Comparative Study of Hydrocarbon Mixtures & MP-39 as Refrigerants to Retrofit CFC- 12 Based Domestic Refrigerator-Freezers

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COMPARATIVE STUDY OF HYDROCARBON MIXTURES & MP-39 AS REFRIGERANTS TO RETROFIT CFC-12 BASED DOMESTIC REFRIGERATOR-FREEZERS

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ABSTRACT

The present work aims to make a comparative study of MP-39 and mixtures of propane, isobutane as refrigerants to retrofit the existing CFC-12 based refrigerator-freezers. Mixtures have been selected because they provide a flexibility of modulating the capacity by varying the constituent's composition. Theoretical and experimental investigations have been carried out using MP-39 and mixtures of propane /isobutane with varying compositions. Performance of retrofitted units have been evaluated and reported in this paper.

INTRODUCTION

Approximately 64 million units are manufactured worldwide each year and hundreds of millions are currently in use. It is anticipated that the production of refrigerator-freezers and the inventory will substantially increase in the near future due to an increased demand, especially in article-5 countries. In order to protect the environment, non CFC refrigeration systems have been adapted in non-article-5 countries recently, while attempts are being made to phase out CFC in new OEM in article-5 countries.

Retrofitting of existing units may be necessary, in both developed and developing countries so that phase out of CFCs does not result in writing of the appliances with useful life left in it. Thus, there is a need to develop retrofits for existing units using suitable substitutes. A number of refrigerants, pure as well as blends, have been considered as retrofits. The initial selection of the alternative refrigerants was based on their vapour pressures. Fig.1 shows the vapour pressures of the potential refrigerants considered in this study. HFC-134a and HFC-152a are pure refrigerants, while the others are zeotropic mixtures. HFC-134a is not suited for retrofitting of existing refrigerators due to non compatibility with mineral oil, loss of capacity and results in energy inefficiency, /Vineyard 89,91/. It also requires changes in the compressor including materials of construction. HFC-152a is a flammable refrigerant and uses almost the same amount of charge as that of CFC-12. /He91/.

The ternary blend of HCFC-22,/124, and HFC-152a (MP-39) has been considered as one of the candidates for retrofitting the existing units since it is non-toxic, non-flammable, chemically stable, compatible with refrigeration system materials & lubricants and have transport and thermodynamic properties similar to CFC-12. The hydrocarbon refrigerants especially propane and isobutane, and their mixtures recently reintroduced have been successful precursors to chlorofluorocarbon refrigerants in modern refrigerator industry. The thermodynamic characteristics of these refrigerants have even known to be better than many of the common refrigerants used /Meyer93/. Although, these refrigerants are flammable but with the technological developments and with proper safety measures this drawback can be overcome.

Some of the European countries especially Germany have recently started implementing use of hydrocarbons both as refrigerant and foam blowing agent. The primary motivation for early adaption of the hydrocarbon refrigerant despite of their high flammable characteristics has been threefold. Firstly, these refrigerant do not react and deplete atmospheric ozone; secondly, the global warming potential (GWP) of these refrigerants is almost negligible. In other words these refrigerants will generate extremely small environmental loading. Thirdly, they are naturally available, compatible with mineral oil, and are low cost. This paper presents the retrofitting of two temperature domestic refrigerator-freezer with a mixtures of propane (HC-290) and isobutane (HC-600a) in different compositions (50-50, 40-60, 60-40% by weight) and MP39.

TWO TEMPERATURE DOMESTIC REFRIGERATOR

In the present study conventional two temperature domestic refrigerators have been used for study. These refrigerators are operated with freezer temperature about-15°C and fresh food compartment temperatures about 5°C. The refrigerator has only one top mounted evaporator and cooling in the fresh food compartment is achieved by natural convection. Fig.2 shows the schematic diagram of the refrigeration system of the unit. The thermodynamic processes involved when the system is charged with a zeotropic mixture are illustrated on temperature-entropy (T-s) diagram (Fig.3). The evaporation and condensation processes with the use of mixture results in non-isothermal processes while, with a single component refrigerant these processes are isothermal.

THERMODYNAMIC ANALYSIS OF REFRIGERATION SYSTEM

The thermodynamic analysis of the refrigeration system of domestic refrigerator has been carried out with the aim to establish the suitability of alternative refrigerant to retrofit a CFC-12 refrigerator-freezer. The approach used in the analysis is that the existing CFC-12 refrigeration system has been taken for the study and its performance has been evaluated at design as well as off design conditions assuming that the system is charged with alternative refrigerant. The thermodynamic analysis results for the six refrigerants viz., CFC-12, MP-39, MP-66, HC-55, HC-46, HC-64 have been summarized in the graphical form through Figs. 4 to 6. The cooling capacity (Fig.4) of the refrigeration system using hydrocarbon mixtures and ternary mixtures is almost same as that for CFC-12. The amount of heat to be rejected in the condenser in case of hydrocarbon refrigerant is the same as that for CFC-12, while with the ternary blend the heat to be rejected is slightly more as compared to CFC-12 refrigeration system. This suggests that the condenser of the existing refrigeration system is adequate for the hydrocarbon refrigerants while for ternary mixtures the surface area of the condenser will have to be increased accordingly. The mass flow rate of refrigerant in the refrigeration circuit is quite low in case of hydrocarbon refrigerants.

REFRIGERATION SYSTEM SIMULATION

Simulation of refrigeration system components viz., condenser, evaporator & capillary tube have been carried out keeping the compressor same as that of CFC-12. For condenser simulation Nozu & Fujii /86/ approach has been adapted while evaporator is simulated using the free convection correlations. The sizing of capillary tube has been carried out as suggested by Koizumi and Yokayama /80/. The results of simulation has been presented through tables 1 to 3. Table 1 shows the condenser simulation results. From the table it can be seen that the actual length for CFC-12 is 9.2 m and simulated length is 9.42m. The condenser length required 9.2m for 50-50 hydrocarbon mixture & 9.72m for MP-39. It indicates that for hydrocarbon mixture the condenser size is adequate while for MP-39 this may result in loss of capacity. Table-2 shows the evaporator simulation results table it can be seen that the actual length of evaporator for CFC-12 is 6.8m and simulated length is 7.4m. The simulated length of evaporator for 50-50 hydrocarbon mixture is 7.15m & 7.82 for MP-39. It indicates that evaporator is almost adequate in size both for hydrocarbon as well as MP-39. Table-3 shows the capillary simulation results. From the table it can be see that the actual & simulated length of capillary length for CFC-12 is 3.42 and 4.2 respectively. The simulated capillary tube length for 50-50 hydrocarbon mixture is 7.52m and 4.36m for MP-39. It indicates that there is a wide variation in the simulated length and actual length for CFC-12. Hence it has been decided that the capillary length is required to be changed and size experimentally.

Table 1 Condenser Simulation Results

Name of Refrigerants	Length (m)	
	Actual	Simulated
CFC-12	9.2	9.42
MP-39	-	9.72
MP-66	-	9.68
MP-52	-	9.58
HC-55	-	9.27
HC-64	-	9.32
HC-46	-	9.48

Table 2 Evaporator Simulation Results

Name of the Refrigerants	Length (m)	
	Actual	Simulated
CFC-12	6.8	7.45
MP-39		7.82
MP-66		7.91
MP-52		7.56
HC-55		7.15
HC-64		7.85
HC-46		7.42

Table 3 Capillary Simulation Results

Name of the Refrigerant	Length (m)	
	Actual	Simulated
CFC-12	3.42	4.20
MP-39		4.36
MP-66		4.47
MP-52		4.41
HC-55		7.52
HC-64		7.71
HC-46		7.31

RETROFITTING OF DOMESTIC REFRIGERATOR

A two way approach viz., a drop-in & with minor modification in the refrigerator, has been adapted

***Use of Refrigerant as a Drop-In Substitute*:**
Two single door, single evaporator, two temperature, 165 litre capacity domestic refrigerators of the same make and model were taken for this study. One of the refrigerator was prepared for charging by withdrawing the refrigerant. Then the evacuated refrigeration system was charged with a specified mixture of hydrocarbons. Due care was taken to charge a mixture of proper compositions. These two refrigerators were instrumented to measure pressures and temperatures of the refrigeration circuit as well as the temperatures in freezer and fresh food compartments. Instruments for measurement of power, current drawn and the energy were also connected in the circuit. Attempts were also made to obtain an optimal quantity of the charge. Initially the system was charged and tested with 35g of hydrocarbon mixture which was subsequently increased in five steps to 55g. Also the unit was charged and tested with 60g HFC mixtures which was subsequently increased in five steps to 100g. During all these charging with these refrigerants the compressor was operational which helped a thorough mixing of the refrigerant with oil.

Use of Refrigerant in a Modified Refrigerator :
The refrigerator after being tested with these refrigerants as a drop-in substitute was subsequently modified by changing the capillary length. The approximate capillary length required was first calculated theoretically and then further the length was adjusted by cut and try method. This refrigerator was again charged with mixture of hydrocarbon and tested. A number of sets of experiments were conducted with different length of capillary tube finally the length of capillary tube which gives the optimum performance was determined.

PERFORMANCE TESTS

Following performance evaluation tests were conducted:

Rated Energy Consumption Test: Rated energy tests were conducted with ambient temperature 32°C, the freezer temperature -5°C and fresh food compartment temperature 5°C. Difficulties were observed in maintaining this combination of temperature with single thermostat control. The tests were repeated continuously for a number of days.

Ice Making Test : Ice making test has been performed to judge the ice making capability of the two refrigerators. The environment temperatures in this test have been maintained at 43°C. The material of the ice trays used was aluminium and the quantity of water taken was 500 ml.

Pull Down Test : This test has been conducted at 43°C ambient temperature. In this test pull down characteristics and energy consumption have been measured for a period of 6 hrs. both for hydrocarbon and CFC 12 charged refrigerators.

TEST RESULTS AND DISCUSSION

The test results of energy consumption test, pull down test, and ice making test of modified refrigerator is graphically represented in Figures 7 to 10. Figs 7 & 8 show energy consumption test results of hydrocarbon mixtures and HFC mixtures respectively. The energy consumption test results were compared with that of CFC-12 (Baseline). From the results it can be seen that HC-55 consumed slightly less energy than that of CFC-12 while MP-39 consume slightly higher energy that of CFC-12. The ice making test results show that ice making time for hydrocarbon mixtures as well as HFC mixtures was almost the same ie., 150 minutes as against 140 minutes for CFC-12. Figs 9 &10 show the pull down test results. The pull down time with hydrocarbon mixtures as refrigerants varies from 2 hrs 50 minutes to 3 hrs and 2 hrs 55 minutes to 3 hrs 05 minutes for ternary mixtures.

CONCLUSIONS

Hydrocarbon mixtures and MP-39 as refrigerants are compatible with mineral oils and are promising substitutes for retrofitting of domestic refrigerators. The performance of the retrofitted refrigerator is more or less similar to that of CFC-12. Although hydrocarbons are flammable but the quantity of charge used is very small which will not cause any major safety concern.

ACKNOWLEDGEMENT

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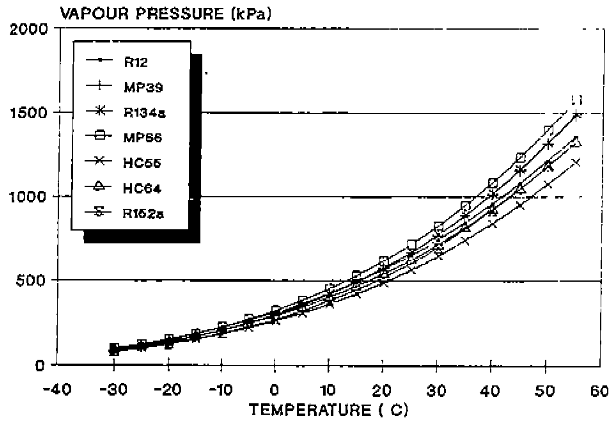

Fig 1 VAPOUR PRESSURES POTENTIAL REFRIGERANTS

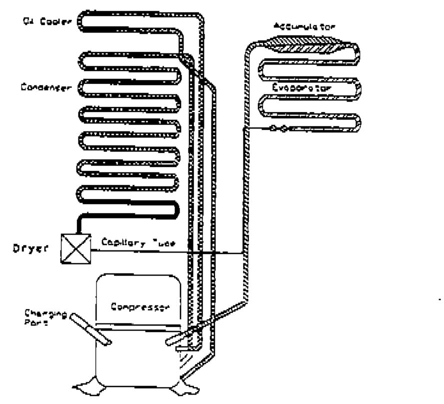

Fig.2 Schematic Diagram of Refrigerator

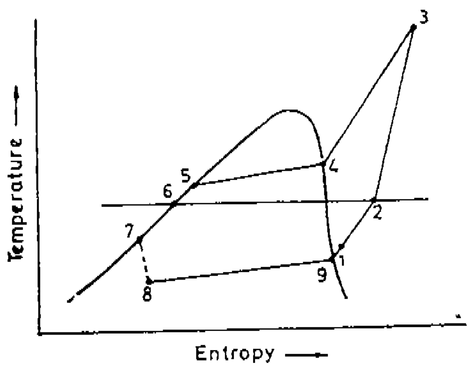

Fig.3 T-S diagram of refrigerator

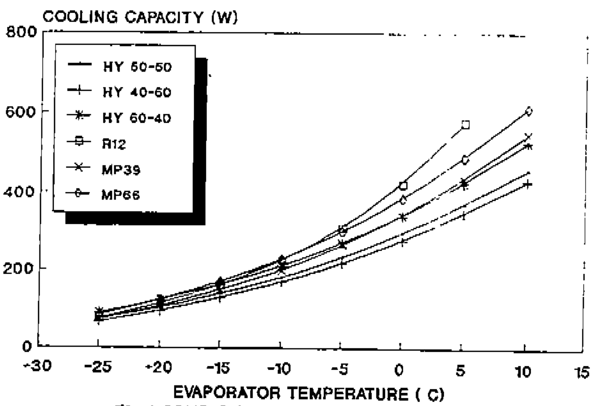

Fig 4 COMPARISON OF COOLING CAPACITY OF HYDROCARBON MIXTURES FOR REFRIGERATOR (CONDENSER TEMP - 55 C)

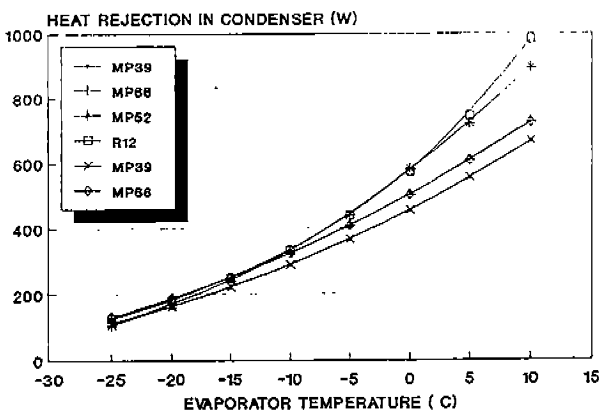

Fig 5 COMPARISON OF HEAT REJECTION IN CONDENSER OF TERNARY MIXTURES FOR REFRIGERATOR (CONDENSER TEMP - 55 C)

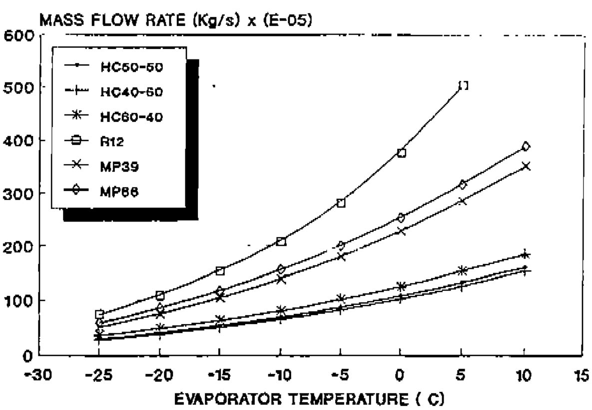

Fig 6 COMPARISON OF MASS FLOW RATE FOR HYDROCARBON MIXTURES IN REFRIGERATOR (CONDENSER TEMP - 55 C)

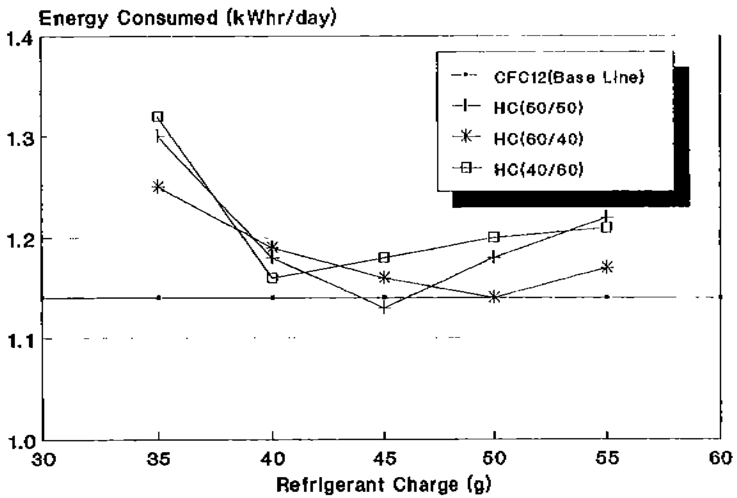

Fig.7 ENERGY CONSUMPTION VS CHARGE
HC MIXTURES AS REFRIGERANT
WITH ADDITIONAL CAPILLARY LENGTH 2.44m

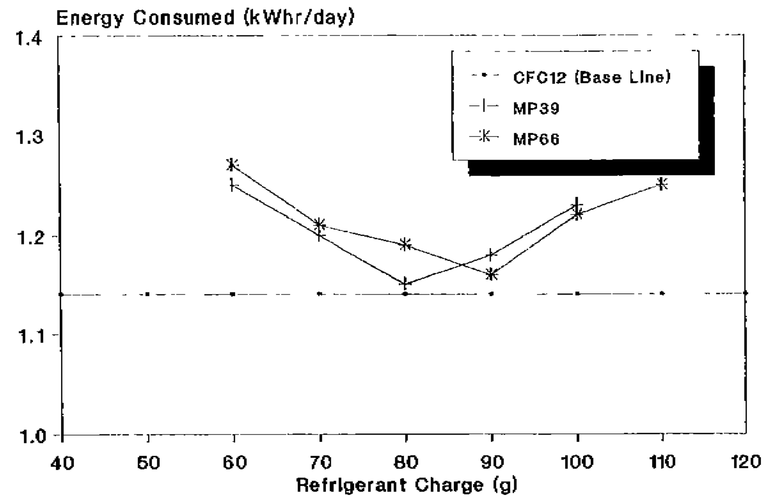

Fig.8 ENERGY CONSUMPTION VS CHARGE
TERNARY MIXTURES AS REFRIGERANT
WITH ADDITIONAL CAPILLARY LENGTH 0.7m

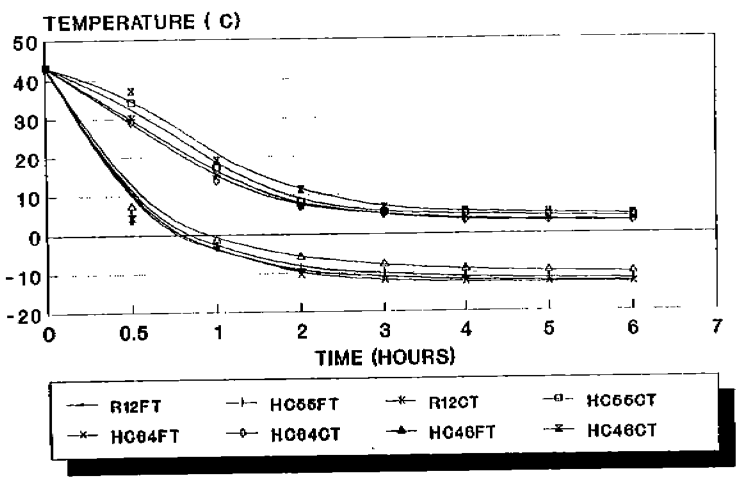

Fig 9 (PULLDOWN TEST) TEMPERATURE VS
TIME FOR REFRIGERATOR - HC MIXTURES
AS REFRIGERANT

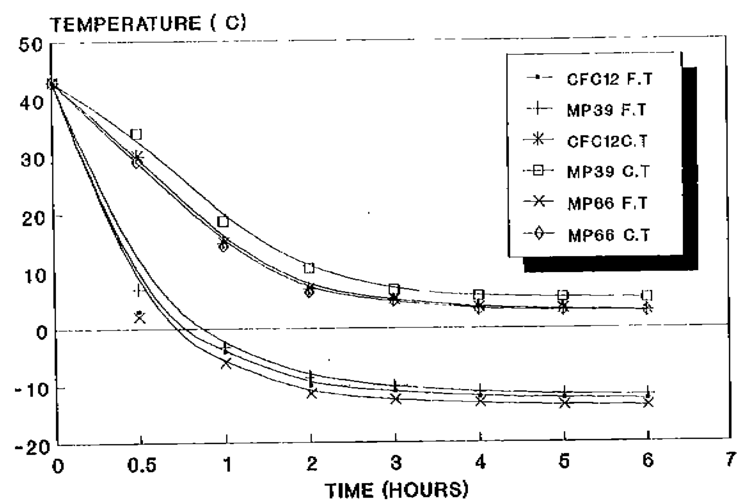

Fig 10 (PULLDOWN TEST) TEMPERATURE VS
TIME FOR REFRIGERATOR - TERNARY MIXTURES
AS REFRIGERANT