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"PERFORMANCE COMPARISON OF R290, R600A AND R134A IN VAPOUR COMPRESSION REFRIGERATION CYCLE"

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ABSTRACT

The refrigerating effect is an important parameter that determines the cooling capacity of a refrigerant. In this study, we investigated the variation of the refrigerating effect with evaporating temperature using different refrigerant mixtures. The results showed that the refrigerating effect is influenced by the percentage composition of the refrigerant mixture. As the percentage of R600a in the mixture increased, the refrigerating effect decreased. Furthermore, we observed that the refrigerating effect increased with an increase in evaporating temperature. This can be attributed to the higher latent heat value of the refrigerant at higher temperatures. A higher latent heat value is advantageous as it allows for a lower mass flow rate per unit of capacity, leading to increased compressor efficiency and capacity. This, in turn, reduces power consumption and enables the use of smaller and more compact equipment. Comparing the refrigerating effects of the hydrocarbon mixtures to R134a, we found that the hydrocarbon mixtures exhibited higher refrigerating effects. This implies that for the same cooling capacity, a lower mass of refrigerant and a smaller compressor size would be required due to their higher latent heat values. Additionally, we assessed the actual Coefficient of Performance (COP) of the refrigerants. R-290 + R-600a (56/44) demonstrated a higher actual COP of 2.89 compared to R-134a with an actual COP of 2.28. This confirms the superior efficiency of R-290 + R-600a in practical applications. In conclusion, our findings highlight the importance of considering the refrigerating effect, evaporating temperature, and composition of refrigerant mixtures when designing refrigeration systems. Hydrocarbon mixtures, particularly R-290 + R-600a), show promising characteristics in terms of refrigerating effect, energy efficiency, and environmental impact, making them potential alternatives to traditional refrigerants like R134a.

Keyword: *COP, R134a, R600****a,*** *cooling****,*** *refrigerating effect, energy efficiency*

I. INTRODUCTION

R134 is widely used refrigerant in air conditioning all over the world. The growing global demand for room air conditioner increases the usage of R134A. Due to its environmental concern of ozone depletion, it is a controlled substance under the Montreal Protocol. As per accelerated phase out schedule, the R134A has to be phased out before 2030 in developing countries and 2020 by developed countries [1, 2]. The accelerated phase out schedule poses a major challenge for developing countries. At present, HFC (hydrofluorocarbon) alternatives to R134A for ACs are R407C & R410 A. However, with a relatively high GWP (global warming potential) of HFC & uncertainties of the future of such

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HFCs, they are not preferred as long term alternatives. Some developing countries, including India and China, are searching for a long term alternative instead of opting for an intermediate solution of HFCs. Therefore, there is a lot of interest in natural fluids like hydrocarbon. Propane (R290) is considered as an energy efficient replacement due to its similarity to R134A except for its flammability. Many studies have revealed the advantage of R290 in air conditioner and heat pump. Park and Jung (2008) [3] showed that R290 when used in air conditioner, the refrigeration capacity was lowered by 8.2% and coefficient of performance was 11.5% higher than that of R134A system. Zhou et.al. (2010) [4] has found in air conditioner R290 had 4.7-6.7% lower cooling capacity & 8.5% higher EER (energy efficiency ratio) as compared to R134A systems. Tun-Ping Teng et.al. (2012) [5] found experimentally best charged mass for air conditioner of refrigerant R290 was 50-55% than that of R134A by weight . EER of R290 increases by 20% of than that of R134A system. J.H. Wu et.al. (2012) [6] found 550g R290 optimum charge, EER is 0.8% higher than R134A under normal condition. The optimum charge to obtain by performance is far beyond the regulated by EN378. It has been found by many researches that R290 performance was equal to or better than the existing system with HCFCs or HFCs. This paper presents the experimental performance of 1 ton capacity Window air conditioner with R134A as baseline refrigerant and R290 as an alternative refrigerant. R290 refrigerant to the original system with air cooled condenser and optimized system with evaporative cooling condenser for better performance of the air conditioner.

II. METHODOLOGY

The performance parameters of the refrigeration cycle, including vapour compression, refrigerant temperature, operating pressure, temperature, power consumption, and coefficient of performance (COP), were analyzed. The thermodynamic properties of R134A and R290 refrigerants were calculated using COOLPACK software. The following equations were used to determine the pressure ratio, refrigeration effect, and COP [8, 9, 10]:

1. Pressure ratio calculation: Pressure ratio = $Pcondenser$ / $Pevaporator$ (2)
2. Refrigeration effect calculation: Refrigeration effect (Qe) = $\Delta h_{evaporator}$ = ($h1 - h4$) KJ/kg (3)
3. COP calculation: C.O.P. = ($Wevaporator$ / $Wcompressor$) = ($h1 - h4$) / ($h2 - h1$) KJ/kg (4)

Please note that the equations have been rearranged to represent the proper calculations. R290, also known as propane, is a hydrocarbon refrigerant commonly used in various cooling and refrigeration systems. Here are some of the properties of R290: Here is the table summarizing the specifications of the chemical compound C3H8 (Propane):

Table 1. Properties of R290

Specification	Value
Chemical Formula	C3H8
Molecular Weight	44.097 g/mol
Boiling Point at Atmospheric Pressure	-42.07°C (-43.73°F)
Critical Temperature	96.67°C (206.01°F)
Critical Pressure	4.25 MPa (61.6 psi)
Ozone Depletion Potential (ODP)	0
Global Warming Potential (GWP)	3 (over a 100-year time horizon, relative to CO2)
Flammability	Highly flammable, requires careful handling and storage

R600a is a hydrocarbon refrigerant, also known as isobutane. It is commonly used as a replacement for chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) refrigerants due to its low environmental impact and favourable thermodynamic properties. Here are some key properties of R600a: Here is a table summarizing the specifications of the chemical compound C4H10 (Butane)

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Table 2 Properties of R600a

Specification	Value
Chemical Formula	C4H10
Molecular Weight	58.12 g/mol
Boiling Point	-11.7°C (-10.9°F)
Critical Temperature	134.7°C (274.5°F)
Critical Pressure	36.5 bar (529.6 psi)
Ozone Depletion Potential (ODP)	0 (R600a is ozone-friendly)
Global Warming Potential (GWP)	3 (GWP of 1 for R600a over a 100-year time horizon)
Flammability	Flammable (ASHRAE safety group classification A3)
Lower Flammability Limit (LFL)	1.8% by volume
Upper Flammability Limit (UFL)	8.5% by volume
Heat of Vaporization	367 kJ/kg at boiling point
Heat Capacity	2.22 kJ/(kg•K) at 20°C (68°F)
Thermal Conductivity	0.078 W/(m•K) at 25°C (77°F)
Density	551 kg/m³ at 20°C (68°F)

In this chapter detail of experimental setup and also specifications of the project is given. The experiment will be carried out on Ice Plant Test Rig system. Experimental data from system is taken and performance evaluation is made with R-134a a primary refrigerant and new hydrocarbon mixture refrigerant. This Chapter deals with procedure of setting up the experiment, measurement of parameters, and description of measuring instruments, observations are explained.

Fig 1. VCRS Test Rig

Here is the table summarizing the specifications of the components:

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Table 4. Specification of Test Rig

Sr. No.	Component Name	Specifications
1	Capacity	30 Kg/day
2	Refrigerant	R-134a
3	Compressor	KCN 411 LAG
4	Condenser	Air cooled, 10*112*
5	Evaporator	Water cooled
6	Ice Can	Size: 150 ml, Qty: 12
7	Drier	1/4"
8	Tank	Capacity: 48 lit, SS tank, Insulated
9	Pressure Gauges	Range: 0-16 Kg/cm2, Qty: 1
		Range: 0-28 Kg/cm2, Qty: 1
10	Temperature Sensors	Pencil Type: pt. 100, Qty: 2
		Bare Type: pt. 100, Qty: 4
11	Charging Valve	1/4" NPT
12	Brine	Water: 50%, Glycol: 50%
13	Power Supply	230V, 5 Amp

III. RESULT

The variation of the refrigerating effect with evaporating temperature. As shown in the figure, the higher the percentage of R600a in the mixture, the lower the refrigerating effect of the mixture. The refrigerating effect increases with an increase in evaporating temperature, which is due to the increase in the latent heat value of the refrigerant. A very high latent heat value is applicable, since the mass flow rate per unit of capacity is less. When the latent heat value is high, the efficiency and capacity of the compressor are greatly increased. This decreases the power consumption and also reduces the compressor displacement requirements that permit the use of smaller, more compact pieces of equipment. It is clearly shown that the hydrocarbon mixtures exhibited higher refrigerating effects than R134a. Therefore, a very low mass of refrigerant would be required for the same capacity, and a smaller compressor size would also be required, due to their high latent heat values.
Designation R-134a R-290 + R-600a (56/44)

Table 5. Comparing the specifications of R-134a and the mixture of R-290 and R-600a:

Specification	R-134a	R-290 + R-600a (56/44)
Designation	HFC	HC
Chemical Type	Pure	Zeotropic mixture
Composition	100%	56% R-290, 44% R-600a
Ozone Depletion Potential	0	0
Global Warming Potential	1600	3
Normal Boiling Point	-26°C	-31°C
Latent Heat	189 KJ/kg	367 KJ/kg
Theoretical COP	3.02	3.43
Actual COP	2.28	2.89
Refrigerating Effect	279 KJ/kg	306 KJ/kg
Time taken to ice Formation	180 min	150 min

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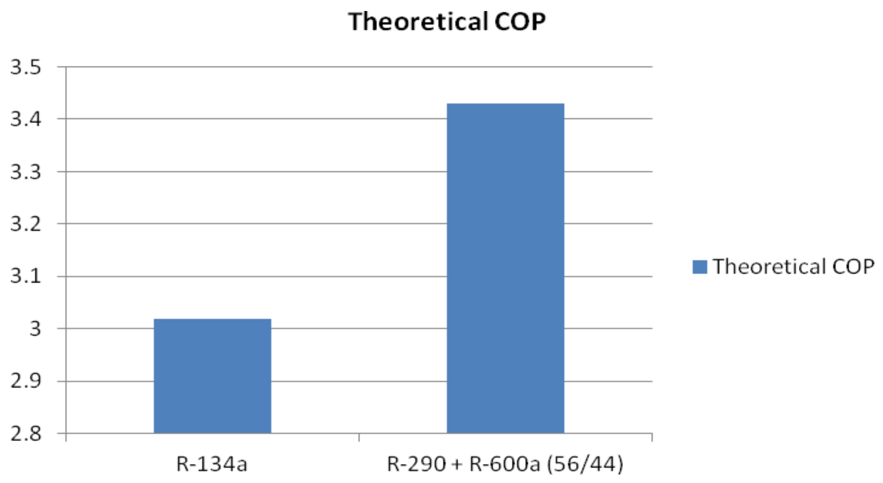

Fig 2 Comparison of Theoretical COP

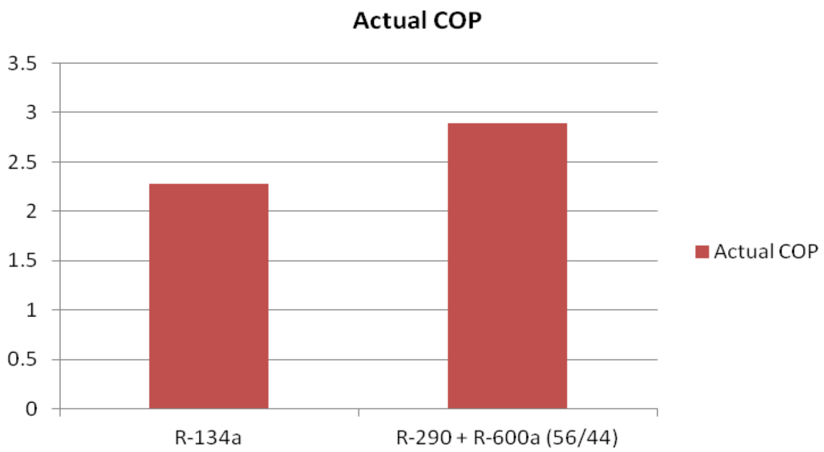

Fig 3 Comparison of Actual COP

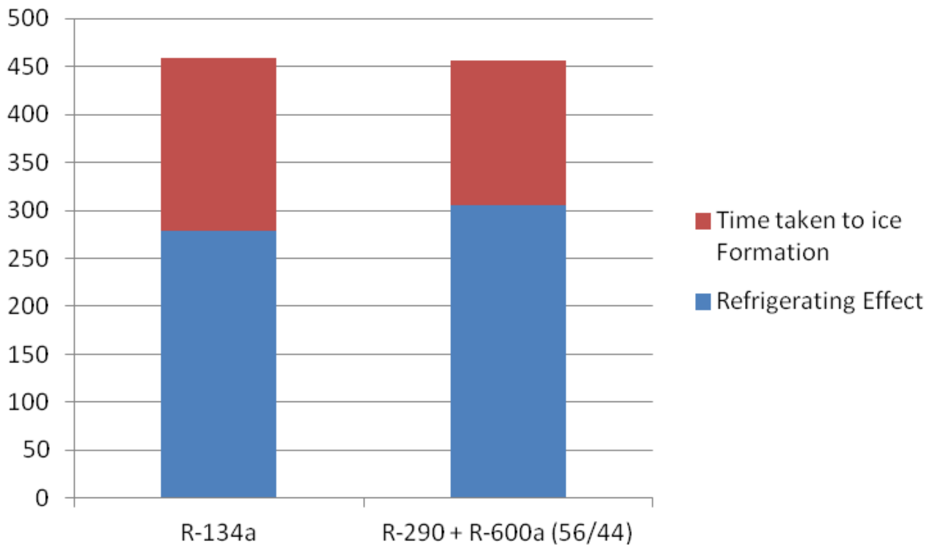

Fig 3. Comparison of Refrigeration Effect

All the above figures based on the provided table comparing the specifications of R-134a and R-290 + R-600a, we can draw the following conclusions:

1. Global Warming Potential (GWP): R-290 + R-600a (56/44) has a significantly lower GWP of 3 compared to R-134a, which has a GWP of 1600. This indicates that R-290 + R-600a (56/44) has a much lower impact on global warming potential, making it a more environmentally friendly choice.
2. Theoretical COP: R-290 + R-600a (56/44) exhibits a higher theoretical Coefficient of Performance (COP) of 3.43 compared to R-134a, which has a theoretical COP of 3.02. A higher COP suggests that R-290 + R-600a (56/44) is more efficient in converting input energy into useful cooling output.
3. Actual COP: R-290 + R-600a (56/44) also demonstrates a higher actual COP of 2.89 in comparison to R-134a with an actual COP of 2.28. This further supports the efficiency advantage of R-290 + R-600a (56/44) in practical applications.
4. Refrigerating Effect: R-290 + R-600a (56/44) showcases a slightly higher refrigerating effect of 306 compared to R-134a with a refrigerating effect of 279. This indicates that R-290 + R-600a (56/44) is capable of providing a greater cooling effect.

Time taken to ice Formation: R-290 + R-600a (56/44) exhibits a shorter time taken to ice formation of 150 minutes compared to R-134a, which requires 180 minutes. This

IV. Conclusion

The present demonstration provides a comprehensive review of various studies on hydrocarbons as alternative refrigerants in refrigeration, air conditioning, heat pump, and automobile air conditioning systems. Many hydrocarbons exhibit suitable characteristics as refrigerants from thermodynamic, thermo physical, exergetic, and heat transfer perspectives. They have excellent environmental characteristics, with zero Ozone Depletion Potential (ODP) and negligible Global Warming Potential (GWP). Hydrocarbons such as R290 and R600a demonstrate superior performance in terms of energy, exergy, and heat transfer in domestic refrigerators. Based on different studies and previous summaries, the following points can be drawn:

1. Hydrocarbons exhibit thermodynamic and thermo physical properties that are comparable to traditional refrigerants.
2. Using hydrocarbons as alternatives to existing HCFC refrigerants is not only beneficial for the environment but also helps reduce energy consumption.
3. Hydrocarbons show promising characteristics in terms of energy efficiency, Coefficient of Performance (COP), refrigerant charges, and compressor discharge temperatures, making them viable alternatives to conventional refrigerants.
4. Blends of hydrocarbon/HFC mixtures can be used as replacements for CFCs and HCFCs while maintaining the same lifespan as existing systems.
5. Due to their flammability, researchers often use low refrigerant charges in large capacity systems when working with hydrocarbons.
6. R290 has been successfully commercialized as a replacement for R134A in low charge, room, and portable air conditioners. Hydrocarbon mixtures like R432A and R433A, as well as HC/HFC mixtures such as R470c/R600a/R290, are considered environmentally friendly options for replacing R134A in air conditioning and heat pump applications.

Hydrocarbons and HFC/HC mixtures have shown promise as substitutes for replacing R12 and R134a in domestic and commercial refrigeration systems.

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