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Hydrocarbon Blends and Blends of HFC-134a-HC600a as Drop In Refrigerants for Small Capacity Commercial Refrigeration Appliance - An Experimental Study

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HYDROCARBON BLENDS AND BLENDS OF HFC-134a-HC600a AS DROP IN REFRIGERANTS FOR SMALL CAPACITY COMMERCIAL REFRIGERATION APPLIANCE - AN EXPERIMENTAL STUDY

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ABSTRACT

The awareness to protect the environment from the harmful effects of CFCs has motivated the refrigeration scientists and engineers to study alternative refrigerants to replace the CFCs even in the existing units. This paper presents a thermodynamic study of hydrocarbon blends (Propane/Isobutane) and blends of HFC-134a-HC-600a as a possible "drop-in" (some electrical component to be changed to make the appliance safe) substitute to CFC-12. Thermodynamic properties of these mixtures needed for the analysis have been computed using "Refprop". An extensive experimental work has been carried out to evaluate the performance of the proposed blends for small capacity commercial refrigeration appliances such as bottle coolers. The quantity of refrigerant charge has been determined experimentally for the minimum energy consumption for the best composition. The results show that the hydrocarbon blend with 50 percent by mass of isobutane and HFC-134a-HC-600a mixture are potential drop-in candidates. The hydrocarbon blend consumes about 12% less energy in comparison to HFC-134a-HC-600a. However, these refrigerants are flammable which require some changes in electrical components to make the appliance safe.

INTRODUCTION

A great emphasis is being paid world wide to search for the substitute for CFCs, which cause the depletion of ozone layer in the stratosphere [8]. Among CFCs, CFC-12 is very widely used refrigerant including in domestic and small capacity commercial refrigeration units such as display cabinets, bottle coolers etc. Among the refrigerants, which have been identified as possible alternative to CFC-12 for the use in domestic and small capacity -commercial refrigeration units, the leading candidates are HFC-134a and hydrocarbons (pure isobutane and blends of Propane/Isobutane). Other possible substitutes are HFC-152a and a near azeotropic ternary blend of HCFC-22, HCFC-124 and HFC-152a.

HYDROCARBON REFRIGERANTS

Isobutane as Refrigerant.

Isobutane is currently being applied in domestic refrigeration system and on a small scale, also in commercial refrigeration system. It can very well be used with the commonly used mineral oils which implies that no lubricant change is required. A further advantage of the hydrocarbons is that they have zero O.D.P. and a very low G.W.P. The main drawback of hydrocarbon is that these are flammable. However, these refrigerants have high latent heat of vapourization, the circulation rates of refrigerants and the refrigerant charge quantities are quite small. With a minor modification in electrical components, it is possible to make the appliance safe.

Binary Blends of Isobutane and Propane as Refrigerant

The mixture of isobutane and propane 50% by mass is a good substitutes for CFC-12 from thermodynamic properties point of view [1,2,3,5,6]. It's N.B.P. ranges from -32 °C to 24 °C which is very close to the N.B.P. of CFC-12, the latent heat of vaporization (320Kj/kg) is also very high in comparison to CFC-12, due to which low circulation rate and low charge quantity is required and hence the flammability does not present a serious problem.

HFC-134a AS REFRIGERANT

HFC-134a is one of the leading candidates to replace CFC-12. It has got zero ODP and low GWP (0.115). The thermodynamic properties of HFC-134a are similar to CFC-12 NBP of HFC-134a is -26.8°C, which is very near to NBP of CFC-12 (-29.8°C). It's critical temperature (374.2K) is also high. The main problem with HFC-134a is its incompatibility with the existing lubricating oils (used with CFC-12). It is not miscible with mineral oils, which are commonly used in refrigeration equipments. Therefore new types of lubricants i.e, polyolester oils [10] have been developed and are successfully applied to new equipments. However, polyolester oils are highly hygroscopic and creates problems of choking of systems especially incase of serviced appliances.

MIXTURE OF HFC-134a AND HC-600a AN ALTERNATIVE FOR CFC-12.

The application of pure HFC-134a in a refrigeration circuit together with mineral oil could lead separation of oil and chocking of capillary as the mineral oils are not compatible with HFC-134a. There are problems during the manufacturing and servicing of these appliances due to hygroscopic nature of lubricants. Therefore solution to the lubricant return problems may be to use a mixture of HFC-134a and isobutane which has good compatibility characteristic with the mineral oils. This mixture was proposed by Janssen [4]. This study has selected a mixture of HFC-134a and isobutane, as one of the refrigerants. The percentage of isobutane is to be restricted such that the mixture should not be flammable.

SYSTEM ANALYSIS

The cycle analysis of vapor compression refrigeration system has been carried out to know the mixture compositions suited to replace CFC-12. The cycle considered is the simple vapour compression with sub cooling and super heating. The temperature glide has been taken into account by taking average condensing and evaporator temperature. The results obtained have been presented in the tabular form (Table-1)for HFC-134a-HC-600a mixtures and through Figs. 1 to 3 for HC blends. In case of hydrocarbon blends a mixture of 50 percent by mass Isobutane in Propane was found suitable. While in the case of HFC-134a-HC-600a blend a mixture of 12 percent HC-600a in HFC-134a was found suitable to replace CFC-12 for such applications. A mixture of 20 percent HC-600a in HFC-134a as shown in Fig-4 makes an azeotropic mixture. This composition is quite useful but makes the mixture flammable.

PERFORMANCE EVALUATION

In order to evaluate the performance of the appliance using mixtures of HFC-134a and HC-600a, and HC blends detailed experimental studies have been conducted. The performance evaluation in the present case has been carried out on horizontal bottle coolers by conducting tests such as Rated Energy Consumption test and Pull Down test.

The capillary lengths were changed in case of HC blends to see the effect of capillary length on the system performance. For each length of the capillary, different mass of the charge were tried to get optimal charge for each case. Then out of these optimal points. The minimum energy consumption point can be selected as the optimal combination of mass and capillary length. Further pull down tests have also been conducted using both the HC blend and the mixture of HFC-134a and HC-600a for the optimal charge and the mixture.

A set of performance results of horizontal bottle cooler (HBC) using HFC-134a and HC 600a are give in Table-2 and Table-3. While the results for HC blends are given through Figs. 5 to 8. The performance results indicate that the energy consumption in case of HC blends is substantially less than the HFC-134a -HC-600a blend. The energy consumption with the increase in the length of capillary decreases upto a certain extent.

Table-1 Thermodynamic analysis comparing CFC-12 with mixtures of HFC-134a and HC-600a

Parameters	CFC-12	Mixture of HFC-134a and HC-600a			
		6% HC-600a	8%HC-600a	10% HC-600a	12% HC-600a
Condenser Temperature° C	55	55	55	55	55
Evaporator Temperature °C	-20	-20	-20	-20	-20
Condenser Pressure kPa	1357	1598	1625	1649	1667
Evaporator Pressure kPa	148.6	171.4	175.4	177.6	178.7
Pr. Ratio for Compression	10.55	12.76	12.54	12.30	12.02
RPM	2900	2900	2900	2900	2900
Piston Displacement CC/Cycle	8.44	8.44	8.44	8.44	8.44
Suction Volume cu m/kg	0.159	0.2031	0.1988	0.1947	0.1909
Mass Flow Rate g/s	1.849	1.376	1.419	1.462	1.506
Specific Refn Effect kj/kg	103.8	129.5	128.7	128.2	127.9
Cooling Capacity Q_o Watts	191.93	178.192	182.625	187.428	192.617
Heat Rejection Q_c	338.55	325.97	336.57	347.329	358.88
COP	1.9445	1.8369	1.8178	1.8081	1.7938

Table-2 Rated Energy Consumption test for the mixture of HFC-134a and HC-600a

Refrigerant	Ambient Temp (°C)	Average Cabinet Temp (°C)	Average Power (W)	% of Run Time	Energy Consumption in 24 (hrs)
R-12	32	2	142.25	37.1	2.95 kWhr
6% Mixture of HC-600a and HFC-134a	32	2	147.602	40	3.542 kWhr
12% Mixture of HC-600a and HFC-134a	32	2	145.421	38.4	3.49 kWhr

Table-3 Pull Down Test Results

Refrigerant	Ambient Temperature °C	Temp after Pull Down° C	Time Required in hrs
R-12	43	2	13 hrs 15 mn
12% Mixture of HC-600a HFC-134a	43	2	11 hrs 50 min
HC blends with 50% HC 600a	43	2	12 hrs 35

PRODUCT SAFETY

The product design is to be developed in such a way that it is safe. An explosion can take place only if combustible mixture of HC refrigerants and air is present within the flammable limits and simultaneously if an ignition source of sufficient intensity is present. The first step is therefore to avoid the possibility of leak. Should there be a leak, the next logical step is to ensure that a combustible mixture is not formed. In addition the system should be designed or existing systems should be modified so that sources of ignition are eliminated. This aspect can easily be incorporated in the product.

CONCLUSION

The primary objective which motivated the present work was to study a suitable refrigerant mixture to replace CFC-12 in existing small capacity commercial refrigeration appliances with the minimum changes in refrigeration system. The system analysis gives a composition of 12% HC-600a in HFC-134a and HC blends with 50% by mass isobutane in propane as suitable mixture compositions which give almost the similar capacity as of CFC-12. The results of experimental study show that HC blends consumes slightly less energy in comparison to HFC-134a-HC600a blends. Hence it can be concluded that the HC blends as well as mixtures of HFC-134a and HC-600a are appeared to be promising alternative refrigerant to CFC-12 for small capacity commercial refrigeration appliances.

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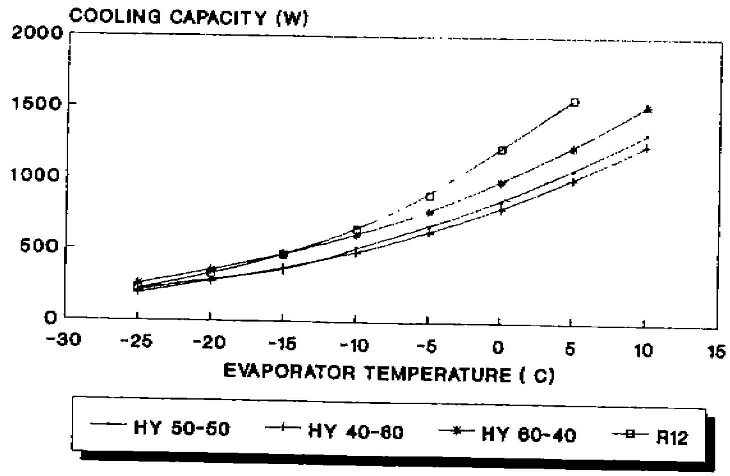

FIG-1 COMPARISON OF COOLING CAPACITY OF HYDROCARBON MIXTURES FOR HBC (CONDENSER TEMP = 55 C)

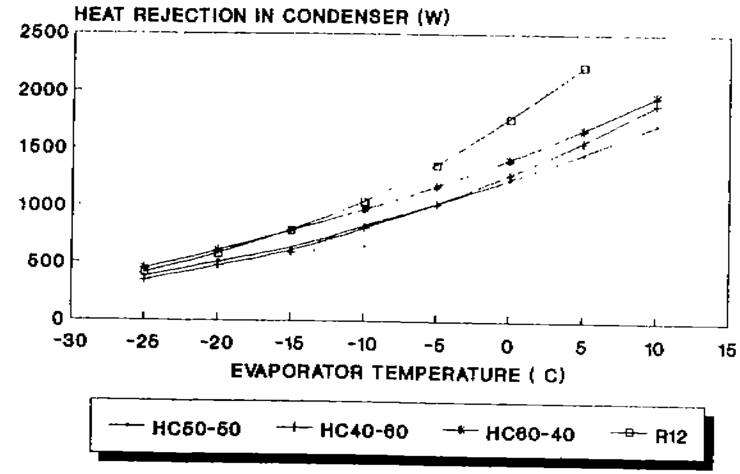

FIG-2 COMPARISON OF HEAT REJECTION IN CONDENSER OF HYDROCARBON MIXTURES FOR HBC (CONDENSER TEMP = 55 C)

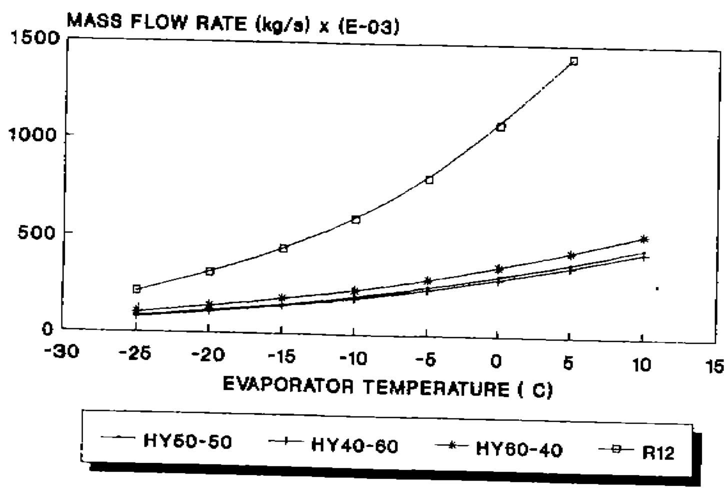

FIG-3 COMPARISON OF MASS FLOW RATE OF HYDROCARBON MIXTURES FOR HBC (CONDENSER TEMP = 55 C)

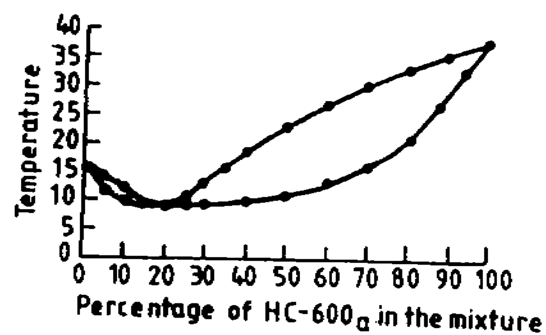

FIG-4 TEMPERATURE COMPOSITION DIAGRAM FOR 20% MIXTURE OF R-600a IN R-134a

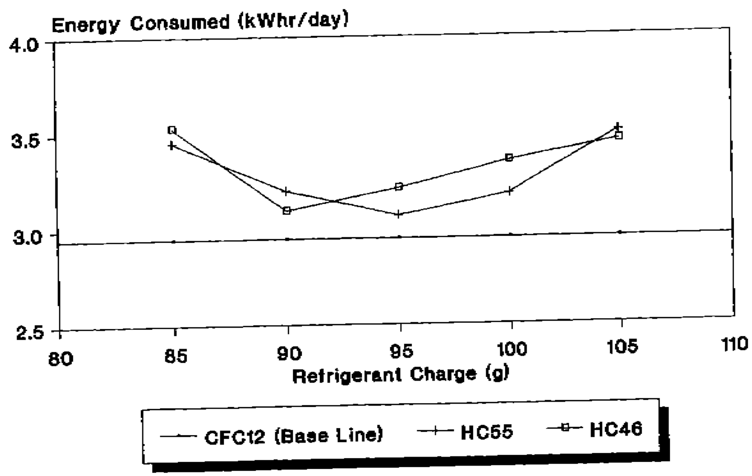

FIG-5 ENERGY CONSUMPTION VS CHARGE FOR HBC - HC MIXTURES AS REFRIGERANT WITHOUT CHANGE IN CAPILLARY LENGTH

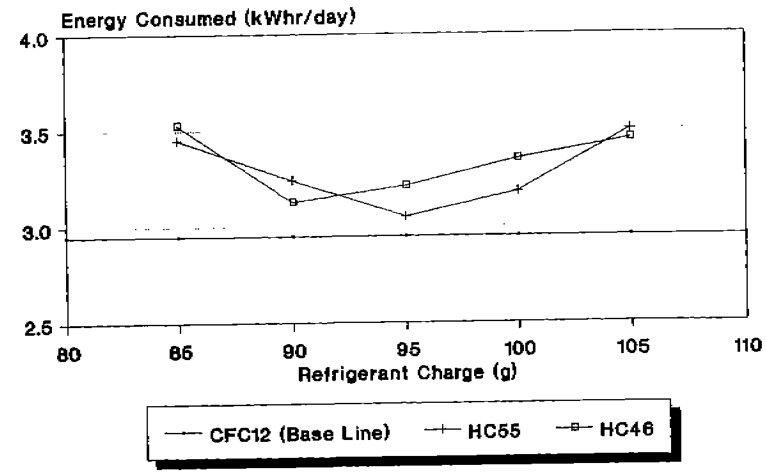

FIG-6 ENERGY CONSUMPTION VS CHARGE FOR HBC - HC MIXTURES AS REFRIGERANT WITH ADDITIONAL CAPILLARY LENGTH 0.3 M

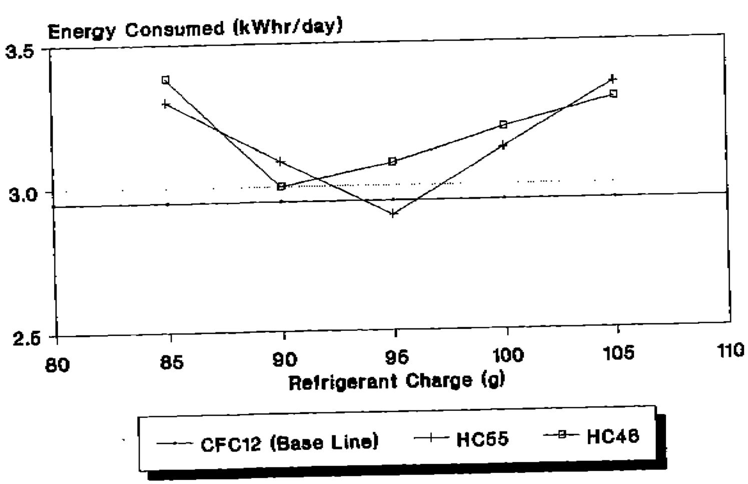

FIG-7 ENERGY CONSUMPTION VS CHARGE FOR HBC - HC MIXTURES AS REFRIGERANT WITH ADDITIONAL CAPILLARY LENGTH 0.6 M

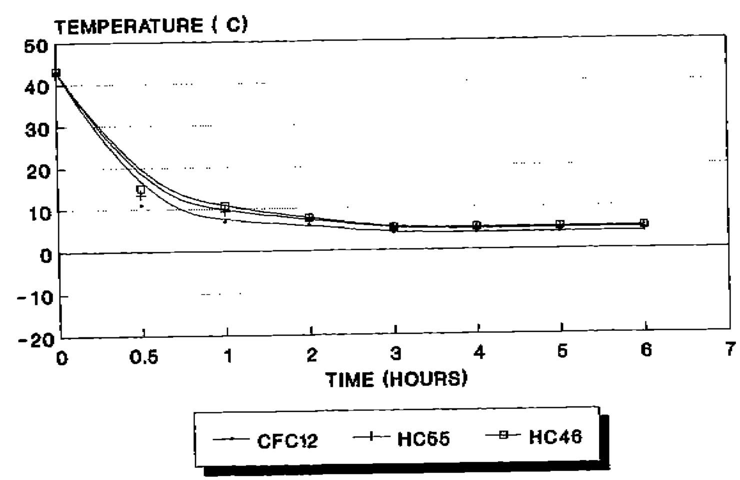

FIG-8 PULLDOWN TEST TEMPERATURE VS TIME FOR HBC - HYDROCARBON MIXTURES AS REFRIGERANT