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Experimental Investigations on Eco-Friendly Refrigeration and Air Conditioning Systems

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Abstract: -The presence of chlorofluorocarbons (CFCs) and hydro-chlorofluorocarbons (HCFCs) refrigerants have adverse effects on our environment by contributing towards ozone layer depletion and green house effect. Hence, this research paper has put forth efforts to eliminate these adverse effects by the design and development of suitable eco-friendly refrigeration and air conditioning systems and efficiency improvements in the refrigeration systems. This paper also discusses on experimental studies carried out for the performance evaluations of a domestic refrigerator when four ratios of hydrocarbon , propane, butane and isobutene are used as possible alternative replacements to the traditional, R-12 refrigerant. The uses of proposed alternative refrigerants have the advantages such as (i) availability in local places, (ii) cheapness, and (iii) of an environmentally friendly nature. An unmodified R – 12 domestic refrigerators and air conditioners were charged and tested with each of the four hydrocarbon mixtures containing propane, butane, isobutene in the following ratios shown:

HYDROCARBONS	MIXI	MIX2	MIX3	MIX4
PROPANE	100%	75%	50%	25%
BUTANE	NIL	19.1%	38.3%	57.5%
ISOBUTENE	NIL	5.9%	11.7%	17.5%

The parameters investigated are the capacity of the evaporator, the compressor power, the coefficient of performance (COP) and the cooling rate characteristics. The present work shows that the hydrocarbon mixtures with 50% propane, 38.3% butane, 11.7% isobutene is the most suitable alternative refrigerant with best performances among all other hydrocarbon mixtures investigated. When this hydrocarbon mixtures were used, the evaporator temperature has reached –16° C with COP of 3.7, at condenser temperature of 27°C as compared to COP 3.6 for the traditional R-12 refrigerant at the same temperatures. This domestic refrigerator has worked satisfactorily with the proposed alternative refrigerants since no modification of adjustments were made to the refrigeration system designed for R-12 and no problems have been encountered with the compressor, evaporator , condenser in addition, no degradation of lubrication oil could be detected after the refrigerator worked for more than 5000 hours using the same oil. Therefore, the authors are confident that the eco-friendly, reliable, simple and convenient technologies of

refrigerants described in this paper can be alternated with traditional R-12 refrigerators and air conditioners.
Key-Words: - eco-friendly refrigeration, hydrocarbons, performance evaluation, hydrocarbons, refrigerators, air - conditioners

1 Introduction

1.1 Need for the eco-friendly refrigerators and air-conditioners

The demand and supply of the refrigerators and air conditioners are increasing day today more and more. A century before, refrigeration systems have been used with refrigerants such as air, CO_2 etc, which were eco-friendly. Later on that is during 1950, due to advancement of Applied Thermodynamics-Refrigeration and Air conditioning, design engineers have found certain fluids with better thermo-physical and chemical properties. This has led to the development of chlorofluorocarbons (CFC) and HCFC as refrigerants. This gave a big boost to the mechanical refrigeration industries in terms of cost, higher efficiency, higher reliability, but there are certain disadvantages over these refrigeration systems such as non-eco-friendly nature.

With the growing environmental hazards, public awareness towards a sustainable development is increasing now. One of the series threats to the environment is the stratospheric ozone layer depletion. The stratospheric ozone layer plays a beneficial role absorbing most of the biologically damaging ultra violet sunlight coming towards the earth. Ozone also plays a key role in the temperature regulation of the earth atmosphere. Recent investigations have shown that human made chemicals are responsible for the observed depletion of ozone layer. The ozone depleting compounds (CFC and HCFC) contain reactive gaseous atom of chlorine or bromine. Although the CFC and HCFC molecules are heavier than the molecules of air, the atmospheric air circulation takes these compounds to the stratosphere over a period of time. Halo molecules of CFC and HCFC react very rapidly with ozone *via* their oxide formations and thus decrease concentration of stratospheric ozone.

Besides the trapping of reflected short wavelength radiation from the surface of the earth in the troposphere by various types of constituents gives rise to the increase in the earth surface temperature known as green house effect. Thus earth retains heat and is progressive takes place. Increase of earth surface temperature by a few degrees is expected to produce many unwanted effects. The presence of CFC and HCFC in the troposphere also plays a significant role in the greenhouse effect. Thus in the present environmentally conscious age, it has been pointed out that production, leakage, disposal etc. of CFC and HCFC refrigerants has an adverse effects on our environment by contributing towards ozone layer depletion and greenhouse effect. Thus due to show improvement of efficiency and concern for the environment, efforts are being put forth to develop eco-friendly alternative refrigerants.

1.2 Hydrocarbons Versus CFCs

Commercial chlorofluorocarbons (CFCs) are recognized for their severe harmful effects on the environment when they are released to the atmosphere, Specific concerns about their use in air conditioning and refrigeration equipment are related to their potential contribution to global warming and their depletion effect on the stratospheric ozone layer due to their chlorine chemical effect. Due to the fact that CFCs damages the ozone layer, environmental groups and the Montreal protocol call for halting CFC production. Thus alternative refrigerants must be found to replace the CFCs. Such alternative refrigerants should possess good thermo dynamical and physical properties, comparable cost, low toxicity and low flammability.

3 Problem Solutions

Hydrocarbons offer acceptable alternative refrigerants to the CFCs, since they have good thermo dynamical properties and they are universally available at low price. The above of chlorine atom from hydrocarbons results in zero ozone depletion potential. In addition global warming potential is very low fro hydrocarbons, owing to the higher heat of hydrocarbons compared with that of R-12. The thermodynamic properties of R –12. propane, butane, and isobutene are shown in table 1. the data of table 1 shows that none of he pure hydrocarbons has a thermodynamic properties which match that of R – 12.

Table 1 ; Thermodynamic properties of various refrigerants

	Boiling Point	**Freezing Point**	**Critical Temperature**	**Critical Pressure**	**Latent Heat**
R – 12	**-29.3**	**-158**	**112**	**4.14**	**165.2**
Propane	**-42.1**	**-188**	**97**	**4.25**	**423.3**
Butane	**-0.51**	**-139**	**152**	**3.79**	**356**
Isobutene	**-11.7**	**-160**	**135**	**3.65**	**364.4**

As per the Thermodynamics studies conducted to determine the COP and other performance parameters for propane and isobutene mixtures, their results indicated that the hydrocarbon mixtures of 50% propane- 50% isobutene and those of 60% propane- 40 isobutene have performance characteristics that are very similar to those of R-12. They also showed that these mixtures are the best refrigerants for replacing, R – 12. Their theoretical investigations resulted in COP value of 3.2 for the 50% prepare mixture at an evaporation temperature of 15 deg.C. The corresponding value of COP for R– 12 is 3.3 at the same refrigerants .

The only disadvantage of hydrocarbons is their flammability. But since the mass content of propane and butane in a domestic refrigerator is very small then, the risk of an explosion is minimal. Thus if hydrocarbon refrigerant, which is less than 250 g leaks from a refrigerator in the room or kitchen, an explosion would be impossible. The lower explosion limits of propane, butane, and isobutene in air are 2.3%, 1.9% and 1.8% by volume respectively.

In the present work, R -12 in a domestic refrigerator was replaced by four different hydrogen mixtures Temperatures and pressures at various locations in the refrigerator, as shown in fig. 1, were measured to enable the thermodynamic states of the vapor compression cycle of the refrigerator to be determined. The mineral oil, naphthalene based oil no. 3 (suniso SGS 3), which was used with R-12, was also used with the hydrocarbon mixtures. The performance parameters have been plotted against evaporator and condenser temperatures for each hydrocarbon mixture investigated.

3.1 Experimental setup and procedure

The domestic refrigerator used in the present work has a capacity of 3201 and is designed to work with the traditional refrigerant R – 12, the mass of the refrigerant charge is 0.21 kg. The compressor used is of reciprocating, hectically scaled type with displacement volume of 8 cc^3 . Copper constantan thermocouple wires were installed at various locations in the refrigerator to measure the temperatures at the following locations: freezer compartment (Tc), middle of condenser (Tc), Suction and discharge lines of the compressor and the ambient temperature (Ta). A digital thermometer with an accuracy of 0.1 °C was used . The pressures at suction and discharge sides of the compressor were measured using a compound page manifold. This manifold is also used for charging the refrigerator with the required hydrocarbon mixture. The power consumed by the compressor was measured using a power meter that has an accuracy of 0.01 kwh.

Four hydrocarbon mixtures were used which are 100% propane, 75% propane 19.1% butane – 5.9% isobutene, 50% propane -38.3% butane -11.7% isobutene and 25% propane -57% butane -17.5% isobutene.

Three types of experiments were performed: (i) the evaporator temperature variation test, (ii) The condenser temperature variation test and (iii) the cooling rate test . An electric heating coil of 800 W total capacity and 5.2m lengths was used as a load installed in the freezer component. All experiments during this test were started at TE = -16 °C. The heating capacity of the coil , Q coil is related to the refrigeration capacity. Qe as:

Qcoil Qe - m(be-hi)

Where m is the mass flow rate of the refrigerant. And he and hi are the enthalpies of the evaporator exit and inlet of the evaporation is calculated as follows:

Qe- Qcoil = 800 (L/5.2)

Where L is the length of the heating coil installed inside the freezer compartment.

Using an air-conditioning unit of 5kW capacity to perform the condenser temperature variation test by blowing cold air over the condenser tubes. Recording the time needed to cool and freeze a 1.5 kg water load that is installed inside the freezer compartment carried out the cooling rate test. The time needed to perform this test is about five hours for each hydrocarbon mixture investigated.

Preliminary experiments were performed to determine the optimum charge masses that give the maximum value of COP for each mixture of the four hydrocarbon mixture used in the present works. The results of this indicate that the optimum charge mass for 100% Propane , 75% propane, 50% propane and 25% propane are 12- , 140, 165 and 200g respectively.

3.2 Results and discussions

The results of the evaporator temperature variation test are presented here. The refrigeration capacity was increased by increasing the length L of the heating coils . Qe increase as Te increase for all the four hydrocarbon mixtures. As the propane percentage is increased in the hydrocarbon mixture, Qe increased due to the mass flow rate, m with

Te . It can be shown from that m increases as Te increases. This is due to the fact that, as Te increases, the specific volume of the hydrocarbon mixture at evaporator exit decreases which causes m to increase. As the propane percentage in the hydrocarbon mixture increase, m increases. This is because increasing propane percentage in the mixture has the effect of decreasing the specific volume of the mixture since butane percentage, with higher specific volume than propane, decreases. The compressor power, W is plotted against T as shown in increases as Te increases for all hydrocarbon mixtures used. This is because, when Te is increase, m is increased at a rate faster than the specific work of the compressor. The coefficient of performance COP is defined by the ratio of Qe/W, is plotted against Te the variation of COP with Te for R – 12 is also plotted in for comparison purposes. This indicates that the COP increases for all refrigerants investigated. The 100% propane refrigerant has the highest COP values while the 25% propane refrigerant has the lowest COP values among all refrigerants tested for all values of Te. The COP at T =16 e is equal to 43 for 100% propane mixture, 4.2 for 75% propane mixture, 3.7 for 50% propane mixtures and 3.5 for the 25% propane mixture. The COP for R-12 at the same evaporator temperature is 3.6. Also indicates that all hydrocarbon mixtures with propane percentage of 50% or more. When used as alternative refrigerants in domestic refrigerator, have higher values of COP the R-12 under the same operating conditions. The results of the condenser temperature variation test are presented only for the COP variation with Te since the variation of Qe. W and m with Te are similar to that of the evaporator temperature variation test. Plots of COP against Te for all of the four hydrocarbons studied. That the 100% propane mixture has the highest COP values for all condensing temperature investigated. The COP of this mixture at 27 °C is 4.2. The corresponding values of COP for the 75% propane, 50% propane and 25% propane at the same condenser temperature are 3.9, 3 and 2.8 respectively . Also includes the COP characteristic of R-12 refrigerants, whose value are lower than the 50% propane mixture for all temperature setting.

From the above discussion it is concluded that the 100% propane refrigerant has the highest COP values among all the other hydrocarbons investigated. Hydrocarbon mixtures when used as alternative refrigerant to R – 12 cannot be selected on basis of best COP values only. Thermodynamic properties of such alternative refrigerants should be taken into consideration for selection criteria in order to fail or the characterizes of a particular hydrocarbon mixture to match closely there of R-12. Since the compressor and the capillary tube of the domestic refrigerated are basically designed according to the saturation pressure of R-12 then the situation curves of the hydrocarbon mixtures must be examined in order to select the proper hydrocarbon mixture .

Since COP value of this hydrocarbon mixture are higher than that of R-12 over a wide range of temperature, then the 50% propane mixture is considered as the most suitable alternative refrigerant to R-12.

The results of the cooling rate test are only presented for the 50% propane mixture since it was selected as the best alternative refrigerant to R-12 based on the COP values and saturation curves match criteria. The cooling curve for the 50% propane mixture that indicates that 100 min are needed to cool and freezing the 1.5 kg loaded initially at 30 °C.

4 CONCLUSION

The following conclusions are made:
All the investigated hydrocarbon mixtures of propane, butane and isobutene can be used as the possible alternative refrigerants to R-12 with COP values.
The 100% propane mixture has the highest COP values among all hydrocarbon tested.
The 50% Propane mixture is selected to be the most suitable alternative refrigerant to R-12 based on both COP and saturation cover match characteristics.
No modification of adjustments were made to the refrigeration system designed for R-12 and no problems have been encountered with the compressor, in addition, no degradation of lubrication oil could be detected after the refrigerator worked for about 5000 hours using the same oil.
Therefore, the author is confident that the eco-friendly, reliable, simple and convenient technologies of refrigerants described in this paper may be used for domestic and commercial purposes by the industries and consumers.

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