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R. S. Agarwal
Indian Institute of Technology

S. Roy
Indian Institute of Technology

T. Sharma
Indian Institute of Technology

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AN INVESTIGATION INTO THE INFLUENCE OF IMPROVED REFRIGERATION CYCLE AND REFRIGERANTS ON AN ENERGY EFFICIENT DOMESTIC REFRIGERATOR

R.S. Agarwal*, S. Roy and T. Sharma
Mechanical Engineering Department
Indian Institute of Technology, Delhi
New Delhi - 110016, INDIA
Tel: 91-11-6591120, Fax: 91-11-6526645
Email: rsarwal@mech.iitd.ernet.in

ABSTRACT

Domestic refrigerator-freezers are very widely used for food preservation. There is still growing demand especially in developing countries like India. The growth rate in India for domestic refrigerators is about 15 percent. A large inventory of such appliances exists in India.

In recent years, an emphasis is paid to improve the energy efficiency of domestic refrigerator-freezers have to reduce Green House Emissions. This paper presents, results of a study undertaken to look into some of the aspects, such as alternative refrigerants, liquid suction heat exchanger cycles and optimized refrigerant charge to improve energy efficiency of domestic refrigerator-freezers.

***Keywords:* *Alternative Refrigerants, domestic refrigerator, Energy Efficiency, Montreal Protocol, Kyoto Protocol, Green House Gas Emissions*.**

INTRODUCTION

Green house gas emissions and their damaging effects on the atmosphere have received increased attention following the release of scientific data by the United Nation Environmental Program (UNEP) and World Metrological Organization (WMO) that shows carbon-dioxide (CO_2) to be the main contributor to increased global warming. In case of the refrigeration appliances, the indirect contribution to global warming potential (GWP) resulting from the amount of CO_2 produced by the power plant in generating electricity to operate a unit over its life time.

Customer expectations and competitive pressures impose an unwritten set of constraint on refrigeration appliances produced. Studies have shown that domestic refrigerators give satisfactory performance for approximately 15 years on an average. This high degree of reliability has caused consumers to expect long life and trouble-free operation from these appliances. Therefore increased costs associated with efficiency improvements must be justified on the basis of an improved environment and lower operating cost to the consumer. Unless consumers are motivated to spend more on efficiency, further improvements will be hard for the manufacturers to justify based on existing market conditions. Moreover, the demand of electricity is much more than its availability and this energy deficit are increasing with time. So, it is a challenge for appliance manufacturers to make the appliance energy efficient.

A comprehensive study is undertaken to look into the various aspects, such as increased insulation, liquid suction heat exchanger and optimized refrigerant charge, to improve energy efficiency of commercial refrigeration appliance.

OPTIONS FOR REDUCING POWER CONSUMPTION

Some of the options have been studied for reducing the energy consumption of the refrigeration appliances such as Insulation, modified cycles using Liquid-suction line heat exchanger and optimizing refrigerant charge,

Insulation

There is a heat gain from the ambient due to temperature difference between outside and inside of the cabinet. The heat leakage is reduced by providing Polyurethane foam in between. Polyurethane foam insulation minimizing the thermal losses from the cabinet.

There are five low conductivity gas options viz., HCFC-141b HFC-134a HFC-245fa HFC-365mfc cyclopentane, for closed cell foam blowing agents. Their comparative characteristics are given in Table 1. Out of these five, cyclopentane and HCFC-141b are the most commonly used foam blowing agents. HCFC-141b has little better characteristics than cyclopantane but HCFC-141b is controlled substance under Montreal Protocol. Of the remaining four gases HFC-134a and cyclopentane are commercially available, but they have a relatively high Foam Thermal Conductivity Index. HFC-245fa and HFC-365mfc are considered as the possible alternatives because of their low thermal conductivity but they are not commercially available. Currently cyclopentane and HCFC-141b are the most commonly used foam blowing agents.

Table 1: Blowing Agent Comparisons

Characteristics	**HCFC-141b**	**HFC-134a**	**HFC-245fa**	**HFC-365mfc**	**Cyclo-pentane**
Ozone Depletion Potential	0.11	0	0	0	0
Global Warming Potential (100 years)	630	1300	820	840	11
Foam Thermal Conductivity Index	100	117	101	102	113
Refrigerator Energy Use Index	100	112	101	N.A.	110
Relative Foam Ageing Rate	Base	Worse	Better	-	Worse
Flammability	Marginal	No	No	Yes	Yes
Density Index	100	108	98	-	119
Compressive Strength Index	100	100	98	-	120

N.A.: Not Available

REFRIGERATIN CYCLES FOR DOMESTIC REFRIGERATION

Various refrigeration cycles were analyzed, to achieve energy efficiency and feasible cycle. The refrigerant properties were selected in accordance with the specifications provided by the Bureau of Indian Standards (BIS) regarding a domestic refrigerator operating in Indian conditions. The following cycles were analyzed: -

Liquid Suction Heat Exchanger (LSHE) Cycle

The LSHE cycle is to be used with a single evaporator. This cycle employs a heat exchanger between the condenser and the evaporator outlet. Since condenser sub-cooling with evaporator superheating increases the COP of the cycle with R-134a or R-600a as the refrigerant, therefore a LSHE improves the energy efficiency of the refrigerator.

Distributor Cycle

It contains two evaporators and the distributor distributes the refrigerant among the freezer compartment and the fresh food–freezer compartment.

Alternating Evaporator Duty (AED) Cycle

This cycle has two VCR loops that share a common compressor, condenser and suction line heat exchanger. Each of the refrigeration loops has a throttle valve and an evaporator. One evaporator is located in the fresh food compartment and the other is located in the freezer compartment. The solenoid valve directs the flow of the refrigerant through one loop at a time. Only one of the two compartments is cooled at a time. This cycle allows for independent temperature control of the freezer and fresh food compartments. Experiments done on this cycle have shown a COP improvement of about 8.5% over a conventional domestic refrigerator. The refrigerant used in the experiments was R-600a.

Lorenz-Meutzner Cycle

In this cycle, a zeotropic refrigerant mixture is used as the refrigerant. In general, domestic refrigerators are used to hold freezer temperatures near -15°C and fresh food cabinet temperatures near 3°C, which indicates that two evaporator temperature levels exist in refrigerators. By thermodynamic analysis, it is known that if the temperature difference between the evaporator and condenser is smaller, then the COP will be higher. The cooling load of the fresh food cabinet is about 60% of the total cooling load. Thus for this 60% of the total cooling load, the refrigeration cycle operates inefficiently without taking advantage of the smaller temperature lift in the fresh food cabinet. To take advantage of this temperature lift, zeotropic refrigerant mixtures can be utilized as working fluids in refrigerators. During evaporation of zeotropic refrigeration mixtures, the saturation temperature changes due to the volatility difference of pure components, which is called as ‘temperature glide’. When the air temperature in the two cabinets and the zeotropic refrigerant mixtures are well matched, the mixtures with larger temperature glide would yield a larger increase in COP, due to reduction in compressor work.

Lorenz Cycle

This is a two-evaporator cycle having two heat exchangers for sub-cooling of the liquid at the condenser outlet.

Ejector Cycle

The ejector cycle has a second evaporator and expansion device, a separator and an ejector, apart from the simple VCR cycle components. After the first capillary, the refrigerant passes through the fresh food evaporator. At the outlet of the evaporator, the liquid refrigerant is separated from the vapor in the separator. This liquid then expands to the freezer pressure in the second capillary. The vapor at the end of the freezer evaporator enters the ejector as suction flow. The ejector combines the two flows to an intermediate pressure level. Then the refrigerant is sent to the compressor.

Selection of Refrigeration Cycle

The cycle selected for final analysis and design was the LSHE cycle. This was due to the following reasons: -

- Since the project objective was to develop a 210L domestic refrigerator, and 210L refrigerators work on a single evaporator design, the LSHE cycle was selected.

- The LSHE cycle required fewer changes to the existing refrigerator models. Due to ease in fabrication, industry preferred this cycle, taking into account mass production considerations.

EXPERIMENTAL SET-UP

In order to evaluate the performance of the prototype R-134a and R-600a refrigerators, detailed experimental studies were carried out. The tests were conducted in the test chamber at IIT Delhi. The test setup contained a constant temperature chamber, instrumentation and an automatic data acquisition system.

The Baseline Refrigerator

The tests were carried out on the fabricated prototype and the baseline to arrive at the comparative results. The baseline was a 210L refrigerator charged with R-12 having same specifications as the prototype viz. insulation thickness and cabinet dimensions. The baseline was charged with R-12 as the conventional refrigerator available in the Indian market in the 210L segment is charged with R-12.

Description of the Tests

Different tests were carried out on the prototype and the baseline, as recommended by the Bureau of Indian Standards. The test specifications are as follows: -

Rated Energy Consumption Test

The purpose of this test was to lay down the maximum energy consumption for various refrigeration appliances under the standard conditions of operation. This test was conducted at an ambient temperature of 32°C. The refrigeration appliances were tested in the standard test chamber. Operating conditions were taken after the stabilized conditions were reached according to the BIS code. The mean temperature measured at the same portion of the control cycle did not vary by more than 0.5°C from the final regulated figure. The thermostat was set at the position such as to obtain the conditions as laid down in the test procedure. The refrigerator was run under no load conditions at the rated voltage of 220V± 2%. The power consumption as measured was extrapolated for 24 hours of operations. In this test, the temperatures of the freezer and cabinet were measured at different positions along with the energy consumption.

Pull Down Test

The purpose of this test was to check the no load pull down characteristics of the refrigeration appliances. The test was conducted at an ambient temperature of 43°C. The thermostat was set at the coldest position. The refrigerator appliances were placed in such a way that they were shielded from direct air currents of space heating/cooling system. The time required to cool down to the mean cabinet air temperature of 7°C from 43°C without the thermostat in the circuit was noted. In this test, the freezer and cabinet temperatures were measured.

Ice Making Test

The purpose of this test was to check the ice making capability of the refrigerator. The test was carried out at an ambient temperature of 43°C. The thermostat was set in the coldest position before starting the test. The ice trays were filled with water upto 5mm from the top and promptly placed in the evaporator after stable operating conditions were obtained. The water temperature at the moment of placing the ice tray into the freezer was 30±1°C. The contact surface of the ice trays was wetted with water to improve thermal contact. The recording of the test time was started as soon as the placement of ice tray in the freezer and continued till the formation of ice. Through out the freezing time, it was observed that the temperature in the fresh food compartment did not go below 0°C. The ice trays were examined at suitable intervals of time till the complete ice was formed and the freezing time was obtained. During this test, the temperatures of the freezer and different locations of the cabinet were measured along with the water temperature in the freezer.

TEST RESULTS

This section discusses the results of experimental performance evaluation of the prototype refrigerator (charged with R-134a) and the baseline (charged with R-12). The comparative results are discussed below: -

Rated Energy Consumption Test

Table II gives the results of the Rated Energy Consumption Test for R-134a.

Table II: Rated Energy Consumption Test Results for R-134a and R-600a

Refrigerant	Charge (grams)	Average power consumed (Watts)	Power consumed in 24 hours (kWh/day)
R-12(baseline)	**105**	**37.111**	**0.891**
R-134a	75	29.756	0.714
R-134a	80	29.407	0.706
R-134a	**85**	**28.448**	**0.683**
R-134a	90	29.236	0.702
R-134a	95	29.347	0.704

Figure 1 shows the charge optimization curve for R-134a. It can be inferred from Figure 1 that the optimum charge of the refrigerant is 85 grams, having a rated energy consumption of 0.683 kWh/day, as compared to the baseline refrigerator which has an energy consumption of 0.891 kWh/day. Thus, the R-134a prototype shows an energy improvement of 23.3% over the baseline.

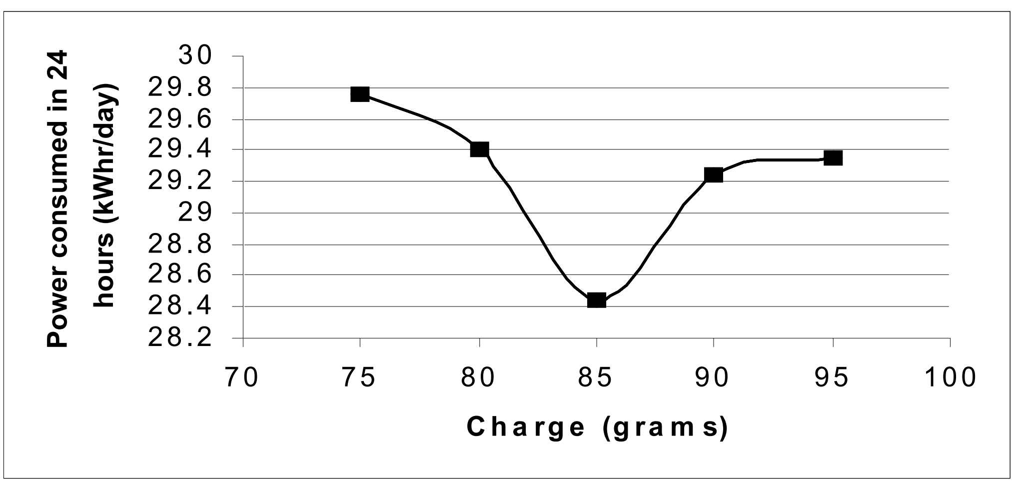

Fig. 1. Charge Optimization for R-134a

Pull Down Test

The pull down test was done on the prototype, having the optimum charge, for R-134a to estimate the pull down time. The pull down test was also done on the baseline and the results for both the baseline and the prototype were compared and analyzed. Table III shows the pull down test results. Time taken for bringing down the temperature of the cabinet from 43°C to 7°C is presented.

Table III: Pull Down Test Results

Refrigerant	Optimized mass (grams)	Mean ambient temperature (°C)	Time taken for pull down (minutes)
R-134a	85	43.9	112
R-12	105	43.9	142

It is evident from Table III that the prototype developed has performed better than the baseline in the pull down time for both R-134a. For R-134a, the time required to bring down the temperature of the cabinet from 43°C to 7°C has been reduced by 21.1% as compared to the baseline.

Ice Making Test

The ice-making test was conducted at an ambient temperature of 43°C on the prototype as well as the baseline. The results of the ice making tests are presented in Table IV.

Table IV: Ice - Making Test Results

Refrigerant	Ice formation starting time	Ice formation ending time
R-134a	51 min	3 hrs 20 min
R-12	1 hr 2min	3 hrs 40 min

It can be inferred from Table IV that the prototype refrigerator having R-134a as the refrigerant takes 9.1% less time for ice formation compared to the baseline. Therefore the performance of the prototype is comparatively better than the performance of the baseline with respect to its ice formation time.

CONCLUSION

The demand of domestic refrigerator-freezers is increasing especially in developing countries. The energy efficiency is the key to reduce the Green House Gas emissions. The results of this study indicate that by incorporating a liquid suction heat exchanger can result in a substantial improvement in energy efficiency of domestic refrigerator-freezer especially units operating in high ambient temperatures.

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