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Performance Analysis of Eco-Friendly HC Mixture (R290/R600a) Refrigerant as an Alternative to R-134a in a Vapour Compression Refrigeration System for Sub-cooling using Heat Exchanger at Condenser Outlet and Diffuser at Condenser Inlet

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Abstract

Most the refrigerants like, R11 and R12, R22 contain chlorine atoms which are responsible for the ozone depletion. These hydro-chlorofluorocarbons will be phased out by the year 2020 according to the Montreal protocol. Thus, alternative refrigerants like R-134a and hydrocarbon mixture (R290/R600a) are used being in place of them. These refrigerants have zero ozone depletion potential and negligible global warming potential. In the present work performance comparison between R-134a and hydrocarbon mixture (R290/R600a) has been carried out in domestic refrigerator. In addition to this, diffuser is incorporated at the inlet of condenser, and heat exchanger is arranged at outlet of condenser. The diffuser main purpose compressor work can be reduced and the heat exchanger main purpose refrigeration effect can be increased. Further the energy performance characteristics such as coefficient of performance (COP) and refrigeration effect, compressor work will be found out the above refrigerants (R-134a and HC mixture (R290/R600a).

Keywords: *Vapour Compression Refrigeration System, Sub-cooling, Diffuser, Heat exchanger, R-134a, HC mixture (R290/R600a).*

1. Introduction

As per Montreal protocol 1987, the use of chlorofluorocarbons (CFCs) was completely stopped in most of the nations. However, hydro chlorofluorocarbons (HCFCs) refrigerants using in developing nations and developed nations should phase out by 2030.Most of the developed nations reduced the consumption of HCFC refrigerants. The Kyoto Protocol of United Nations Framework Convention on Climate Change (UNFCCC) calls for reduction in emission of six categories of green-house gas, which includes hydro fluorocarbons (HFCs) used as refrigerants. To meet the global demand in refrigeration and air-conditioning sector, it is necessary to look for long term alternatives to satisfy the objectives of international protocol. Only a few pure fluids are having properties closer to the existing halogenated refrigerants. The refrigerant mixtures provide much flexibility in searching new environment friendly alternatives to match the desirable properties with the existing halogenated refrigerants. The two alternative options are HC and HFC mixtures with lower GWP.HC based mixtures are environment friendly, which can be used as alternative refrigerants.

In agreement with the Montreal protocol many refrigerants containing CFCs and HCFCs were increasingly replaced with hydro-fluorocarbons (HFCs).Which have zero ozone depletion potential (ODP) and negligible global warming potential (GWP).

Table1: Properties refrigerants for experimental working

Refrigerant	Chem. comp	Mol. Wt. g/mol	C.T ^0C	C.P mpa.	NBP ^0C	ODP	GWP
R-134a	C2H2F4	102	101.1	4.06	-26	0	1430
CARE-30	R290/R600a	50.15	114.8	4.04	-32.8	0	<20

Refrigeration system consists of several equipment's like compressor, condenser, expansion devices, evaporator etc. A refrigerant compressor is a machine used to compress the refrigerant from the evaporator and to raise its pressure so that the corresponding temperature is higher than that of the cooling medium. The condenser is an important device used in the high pressure side of a refrigeration system. Its function is to remove heat of the hot Vapour refrigerant discharged from the compressor. The evaporator is used in the low pressure side of a refrigeration system. The liquid refrigerant from the expansion device enters into the evaporator where it boils and changes into vapour. The function of an evaporator is to absorb heat from the surrounding location or medium which is to be cooled, by means of a refrigerant. The temperature of the boiling refrigerant in the evaporator must always be less than that of the surrounding medium so that the heat flows to the refrigerant. The expansion device which is also known as throttling device, divides the high pressure side and the low pressure side of a refrigeration system. It is connected between the receiver and the evaporator. Many efforts have to be done to improve the performance of vapour compression refrigeration system.

2. Literature Review

Moo-Yeon lee et. al. (1) have studied the performance of a small capacity directly cooled refrigerator by using the alternative to R-134a.The compressor displacement volume of the alternative system with R600a/R290 (45/55) has modified from that of the original system with R-134a to the optimized R600a/R290 system was approximately 50% of that of the optimized R-134a system. The capillary tube lengths for each evaporator in the optimized R600a/R290 system were 500mm longer than those in the optimized R-134a system. The power consumption of the optimized R-134a system was 12.3% higher than that of the optimized R600a/R290 system. The cooling speed of the optimized R600a/R290 (45/55) system at evaporator 0C was improved temperature by 28.8% over that of the optimized R-134a system.

M.Mohanrajet.al. (2) also carried experimental investigation to find out a drop in replacement for R134a with the binary mixture of45.2%R290/54.8%R600a in a 200 liter single evaporator domestic refrigerator. Tests were carried out at different ambient temperatures (24, 28, 32, 38 and 430C); cycle ON/OFF tests was carried out at 32 0C ambient temperature. The results showed that the HC mixture has lower energy consumption; pull down time and ON time ratio by about 11.1%, 11.6% and 13.2% respectively, with 3.25 to 3.6% higher COP. The discharge temperature of HC mixture was found to be 8.5 to 13.4 K lower than that of R134a. The overall result has proved that the above hydrocarbon refrigerant mixture could be the best long term alternative to R134a.

It is clear from the above discussion that various researchers have tried for a suitable alternative for R134a. It has been observed that the energy consumption of R12 appliances tend to increase while they are retrofitted with R134a. These days, the concern for the global warming has never been greater. In 1997 the Kyoto protocol was agreed by many nations calling for the reduction in emissions of greenhouse gases including HFCs (R134a). Pure hydrocarbons are not drop in replacements for R134a refrigerators due to mismatch in saturation characteristics. Zeotropic mixture of 50%R290/50%R600a can be used as drop in replacements for R134a refrigerator by adjusting the capillary length and optimizing the refrigerant charge, but the hydrocarbons have the flammability factor.

NeerajaUpadhyay (3) developed a new configuration of the diffuser and sub-cooling in vapour compression refrigeration cycle, for sub-cooling a fan is used. By using diffuser power consumption is less for same refrigeration effect so performance is improved. The size of the condenser can also be reduced due to more heat transfer. So cost of the condenser will be reduced. The parameters like pressure and temperature were measured. After result analysis, we have found that the COP was enhanced from2.65 to 3.38 in the case when conventional Vapour Compression Refrigeration System was used with Diffuser.

R. T. Saudagar, Dr. U. S. Wankhede (4) developed advances in vapor compression refrigeration system to improve coefficient of performance of system and after comparative study suggest a new area of research. It was found through the literature that advances in the design of compressor reduced the compressor work where in capillary tube increased the refrigerating effect. Modifications in condenser are meant to increase degree of sub-cooling of refrigerant which increased refrigerating effect. The minimization of the hunting behavior of evaporator at the onset of superheat using balanced point approach was reviewed as advances in evaporator. The purpose of a compressor in vapor compression system is to elevate the pressure of the refrigerant, but refrigerant leaves the compressor with comparatively high velocity which may cause splashing of liquid refrigerant in the condenser, liquid hump and damage to condenser by erosion. It is needed to convert this kinetic energy to pressure energy for this purpose diffuser can be used.

R. T. Saudagar, Dr. U. S. Wankhede (5) design and testing of diffuser at condenser inlet in vapour compression refrigeration system. Four diffusers with divergence angle 10^o, 15^o, $20^o$and 30^owere designed for same inlet and outlet diameters. The diffusers used were with inlet diameter equal to discharge tube diameter of compressor and outlet diameter equal to condenser inlet diameter. The system was analyses using the first and second laws of thermodynamics to determine the refrigerating effect, the compressor work input, coefficient of performance (COP) and the rate of heat rejected from the system. During the test, the COPs of the system without diffuser and with optimized diffuser at condenser inlet were found out. With diffuser at condenser inlet, amount of heat rejected from condenser is also increased. To remove the same amount of heat, less heat transfer area required. This concept reduces size of condenser to achieve the same system efficiency.

Amitnarwal, SarveshKumar,RishabhVerma,Ravi Kumar (6) improved coefficient of performance of system. To improve the coefficient of performance, it should be noted that compressor work should decrease and refrigerating effect should increase. Modifications in condenser are meant to increase degree of sub-cooling of refrigerant which increased refrigerating effect or more cooling water is required in condenser. The purpose of a compressor in vapour compression system is to elevate the pressure of the refrigerant, but refrigerant leaves the compressor with comparatively high velocity which may cause splashing of liquid refrigerant in the condenser tube, liquid hump and damage to condenser by erosion. It is needed to convert this kinetic energy to pressure energy by using diffuser. By using diffuser power consumption is less for same refrigerating effect so performance is improved.

Amit prakash (7) improved coefficient of performance of system. To improve the coefficient of performance, it is to require that compressor work should decrease and refrigerating effect should increase. Modifications in condenser are meant to increase degree of sub-cooling of refrigerant which increased refrigerating effect or more cooling water is required in condenser. The purpose of a compressor in vapour compression system is to elevate the pressure of the refrigerant, but refrigerant leaves the compressor with comparatively high velocity which may cause splashing of liquid refrigerant in the condenser tube, liquid hump and damage to condenser by erosion. It is needed to convert this kinetic energy to pressure energy by using diffuser. By using diffuser power consumption is less for same refrigerating effect so performance is improved.

From above literature review it is understood that every scholar tried to improve the COP of VCR system either by increasing refrigeration effect or by decreasing the compressor work. Particularly for sub cooling they used different techniques like forced air cooling and water air cooling .It is understood that same effect of sub cooling can be achieved by using heat exchanger. Further improving of COP of VCR system it is trying to decrease the compressor work by using of diffuser. For decreasing compressor work diffuser placed at inlet of the condenser. For increasing refrigerating effect heat exchanger is placed at out of the condenser. As a result of both diffuser and heat exchanger COP of VCR system may be increased.

3. Experimental Work

A Domestic Refrigerator of capacity 215 liters is selected for this experiment. Present work deals with the improvement of vapour compression refrigeration system by using sub-cooling (heat echanger at condenser outlet) and diffuser at inlet of condenser (Fig.1) and compare refrigerants R-134a,HC mixture (R290/R600a). In this work, individual testing of 1.existing system, 2.modified system with sub-cooling and 3.modified system with diffuser and with sub-cooling both refrigerants carried out by experimentally. For this purpose, first of all vaccum is created in the refrigerating compressor and pressure gauges, i.e. low pressure gauge is fitted at suction line to the compressor and high pressure gauge is fitted at discharge of the compressor. And also thermo couples are fitted for various temperature measurements i.e. at compressor outlet, at condenser outlet, at evaporator outlet, at defreezer.

1.The existing system experiment is started first with R134a. Observations are noted like suction and discharge pressures, various temperature readings. Energy performance calculations are done like Refrigeration effect, Compressor work, COP. Similarly the refrigerant HC mixture (R290/R600a) also be tested with existing system. Finally the existing system of both refrigerants performance values are listed below table 2.

2.For the modified system heat exchanger is arranged at outlet of condenser (Fig.1). The heat exchanger main purpose is increase the refrigerating effect by sub-cooling the refrigerant. Heat exchanger is a passive device for operating heat exchanger no need of power. Finally the modified system with heat exchanger the experiment is started with R-134a and calculations are done. Similarly the refrigerant HC mixture (R290/R600a) also be tested with improved system with sub-cooling. Finally the improved system with sub-cooling of both refrigerants performance values are listed below table 2.

3.Finally the improved system with diffuser at condenser inlet and with heat exchanger at condenser outlet (Fig.1). The diffuser is a device which slows down fluid. That means velocity of fluid decreases with increasing pressure. The main purpose of diffuser is compressor work can be reduced. So finally the improved system experiment will be started R-134a and calculations are done. Similarly the refrigerant HC mixture (R290/R600a) also be tested with improved system. Finally the improved system of both refrigerants performance values are listed below table 2.

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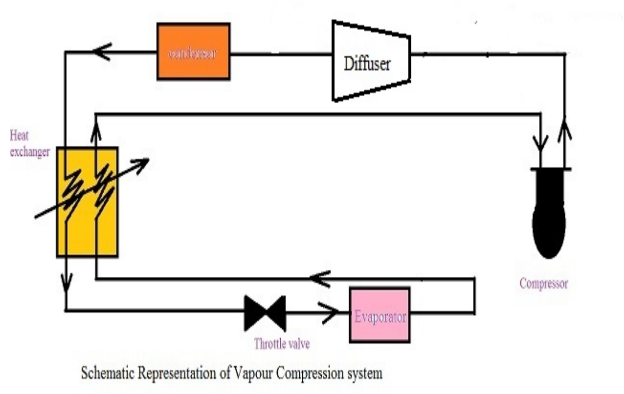


Fig. 1 Line diagram of Experimental setup

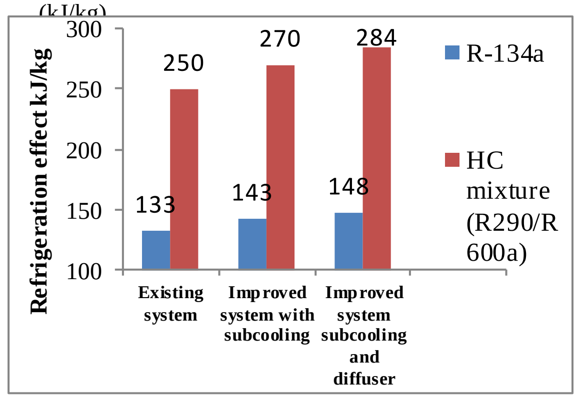
Fig. 2 Experimental Working

4. Results and Discussion

By performing this experiment the following results were obtained.

Table2: Experimental comparison with both refrigerants (R134a and HC mixture)

Parameter		Existing system	Improved System with heat exchanger	Improved system with diffuser and heat exchanger
Refrigerating effect (kJ/kg)	R-134a	133	143	148
	(R290/ R600a)	250	270	284
Compressor work (kJ/kg)	R-134a	46	47	45
	(R290/ R600a)	85	88	84
COP	R-134a	2.89	3.04	3.29
	(R290/ R600a)	2.94	3.06	3.38



Graph 1: Variation of Refrigeration effect

The above graph shows that Refrigeration effect of the both systems compare the refrigerants is R-134a and HC mixture (R290/R600a).

Refrigeration effect of the existing system R-134a is 133 KJ/kg and refrigeration effect of the existing system HC mixture is 250 KJ/kg.

Refrigeration effect of the improved system with sub-cooling R-134a is 143 KJ/Kg and refrigeration effect of the existing system and sub-cooling HC mixture is 270 kJ/kg.

Refrigeration effect of improved system with sub-cooling and diffuser R-134a is 148 kJ/kg and refrigeration effect of improved system with sub-cooling and diffuser HC mixture is 284 kJ/kg.

The refrigeration effect of the modified system with sub-cooling and diffuser is increased due to the refrigerant is HC mixture (R290/R600a) by compare to R-134a.

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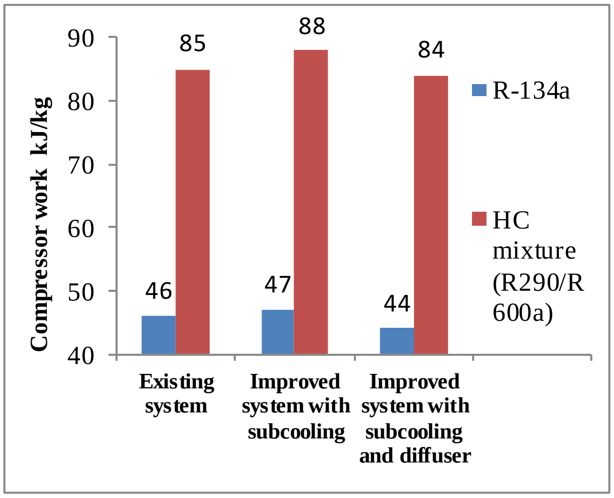
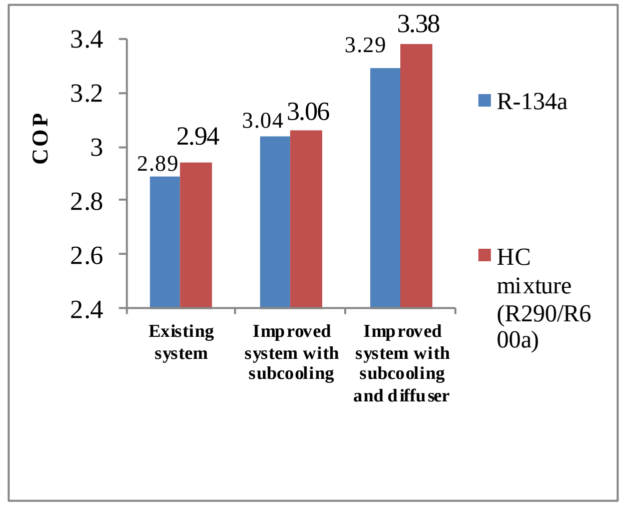


Graph 2: Variation of Compressor work



Graph 3: Variation of COP

The above graph shows that compressor work of the both systems compare the refrigerants is R-134a and HC mixture (R290/R600a).

Compressor work of the existing system R-134a is 46 KJ/kg and compressor work of the existing system HC mixture is 85 KJ/kg.

Compressor work of the improved system with sub-cooling R-134a is 47 KJ/Kg and compressor work of the existing system and sub-cooling HC mixture is 88 kJ/kg.

Compressor work of improved system with sub-cooling and diffuser R-134a is 44kJ/kg and compressor work of improved system with sub-cooling and diffuser HC mixture is 84 kJ/kg.
The compressor work of the modified system with sub-cooling and diffuser is decreased due to the refrigerants are R-134a and HC mixture (R290/R600a).

The compressor work of modified system is decreased due to diffuser. Refrigerant leaves the compressor with high velocity which may result in splashing of liquid refrigerant in the condenser. A diffuser is placed at the inlet of the condenser, and as a result the compressor work is reduced considerably.

Coefficient of performance of the existing system R-134a is 2.89 and coefficient of performance of the existing system HC mixture is 2.94.

Coefficient of performance of the improved system with sub-cooling R-134a is 3.04 and coefficient of performance of the existing system and sub-cooling HC mixture is 3.06.

Coefficient of performance of improved system with sub-cooling and diffuser R-134a is 3.29 and coefficient of performance of improved system with sub-cooling and diffuser HC mixture is 3.38.

The coefficient of performance of the modified system with sub-cooling and diffuser is increased due to the refrigerant is HC mixture (R290/R600a) by compare to R-134a. COP of modified system is increased due to reduction of compressor work and increase in refrigerating effect. For reduction of compressor work diffuser is used, for increasing refrigerating effect sub cooling is done.

5. Conclusions

Experimental analysis of diffuser at the condenser inlet and heat exchanger at condenser outlet of vapor compression refrigeration system of a domestic refrigerator of 215 liters capacity, with R-134a and HC mixture(R290/R600a) as refrigerants. The results obtained are presented below.

R-134a

For the existing system the COP is 2.89, work done by the compressor in the normal VCR system is 46 KJ/Kg and the power consumption by the VCR system is 1.2 KW.

For the modified VCR system with the heat exchanger at condenser out let, the cop is 3.04, work done by the compressor in the modified VCR system is 47 KJ/Kg and the power consumption by the VCR system is 1.143 KW.

For the modified VCR system with the diffuser at the condenser coil inlet and heat exchanger at condenser outlet, the cop is 3.29, work done by the compressor in the modified system VCR system is 44 kJ/kg and the power consumption by the VCR system is 1.06 KW.

HC mixture (R290/R600a)

For the existing system the COP is 2.94, work done by the compressor in the normal VCR system is 85 KJ/Kg and the power consumption by the VCR system is 1.19 KW.

For the modified VCR system with the heat exchanger at condenser out let, the cop is 3.06, work done by the compressor in the modified VCR system is 88 KJ/Kg and the power consumption by the VCR system is 1.12 KW.

For the modified VCR system with the diffuser at the condenser coil inlet and heat exchanger at condenser outlet, the cop is 3.38, work done by the compressor in the modified system VCR system is 84 kJ/kg and the power consumption by the VCR system is 1.02 KW.

Comparing both the refrigerants R-134a and HC mixture with the modified system with diffuser and heat exchanger it is observed and increase of 0.09 in COP. The modified VCR system with the diffuser at the condenser inlet and heat exchanger at condenser out let.

Comparing both the refrigerants R-134a and HC mixture with the modified system with diffuser and heat exchanger it is observed and decrease of 0.04 in power consumption. The modified VCR system with the diffuser at the condenser inlet and heat exchanger at condenser out let.

Hence it is recommended that to place a diffuser at the condenser inlet and heat exchanger at condenser outlet these gives an increase in discharge pressure and refrigerating effect, reduces the work done by the compressor and power consumption for the refrigerator of 215 liters of capacity with R134a and HC mixture as refrigerants.

From the above results it is also concluded that, all the performance parameters for R134a and HC Mixture (R290/R600a) behave similar and HC Mixture have high COP. Presently R134a is used as a transitional replacement for R12. But R134a has higher GWP. Hence permanent solution is necessary. HC Mixture (R290/R600a) with zero ODP and negligible GWP.
Hence it is recommended that HC Mixture (R290/R600a) may be used as an alternative refrigerant for R-134aapplications.

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