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PERFORMANCE ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH BLENDS OF HYDROCARBON R290/600a-A STUDY

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ABSTRACT

In domestic refrigerators and refrigeration system the most widely used refrigerant is R134a.It must be phased out soon according to Kyoto protocol due to its high Global Warming Potential (GWP) of 1300. Hydrocarbon mixture (HCM) is an alternative refrigerant for Hydro Fluorocarbon (HFC) and Chlorofluorocarbon (CFC) compounds due to their lower GWP and zero Ozone Depletion Potential (ODP). The impact on the environment is also reduced due to usage of hydrocarbon mixture in different mass ratio. In the present work, an experimental investigation has been made with hydrocarbon refrigerant mixture composed of R290 (Propane) and R600a (Isobutane) as an alternative to R134a in a single evaporator domestic refrigerator. The primary object of the proposed work is to evaluate the performance parameters like compressor Input power, Discharge temperature, Heat rejected in condenser, Refrigeration effect and Coefficient of performance (COP) with optimized mixture of R290 and R600a refrigerant and compare it with the performance of R 134a refrigerant. The investigation aims to optimize the suitable blending for the mixture of R290 and R600a refrigerant and validate it towards REFPROP software for optimization of Blends. The hermetically sealed compressor to be used to analyze the performance of refrigeration cycle.

Keywords- *Global Warming Potential, Ozone Depletion Potential, REFPROP, VCRS.*

I. INTRODUCTION

Thermodynamic cycles can be categorized into Gas cycles and Vapour cycles. In a typical Gas cycle, the working fluid (a gas) does not undergo phase change; consequently the operating cycle will be away from the Vapour dome. In a Gas cycles, Heat rejection and Refrigeration take place as the gas undergoes sensible cooling and heating. Whereas in a Vapour cycle the working fluid undergoes phase change and refrigeration effect is due to the Vaporization of Refrigerant liquid. If the refrigerant is a pure substance then its temperature remains constant during the phase change processes. However, if a Zeotropic mixture is used as a refrigerant, then there will be a temperature glide during Vaporization and Condensation. Since the refrigeration effect is produced during phase change, large amount of heat (latent heat) can be transferred per kilogram of refrigerant at a near constant temperature. Hence, the required mass flow rate for a given refrigeration capacity will be much smaller compared to a Gas cycle. Vapour cycles can be subdivided into Vapour compression systems, Vapour absorption systems and Vapour jet systems etc. Among these the Vapour compression refrigeration systems (VCRS) is predominant.

Background

The history of refrigeration is very interesting since every aspect of it, the availability of Refrigerants, the Prime movers, the developments in Compressor and the methods of refrigeration all are a part of it. Refrigeration as it is known these days is produced by artificial means. Though it is very difficult to make a clear demarcation between natural and artificial refrigeration, it is generally agreed that the history of artificial refrigeration began in the year 1755, when the Scottish professor William Cullen made the first refrigerating machine, which could produce a small quantity of ice in the laboratory. The American engineer Alexander Twining (1801-1884) received a British patent in 1850 for a Vapour compression system by use of ether, NH3 and CO2. David Boyle, in fact made the first NH3 system in 1871 in San Francisco. John Enright had also developed a similar system in 1876 in Buffalo. Franz Windhausen developed carbon dioxide (CO2) based Vapour compression system in Germany in 1886. The Carbon dioxide compressor requires a pressure of about 80 atmospheres and therefore a very heavy construction. Linde in 1882 and T.S.C. Lowe in 1887 tried similar systems in USA. The CO2 system is a very safe system and was used in ship refrigeration until 1960. Raoul Pictet used SO2 (NBP-10°C) as a refrigerant. Its lowest pressure was high enough to prevent the leakage of air into the system. Palmer used C2H5Cl in 1890 in a Rotary compressor. He mixed it with C2H5Br to reduce its flammability. Edmund Copeland and Harry Edwards used Isobutane in 1920 in small refrigerators. It disappeared in 1930 when it was replaced by CH3Cl. Dichloro ethylene (Dielene or Dieline) was used by Carrier in Centrifugal compressors in 1922-26.

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II. LITERATURE REVIEW

Each refrigerant blend has its own unique properties that are somewhat different from the original product they are intended to replace. [19] Same works were done by many researchers to find out the best suitable refrigerant for specific need.**P. Thangavel and P. Somasundaram** together studied the performance analysis of VCRS with HC as refrigerants at different loads in evaporator. Various performance parameters like compressor Input power, Discharge temperature, Heat rejected in the condenser, Refrigeration effect and COP were investigated at various loads of 25%, 50%, 75% and 100% in the evaporator. They were used HC mixture of R-290/R-600a in the mass proportion of 50%/50%.From their experimentation results they found that 75% Evaporative load has better performance as compared to other load values. Hence they found such a refrigerant mixture that shall be phase out the refrigerant R-134a. [1] **BUKOLA O. BOLAJI & ZHONGJIE HUAN** were did the Thermodynamic analysis of Hydrocarbon refrigerants in a sub cooling refrigeration system. From their experiment they compared the performance simulation of Three Hydrocarbon refrigerants namely R-290, R-600 and R-600a with R-134a.They were concluded that performance of of R-600 and R-600a in system were better than those of R-134a and R-290. [2]**P. Thangavel, Dr. P. Somasundaram, T.Sivakumar, C.Selva Kumar, G.Vetriselvan** togetherlly studied the Simulation analysis of Compression Refrigeration cycle with Different Refrigerants.Their results were compared with Halogenated refrigerants such as R-134a, R-12 for different condenser and evaporator temperatures. Among the HC refrigerants group, the mixture of R-290 and R-600a at concentration of 50% each has optimum performance in terms of higher refrigeration effect, better heat transfer and COP. [3] **Mohd. Aasim and U.S.Wankhede** were studied the different environmental friendly refrigerants of either Hydrocarbons or Hydro fluorocarbon class.They found that almost in all cases when R-134a was replaced with HC's the COP of the system was improved, ON time ratio and energy consumption was reduced. They observed that due to higher value of latent heat of HC's the amount of refrigerant charge was also reduced as compared to HFC-134a.[4]**N. Austin, Dr.P. Senthil Kumar, N. Kanthavelkumaran** were designed a household refrigerator to work with R-134a was used as an investigation unit to assess the prospect of using mixed refrigerants. They were used mix refrigerant which is locally available and comprises in various properties like, 24.4 % Propane, 56.4% Butane and 17.2% Isobutene. Finally they concluded that every mode of mixed refrigerant yields higher COP than HFC-134a. [5]**A. Baskaran, P.Koshy Mathews** were studied the Performance comparison of Vapour Compression Refrigeration System using various alternative refrigerants. Considering the comparison of performance coefficients (COP) and pressure ratio of the tested refrigerants and also the main environmental impacts of ozone layer depletion and global warming potential they were concluded that, Refrigerant blend R-435A [RE-170 (80%), R-152a (20%)] was found to be the most suitable alternative among the refrigerants tested for R-134a.[6] **A. Baskaran, P.Koshy Mathews** studied the performance comparison of VCRS using Eco-friendly refrigerants having low GWP such as HFC-152a, HFC-32, HC-290, HC-1270, HC-600a and RE-170. They compared the performance of those refrigerants with R134a as possible alternative replacement. Their results showed that the alternative refrigerants investigated in the analysis RE-170,R-152a and R-600a have a slightly higher COP than R-134a for the Condensation temperature 50^0C and Evaporating temperature ranging between -30^0C to 10^0C.They also found that all of the investigated refrigerants have much higher Refrigerating effect and Isentropic compression work than R-134a.[7]**D. Sendil Kumar, Dr. R. Elansezhian** has done the experimental investigation to reduce the usage of HFC-134a.For this they used the mixture of R-134a and R-152a as a refrigerant in the different proportion of 30%/70%, 50%/50%, 70%/30% by mass. Experiment was conducted by Continuous running tests under an ambient temperature of 32^0C. The overall performance proved that COP value increases and the maximum COP (5.26) was obtained for 70%/30% mixtures of R152a and R134a. [8]**B.O. Bolaji, M.A. Akintunde & T.O. Falade** did the comparative analysis of performance of three Ozone friendly HFC Refrigerants R-32, R-134a and R-152a in a Vapour Compression Refrigeration System (VCRS). Their results were showed that R-32 yielded undesirable characteristics such as high pressure and low COP. As a result, R-152a could be used as a drop in substitute for R-134a in Vapour compression refrigeration system. The COP of R-152a obtained was higher than those of R-134a and R-32 by 2.5% and 14.7% respectively. [9] **I. M. G. Almeida, C. R. F. Barbosa, and F. A. O. Fontes** were worked on the research efforts and development in the Refrigeration and Air conditioning sector. A theoretical-computational analysis was developed for R-134a, propane (R-290) and the selected mixtures (R-290/R-600a in 60%/40%, R-290/R-600a/R-134a in 40%/30%/30% and R-600a/R-290 50%/50%) in the standard refrigeration cycle ASHRAE, using the thermodynamic and thermo physical properties provided by the REFPROP 6.0 software. They observed that the hydrocarbons reduced the levels of pressure on the condenser and evaporator, along with smaller compression tasks necessary in the system owing to the thermo physical properties privileged in these fluids. They find out that use of R-290 and their mixture involving

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HC provides a Tripling of the latent heat of vaporization compared to R-134a as this factor leads to a reduction of about 50% of the need to mass charge of Refrigerant in the cooling system for a same capacity of the equipment.[10]**Ki Jung Park and Dongsoo Jung** were studied the performance of Heat pumps charged with R-170/R-290 mixture against the refrigerant R-22.They did experiment with different composition of R-170 and R-290, from which they concluded that 6% R-170+ 94% R-290 mixture was the good long term 'Drop-in' replacement refrigerant for R-22 for both Air conditioning and Heat pumping applications from the view point of energy and greenhouse warming. [11] **M. Mohanraj, S. Jayraj, C. Muraleedharan, P. Chandrasekar** did experimental investigation of R-290/R-600a mixture as an alternative to R-134a in domestic refrigerator of 200 L capacity. They were used mixture R-290 /R-600a in weight proportion of 45.2% /54.8%.They performed Continuous running test under different ambient temperatures of 24^0C, 28^0C, 320C,38^0C and 43^0C.Their overall performance has proved that the above hydrocarbon refrigerant mixture could be the best long term alternative to phase out R-134a. [12]**Mohamed M. El-Awad** described a Computer based analytical model for evaluating the performance of Natural HC fluids as alternative refrigerants in VCRS. The paper demonstrated the improved accuracy of the present compression model compared to the Polytropic model and verifies the self-supported, computer based analytical model of the closed cycle by comparing its estimates for the key cycle parameters with those obtained from the published literature for R-134a, R-290, R-600 and R-600a. [13]**Moo-Yeon Lee, Dong-Yeon Lee and Yongchan Kim** together studied the performance characteristics of a small capacity directly cooled refrigerator using mixture of R-290 and R-600a with mass fraction of 55%/45% as an alternative to R-134a.Both system (R-290, R-600a mixture and R-134a) were tested and then optimized by varying the Refrigerant charge and Capillary tube length under experimental conditions for both the Pull down test and the Power consumption test. From experiment they found that refrigerant charge of the optimized R-290/R-600a system was approximately 50% of that of the optimized R-134a system. They also concluded that Reduction in Power consumption and improvement in cooling speed for optimized Hydrocarbon mixture comparing with R-134a. [14] **Bjorn Palm** presented that the hydrocarbons will continue to be used as refrigerants in small and medium sized refrigeration, air conditioning and heat pump system (< 20 KW cooling).He was investigated that the properties of the Hydrocarbons Propane, Propene and Iso-butane and compared them to R-22, R-134a and ammonia. However, working with these fluids requires careful design and skilled personnel for manufacturing and servicing. [15] **E.Navarro, J.F.Urchueguia, J.M.Corberan & E.Granryd** were studied the performance analysis of a series of Hermetic reciprocating compressors working with R-290 and R-407C as a refrigerant. They were concluded that R-290 (Propane) compared with R-407C tends to improve its performance at Low pressure ratios, while worsening it at High pressure ratios. [16]**M.A. Sattar, R. Saidur, H.H. Masjuki** had designed a domestic refrigerator to work with R-134a was used as a test unit to assess the possibility of using hydrocarbons and their blends as refrigerants. Pure butane, isobutene and mixture of propane, butane and isobutene were used as refrigerants. Their result was showed that compressor consumed 3% and 2% less energy than that of HFC-134a at 28^0C ambient temperature when Iso-Butane and Butane was used as refrigerants respectively. They also concluded that COP for the HC's is comparable with co-efficient of performance of HFC-134a. [17]**Piotr A. Domanski David Yashar** represented comparable performance evaluation of HC and HFC refrigerants in an optimized system. They did the analytical evaluation of Iso-butane (R-600a), Propane (R-290), R-134a,R-22,R-410A and R-32 in VCRS used for comfort cooling applications. Their evaluation performance of R-600a ,R-290, R-134a, R-22, R-410A and R-32 in system with optimized heat exchangers showed the COP for the studied refrigerant to be within 13% with R-32 and R-290 having the highest COP. [18]**Fatouh and Kafafy** experimented with Liquefied Petroleum Gas (LPG) composed of 60% of R-290 and 40% of commercial Butane as an alternative to R-134a in a 280 L domestic refrigerator at 43^0C ambient temperature. Their results reported that COP of the refrigerator using LPG was higher than that of R-134a by about 7.6% with lower values of energy consumption and ON time ratio by about 10.8% and 14.3% respectively. [20]**Wongwises and Chimres** investigated with HCM and HC/HFC mixtures at different mass ratio in a 239 L domestic refrigerator at an ambient temperature of 25^0C to replace R-134a. It has been reported that R-290/R-600 mixture (In the ratio of 60%/40%, by mass fraction) is the most appropriate alternative. [21] **L. Zhao** did the experimental evaluation of a non-azeotropic working fluid for Geothermal Heat Pump System (GHPS).In this paper, a non-azeotropic working fluid R-290/R-600a/R-123 in the mass ratio of 50%/10%/40% is presented for a GHPS where geothermal water is at 40^0C to 45^0C and heating network water at 70^0C to 80^0C serve as the low and high temperature heat sources. Experimental results showed that the COP of a GHPS using the working fluid is above 3.5.where it was observed 3 for R-22 refrigerant. [22]**Bilal A. Akash and Salem A. Said** experimented with LPG composed of R-290/R-600/R-600a in the mass ratio of 30%/55%/15% as an alternative to R-12 in domestic refrigerators. They were used various mass charges of 50g, 80g and 100 g in experimentation. Their experimental result showed that LPG compares very well to R-12.They also concluded that a mass charge of 80g of LPG had the best result when used in the refrigeration setup. [23] **I. L.**

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Maclaine cross E. Leonardi measured comparative performance of R-600a over R-12 and R-134a refrigerant and found that R-600a refrigerator have electricity savings up to 20%. They also concluded that HC refrigerants have environmental advantages and are in safe in small quantities.R-290 can replace R-22 and HC mixture replace R-12 and R-134a in applications using positive displacement compressors. [24]

III. FUTURE SCOPE

Theoretical and experimental studies using various Hydrocarbon mixtures on VCRS cycle were done successfully by many investors. By varying the different cycle parameters like changing the Capillary tube length, Evaporator load, varying Refrigerant Charge etc. performance of cycle found improved.

There were many researchers who work on the blending mixtures of R290/R600a and they concluded that R290/R600a is a best alternative to R-134a comparing its performance and GWP. But find out the optimized blending mixtures of R-290 and R-600a with the help of REFPROP software and validation with it is a new task.

Moreover, by varying the Hydrocarbon mixture ratios with other natural refrigerants in VCRS cycle and to find out the optimized one will be the future scope in refrigeration. Also HC mixture along with addition of nano particles also scope for new researchers. Hydrocarbon refrigerants are flammable in nature hence to work on its safety precautions is future need to phase out R-134 as early as possible.

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