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EVALUATION OF REFRIGERANT R290 AS A REPLACEMENT TO R22

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ABSTRACT

HCFC's are to be phased out in the near future according to some International treaties, like Montreal protocol and Kyoto agreement, due to their negative impact on earth's environment. HCFC-22 is the most widely used refrigerant in air conditioning and commercial appliances and causes ozone depletion, hence need to phase out earlier. This paper discusses the theoretical aspects of HC-290 (propane) as a potential substitute for HCFC-22. Earlier, HC-290 was neglected with contention that flammable fluids are not safe to be used as refrigerants. But, with the technological development, refrigeration industry has started working on flammable refrigerants and hence propane can be effectively employed. Theoretical analysis shows that the thermo physical properties and environmental properties of HC-290 is much better than HCFC-22 hence making it feasible for replacement.

Keywords: Alternative refrigerants, HC290, HCFC22, Refrigeration.

I. INTRODUCTION

With increasing recognition of environment protection, a great deal of attention has been devoted to the negative environmental effect of CFCs and HCFCs refrigerant. Based on scientific findings, regulatory requirements and market pressure, the governing selection criteria for the new alternative refrigerants are changing. New long term alternative refrigerant should have not only zero ODP but it should have low GWP value – initially 150 or less with old requirements of suitability, safety, and material compatibility. At the same time it should have short (but not too short) atmospheric life. Most important, new alternative must offer high efficiency to reduce indirect contribution to the greenhouse effect.In refrigeration and air-conditioning industries, HCFC22 is the most widely used refrigerant. Complying with the Montreal Protocol, R22 must be phased out in developed and developing countries as early as possible. The problems of the depletion of ozone layer and increase in global warming caused scientists to investigate more environmentally friendly refrigerants than HFC refrigerants for the protection of the environment such as hydrocarbon (HC) refrigerants of propane, isobutene, n-butane, or hydrocarbon mixtures as working fluids in refrigeration and air conditioning systems. Accordingly, few environment friendly refrigerants has been recommended by most researchers and refrigerant manufacturers and applied in actual equipment to replace R22. From the recommended refrigerant alternatives, propane is most effective and compatible refrigerant. Propane (R290) is an eco-friendly hydrocarbon refrigerant which has very low Global Warming Potential (GWP) and zero Ozone Depletion Potential (ODP) also it has no direct impact on the greenhouse effect. It has excellent thermal performance, low price, and is compatible with general machinery lubricants and structural material. It has excellent thermodynamic properties leading to high energy efficiency and low charges allow smaller heat exchangers and piping dimensions.

II. EVALUATION OF REFRIGERANTS R22 and R290

2.1 Thermo Physical Properties

Molecular weight of HC-290 is lower than molecular weight of R22 by 49%. Latent heat of evaporation of HC-290 is 82% higher than R22 at normal boiling point. This indicates that per KW of cooling capacity, charge required of HC-290 is less by about 55% than that of R22. Also due to higher heat capacity, discharge temperature of HC-290 will be lower compared to HCFC-22. Normal boiling point of HC-290 is slightly higher than that of HCFC-22. Saturated pressure of HC-290 is slightly lower than that of HCFC-22. Lower saturation pressure of refrigerant allows ease in manufacturing of refrigeration system that too at low cost. The critical temperature of a refrigerant decides the performance of a refrigerant under high ambient conditions. Performance of refrigerants with lower critical temperature decreases fast with increase in ambient temperature than the refrigerants having higher critical temperature. This factor is of more importance in countries like India. Critical temperature of HC-290 is slightly higher than that of HCFC-22.

Table 1: Thermo physical properties of R22 and R290.

Refrigerant	R22	R290
Molecular Weight	86.47	44.10
Normal B.P. ^{0}C	~40.75	~42.2
Critical Temp. $Tc^{0}C$	96.2	96.7
Critical Press MPa	4.99	4.25
Latent heat of Evap kJ/kg	233.7	425.4

2.2 Environmental characteristics

Atmospheric life of R-290 is very less, i.e. almost 99% as that of R-22 which means it will sustain in environment for very less time and hence it is environment friendly. HC-290 is a non-ozone depleting refrigerant whereas R22 is a non-zero ODP refrigerant. GWP value of HC-290 is 20, which is very low value compared to R22.

Table 2: Environmental characteristics of R22 and R290.

Refrigerant	R22	R290
Atm. life (Years)	11.9	0.041
ODP(R11=1)	0.055	0.000
$GWP_{100yr(CO2=1)}$	1700	20

2.3 Safety characteristics

For the development of HC-290, flammability and toxicity are very important parameters due which it was neglected alternative for so many years. R290 is classified under A3 safety class as per ASHRE34-2010 due to this it has been avoided. But it has good thermo physical properties which is similar to R22, hence can be effectively used with taking proper care of leakage factor during operation. The European standard EN378 gives the safety requirements for the use of flammable refrigerants in various applications. As per the EN378 and ASHRAE15, the charge limit is about 8g/m^3 for R290. Toxicity safe index for HCFC22 and R290 are similar.

Table 3: Safety characteristics of R22 and R290.

Refrigerant	R22	R290
LFL by mass kg/m^3	-	0.075
LFL by volume %	-	2.1
Burning velocity cm/s	-	46
Combustion heat MJ/kg	-	50.3
Toxicity ppm	1000	1000
Safety class	A1	A3

2.4 Evaluation of refrigerants R22 and R290

R290 is environment friendly and it has many similar properties compared to R22 except flammability. As compared to R22, propane has higher refrigeration effect and power output along with lower discharge temperature. It has zero ODP and GWP of about 20. Hence, R290 (propane) can be a better alternative as a replacement to R22.

III. PROPERTY COMPARISON BETWEEN R290 AND R22

Various physical and chemical properties of Propane (R290) and R22 are compared graphically, in which, variation in evaporating temperature is considered over a range of -35^{o}C to 70 ^{o}C. All the basic thermo physical properties of both the refrigerant are obtained from REFROF software. These properties were systematically evaluated in both liquid and vapour state and then formulated in an excel sheet. Based on this, the various property comparison graphs are shown below-

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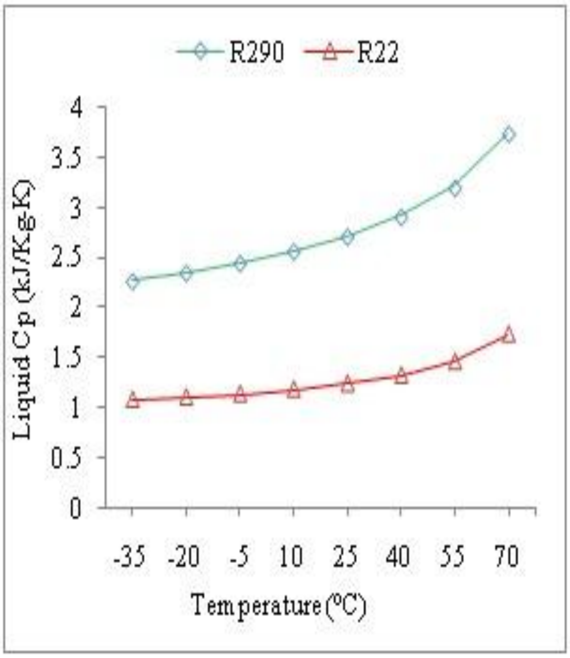
3.1. Variation in specific heat (Cp) with temperature:



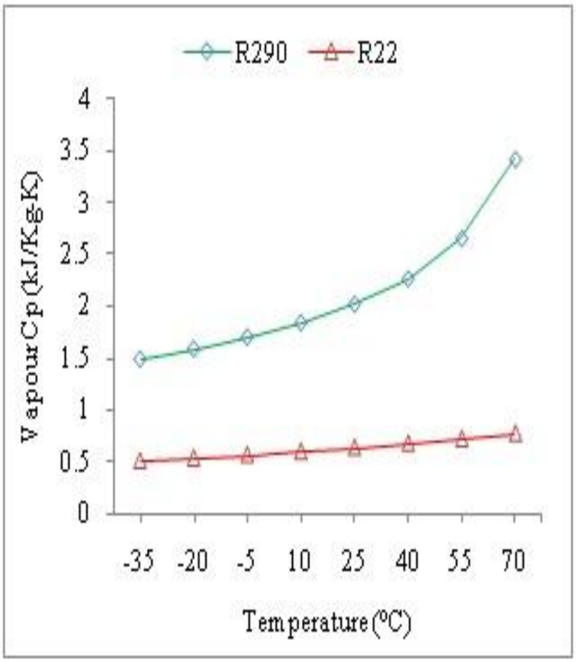
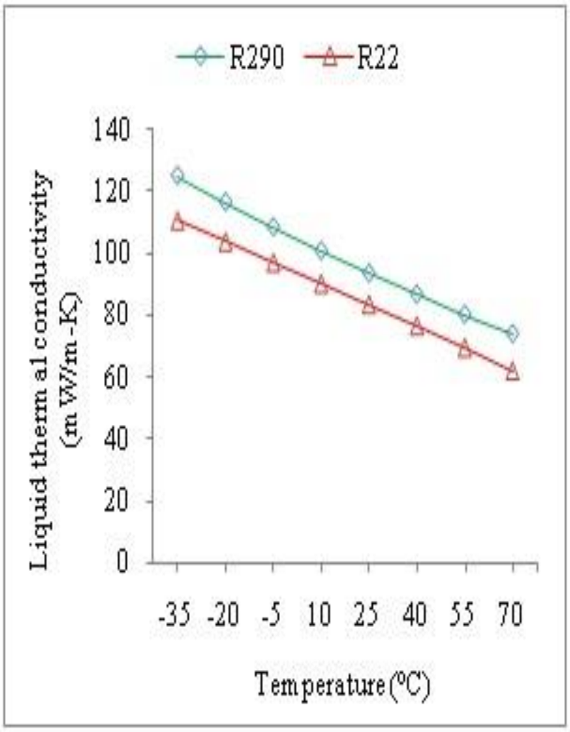


Figure 1: Temperature vs Liquid Cp. **Figure 2: Temperature vs Vapour Cp.**

3.2. Variation in Thermal Conductivity with Temperature



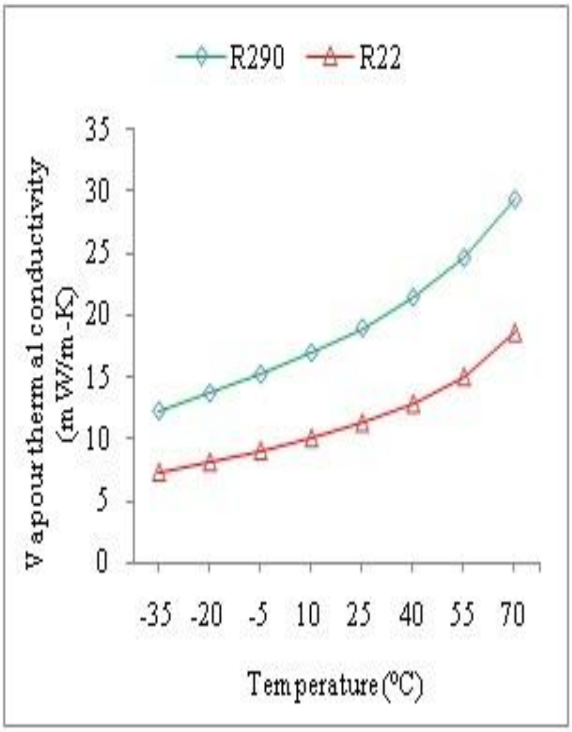


Figure 3: Temp. vs Liquid Thermal conductivity. **Figure 4: Temp. vs Vapour Thermal conductivity.**

3.3. Variation in Viscosity with Temperature:

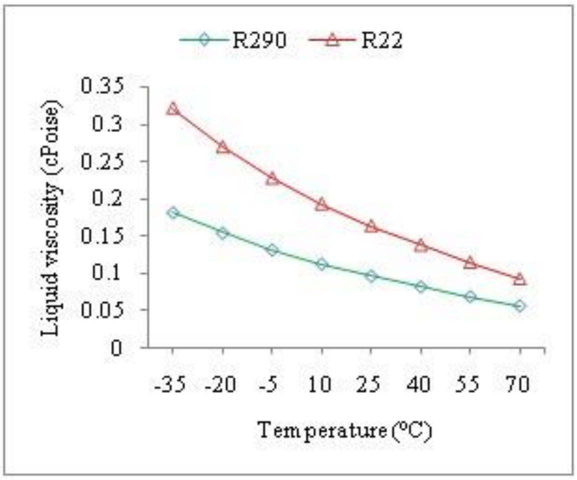


Figure 5: Temperature vs Liquid Viscosity.

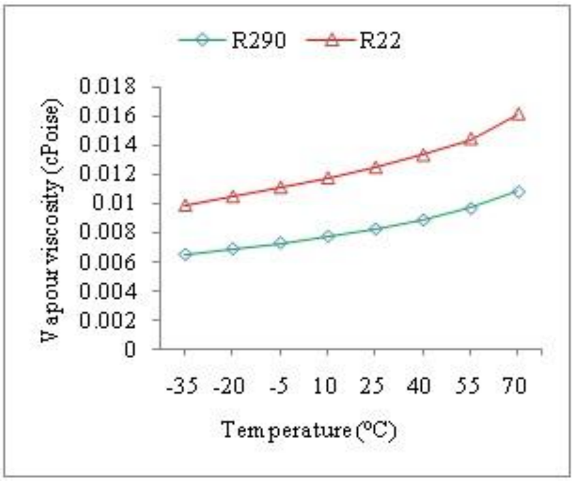


Figure 6: Temperature vs Vapour Viscosity.

3.4. Variation in Density with Temperature

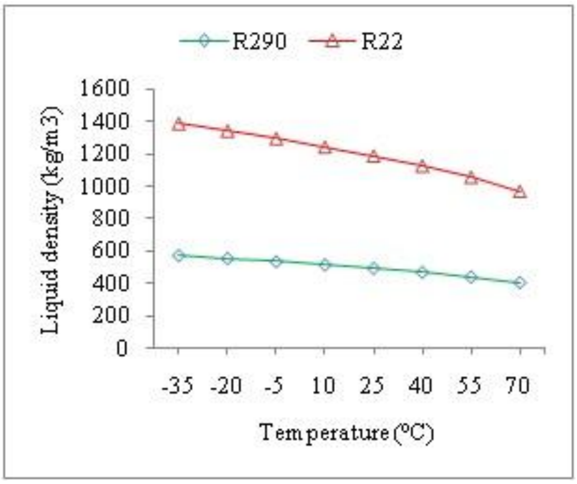


Figure 7: Temperature vs Liquid Density.

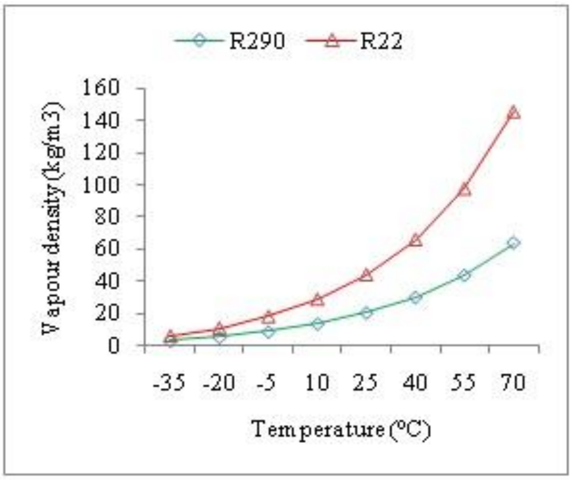


Figure 8: Temperature vs Vapour Density.

3.5. Variation in Pressure with Temperature

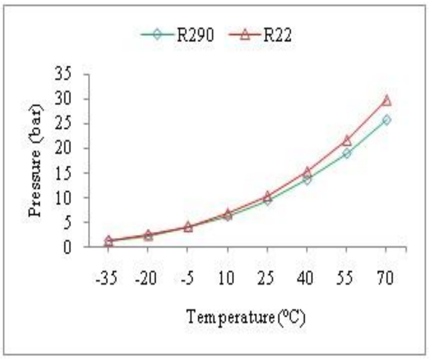


Figure 9: Temperature vs Saturation Pressure

IV.THEORETICAL INVESTIGATION OF PERFORMANCE OF VAPOUR COMPRESSION CYCLE WITH HC290 AND HCFC22

In this study, a theoretical investigation of the performance of the vapour compression cycle with refrigerant HC290 and HCFC22 is carried out. For performance analysis of these two refrigerants, an ideal vapour compression refrigeration system is used. Performance parameters such as Pressure ratio (PR),discharge temperature, refrigerating effect (RE), compressor work, Coefficient of performance (COP), volumetric refrigeration capacity (VRC) and power (P) are investigated for various evaporating temperatures ranging between -30^{0}C to 15^{0}C and constant condensation temperature of 45^{0}C. For cycle performance determination some assumptions are made as ideal vapour compression cycle is considered. Some of the important assumptions are: 10^{o}C superheating and 5^{o}C sub cooling, negligible pressure drops and heat losses to the surrounding, expansion is isenthalpic and compression is isentropic.

Following equations are used for cycle analyse.

Pressure ratio = P_{Cond}/P_{evap} (1)

Compressor work done (kJ/kg) = $P = \gamma/(\gamma-1)\, P_i V_i \left\{ \left(P_o/_i\right)^{\gamma-1/\gamma} - 1 \right\}$ (2)

Refrigerating effect (kJ/kg) = $h_{evap,out} - h_{evap,in}$ (3)

Volumetric refrigeration Capacity (VRC) = ρ_i.RE (4)

COP = RE/P (5)

Using these above equations, all the performance parameters of a standard vapour compression cycle were calculated and results are represented in the following graphs-

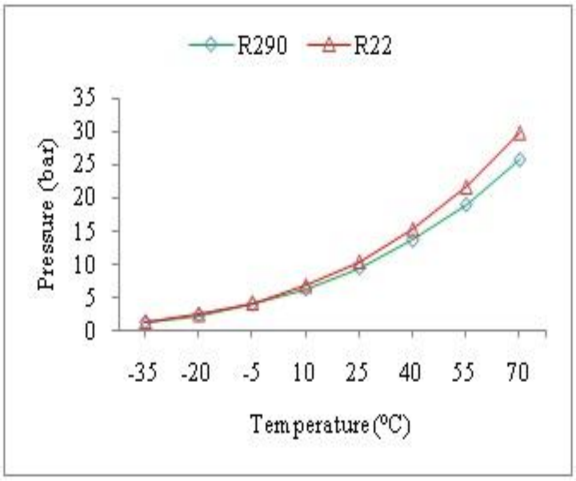


Figure 10: Pressure ratio Vs Temperature

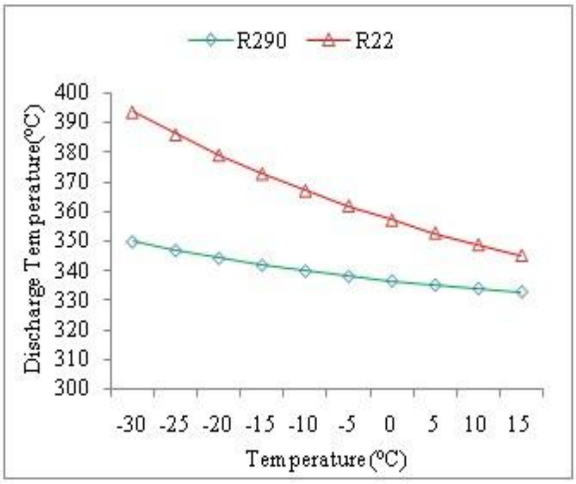


Figure 11: Discharge Temp. Vs Temperature

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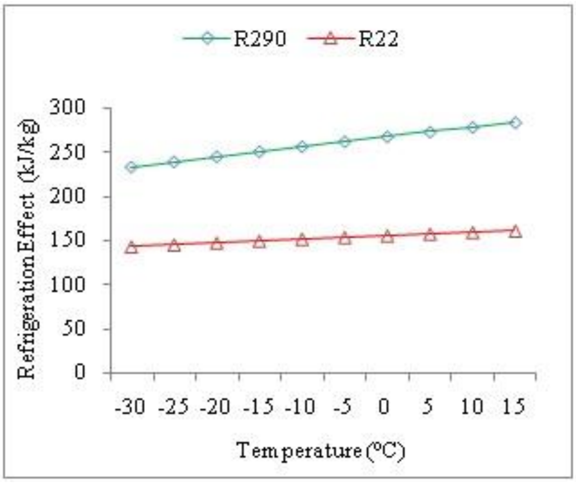

Figure 12: Refrigerating effect Vs Temperature

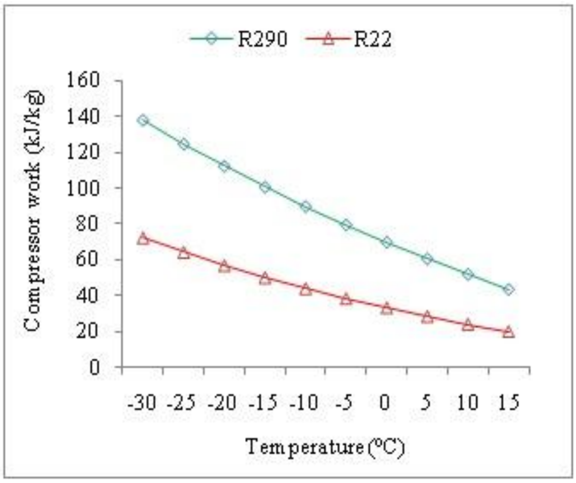

Figure 13: Compressor work Vs Temperature

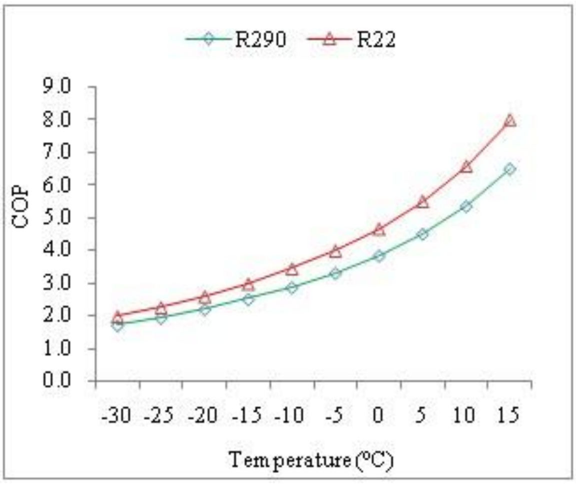

Figure 14: COP Vs Temperature

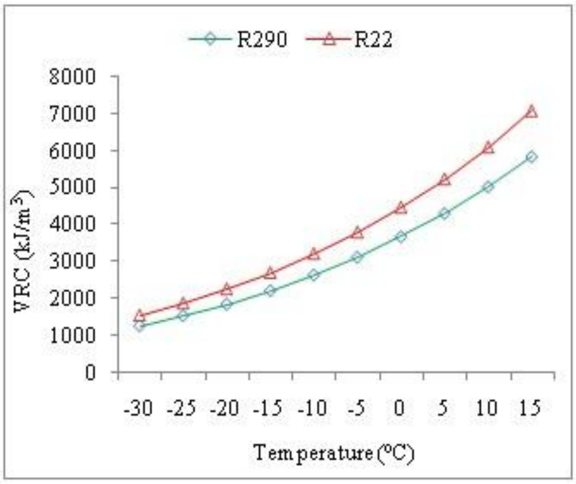

Figure 15: VRC Vs Temperature

V. RESULTS AND DISCUSSIONS

Cycle performance of a refrigeration system, to a large extent, depends on thermo physical properties of a refrigerant. In this paper, thermo physical properties and theoretical performance of HFC290 is compared with HCFC22, which is to be phased out in coming years. In property comparison, figure 1 and 2 show that liquid and vapour specific heat of R290 is almost 53% and 67% higher than that of R22 respectively. From figure 3 and 4, it can be observed that liquid and vapour thermal conductivity is 10.5% and 40% higher whereas, figure 5 and 6 shows that liquid and vapour viscosity are 42% and 34.5% lower for R290 than that of R22 respectively. Figure 7 and 8 shows that liquid and vapour density is 58.5% and 50.5% lower whereas figure 9 shows that saturation pressure is 3.5% lower for R290 than that of refrigerant R22 respectively. In theoretical study, pressure ratio, discharge temperature, refrigerating effect (RE), isentropic compression work, coefficient of performance (COP), volumetric refrigeration capacity (VRC) and power per ton are investigated and plotted against varying temperature as shown in figure 6 to 12 for ideal refrigeration cycle. Temperature range is considered from -30°C to 15°C and condensation temperature at 55°C. Figure 10 shows that pressure ratio decreases with increase in operating temperature. For R290, pressure ratio is slightly higher compared to R22. The difference in pressure ratio decreases from 13.3% to 4.2% with increase in evaporator temperature in the given range. Figure 11 shows that discharge temperature of a refrigerant decreases with increase in evaporating temperature. Discharge temperature for R290 is lower than that of R22 by 11% to 3.4%. Figure 12 and figure 13 shows that refrigerating effect and compressor work for R290 is 41.5% and 51.5% higher than that of R22 at evaporating temperature of -5^{o}C. Figure 14 show that COP for R290 is higher than that of R22 by 18.6% to 14% in the varying temperature range with increase in temperature. From figure 15 it can be seen that, volumetric refrigerating capacity increases with temperature. It is lower for R290 compared to R22.

VI. CONCLUSION

Evaluation of thermo physical properties showed that R290 is far better than R22, i.e. it has high specific heat and thermal conductivity & low viscosity and density values. Theoretical cycle performance of both the refrigerants for the varying temperature range of -30°C to 15°C shows that R290 is a promising alternative refrigerant to R22. Refrigerating effect is higher and discharge temperature is lower for R290 compared to R22. Though, COP value for R290 is slightly lower, but it can be improved by specially designing a refrigeration system for it. Hence, it can be concluded that refrigerant R290 is an excellent replacement for refrigerant R22 for medium temperature

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