COMPUTATIONAL ASSESSMENT OF HFC-161 FOR AIR CONDITIONING APPLICATIONS

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ABSTRACT:

HFC-161 (Fluroethane) is being considered as an alternative to HCFC-22 in air conditioners. It has zero ODP and ultra-low GWP. The thermophysical properties of HFC-161 are very close to HCFC-22 except flammability. The lower flammability limit of HFC-161 is 3.8% by volume in air, which is almost double of HC-290. It is reported that it has good compatibility with mineral oil. HFC-161 has not yet been classified by ASHRAE Standard 34 for safety.

This paper discusses the simulated results on the suitability of HFC-161 as an alternative to HCFC-22 for room air conditioning applications. The simulation has been done using computer simulation tool for drop-in conditions as well as for some design variations including compressor capacity and condenser area. The results show that the cooling capacities are comparable with HCFC-22 and HC-290. COP is higher than both HCFC-22 and HC-290. The discharge temperatures are lower than HCFC-22 but higher than HC-290.

EN 378 specifies the allowable charge in a closed space to avoid any risk due to flammability. While the limit is about 8g/m³ for HC-290, it is about 15 g/m³ for HFC-161. For an air conditioner with a nominal cooling capacity of 5.2 kW, one has to take special efforts to meet this limit for HC-290. However, it may be possible for HFC-161 to meet EN 378 without many changes in the heat exchanger configurations.

Keywords: HFC-161, HCFC-22, air conditioner

[1] INTRODUCTION

HCFC-22, an extensively used refrigerant in air conditioning, is controlled substance under Montreal Protocol. As per accelerated phased out schedule of Montreal Protocol, it has to be phased out by 2020 and 2030 in non-article 5 and article 5 countries respectively. The implementation of this schedule for developing countries like India was challenging task which actually sets the phase out target of 30-40% by 2015. The literature in open domain show that there are a few alternatives available to HCFC-22. The most promising alternatives are R-410A and HC-290. R-410A (blend of R32/R125 50%/50% by weight) has an issue of high GWP and high operating pressures. It needs new system redesigns. HC-290 in air conditioner, consideration must be given to flammability [1, 6].

This paper discusses the potential of HFC-161 as an alternative to HCFC-22 in air conditioning application. HFC-161 is environment friendly and it has many similar properties compared to HCFC-22 except flammability. It has zero ODP and GWP of about 12. It is colourless and odourless gas. The vapour pressure of HFC-161 is marginally lower than HCFC-22. The latent heat of HFC-161 is about 82% higher than that of HCFC-22. It has good compatibility with POE oil. The POE is hygroscopic and thus any moisture presence in system may lead the breakdown of oil and refrigerant. The LFL of HFC-161 is 3.8% by volume. To avoid risk due to flammability, HFC-161 charge is to be limited inside the system.The literature available about use of HFC-161 in air conditioning is very little.

Some researchers reported studies of system performance with mixtures of HFC-161and other refrigerants. However, performance with alone HFC-161 has not been reported yet. Han et al. [3] used ternary non-azeotrope mixture of HFC-32/HFC-125/HFC-161 as an alternative to R-407C and found that refrigeration capacity as well as coefficient of performance was superior to R-407C. Xuan et al. [2] used ternary mixture of HFC-161/HFC-125/HFC-143a (10/45/45% by weight) as drop-in for R-404A in refrigeration application and found COP was nearly equivalent to R-404A. Wu et al. [7] investigated the feasibility of HFC-161 in by experimenting 3.5 kW capacity air conditioner. The result showed that the cooling capacity of HFC-161 was 7.6% lower and EER was 6.1% higher than that of HCFC-22. The optimized charge of HFC-161 was 43% of HCFC-22 charge. The discharge temperature of HFC-161 was 6°C lower than that of HCFC-22. HFC-161 is also recommended by some researchers as replacement option to R410A.

[2] HFC-161 THERMOPHYSICAL PROPERTIES

The thermophysical properties of three substances, HFC-161, HC-290 and HCFC-22 are compared. The refrigerant properties are used from computer simulation tool which uses NIST REFPROP database of refrigerants. The physical properties like critical pressure and temperature of HFC-161 are similar to HC-290 and very close to HCFC-22. The molecular weight of HFC-161 is nearly 55% of HCFC-22 which also indicates the percentage charge required under drop-in conditions. The vapour pressure of HFC-161 is closer to HC-290 and is slightly lower than HCFC-22.

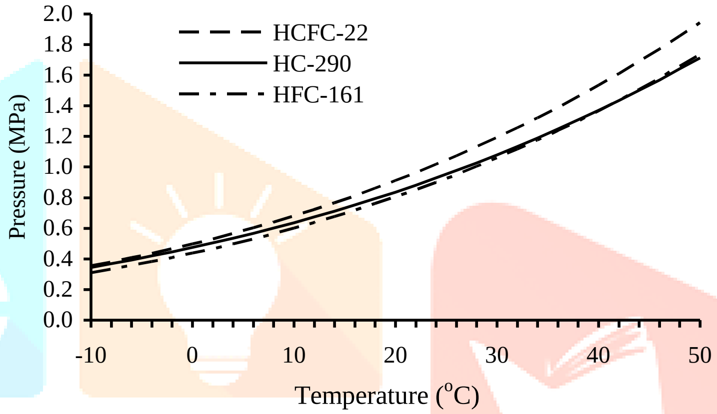

Figure: 1. Saturation temperature vs pressure of HCFC-22, HC-290 and HFC-161

[Figure-1] shows the comparison of vapour pressure for HCFC-22, HC-290 and HFC-161. HFC-161 and HC-290 have latent heat of vaporisation about 82% higher than that of HCFC-22 at normal boiling point. This shows the refrigerant charge required per kW of cooling capacity is much lower. For same cooling capacity, the required charge of HFC-161 would be around 55% of HCFC-22. The volumetric cooling capacity of HFC-161 is about 95% that of HCFC-22. Therefore, HCFC-22 air conditioner when retrofitted with HFC-161 would give nearly equivalent cooling capacity. The discharge temperature with HFC-161 would be lower due to its high specific heat capacity as compared with HCFC-22. The compressor efficiency with HFC-161 may be slightly higher than HCFC-22 due to lower pressure loss in compressor valves. Experiments showed that HFC-161 has good compatibility with polyol ester oil (POE) and poor compatibility with poly alkyl glycol (PAG). Wang Q *et al*. [5] showed that HFC-161 blend and POE are miscible and had a negligible impact on saturation vapour pressure of mixture. The manufacturer recommends Mineral Oil with relative low viscosity. The most suitable oil for HFC-161 and influence of addition quantity is not known.

[3] SAFETY AND MATERIAL COMPATIBILITY

The important issues with HFC-161 are flammability and long term toxicity. HC-290 is classified as Class 3 (high flammability fluid) by ASHRAE standard 34 for safety however HFC-161 yet is not covered in this standard. Table 1 presents the flammability property data for HFC-161 and HC-290.

Table: 1. Flammability of HFC-161 and HC-290

Property		HC-290	HFC-161
		Quantity	
Lower Flammability Limit (LFL)	By volume (%)	2.1	3.8
	By mass (kg/m3)	0.038	0.075
Upper Flammability Limit (UFL)	By volume (%)	9.5	10
	By mass (kg/m3)	0.177	0.196
Auto ignition temperature (°C)		470	Not known

There are some standards which reveal various safety precautions while using flammable refrigerants in air conditioning and heat pump applications. To avoid the risk due to flammability, charge size in the system is required to be limited so that it is well below the LFL. The European standard EN378 allows use of flammable fluids in a broad range of applications, if safety requirements are fulfilled. As per ASHRAE 15, the charge limit is about 8 g/m3 for HC-290. For HFC-161, it is about 15 g/m3. For 5.27 kW air conditioner, the allowable HFC-161 charge could be about 637 g as against 322 g for HC-290 with specific location height of equipment. DIS ISO 5149 allows the varying charge quantities depending upon equipment type and location. The higher value of HFC-161 shows that the less changes are needed in existing system components for better safety. To reduce risk of any ignition, one needs to avoid electrical spark, hot surfaces, static electricity or a flame from brazing torch when equipment is being serviced. The electrical joints needs to be properly sealed. HC-290 and HFC-161 refrigerants are heavier than air – any enclosed area into which refrigerant has leaked must be ventilated to disperse the refrigerant. This is especially important if the refrigerant leaks below ground level. No information available for long term toxicity of R161.

HFC-161 is compatible with almost all construction materials used in air conditioner and heat pump applications [8]. It is compatible with all metals and plastics however no data is available for compatibility with elastomers.

[4] THE CYCLE AND SYSTEM SIMULATION

The objective of this section is to compare theoretical cycle performance and actual system performance simulation of HFC-161 with both HCFC-22 and HC-290. The similar computational methodology was adapted as given by Padlkar et al [4].

[4.1] THE THERMODYNAMIC CYCLE PERFORMANCE

The parameters for HFC-161, HC-290 and HCFC-22 are calculated at standard rating conditions of an evaporating temperature 7.2 ^{o}C, condensing temperature 54.4 ^{o}C, return gas temperature 35 ^{o}C, and liquid temperature entering expansion valve 46.1 ^{o}C. Isentropic and volumetric efficiencies of compressor assumed are 85 and 90 percent respectively. **[Table-2]** presents comparison of HFC-161 with HCFC-22 and HC-290.

Table: 2. Theoretical cycle performance of HCFC-22, HC-290 and HFC-161.

Refrigerant	Pe (MPa)	Pc (MPa)	PR	SCD (m3/MJ)	COP	Q (kW)	W (kW)	Td (oC)
HCFC-22	0.625	2.146	3.43	0.280	3.87	5.260	1.358	91.6
HC-290	0.588	1.883	3.20	0.331	3.85	4.446	1.153	73.2
HFC-161	0.551	1.920	3.48	0.307	3.97	4.803	1.208	85.6

The COP is highest for HFC-161 than both HCFC-22 and HC-290. The cooling capacity of HFC-161 is marginally less than that of HCFC-22 but higher than HC-290 when used drop-in conditions. The power consumption and discharge temperature for HFC-161 are lower than HCFC-22 and higher than HC-290. Therefore, HFC-161 removes the drawbacks of both HCFC-22 and HC-290.

[4.2] THE SYSTEM PERFORMANCE SIMULATION

In this study, a typical 5.2 kW capacity room air conditioner-split unit designed for HCFC-22 was selected for performance evaluation with HFC-161. The simulation has been done for HFC-161 and its performance is compared with both HCFC-22 and HC-290. The input data required for system simulation were collected from the original equipment and compressor manufacturers. Initially an existing system for HCFC-22 has been considered to validate the simulation tool. The simulated results with HCFC-22 are with in ±4% with the experimental.

After establishing the baseline performance with HCFC-22, some optimization study was carried out with various condenser area and higher capacity compressor. The condenser area variation obtained primarily by varying tube diameters to achieve the best possible performance. The following different cases are considered for simulation of HCFC-22, HFC-161 and HC-290.

Case 1: Baseline HCFC-22 and Drop-in for HFC-161 and HC-290 with optimized charge
Case 2: Test with 5% higher capacity compressor
Case 3: Test with 30% higher condenser area
Case 4: Test with 4.75 mm OD condenser tube

[4.3] RESULTS AND DISCUSSION

[Figures-2] to **[Figures-5]** show the COP, cooling capacity, power consumption, and discharge temperatures for various cases considered. Constant evaporator superheat was maintained during all simulated cases to ensure vapour before compressor.

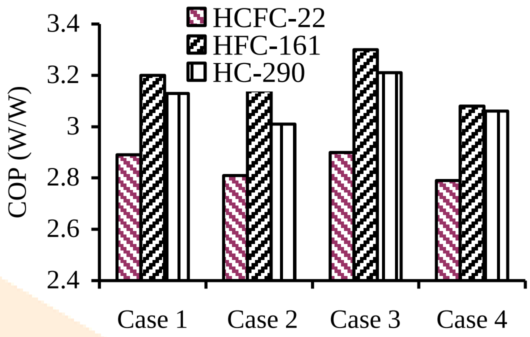

Figure: 2. COP of HCFC-22, HC-290 and HFC-161 for various cases

Coefficient of Performance: The baseline COP with HCFC-22 is 2.89. For both HFC-161 and HC-290, the coefficient of performance has been higher for all cases compared to HCFC-22. The highest COP with HFC-161 is 3.3 with 30% more area condenser. For condenser with 4.75 mm OD tube, HFC-161gives 10.4% higher COP than that of HCFC-22.

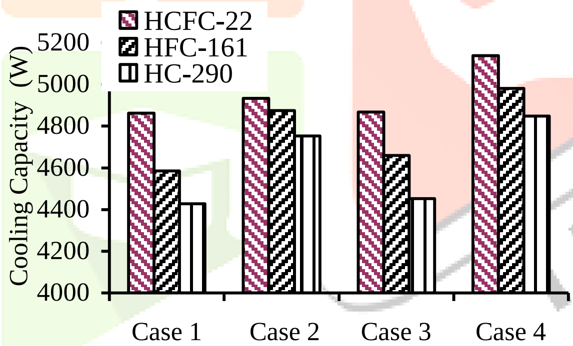

Figure: 3. Cooling capacity of HCFC-22, HC-290 and HFC-161 for various cases

Cooling Capacity: HCFC-22 baseline cooling capacity is 4.86 kW. In all cases considered, the cooling capacity with HFC-161 varies in the range 94.3% to 98.8% to that of HCFC-22 whereas it varies in the range 102.6% to 104.6% to that of HC-290. For HFC-161, the highest cooling capacity is 4980W and it is in case 4. This is higher by 2.7% than HC-290.

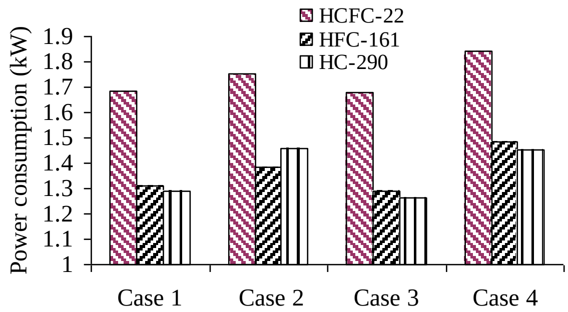

Figure 4. Power consumption of HCFC-22, HC-290 and HFC-161 for various cases

Power Consumption: For baseline test, the power consumption with HCFC-22 is 1.68 kW. The power consumption with HFC-161 is lower in the range 19.3% to 23% than that of HCFC-22 and is comparable with HC-290. In the case 4, it is 19.3% lower that that of HCFC-22.

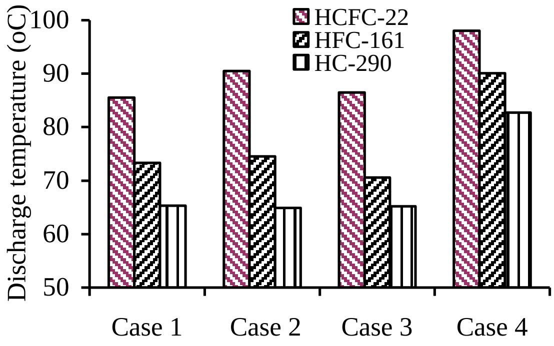

Figure: 5. Discharge temperature of HCFC-22, HC-290 and HFC-161 for various cases

Discharge Temperature: In all cases the discharge temperature with HFC-161 are lower in the range 7.9^{o}C to 16^{o}C than that of HCFC-22. For HC-290, it is lower in the range of 5.4^{o}C to 9.6^{o}C than that of HFC-161.

Charge of Refrigerant: Under drop-in, HFC-161 and HC-290 optimised charge are 53.2% and 50.5% of HCFC-22 respectively. In all cases, HFC-161 charge varies in the range 33% to 67% to that of HCFC-22. Whereas for HC-290, it varies in the range 30% to 63% to that of HCFC-22. With 4.75 mm condenser tube outer diameter, HFC-161 and HC-290 charge are 33% and 30% to that of HCFC-22 respectively.

[6] CONCLUSIONS

HFC-161 can be considered an alternative to HCFC-22 in air conditioners. LFL of HFC-161 is almost double of the HC-290 which indicates more quantity of HFC-161 may be allowed when used for room air conditioner applications.

The simulated performance shows that HFC-161 is more energy efficient than both HCFC-22 and HC-290. The cooling capacity is comparable to HCFC-22 and more than HC-290. The discharge temperatures are lower in the range 7.9^{o}C to 16^{o}C than that of HCFC-22. For HFC-161, the power consumption is comparable with HC-290 and 19.3% to 23% lower than that of HCFC-22. For all cases considered, HFC-161 charge varies in the range 33% to 67% that of HCFC-22.

In the case of condenser with 4.75 mm outside diameter, the HFC-161 has charge 33% that of HCFC-22 which is in limit of EN378 and COP is 10.4% higher than that of HCFC-22 with minor loss of cooling capacity by 3%. It concludes that HFC-161 has greater potential to replace HCFC-22 in room air conditioners.

NOMENCLATURE

ODP: Ozone depletion potential
GWP: Global warming potential
HCFC: Hydrofluorocarbon
HC: Hydrocarbon
Q: Cooling capacity
HFC: Hydrofluorocarbon
LFL: Lower flammability limit
UFL: Upper flammability limit
W: Power consumption
COP: Coefficient of performance
Pe : Evaporating pressure
Pc : Condensing pressure
Td: Discharge temperature
PR : Pressure ratio
SCD: Specific compressor displacement
EN: European Nation

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Author[s] brief Introduction

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