International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Special Issue - AMET-2019

Performance Assessment of Air Conditioner with HC-290 And HFC-410A Alternative Refrigerants to HCFC-22

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Abstract - **This paper presents the simulation results of various refrigerants in comparison with baseline refrigerant HCFC-22. HCFC-22 is ozone depleting substance and contributes to global warming. According to the revised phase out schedule of Montreal Protocol, HCFC-22 has to be phased out by 2030. There is an urgent need to search an alternative to HCFC-22 in ACs. The alternative refrigerants used for study are HC-290 and HFC-410A which has zero ODP and low GWP value. A 3.52KW capacity split air conditioner is considered for study purpose. The air conditions required for study are directly taken from Indian Standard IS 1391 (1992) Part I. First the baseline test is carried out with HCFC-22. The performance of HC-290 and HFC-410A is obtained from simulation by using ORNL simulation tool. Theoretical and simulation results show that the charge required for HC-290 and HFC-410A is comparatively low and the discharge temperature of HC-290 is lowered as compared to HCFC-22 and HFC-410A. EER of HCFC-22 is lower than HC-290 but greater than HFC-410A. The major problem associated with HC-290 is its flammability characteristics. Standards like EN 378 specify the allowable charge of HC-290 in a closed space to avoid risk due to flammability.**

Key words: HCFC-22, HC-290, HFC-410A Alternative refrigerants, GWP, ODP, ORNL.

I. INTRODUCTION

According to Montreal Protocol (1987) and Kyoto Protocol (1997) certain CFC's and R's have been banned in developed countries and are going to be banned in developing countries until 2030.So it has been a demand of time to search for promising alternative refrigerants.

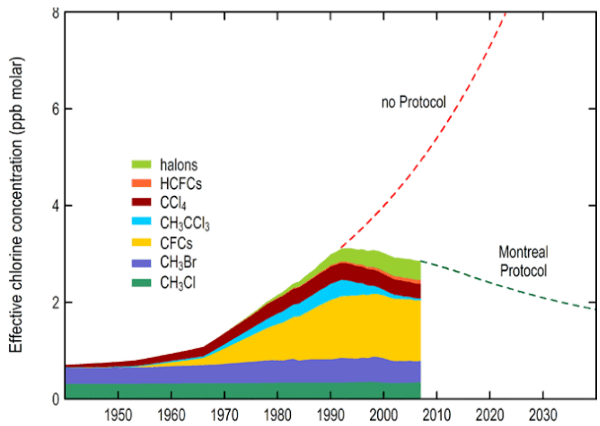


Fig. 1 Effective chlorine and Montreal Protocol [8]

As per the new regulatory policy, a refrigerant is required to have zero ODP and a very low GWP values. The alternate refrigerants currently being proposed have zero ODP values but a very high GWP value. This has led researchers to propose various new refrigerants with low GWP value.

The refrigerant used in an Air conditioning system is also important factor for the efficient working of system. HCFC-22 is one of the most common refrigerants used in HVAC sector. But, due to its environmental nuisance properties, like high GWP value, it is being phase out. For developing countries, the Montreal Protocol suggests to phase out HCFC-22 as well as other HCFCs, harmful to the environment before 2030. At present HCFCs are being replaced by HFCs and natural refrigerants such as carbon dioxide and ammonia as alternate refrigerants.

The various promising alternatives being considered seriously are HFC-410A, HC-290, HFC-161, HFC-32 etc. HFC-410A, a mixture of HFCs has zero ODP but it has high global warming potential of around 2100 and thus attracted the world-wide attention. This resulted in the restricted long-term use of R-410. R-32 has moderate GWP and is mildly flammable. In this context, HFC-290 stood important. Apart from zero ODP value, it has a very low GWP value of 20. HFC-290 was not considered as a potential candidate due to its flammable properties. Extra precautions need to be taken while using them in Air conditioners. A recent study has shown that the use of HFC-290 in Air conditioners is not that harmful, as it was previously thought of. Thus, HFC-290 is again considered as a potential alternate refrigerant. As per ASHRAE

Standard 34, HC-290 is classified as Class 3 (high flammability fluid) whereas ISO 817 and EN 378 classify HC-290 as A3 class fluid (low toxicity and high flammability). LFL of HC-290 is 0.038 kg/m3 by mass and 2.1% by volume. As per the existing regulations, the flammability risk can be avoided if the HC-290 charge in the system is less than 20% of the lower flammability limit (LFL).

II. LITERATURE REVIEW

Number of theoretical and experimental studies are carried out in order to investigate the performance of alternative refrigerants for HCFC-22. Following are the various studies carried out by researchers.

Sapali et al. (2017)[1] presented the performance investigation of HC-290 as a substitute to HCFC-22. Thermodynamic performance analysis is carried out with standard vapour compression cycle with different evaporating temperature and constant condensing temperature. Results showed that lower discharge temperature for HC-290 and mass flow rate required is 50% of HCFC-22. COP of HC-290 is slightly less than HCFC-22 but can be improved with specially designed system.

Padalkar et al. (2014)[2] reported simulation and experimental study of HC-290 as a substitute for the HCFC-22. In order to reduce charge of HC-290 different type of condensers used. Experimental results showed that charge required for HC-290 is 50% of HCFC-22, cooling capacity is 7% lower and EER is 3.7. Safety aspects are discussed and considered in paper.

Antunes et al. (2014)[3] focused on experimental study of alternative refrigerantsHFC-32, HC-290 and HFC-410A as a substitute for the HCFC-22. Experimental tests performed at steady state. The results obtained in steady state show that use of HC-290 gave the maximum values of refrigeration capacity, exceeding the HCFC-22 in refrigeration applications. Maximum values of COP obtained by using hydrocarbon (HC).

Venkataiah et al. (2013)[4] presented simulation result for 5.2 KW capacity air conditioner by comparing various refrigerants such as HCFC-22, HFC-134a, HFC-407C, HFC-410A, HFC-404A, HFC-507A. Results showed that R290 require lower discharge temperature, pressure ratio and mass flow rate as compared other refrigerants. However, COP is not greater than HCFC-22.

Devottaa et al. (2005)[6] presented experimental performance and simulation study of HC-290 as drop in substitute for HCFC-22. Obtained experimental results show that lower cooling capacity for HC-290 is 6.6% lower for the lower operating conditions and 9.7% lower for the higher operating conditions with respect to HCFC-22. HC-290 COP value was 7.9 higher for the lower operating conditions and 2.8% higher for the higher operating conditions. Energy consumption was lower in the range of 12.4-13.5% than HCFC-22. The discharge pressures for HC-290 were lower in the range 13.7–18.2% than HCFC-22. In both heat exchangers, the pressure drop for HC-290 is lower than HCFC-22.

III. TEST CONDITIONS

Test conditions for the performance evaluation of split air conditioner are described in IS1391 (B.I.S 1992) part 1. This standard prescribes performance requirements, test conditions and corresponding test procedures of split air conditioner. For the evaluation of energy efficiency of split air conditioner, capacity rating test is an important test. CRT is an important for calculating magnitude of cooling capacity and energy consumption. The various test conditions of performance evaluation are indoor and outdoor unit. The test conditions in the form of DBT and WBT are as given in following table:

Table 1: - Test conditions [7]

Test	DBT(°C)	WBT(°C)
Indoor Room Conditions	27	19
Outdoor Room Conditions	35	24

IV. SIMULATION

A 3.52 KW split air conditioner is considered for study purpose. The simulation tool that has been used for this purpose is DOE/ORNL heat pump design model. The DOE/ORNL Heat Pump Design Model is a research tool for use in steady-state and quasi-steady-state design analyses of extensive thermal system configurations and HVAC applications. As this is a hardware-based model, the user can specify the inputs of each component, i.e. compressor, heat exchanger, fan and pump, etc. The program analyzes steady-state performance for indoor and outdoor operation conditions provided by the user. The performance of air conditioners with HCFC-22 has been considered as base line data.

The required input data for system simulation were collected from original compressor manufacturer and equipment manufacturer. The input data required for study is as shown in fig.2.

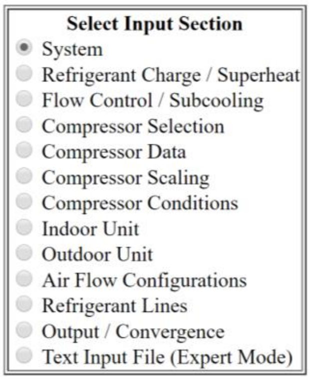


Fig.2 Inputs required for simulation study

Table 2: - Specifications of unit under test

Component	Parameter	
Compressor	Cooling capacity (KW)	5.090
	EER(W/W)	3.25
	Displacement(m^3)	$2.88*10^{-5}$
Condenser	Frontal area (m^2)	0.422
	Tube hydraulic diameter(mm)	9.52
	Number of tube rows per pass	19,14,11,6
	Fin spacing(mm)	19,25.4
	Air flow(m^3/h)	1328.6259
Evaporator	Frontal area (m^2)	0.316
	Tube hydraulic diameter(mm)	6.35
	Number of tube rows per pass	2
	Fin spacing(mm)	19,25.4
	Air flow(m^3/h)	900
Capillary	Numbers	01
	Diameter(mm)*Length(mm)	1.52*610

First the baseline performance for the split air conditioners has been established. An existing system data for HCFC-22 is used to validate the simulation tool. Existing system with HCFC-22 consists a compressor, heat exchangers, a capillary tube, and connecting tubing. Table 1 presents the system component specifications considered for simulation. In case of heat exchangers, the same frontal areas are considered.

To avoid the risk due to flammability it is necessary to use minimum possible charge of HC-290 in the split air conditioners. LFL of HC-290 is 0.038 kg/m. As per latest EN 378, DIS ISO 5149 and EN 60335-2-40 for room area of 14 m^2 the allowable HC-290 charge could be 300 g provided that the installation height of the

unit is 2.2m. There is an opportunity to reduce the size of heat exchanger tubing especially condenser with HC-290 for equivalent capacity of HCFC-22 due to good transport properties of HC-290. Therefore, condenser tube OD of 9.52 mm, 7.92 mm, 6.35 mm, 4.75 mm and 3.18 mm, are evaluated. For all the evaluated tube diameters, connecting tubing data liquid line, suction line and discharge line considered are 6.35 mm, 12.7 mm and 9.52 mm respectively. The evaporator specifications considered are same for HC-290 and HCFC-22.

V. REFRIGERANTS PROPERTIES

The various properties of refriferants required for study purpose contains thermodynamic, thermophysical and chemical properties. The chemical properties contain toxicity, flammability compatibility with other substance such as compressor lubricant and construction materials.

Table 3 presents comparison of thermodynamic and thermophysical properties of the three refrigerants which may have effect on system performance. As normal boiling point and critical parameters of these three refrigerants are close to each other they implicate similar working condition

Table 3: - Properties of various refrigerants [5]

Sr. No.	Property	Unit	R22	R290	R410A
1	Chemical formula	-	CHCLF2	C3H8	50%CH2F2/ 50%CHF2CF3
2	Lubricant	-	Mineral oil	Mineral oil	PVE oil
3	Molecular weight	kg/kmol	86.48	44.1	72.585
4	Normal Boiling Point	°C	-40.8	-42.1	-51.4
5	Critical Temperature	°C	96.1	96.7	71.358
6	Critical Pressure	Mpa	4.99	4.25	4.90
7	Liquid state density(@ 25℃)	kg/m3	1190	493	459.53
8	Safety Class		A1	A3	A1
9	ODP		0.05	0	0
10	GWP		1810	20	2000

VI. SAFETY CONSIDERATION

HC-290 is flammable and its flammability characteristics has to be study from safety aspects. Various domestic and international standards have designed for safety consideration of HC-290. As per EN 378 HC-290 is classified as A3 class type fluid i.e. highly flammable and low toxicity fluid. As per this norm for safe use of HC-290 it should be less than 20% of its lower flammable limit. For safety consideration charge should be reduced. the reduction in charge is possible with reduction in the internal volume of the systems, including heat exchangers, liquid line, and receiver. Use of mini-channel in compact heat exchangers enables refrigerant charge reduction compared to other options without affecting the system performance. In some applications, this safe limit is extended up to as 25% of LFL

VII. RESULTS AND DISCUSSION

1) <u>Power consumption: –</u>

HC- 290 has better thermo-physical properties than HCFC-22 i.e. it has low mass flow & low compressibility index. Fig.3 shows HC-290 required 6% lower input than that of HCFC-22 hence HC-290 have lower power consumption than HCFC-22 where as HFC-410A consumes maximum power for its performance.

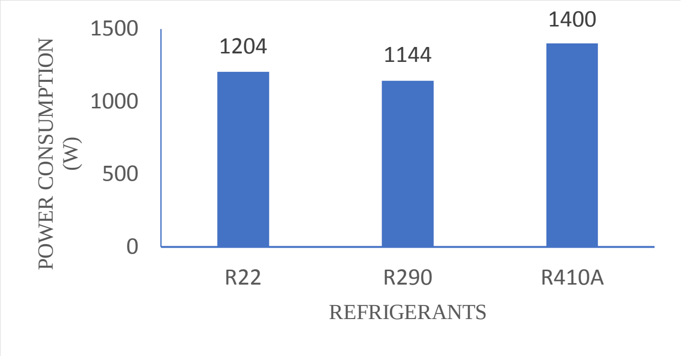


Fig.3. Power consumption of HCFC-22, HC-290, and HFC-410A

2) EER: –

As per simulated results, EER of HCFC22 is 2.92. Also, from fig.4, HC-290 has less energy consumption & higher EER than HCFC-22. Under drop in condition, there is improvement in EER of HC-290 than HCFC-22 by 5.13%. HFC-410A has lowest EER i.e. 2.7.

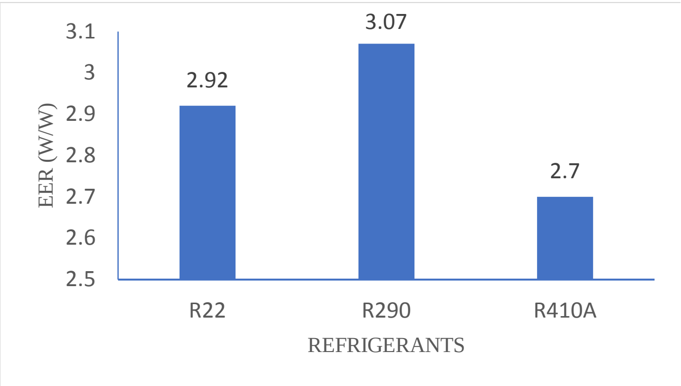


Fig. 4. EER of HCFC-22, HC-290 and HFC-410A

3) Discharge temperature: –

Fig. 5 represents the variation of compressor discharge temperature of HCFC-22, HC-290 and HFC-410A.Under drop in condition HC-290 gives discharge temperature of 75℃ which is lesser than the HCFC-22 and HFC-410A.

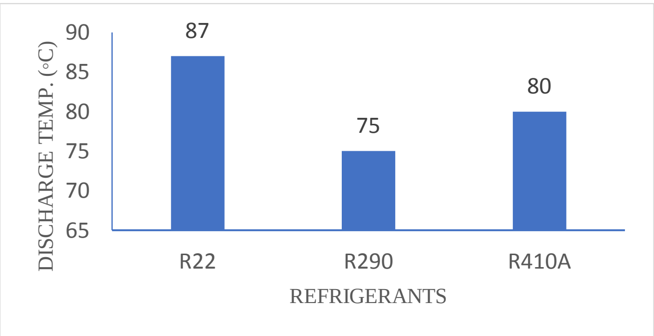


Fig.5. Discharge temperature of HCFC-22, HC-290 and HFC-410A

4) Charge: –

Fig. 6 shows the variation of charge required for various refrigerants in air conditioner. HC-290 required minimum charge for its performance i.e. 56% of HCFC-22 and 23% less than HFC-410A.

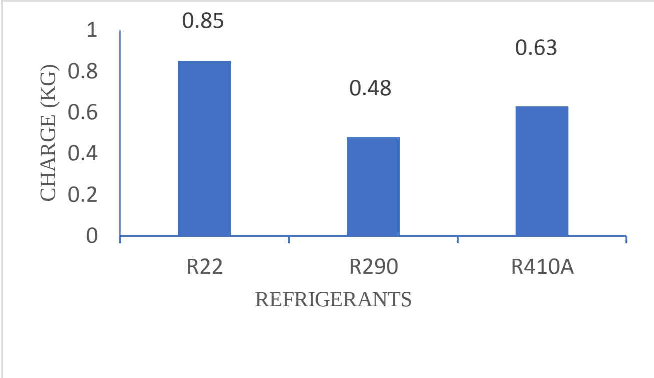
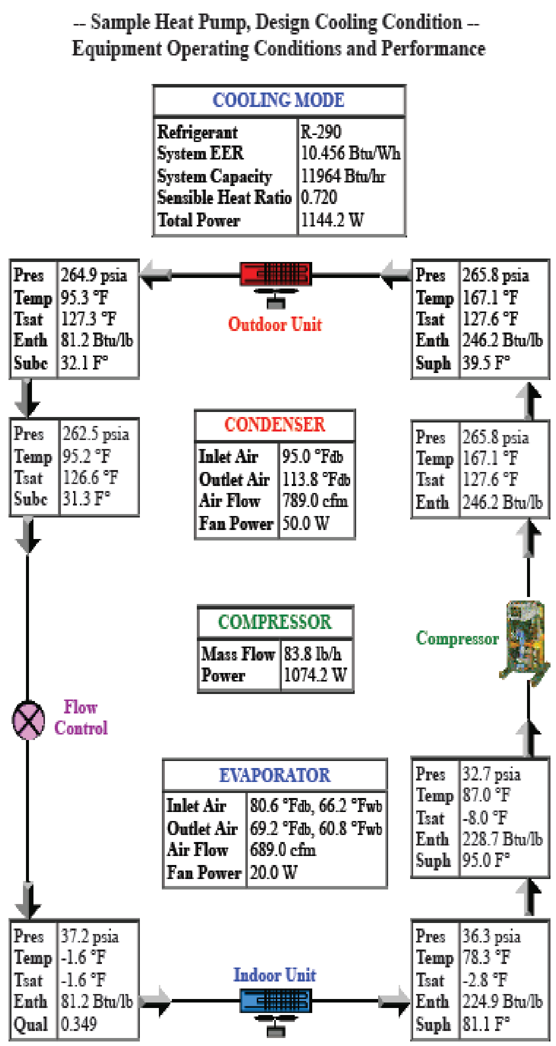


Fig. 6. Charge of HCFC-22, HC-290 and HFC-410A



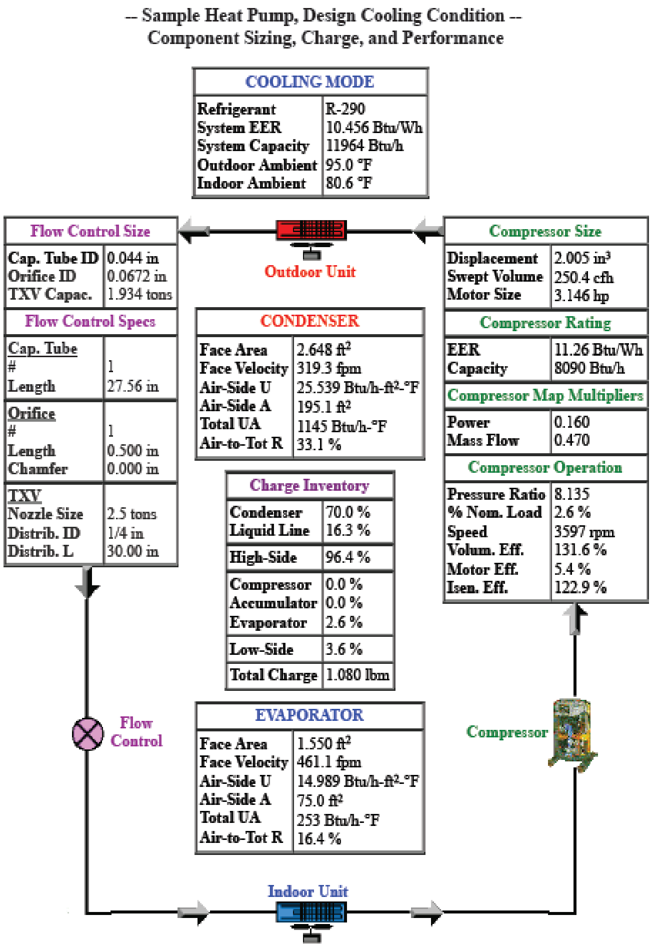


Fig. 7. Outputs of simulation software

VIII. CONCLUSIONS

The simulated result and thermophysical properties show that HC-290 is far better than HCFC-22 and best promising alternative to HCFC-22. The EER of HC-290 is Higher than both HCFC-22 and HFC-410A also Discharge temperature of HC-290 75°C which is Lower than HCFC-22 and HFC-410A.Because of Lower discharge temperature of HC-290, compressor life is increases.

Refrigerant COP value for HC-290 is slightly lower, but it can be improved by specially designing a refrigeration system for it. Power consumption for HC-290 is 1144 w which is less than HCFC-22 and R410 A. If we consider the charge factor then charge required for HC-290 is almost 56 % lesser than HCFC-22

IX. ACKNOWLEDGEMENTS

We are grateful for all the support given by our head of department of Mechanical Engineering and the principal of MIT College of Engineering, Pune.

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