Use of Hydrocarbons and Other Blends as Refrigerant

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Abstract: *This paper presents a study of different environmental friendly refrigerants of either hydrocarbon or Hydro fluoro carbons (HFC) class. Hydrocarbons (HCs) have zero ODP and very low GWP whereas HFCs have zero ODP but a quite higher GWP. Almost in all the cases, when R-134a was replaced with HCs the COP of the system was improved, ON time ratio and energy consumption was reduced. Due to a higher value of latent heat of HCs, the amount of refrigerant charge was also reduced as compared with HFC-134a. When hydro chloro fluoro carbons (HCFCs) were replaced with HFCs the system delivered a poor performance with increased energy consumption. When nano particles were added to the refrigerant, system delivered better performance with reduced energy consumption than that of pure refrigerant.*

Keywords: TEWI, ON time ratio, Pull down time.

I. Introduction

The most commonly used refrigerants in the late 1800s and in the early 1900s were natural refrigerants such as ammonia, carbon dioxide, sulphur dioxide and methyl chloride. All these refrigerants were found to be toxic or hazardous. In 1928, a safer class of alternative refrigerants became available with the invention of chlorofluorocarbons (CFCs) and hydro chloro fluorocarbons (HCFCs). CFCs and HCFCs have many suitable properties such as stability, non–toxicity, non–flammable, good material compatibility and good thermodynamic properties, which led to their common wide spread use by both consumers and industries around the globe, especially as refrigerants in air–conditioning and refrigeration systems.

Results from many researches show that ozone layer is being depleted due to the presence of chlorine in the stratosphere. The general consensus for the cause of this is that CFCs and HCFCs are large class of chlorine containing chemicals, which migrate to the stratosphere where they react with ozone. Later, chlorine atoms continue to convert more ozone to oxygen. The discovery of the depletion of the earth's ozone layer, which shields the earth's surface from UV radiation, has resulted in a series of international treaties demanding a gradual phase out of halogenated fluids. The CFCs have been banned in developed countries since 1996, and in 2030, producing and using of CFCs will be prohibited completely in the entire world. Also, the partially halogenated HCFCs are bound to be prohibited in the near future.

The researches are going on to find out some alternate refrigerants which does not harm to the environment and the protective ozone layer. Research has shown that hydrocarbons are good alternative to existing refrigerants.

II. Refrigerants under Considerations

Hydrocarbons, propane (R–290) and isobutane (R–600a) were among the first refrigerants, but due to their flammability and safety purposes, their use was abandoned and the direction of researches was shifted towards a safer and inert class of refrigerants. Thus the use of HCs as a refrigerant is not a new technology. Since 15 years, hydrocarbon and their blends are again being used at commercial scale [1].

Isobutane (R–600a) is the most frequently used hydrocarbon refrigerant. In Europe it is the most dominating refrigerant in domestic refrigerators. In 2004, the use of isobutane and its blend was 33% in domestic refrigerators and freezers at global level. Propane (R–290) and propene (R–1270) are widely being used in heat pumps, air conditioners and commercial refrigeration systems. Butane (R–600) is also under consideration but it has not been used commercially. Pentane and pentene also have the potential to be used as refrigerant and they are to be considered as the replacement to R–11 in centrifugal systems [2].

PROPERTIES OF REFRIGERANTS AT 40^{O}C

Ref.	No.	Formula	M (kg/kmol)	Tbp (OC)	Ttr (OC)	Tcr (OC)	hfg (kJ/kg)	□ l (kg/m3)	□ v (kg/m3)
Isobutane	R600a	CH–(CH3) 3	58.12	–11.67	–159.59	134.67	311.4	530.0	13.667
Propane	R290	CH3–CH2–CH3	44.096	–42.09	–187.67	96.675	306.51	467.07	30.202
Propene	R1270	CH2=CH–CH3	42.08	–47.69	–185.2	92.42	303.14	476.66	35.708
R134a	R134a	CF3–CH2F	102.03	–26.074	–103.3	101.06	163.02	1146.7	50.085
R22	R22	CHClF2	86.468	–40.81	–157.42	96.145	166.6	1128.5	66.193
Ammonia	R717	NH3	17.03	–33.327	–77.655	132.25	1099.31	579.44	12.034

Ref.	Refrigerant name	no.	Refrigerant number
Formula	Chemical formula	M	Molecular weight
T_{bp}	Normal boiling point	T_{tr}	Triple point
T_{cr}	Critical temperature	h_{fg}	Latent heat of vaporization
□$_l$	Liquid density	□$_v$	Vapor density

III. Literature Survey

a) Replacement of R-22 with HFCs

A trial was performed by Rocca and Panno [3] to replace R22 with new HFC refrigerants and the performance was compared with R–22. The plant working efficiency was first estimated with R–22 and then with three new HFC refrigerants, R–417a, R–422a and R–422d. The experimental results showed that R–22 has the least energy consumption among all the refrigerants under trial. Results also reveal that the three HFC refrigerants can replace R–22 without any change in lubricant or without any modification in the system and the accessories. These refrigerants also provide the safe and reliable working conditions. The results also verified that despite these advantages, the performance of the new tested HFCs was not as efficient as with R–22.

Experimentation was made to replace R–22 with a new refrigerant R–422d by Aprea et al. [4]. The experiment was carried out under three different operating conditions. The experimental results showed that COP of the system with R–422d was 20% lower than that of using R–22, the reason behind is high vapor density that also leads to lower cooling capacity and increased energy consumption. The discharge pressure was 15% higher than that of R–22 but it was under design limit. The discharge temperature was 20^{O}C lower which offers a longer compressor life. The improvement in heat exchange by condenser in order to improve the performance was carried out by using a fan. Increasing the fan speed only by 20% improved COP in the range of 14.5–23.5%.

Llopis et al. [5] replaced R–22 by two refrigerants HFC–422a and HFC–417b in medium and low evaporating temperatures. The test was conducted in a two stage refrigerating plant equipped with subcooling. The evaporator and condenser temperature range were -31^{O}C to 17^{O}C and 30^{O}C to 48^{O}C respectively. The experimental results showed that with the use of new refrigerants, the refrigerant mass flow rate need to be incremented. The new refrigerants also lead to lower specific refrigerating effect that tends to reduced cooling capacity. This reduction in the plant capacity was much more than expected from the theoretical analysis.

b) Replacement of R-134a with other HFCs

Bolaji [6] carried out a trial on domestic refrigerator designed to work with R–134a and replaced it by R–152a and R–32 which have zero ODP and low GWP. The performance with the new refrigerant was evaluated and compared with R–134a. The result showed that the average COP obtained with R–152a was 4.7% higher while average COP with R–32 was 8.5% lower as compared to R–134a. The energy consumption by the system was also reduced. The compressor consumed 4.0% and 3.2% lesser energy with R–152a as compared to the energy consumption with R–134a and R–32 respectively. The design temperature and pull down time using R–152a and R–134a were achieved earlier than using R–32. The discharge pressure of R–152a was about 0.8% less than that of R–134a while the discharge pressure using R–32 was the highest with average value of 8.1% and 7.2% higher than those of R–134a and R–152a respectively. In general, the system performed better than the other two refrigerants this shows that R–152a can be used to replace R–134a in domestic refrigerators.

A trial was made by Khorshid et al. [7] on domestic refrigerator to replace R–134a by two different blends one as R–134a (6.61%), R–32 (5.64%) and R–152a (87.75%) and the other as R–32 (15.34%), R–600a (8.79%) and R–152a (75.87%). The results of the test show that COP was improved by 11.93% and 2.07% by using the former and latter respectively as compared with R–134a. The new refrigerant blends have zero ODP and low GWP of the order of 242 and 200 respectively.

IV. Replacement of R-134a with HCs

Jwo et al. [8] used a blend of R–290 and R–600a instead of R–134a. The experiment was performed on a 440 liters domestic refrigerator. During test refrigerant R–134a was replaced with varied mass of hydrocarbon blends. The results show that refrigerating effect was improved by using hydrocarbon blends. The refrigerator which was designed to work with 150 gm of R–134a gave best result with 90 gm of hydrocarbon refrigerant that implies a reduction of 40% in refrigerant charge. The design temperature was obtained quicker when the mixture of R–290 and R–600a was used that reduced the individual working time, hence the total working time per month was lesser than by using R–134a. On average, the new refrigerant mixture offers a better refrigerating behavior and reduces the energy consumption by 4.4%.

Rasti et al. [9] substituted R–134a with R–436a (mixture of R–290 and R–600a with a mass ratio of 56/44) in a 238 liter domestic refrigerator without any modification in the system. The compressor was charged with different amount of R–436a. The various results of the experiment showed that the refrigerant R–436a has better performance compared to R–134a considering various parameters. The ON time ratio was reduced by 13% when R–436a was used. The energy consumption per day was reduced by 5.3%. The refrigerant charge required in case of R–134a was 105g and the optimum amount of refrigerant for R–436a was 55g which implies a saving of 48% in refrigerant charge. The evaporator inlet temperature was reduced by 3.5^{o}C. The energy efficiency index was raised from E to D. The results also showed that Total Equivalent Warming Impact (TEWI) of R–436a is 11.8% lesser than R–134a. Thus R–436a appears to be a good replacement for R–134a.

Sattar et al. [10] used a domestic refrigerator to conduct trial which was designed to work with R–134a. The trial was conducted to check the possibility of using hydrocarbons as refrigerants. Pure butane, isobutane and mixture of butane, isobutane and propane were used as alternate refrigerants. The performance of the system was compared with R–134a. The compressor consumed 3% and 2% lesser energy when iso butane and butane were used at 28^{o}C ambient condition. The amount of refrigerant charge with R–134a was 140 gm and it was reduced to 70 gm with the pure hydrocarbon and its blends which exhibits a saving of 50% in refrigerant charge. The trials were performed without any alteration in the system that shows the possibility of using hydrocarbons and their blends without any modification.

V. Replacement of Pure Refrigerant with Nano Refrigerant

Shengshan Bi et al. [11] made use of TiO2–R600a nano refrigerant in a domestic refrigerator without any system modification. The experimentation was performed using TiO_2–R600a with 0.1 g/lit and 0.5 g/lit of TiO_2 nano particles concentrations. The performance was compared with pure R-600a. The design temperatures were obtained at a quicker rate with TiO_2–R600a nano refrigerant. The energy consumptions were reduced by 5.94% and 9.60% with the concentrations as 0.1 g/lit and 0.5 g/lit of TiO_2 nano particles respectively. All the results obtained exhibited that TiO_2–R600a nano refrigerant worked safely and normally in the refrigerator with better performance than pure R–600a system. Thus TiO_2–R600a nano refrigerant may be used in domestic refrigerator with better performance and lower energy consumption without any alteration of the system.

Saidur et al. [12] conducted experiment with HFC–134a in domestic refrigerator with TiO_2 nano particles. The results showed that this nano refrigerant gave better performance. The energy consumption of HFC–134a refrigerant using mineral oil and nano particles mixture as lubricant was lesser than with pure HFC–134a and it saved 26.1% energy with 0.1% mass fraction TiO_2 nano particles compared to the HFC–134a. 60% HFC–134a with mineral oil and 0.1% wt Al_2O_3 nano particles gave optimal performance. The power consumption was reduced by 2.4% and the COP was improved by 4.4%. It has been identified that fundamental properties of nano fluids change drastically and depend upon the concentration of suspension of the nano particles in the base fluid.

VI. Conclusions

As per the Kyoto and Montreal protocols, the harmful refrigerants are to be phased out and are to be replaced with alternate environmental friendly refrigerants. The objective of this paper is to evaluate different environmental friendly refrigerant. On the basis of collecting information, the following conclusions may be drawn.

HFCs can replace R-22 without any modification in the system. Despite having the advantage of zero ODP, the system delivers the poor performance with increased energy consumption as compared with R-22. Hydrocarbons and their various blends may replace R-134a without any system modifications. COP of the system is improved with reduced energy consumption. ON time ratio and pull down time are also reduced. The system requires to be charged with 40% to 50% lesser amount of refrigerant due to a quite higher value of latent heat of hydrocarbons.

When nano particles are added to the refrigerants, thermo physical properties change drastically and depend on the concentration of the nano particles. Nano refrigerant can be used in the refrigeration system without any modifications. The system delivers better performance than with pure refrigerant; the energy consumption is also reduced. However optimum blend composition for maximum performance of the system is not much studied. Research work for deciding the concentration of blends has to be undertaken to have better performance of the system.

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