in evaporating temperature. For R161, pressure ratio is slightly higher compared to R22. That difference in pressure ratio decreases from 2.5% to 1.4% with increase in evaporator temperature in the given range.

IV.2 Discharge temp. Vs Evaporating temp.

Above graph shows that discharge temperature of a refrigerant decreases with increase in evaporating temp. Discharge temp. for R161 is lower than that of R22 by 11.6% to 9%.

IV.3 COP Vs Evaporating temperature

Above graph shows, COP for R161 is higher than that of R22 by 29% to 15.3% in the evaporator range with increase in evaporator temp. Improvement in COP with R161 can be achieved by reducing power required which is much higher compared to R22.

IV.4 Power Vs evaporating temperature

Above graph shows, Power requirement with R161 is higher by 45% to 61% with increase in evaporator in the given evaporator range.

IV.5 Refrigerating effect Vs Evaporating temperature

Above figure shows, refrigerating effect for R161 is 87.4% higher than that of R22 at -10°C evaporating temperature.

IV.6 C.O.P. Vs Evaporating temperature

In above graph it can be seen that, volumetric refrigerating capacity increases with evaporating temperature. It is lower for R161 compared to R22.

V. Evaluation of Refrigerant R22 & R161

V.1 Thermo Physical Properties

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>MOL. WEIGHT (g/mole)</th>
<th>Normal B.P. (°C)</th>
<th>Critical Temp. Tc (°C)</th>
<th>Critical press. Pc (MPa)</th>
<th>Latent heat of Evap (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R22</td>
<td>86.47</td>
<td>-40.7</td>
<td>96.2</td>
<td>4.99</td>
<td>233.7</td>
</tr>
<tr>
<td>R161</td>
<td>48.06</td>
<td>-37.1</td>
<td>102.2</td>
<td>4.70</td>
<td>421.3</td>
</tr>
</tbody>
</table>

Molecular weight of R161 is lower than molecular weight of R22 by 45%. Latent heat of evaporation of R161 is 82% higher than R22 at normal boiling point. This indicates that per KW of cooling capacity, charge required of R161 is less by about 55% than that of R22. Also due to higher heat capacity, discharge temperature of R161 will be lower compared to R22. Normal boiling point of R161 is slightly lower than that of R22. Saturated pressure of R161 is slightly lower than that of R22 and it is similar to R290. Lower saturation pressure of refrigerant allows ease in manufacturing of refrigeration system and at low cost also.
V.2 Environmental Properties

<table>
<thead>
<tr>
<th>Environmental Properties</th>
<th>ODP(R11=1)</th>
<th>GWP10 (R12=1)</th>
<th>Atm. Life (Yrs)</th>
<th>POCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R161</td>
<td>0.055</td>
<td>12</td>
<td>0.21</td>
<td>5.5</td>
</tr>
<tr>
<td>R22</td>
<td>0.180</td>
<td>0.21</td>
<td>11.9</td>
<td>~1</td>
</tr>
</tbody>
</table>

R161 is a non-ozone depleting refrigerant whereas R22 is a non-zero ODP refrigerant. GWP value of R161 is 12 which is very low value compared to R22. Photo Chemical Ozone Creation Potential (POCP) value of R161 compared to R290 is much lower. More recently hydrocarbons have been compared in terms of their photochemical ozone creation potential or POCP.

V.3 Safety characteristics:

<table>
<thead>
<tr>
<th>Safety Properties</th>
<th>LFL Kg/m3</th>
<th>LFL volume%</th>
<th>Burning Velocity Cm/s</th>
<th>Combustion heat MJ/Kg</th>
<th>Toxicity PPM</th>
<th>Safety Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>R161</td>
<td>0.038</td>
<td>3.8</td>
<td>38.3</td>
<td>26.6</td>
<td>1800</td>
<td>A3</td>
</tr>
</tbody>
</table>

For the development of R161, flammability and toxicity are very important parameters due which it was neglected alternative for so many years. R22 is non-flammable and non-toxic. R290 and R161 are classified as A3 as per ASHRE34-2010. However lower flammability limit (LFL) for R161 is 0.075Kg/m3 by mass whereas for R290 it is 0.038Kg/m3. LFL value of R161 is approximately double the LFL value of R290. To avoid risk due to flammability, charge in the system should be well below the LFL. The European standard EN378 gives the safety requirements for the use of flammable refrigerants in various applications. As per the EN378 and ASHRAE15, the charge limit is about 15g/m3 for R161 and for R290 it is 8g/m3. This shows the more scope for mass of R161 in a system. Burning velocity and combustion heat of R161 are lower than R290. Toxicity safe index for R161 is higher than R22 and R290. From toxicity tests it has been observed that Occupational exposure limit (OEL) of R161 is 1822 ppm when mouse sucks the refrigerant for 28 days. The OELs for R22 and R290 are 1000.

VI. Theoretical cycle performance of R22 and R161 at condensing temperature of 55°C and evaporating temperature of –10°C.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>PR</th>
<th>RE</th>
<th>P</th>
<th>VRC</th>
<th>Td</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R22</td>
<td>6.1</td>
<td>131.04</td>
<td>62.92</td>
<td>1997</td>
<td>98.85</td>
<td>2.08</td>
</tr>
<tr>
<td>R161</td>
<td>6.28</td>
<td>245.60</td>
<td>93.42</td>
<td>1832</td>
<td>87.67</td>
<td>2.62</td>
</tr>
</tbody>
</table>

\% deviation of R161 from R22

|                | 2.2 | 87.4 | 48.4 | 8.29 | 11.4 | 26.3 |

VII. CONCLUSION

In order to great deal of attention has been devoted to the negative environmental effect of CFCs and HCFCs refrigerants. Based on scientific findings with regulatory requirements the refrigerant R161 may use as excellent replacement for refrigerant R22 for medium temperature applications. In this paper, Theoretical cycle performance of both the refrigerants for the evaporator temperature range of -15°C to 10°C shows that R161 is a promising alternative refrigerant to R22. COP values are higher and discharge temperature is lower for R161 compared to R22. COP value with R161 can be improved by designing a refrigeration system especially for R161 extensively as per the nature of work.

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