

Performance Analysis of Vapour Compression Refrigeration System Using HC Refrigerant Mixtures for Water Chiller

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Abstract: The use of HC refrigerant mixtures has been a topic of current research in view of the concerns related to global warming and Ozone depletion problems caused by CFCs and HFCs. The HC mixture as an alternate refrigerant has been reported to be a promising one in addressing the global warming and Ozone depletion problems. In the present work an experimental set-up is built up to test Vapour Compression Refrigeration (VCR) system with different refrigerants. The aim of this work is to investigate the performance analysis of Vapor Compression Refrigeration system with alternate refrigerants such as Hydrocarbon (HC) refrigerants mixture and compare with Hydro Fluoro Carbon (HFC) refrigerant (R134a) under the similar operating conditions. The alternate refrigerant mixture is selected in the combination of Propane (R290) and Iso-butane (R600a). The refrigeration system variables considered for the investigation of performance are evaporating temperature, condensing temperature and power consumption. The HC refrigerant mixture is observed to give superior performance compared to HFC refrigerant in terms of global warming.

I. INTRODUCTION

A lot of experimental investigations are happening on the replacement of refrigerants that has negative impact on environment. The most common refrigerants being used is tri fluoro ethane, R-410A, R-404A. They have a huge Global Warming Potential (GWP) and negligible Ozone depletion potential (ODP). Refrigerants such as Dichlorodifluoromethane, difluoro mono chloro methane are banned because of the harm they cause in depleting the Ozone layer. The investigation is being made on replacement of these refrigerants with the Hydrocarbons (HC) mixtures to reduce the GWP. Ching-Song Jwo et.al reported Efficiency Analysis of Home Refrigerators by Replacing the R-134a refrigerant with Hydrocarbon Refrigerants. They used varying strengths of HC refrigerant mixtures with R-290 and R-600a in the ratio 50%. The results were shown to encouraging in terms of improved refrigerating effect and reduced power consumption. A.S. Dalkilic and S. Wongwises studied the Performance Comparison of Vapor-Compression Refrigeration System Using Various Alternative Refrigerants based on hydro carbon and hydro fluoro carbon refrigerants with varying mixture ratios.

The results were compared with the performance of Dichlorodifluoromethane, difluoro monochloro methane and tri fluoro ethane. The results were shown that all the alternate refrigerants investigated in this analysis have a slightly lower coefficient of performance than Dichlorodifluoromethane, difluoromonochloromethane and trifluoroethane for the condensation temperature of 50°C and evaporating temperature ranging between -30°C and 10°C. propane/Isobutane (40/60 weight %) mixture was reported to give superior performance and is suggested as an alternative to Dichlorodifluoromethane. Similarly the propane/ Propylene (20/80 by 28 weight %) mixture was suggested as an alternative in the place of difluoromonochloromethane. QiqiTian, DehuaCai et al conducted experimental Investigation of Refrigerant Mixture Difluoromethane /propane as an alternative to HFC410a. They reported reduced power consumption by 34.1%, increased cooling capacity by 64.4% and increased COP by 6.8%. S. Wongwises and N.Chimires (2005,) conducted Experimental Studies with HC Refrigerants propane, butane, Isobutane and compared with trifluoroethane as baseline refrigerant. Experimental results showed that the mixture of propane and Isobutane (60% & 40% according to mass respectively) was the most appropriate alternative compared with trifluoroethane they reported a reduced power consumption by 86% and reduction charge by approximately 50%. ShridharVasantRaskar, SachinVyasMutalikdesai presented the analysis of vapour compression system with alternative refrigerants Difluoroethane. The performance of alternative refrigerant Difluoroethane is evaluated through evaporating pressure, pressure ratio, compression work, coefficient of performance etc. It showed that Difluoroethane would be better replacement for trifluoroethane. Arthur Heleno Pontes Antunes and EnioPedoneBandarraFilho conducted Experimental Investigation on the Performance and Global Environmental Impact of a Refrigeration System Retrofitted with alternative refrigerants. This paper presents associate experimental investigation of the drop-in method for difluoromonochloromethane in a 5-ton cooling system. The original refrigerant was replaced by different halogenated refrigerants like HFC-438A, HFC-404A, HFC-410A and Difluoromethane and also with hydrocarbons propane and Propylene. Results showed that the natural refrigerants presented the best coefficient of performance compared to HFCs, except for Difluoromethane which remained below that of difluoromonochloromethane. Regarding the environmental impact the parameter TEWI, the simplest results were reached with hydrocarbons; in the meantime the refrigerant HFC-404A gave the best environmental impact. Selection of a refrigerant is a critical process involving analysis of environmental, thermo physical and safety



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property. Ozone depletion potential, Global Warming Potential and atmospheric life are the significant factors of refrigerant that effect the environment. Ozone depletion potential of a refrigerant is the measure of its ability to destroy ozone layer of the atmosphere. Global Warming Potential is an indicator of potential of refrigerant to warm the planet by its action in contributing to greenhouse gases. Propane and Isobutane are considered to be non-Ozone depletion potential refrigerants and have a very low Global Warming Potential as compared to trifluoroethane. It has very less adverse effect on the environment.

Table1: Environmental Properties of refrigerants

Refrigerant	Chemical formula	Atmospheric life in year	GWP	ODP
Iso Butane	C ₄ H ₁₀	1<	8	0.05
Propane	C ₃ H ₈	0.041	20	0
Trifluoroethane	CH ₂ FC	13.8	1300	0

The heat energy required for evaporation of propane, iso butane and Trifluoroethane is less than difluoromonochloromethane by 80% at normal boiling point. The amount of refrigerant charge required is inversely proportional to the latent heat of evaporation.

Table 2 Physical properties of refrigerants

Refrigerant	Molecular Weight (Kg/Kmol)	Normal Boiling point (°C)	Critical Temperature (°C)	Critical Pressure (bar)	Latent Heat of Evaporation (kJ/Kg)
Iso Butane	58.1	-11.6	135	3	367
Propane	44.1	-42.2	96.7	425	425
Trifluoroethane	102.03	-26.1	101.1	4.06	377

The thermophysical properties of the charge influence the performance of the system. The mass density of propane and Iso-Butane is less than Trifluoro-methane. The mass density and refrigerant charge flow rate are directly proportional to each other. Therefore propane exhibits less frictional losses and enhanced heat transfer in the condenser and evaporator. Butane and propane have lower viscosity when compared with Trifluoroethane resulting in higher heat transfer rates.

Table3: Thermo-physical properties of the refrigerants

Property	R600a		R290		R134a	
	23°C (liquid)	59°C (vapour)	25°C (liquid)	55°C (vapour)	11°C (liquid)	50°C (vapour)
Pressure (MPa)	3.3	8.4	0.9	1.9	0.4	1.3
Density (Kg/m ³)	8.6	21.8	493.9	0.0	1254.0	0.0
Viscosity (µPa-s)	15.4	8.5	18.1	9.7	232.9	12.9
Thermal Conductivity (W/mK)	0.0	0.0	0.1	0.0	0.1	0.0
Specific heat (kJ/Kg°C)	1.7	1.8	2.7	1.5	1.4	1.2

II. EXPERIMENTAL SETUP

Figure 1 shows a photographic view of vapour compression refrigeration test rig made with 30 liter capacity for cooling water. The evaporator coil is submerged in water made with a metal container insulated with polymer foam. Filter-drier is set up before the capillary tube to absorb any moisture that may be present within the refrigerant circuit so that the refrigerant condensed inside the condenser flows via the filter-drier right into a capillary tube. The test rig used for the experiment is a vapour compression refrigeration system designed to work with R134a and blend mixture of R600a and R290. It consists of an evaporator, cord mesh air cooled condenser and a hermetically sealed reciprocating compressor. Four pressure gauges are hooked up at compressor inlet and outlet, condenser outlet and evaporator inlet. Five calibrated temperature sensors (thermocouples) are mounted at the evaporator inlet, evaporator outlet, compressor outlet, condenser outlet and inside the water container. The supply voltage and the current are measured from the display unit. A Digital Energy meter is used to measure the actual power consumption. Service ports are provided at the pinnacle aspect of the compressor for charging and recuperating the refrigerant. The evacuation of moisture within the device was executed via the carrier port to start with. The device is flushed with nitrogen fuel to eliminate air, impurities, moisture and other particles in the device, which may additionally affect the overall performance of the system. The rig is charged with the assistance of charging machine and evacuated with the help of a vacuum pump to a pressure of -30mm of Hg. Figure indicates a schematic diagram of the measurement machine used inside the experimental setup. The most crucial specifications of the fridge are summarized within the below Table 4. Measured quantities with their range and accuracy are indexed in the below table. An electronic weighing device of 1 gram decision become used to degree the quantity of refrigerant to be charged to the rig during



examine. A digital data logger along with HMI device was used to collect the experimentally measured values.



Fig.1 Vapour compression Test Rig

Table 4 Technical specifications of Vapour compression Test unit

Storage Volume	30L
Current rating	1.1 max
Voltage	220-240V
Frequency	50Hz
Refrigerant type	R134a & Blend(R600a+R290)
Mass of charge	0.140 kg
Capillary tube length	1.5m
Capillary tube inner diameter	1.2mm
Refrigeration capacity	240 W

Table 5 Measured quantities with their range and accuracy

Quantity	Range	Accuracy
Temperature	-0.1°C to 35°C	+0.1°C
Power consumption	0 to 1000 watts	1 watts
Voltage	0 to 240Volts	0.1Volts
Current	0 to 10Amps	0.1Amps
Pressure	0 to 21bars	+0.7bars

In this test, the freezer is completely loaded, and the thermostat is by way of-passed. the thermocouples are located at distinct locations as designated before besides on the air centre and a few thermocouples are stated until steady country is reached via the digital temperature control unit. Importance of this take a look at is to discover how a good deal time is required by the loaded product to acquire the desired temperature. The system performance is examined in keeping with centre temperature of cupboard and time, which indicates how the machine runs at full load condition and how much time is needed to drag down the

burden. In load biking take a look at, the thermostat is hooked up to the circuit at complete load condition. because the temperature reaches maximum set freezing temperature the compressor stops that's referred to as the cut-off time, and because the temperature in the cabinet reaches the lowest set freezing temperature, the compressor starts off evolved that is known as the reduce-in- time, taking the strength retaining the temperature within the cupboard at stabilized condition. significance of this test is to find out how an awful lot time is needed by using the loaded product to gain the desired temperature at full load circumstance additionally indicates how energy is required by way of the compressor at reduce-in and cut-off positions. From the experimental system with the intention to discover the refrigeration effect, C.O.P, and work completed on the system the above may be received by way of using p-h chart. the subsequent experimental values are plotted on the p-h to realize the behavior of the easy vapour compression cycle with and without low receiver.

III. RESULTS AND DISCUSSION

The basis for present work is the result reported by M. Mohanraj et.al [18] for selection of combination of refrigerant mixture. Firstly the vapour compression test is carried out with R-134a to assess the parameters like evaporator temperature, coefficient of performance, power consumption, refrigerating effects. Later the experiment is repeated with alternate blended mixture R290 and R600a (50:50 weight proportions). Figure 2 shows the Evaporator temperature drop for R-134a refrigerant and the blended refrigerant mixture. The lowest Evaporator temperature achieved is 0.1°C with 135g of R134a and 0.05°C with 135g of blend. It is observed that as the time increases the cooling capacity also increases and reaches 200 W at 0.05°C with hydrocarbon blend and 0.1°C for R-134a.

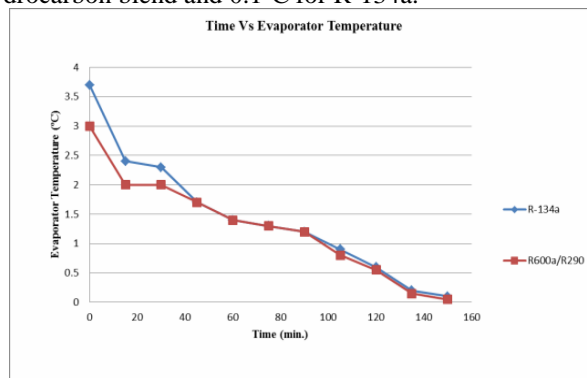


Fig.2 Variation of Evaporator Temperature of Vapour compression refrigeration system with respect to time

Figure 3 shows the variation of power consumption for 134a and the blend of R600a/R290. The power consumption with R134a is observed to be 25% higher than the blend of R600a/R290, due to larger amount of charge. Maximum power consumption is noted as 0.10 kWh for R134a and 0.07 kWh for HC blend. Figure 4 shows that the coefficient of performance of blend is higher than R-134a.



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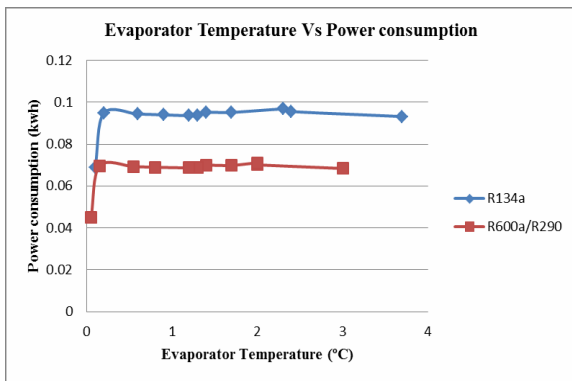


Fig.3 Power consumption of compressor between R134a and Blended mixture

Figure 5 shows the variation of COP with respect evaporator temperature, while evaporator temperatures falls COP is falls but the blended mixture had less COP compare to R134a

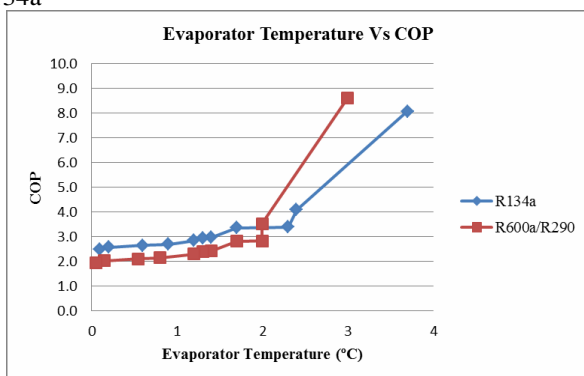


Fig.4 Variations of COP of vapour compression system with respect to evaporator temperature

The variation of condenser temperature with time is shown in Fig.5. It is observed that using the blend lower condenser temperatures are recorded than R-134a. Therefore, to achieve the same refrigeration effect the blend takes less condensation time.

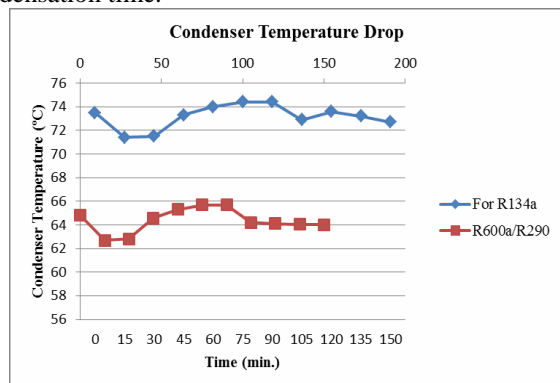


Fig.5 Condenser temperature Drop for vapour compression refrigeration system by R134a and blended mixture

The global warming potential for the propane and isobutene blend is obtained by the sum of their individual GWP values based on mass composition and its value is 14.

IV. CONCLUSIONS

In the present work experimental investigation is carried out to investigate the performance of vapour compression refrigeration system for water chiller of 30 liters capacity, with R134a and blended mixture of propane (R290) and Iso

butane (R600a). The test rig is suitably modified by adopting different lengths of liquid line suction line heat exchanger.

1. The combination of propane and isobutane in equal proportions as a blend can be used in the place of trifluoroethane.
2. A least mass of refrigerant charge for the above blend of 134 g is recorded which is considerably lower than the trifluoroethane as charge.
3. The Coefficient of Performance for the combination of propane and isobutane in equal proportions is observed to be higher at all operating conditions when compared with trifluoroethane.
4. Also the cooling rate is noted to be higher for the above blend when compared with trifluoroethane.
5. The condenser temperature, during the condensation process for the blend is less. It shows that it doesn't require any external energy for condensation
6. Also the above blend is seen to consume lower power than with trifluoroethane.
7. It is evident that the combination of propane and isobutane in equal proportions as a blend is superior in performance than trifluoroethane hence a better choice.
8. The global warming potential for blended mixture is less when compare with the trifluoroethane.

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