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Analysis of Effectiveness of Eco-Friendly Refrigerant Combinations in a Domestic Air Conditioner System: A Review

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I. INTRODUCTION

It has become a worldwide concern that the role of refrigerants is considered as vital for their impact in the ozone layer depletion along with all other sources pertaining to global warming. Though the traditional refrigerants possess many desirable thermodynamic properties like higher energy efficiency, stability, flammability and non-toxic characteristics, the hazardous effects these refrigerants could cause on the stratospheric region and the consequent increase in the temperature of the earth have compelled the scientific community to find suitable eco-friendly alternatives to these toxic refrigerants. This problem requires urgent attention given its global proportions affecting lives of the people.

In Vapor Compression System (VCS), HCFC 22 is prominently used as working fluid in India. Due to its aggressive environmental effects like high Ozone Depleting Potential (ODP) and Global Warming Potential (GWP), the refrigerant will be phased out completely by the year 2020 in India according to Montreal and Kyoto Protocol. In developed countries, where such facilities were in use for many years now, HCFC 22 production has been limited and banned from use as working fluid in air conditioning systems. In order to solve the ill-effects caused by traditional refrigerants like ozone layer depletion and its associated problems, research works are carried out widely around the world to identify appropriate alternative refrigerant mixtures for application in residential air conditioners and heat pumps.

II. THE EFFECTIVENESS OF A VARIETY OF ALTERNATIVE REFRIGERATING MEDIUM AND THEIR MIXTURES:

The individual researchers as well as companies producing refrigeration equipment have begun to investigate substitutes for conventional refrigerants to reduce environmental hazards. During 1920s 'Carrier and Water Fills' investigated refrigerants for chillers with improved performance and potential to replace R22. The approach was based on characteristics such as toxicity, flammability, boiling point, instability, molecular weight, ozone depleting potential and commercial availability. Around 200 pure compounds which could be combined to make zeotropic mixtures have been analyzed under this investigation by Vineyard *et al*. (1989).

Individual works by many researchers/groups have also been reported in this area. The research works on various alternative refrigerants in varied aspects over the years have been discussed below.

The work of Fischer & Sand (1993) was aimed at finding a chlorine- free alternative refrigerant for R-22 used in air-conditioning systems. The study offered nine ternary blends having E-125 and eleven ternary blends without E-125 as alternatives. The performance analysis of the proposed blends showed that R32/ R-125 / R-134a mixture could produce 20% higher capacity and 4% higher COP and that of R-32 / E-125 / R-134a mixture could give 6% to 8% higher COP and 30% higher capacity than the existing R-22.

To replace R-22 with a close match for use in heat pumps and air- conditioners, Donald *et al.* (1994) investigated the performance of R-407C. The energy efficiency test of R-407C gave 6% to 7% higher values than R22. It was suggested that further improvements in performance could be achieved by optimizing system components and using liquid line or suction line heat exchanger along with counter flow components. Kim *et al.* (1994) carried out experiments on heat pump using R-134a / HC- 290 and R-134a / R-600a, both azeotropic refrigerant mixtures. The results revealed that R-290 / R-134a is having a lower COP compared to R-22 and R-290. But the COP of R- 134a / R-600a was higher than that of CFC12 and R-134a. The value of the discharge temperature of R-290/ R-134a was observed to be lower than R-22 and very slightly higher than R-290. The R-134a / R-600a mixture provided a lower discharge temperature than R12.

Experiments were conducted to compare R-407C with R-22 by Vince *et al.* (1995). The cooling capacity of the mixture of R-32 (30%)
+ R-125 (10%) + R-134a (60%) was observed to be 7.7% lower than R-22 at 35ºC ambient temperature for baseline operation. For the operation of liquid overfeeding, the mixture showed mere 1.1% less cooling capacity than R-22. The study also revealed that the test mixture is having lower compressor discharge temperature, slightly lower compressor power consumption and higher compressor pressure ratio compared to that of R-22.

An attempt to find an alternative to R-22 with pure non-flammable nature was carried out by Yunho *et al.* (1997). The report states that no such substitute was available. Only R-407C and the ternary mixture containing R32 + R 123 + R134a gave close performance to R-22 and required some minor changes in the hardware.

Sami *et al.* (1997) produced a new ternary composition by blending R23/ R32 / R125 and tested its energy efficiency against R-22 and CFC 502 using an experimental setup comprising heat pump with a rotary compressor of 3kW capacity. The HC mixture of R23/ R32 / R-125 has given the best performance among the three. Macline & Leonardi (1997) have carried out performance measurements of refrigerants and suggested that the high energy consumption of appliances of air-conditioning system run with HC and HFC refrigerants could be decreased by using zeotropic blends.

The performance characteristics of HFCs such as R-32, R-407C and R-410A have been tested by Yunho & Reinhard (1998) in terms of COP, steady state capacity and seasonal performance factors. As per the report, the COP and steady state capacity of R-407C and R-410A were very close to R-22 with less than 6% variations. The COP of R-32 was similar, but it had 12 to 14% higher steady state capacity than R-22. From the analysis of seasonal performance factors (Total amount of cooling offered by the system in a season / Total consumption of electrical energy in that season), it was observed that the performance factor value of R-407C was lesser (by 6 to 7%), R-410A almost equal (less than 4% variation) and R-32 showed better performance (by 2 to 5%) when compared to R-22.

Purkayastha and Bansal (1998) studied the performance of HC290 + LPG mixture for replacement of R-22. The HC refrigerants have produced a better performance than R-22 except for a small loss in condenser capacity. Other important observations were the substantially lower values of compressor discharge temperature and mass flow rate of the tested mixture as compared to R-22. The report recommends LPG for refrigeration and heat pump applications as a better refrigerant.

A drop-in test for R-407C using an off-the- shelf air conditioner under both counter cross-flow and parallel cross-flow conditions was carried out by Vince *et al.* (1998). For examining the evaporator, ARI rated indoor and outdoor conditions were utilized. The counter cross-flow evaporator has given higher COP (by 3.8%) and higher cooling capacity (by 8%) compared to parallel cross-flow evaporator.

To find a replacement for R-22, Yang *et al.* (1999) have studied the performance of some new mixtures comprising R-32 / R-290, R-125 / R-290, R-32 / R-125 / R-152a, R-32 / R125 / R-290 at different working conditions. Among the mixtures tested, R-32 / R-125 / R-152a was found to be close in performance to R-22 under all working conditions. The report also states that the composition of refrigerant mixture is required to be optimized for different operating conditions of the specific applications.

New refrigerant mixtures such as R-404A, R-407C, R-408A, R-410A and R-507 were analyzed for their performance to replace R-22 by Samuel and Daniel (2000).

Among the proposed alternatives, R-410A has shown highest discharge pressure, but the discharge pressure and temperature of R407C has been similar to that of R-22 and also the R-407C mixture has consumed the lowest power as per the report. A screw chiller, designed for R-22 mixture with shell and tube heat exchangers was used by Lee et al. (2002) to perform a drop-in test with R-407C. A huge reduction in performance was reported due to larger heat transfer degradation in the evaporator which was indicated to be roughly two times when compared with the performance reduction caused by the condenser.

The vapour compression system with a reciprocating compressor was used to evaluate the performance of R-407C and R-22. The comparison showed that R-22 provided better performance than R-407C by 8% -14% which was due to better compression process caused by factors like better volumetric and isentropic efficiencies of R-22 mixture. The comparison work was done by Aprea & Greco (2003)

Performance study was carried out on R-407C by Adriano et al. (2003) to use it as a substitute in vapour compression plant normally operated by using R-22. It was found that for the same load conditions, R-407C consumed higher

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compressor power and its COP was lower than R-22 by 5- 17%. For conditions of higher evaporator and condenser temperatures, the performance of R-407C was found to increase. Hence the report has suggested the use of R-407C for high temperature applications.

Aprea et al. (2004) used a variable speed compressor to experimentally analyze the performance of refrigerants such as R-407C, R-417A, R507 and R22. At a nominal frequency of 50Hz, R-407C consumed 12% lower energy than R-22. Among the tested refrigerants the performance of R-407C was found to be superior to other new refrigerants. However R-22 has exhibited the best performance of all the examined refrigerants.

A new blend comprising R-134a and a binary mixture of R-134a / R-22 as a substitute for R-22 in vapour compression type heat pumps was proposed by Karagoz et al. (2004). The operating system was influenced mainly by characteristics such as mixture ratio, COP and evaporator inlet air temperature. It was observed from the results that the influence of mixture ratio on COP was significantly high and also the outcome showed that instead of using pure R-22, usage of pure R-134a or a mixture of R-134a/ R-22 at appropriate proportions could improve the COP. The maximum COP has occurred at a mixture ratio comprising roughly 50% of R-134a and 50% of R-32.

Dalkilic et al. (2010) investigated theoretically the performance of conventional vapour compression refrigeration system using various refrigerant mixtures such as R152a, R134a, R32, R1270, R600 and R600a with various compositions and the results are compared with R12, R22 and R134a as potential replacements. In this study, the theoretical results revealed that the investigated refrigerants are having slightly lower Co-efficient of Performance (COP) than R12, R22 and R134a for the operating temperatures from -30oC to 10^{o}C and condenser temperatures of 50^{o}C. Instead of R12, the refrigerant mixtures of R290/R600a (40/60 by weight) and instead of R22, the refrigerant mixtures of R290/R1270 (20/80 by weight) are found to be the drop-in substitute refrigerant mixtures among the other alternatives. The study has also stated that the mixed refrigerants (binary non-azeotropic) are used to obtain better performance, the binary zeotropic mixture with various proportions such as R290/R600 (40/60),R290/R600 (50/50), R290/R600a (60/40), R290/R600a (50/50), R290/R600a (70/30),R290/ R1270 (50/50), R290/R1270 (20/80), R290/R1270 (80/20) ,R290/R1270 (60/40), R290/152a (70/30), R290/R152a (60/40),R152a/R290 (80/20) and R32/R134a (30/70) are used as the alternative working substance for comparison with the traditional refrigerants such as CFC12, HFC 134a and HCFC 22. The main performance parameters such as refrigerating effect, COP and volumetric capacity of refrigeration are investigated in terms of degree of sub cooling and superheating for the operating conditions of condensing temperature at 50oC and evaporating temperature range from -30^{o}C to 5^{o}C.

III. RETROFITTING ON COMPRESSOR COMPATIBILITY

To find a substitute for R-22, fourteen refrigerant mixtures comprised of R-32, R-125, R-134a, R290 and R-1270 were tested for their performance in a heat pump. The test results revealed that the ternary blends containing R-32, R-125 and R134a possess 4% to 5% higher capacity and COP compared to R-22. Compressor discharge temperature of all the tested mixtures were also found to be lesser than R-22. It was inferred from the results that the above mixtures would serve better than R-22 in terms of fluid stability, system reliability and longer lifetime.

The investigations of different alternatives to replace R-22 in air-conditioning system by Devotta et al. (2001) have shown R-134a as possessing highest COP, but required larger compressor due to its lowest capacity. The investigations further revealed that R-290 is very close to R-22 in various characteristics but the compressor is to be modified a little to use R-290.

IV. CONCLUSION

From the review of the literature, it is evident that R22 is the prominent refrigerant in India and continues to be in usage even at present days. Even though R22 is nontoxic, non-flammable, and has a low ozone depletion potential (0.05), it is one among the greenhouse gases notified for phase out. Hence its usage should be reduced as per the Kyoto Protocol. It has been observed that most of the available alternative refrigerants are not matching with R22 in various aspects such as saturation properties, energy efficiency and safety.

On the other hand Hydrocarbon (HC) blend has better energy efficiency but has inflammable nature, which limits the usage in the existing systems. However, they can be made less flammable by mixing flammable refrigerant with non-flammable refrigerants such as HC refrigerants with HFC refrigerants. It is also possible to mix HC refrigerants with other alternative refrigerants such as HFCs. The miscibility of HFC/HC mixtures with Polyester oil has been reported to be good. The Global Warming Potential (GWP) of HFC/HC mixtures is less than one third of HFC, when it is used alone. Some researchers have used different HFC/HC (R134a, R32, R404A, R407C, and R410A with HCs) blended refrigerants with various mass proportions for conducting performance studies. This research has identified and proposed a suitable HC (R290/R600) and its composition with R152a to retrofit the R22 systems that has not been attempted so far. Since these mixtures were found to possess the desirable properties such as molecular weight, boiling point, temperature glide and critical pressure and critical temperature, they could be considered for selection as alternative mixtures to R22. Another obvious point is that the resultant mixture is expected to be energy efficient also. The present work gains significance from the research scenario prevailing now in this area.

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