An Evaluation of Options for Replacing HCFC-22 in Low and Medium Temperature Refrigeration System

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Abstract - Due to the ongoing global phase out of R-22, which is still the most widely used refrigerant around the world, there is a need to replace this refrigerant in many different application. This paper focuses on a thorough evaluation of the R-22 replacement options for low and medium temperature refrigeration system. It includes a thermodynamic analysis, safety issue, system performance comparisons using a validated system model, coefficient of performance (COP) and the determination of the environmental impact of refrigerant selection. The refrigerants considered are R-22, R-134a, R-290, R-600a, and mixture of R-32/R-134a, R-290/600a in different ratios. Relative merits of these fluids are evaluated using the 2.1 version of NIST's CYCLE_D semi theoretical vapor compression cycle design program.

Keywords –Alternative refrigerants, Hydrocarbon refrigerants, R-22, Montreal Protocol, Kyoto Protocol.

I. INTRODUCTION

Recently, The problems of the depletion of ozone layer and increase in global warming caused scientists to investigate more environmentally friendly refrigerants than CFC's and HFC's 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. Although HC refrigerants have highly flammable characteristics (A3) according to the standards of ASHRAE as a negative specification, they have not only several preferable specifications such as zero ozone depletion potential, very low global warming, non-toxicity, and higher performance than other refrigerant types but also high miscibility with mineral oil and good accordance with the existing refrigerating systems. They are used in many applications with attention being paid to safety of the leakage from the system as for other refrigerants in recent year. Many investigations have been conducted in the research into substitutes for R – 22. Mark W. Spatz, Samuel F Yana Motta (1) presented, "An evaluation of options for replacing HCFC-22 in medium temperature refrigeration systems". By this paper, The R-290 system's efficiency was also quite good. Thorough examinations of all the fluid properties of R-290 lead to the conclusion that systems employing this refrigerant would have comparable or slightly better efficiency than R-22. The environment impact (from GWP prospective) of refrigeration systems can be reduced using optimized R-410A refrigeration system, and approach appears preferable to the use of R-290 in this application the added risks of using a highly flammable refrigerant are not justified when there are equally or more efficient and environmentally acceptable alternatives such as R-410A and 404A. S. Wongwises and A. S. Dalkilic (2) Presented "A performance comparison of vapour compression refrigeration system using various alternative refrigerants," All of the alternative refrigerants investigated in the analysis have a slightly lower COP than CFC12, CFC22. Refrigerant blends of HC290/HC600a

(40/60 by wt. %) instead of CFC12 and HC290/HC1270 (20/80 by wt. %) instead of CFC22 are found to be replacement refrigerants. S. Devotta, A. S. Padalkar and N. K. Sane (3) presented," Performance analysis of window air conditioner with alternatives to HCFC-22" in this paper he presents the simulation performance analysis of a 1.5 TR window air –conditioner with alternative refrigerants to HCFC-22. HC-290 is better energy efficient than HCFC-22 with marginal loss in refrigerating capacity. However, the cost of equipment, to make the system safe against flammability, will be higher. The preliminary results show that the performance of the air–conditioner with R-407C is comparable with the baseline performance with HCFC-22. Samuel F Yana Motta and Piotre A. Domanski (4) presented, "Performance of R-22 and its alternatives working at high outdoor temperatures" this paper present simulation results on performance of R-22 and its possible replacements (R-134a, R-290, R-410A, and R-407C) in an air –cooled conditioner at high outdoor temperatures. The examined refrigerants exhibit varying degradations in performance at elevated temperatures compared to their performance at a typical operating regime. M. Mohanraj, S. Jayaraj, and C. Muraleedharan (2007) (5) This paper present experimental result of an energy- efficient Hydrocarbon (HC) mixture consisting of 45% HC 600a as a drop-in substitute for R-134a at various mass charge 40g, 50g, 70g, and90g in domestic refrigerators. The performance characteristic such as COP, energy consumption, pull-down time and discharge temperature of HC mixture were measured and compared with those of R-134a. The shows that the 70g mixture has better COP, lower power consumption, lower pull-down time and lower discharge temperature than R-134a. The miscibility of synthetic oil with HC refrigerant mixture was also found to be good. A.K.Ahluwalia and A.K.Saluja (6) presented, "Thermo physical properties of HC 290 and HC 600a a promising substitute to R-12." These methods predicted reasonably good result for the mixtures whose thermo physical properties are well established. The properties predicted include Density, Viscosity, Thermal conductivity and Specific heat of liquid mixture and vapour mixture in the working temperature range from -40 ^{o}C to 60^{o}C and result are shown for 50/50, 55/45, 65/35, 70/30 mixtures of HC 290/HC600a.

The Montreal Protocol - The Montreal protocol[10] is the first global effort to protect the environment and was signed in Montreal, Canada on 16th September 1987 under the auspices of the United Nations Environment programmed //UNEP 1989//. It currently has the following control schedules for chemicals used as refrigerants:-

(a) A phase out by 1.1.1996 of CFCs in the developed countries.
(b) A grace period until 2010 for a CFCs phase out in the developing countries, with freeze in 1999 and gradual reduction steps thereafter.
(c) A HCFC control schedule for the developed countries which requires gradual a phase out of HCFCs over the period of 1996-2020 based upon a cap of 2.8% of the 1989 CFC consumption and the 1989 HCFC consumption (in ODP- tones).
(d) A HCFC control schedule for the developing countries, which legs that of the developed countries by 10 years.

India's Commitment To The Montreal Protocol - India became party to the Montreal protocol [11] on Sept 17, 1992. India mainly produced and used seven of the 20 substances controlled under the Montreal protocol. These are CFC-11, CFC12, CFC113, Halon1211, Halon-1301, CTC, methyl chloroform and methyl bromide. India had prepared a detailed country programmed (CP) in 1993 to phase out ODS in accordance with its national industrial development strategy (INFRAS, 2000). The objectives of the CP were to phase out ODS without undue economic burden to both consumers and industry manufacturing equipments using ODSs and provided India with an opportunity to access the protocol's financial mechanism.

In India, the manufacturing of new products using R12 has been banned on Dec 31, 2002. As of Jan 1, 2007, the country achieved an 85% reduction in CFC production and consumption-a full year ahead of the Montreal protocol schedule for CFC phase out for article 5 countries. Now, it must focus on further reducing its consumption to zero by 2010. In anticipation of this step down in just few months, CFC manufacturer have already stopped supplying CFCs for consumption in India. This action will result in shortages for servicing CFC equipment in the very near future.

Kyoto Protocol - The Kyoto protocol[10] (KP) at the 3rd conference of parties on the frame work convection of the Global warming climate change in Kyoto in 1997 has decided to put HFCs together with other five gases such as CO_2, NO_2, CH_4, PFCs and SF_6 in one basket of controlled substances. Although CFCs, HCFCs contribute Global Warming, the KP does not address these substances, since these are already controlled under the Montreal Protocol with specific phase-out regimes. The KP aims at the reduction and control of GHG emissions and its obligations only for developed countries. While developing countries have no such commitments. The issues of Ozone depletion and climate change are scientifically and technically interconnected. Ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere. Changes in Ozone affect the Earth's climate and change in climate and meteorological condition affects the ozone layer. Because ozone–depleting substances (ODSs) are also GHGs, ODS phase-out help to protect the climate. The Montreal and Kyoto Protocol are interconnected because of HFCs, which are alternatives to the ODS have been included in the basket of GHGs of the KP due to their high GWP.

Phase Out Schedule For HCFCs Including R-22 - Under the terms of the MP, the U.S. agreed to meet certain obligations by specific dates that will affect the residential heat pump and air-conditioning industry:

January 1, 2004. The MP required the U.S. to reduce its consumption of HCFCs by 35% below the U.S. baseline cap. As of January 1, 2003, EPA banned production and import of HCFC-141b, the most ozone-destructive HCFC. EPA was able to issue 100% of company baseline allowances for production and import of HCFC-22 and HCFC-142b.

January 1, 2010. The MP requires the U.S. to reduce its consumption of HCFCs by 75% below the U.S. baseline. Allowance holders may only produce or import HCFC-22 to service existing equipment. Virgin R-22 may not be used in new equipment.

January 1, 2015. The MP requires the U.S. to reduce its consumption of HCFCs by 90% below the U.S. baseline.

January 1, 2020:-The MP requires the U.S. to reduce its consumption of HCFCs by 99.5% below the U.S. baseline. Refrigerant that has been recovered and recycled/reclaimed will be allowed beyond 2020 to service existing systems, but chemical manufacturers will no longer be able to produce R-22 to service existing air conditioners and heat pumps.

II. PERFORMANCE AND ANALYSIS

The theoretical performances of selected refrigerants and their mixtures are compared to R-22 (baseline refrigerant) for 1.5 Ton or 5.25 kw refrigeration systems cooling capacity of the system with evaporating temperature of -10^{o}C to 10^{o}C variation of 5^{o}C and condensing temperature 55^{o}C. The performances results of refrigerants obtain with the help of NIST CYCLE_D simulation software. Performances results are find out the more suitable as an alternative refrigerant for low and medium temperature refrigeration system which is eco-friendly with the nature. First of all we select some refrigerant with the help of the thermodynamic properties, and some other properties like ODP, GWP, chemical properties, etc. And specify the refrigeration system, 1.5 Ton unit of refrigeration and some other units such as isentropic efficiency 0.85, volumetric efficiency 0.88, and electric motor efficiency 0.80. These are the basic refrigeration data. Performance is calculated on the basis of Mass flow rate of refrigerants, COP (cooling), Compressor power, compressor work, Evaporator capacity, Condenser capacity, discharge temperature and Pressure ratio.

Refrigerant Mass Flow Rate - In order to determine mass flow rate of refrigerant, the enthalpy at the inlet and outlet of the evaporator was obtained from the p-h diagram of the respective refrigerant corresponding to the evaporator pressure and inlet and outlet temperature of the evaporator. The specific mass flow rate was calculated by dividing it with the refrigerating effect produced by the air conditioner as follow:-

,kg/s

Coefficient of Performance - Coefficient of performance indicates the overall power consumption for a desired output and is evaluated using the following equations:

$$COP_{ref.} = \frac{heat\ extracted\ from\ evaporator}{electric\ energy\ supplied\ to\ compressor}$$

$$COP_{ref.} = \frac{Q_{ref.}}{WE}$$

In order to determine the COP of the system, the enthalpy at the inlet and outlet of the evaporator was obtained from the p-h diagram of the respective refrigerant corresponding to the evaporator pressure and inlet and outlet temperature of the evaporator. The COP was calculated by dividing the R.E. (refrigerating effect) with the work done in the compressor:-

$$COP = \frac{(h1 - h4)}{(w)}$$

Thus in theory

$$\text{COP of HP} = COP_R + 1$$

It was found that experimental values of COP_R were about 0.95 to 1.10 than COP_{HP} for the same operating condition due to heat losses. This paper shows on the values of $COP_{R.}$

Condenser Capacity - Calculated using the equation:

$$Q_c = \qquad {}_c\,(KJ/Kg)$$

Where, *m* is the mass flow rate of refrigerant and h_c is the enthalpy difference across the heat exchanger.

Compressor Work (Work Done By Compressor) -In order to determine compressor work, the enthalpy at the inlet and outlet of the compressor was obtained from the p-h diagram of the respective refrigerant corresponding to the evaporator pressure and outlet and condenser pressure inlet. The compressor work was calculated by subtracting enthalpy inlet of condenser and enthalpy at the inlet of the Evaporator.

Compressor work or work done by compressor = (*enthalpy inlet of condenser - enthalpy at the inlet of the Evaporator)*

$$w = (h_2 - h_1)\ (KJ/Kg)$$

Compressor Power - In order to determine compressor power, the enthalpy at the inlet and outlet of the compressor was obtained from the p-h diagram of the respective refrigerant corresponding to the evaporator pressure and outlet and condenser pressure inlet. The compressor power was calculated by multiplying mass flow rate with compressor work.

Compressor power = *mass flow rate* (*enthalpy inlet of condenser - enthalpy at the inlet of the Evaporator)*

$$w = m\,(h_2 - h_1)\ KW$$

Discharge Temperature - The discharge Temperature is an important parameter considered for selection of an alternative. The discharge temperature influences the stability if the lubricants and compressor component. The discharge temperature of R-134a is 84^oC to 71^oC at evaporating temperature from -10^oC to 10^oC. The discharge Temperature of Hydrocarbon refrigerant mixtures is found to be lower than that of HFC 134a. It is seen that as Hydrocarbon Mixture charge increases, discharge Temperature also increases. This is also due to increase in condensation pressure when Hydrocarbon Mixture charge is increased. Thus, using Hydrocarbon Mixture has lower impact on the compressor components and stability of lubricants. This means that compressor lifetime can be expected when Hydrocarbon Mixture is used as a drop- in substitute for HFC-134a in the refrigeration system. A high discharge temperature can lead to the failure of internal components due to material degradation or excessive thermal expansion.

III. RESULT AND DISCUSSION

The evaluation results have been obtained for a low and medium temperature refrigeration system by using HFC 134a, R-290, R-600a, R-290/600a (50/50), R-290/600a (30/70), R-32/134a (30/70), and R-22 (Baseline Refrigerant). The results have been carried out at evaporating temperature varying from - 10^oC to 10^oC and Condensing Temperature 55^oC for 1.5 Ton refrigeration system with Liquid Line/Suction Line Heat Exchanger in different performance parameters. Results have been plotted in figure 1.1 to 1.9.

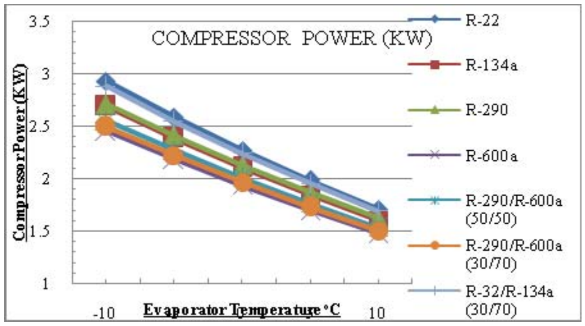

Fig. 1.1. Variation of Compressor Power (KW) with Evaporating Temperature (^oC).

The changes in the value of compressor power required for the low and medium temperature refrigeration cycle for all refrigerants (which are studied in this project) is shown in the figure 5.1. The requirement of compressor power reduces with increasing evaporating temperature. The rate of reduction is more for the change in evaporating temperature from -10^{o}C to 10^{o}C and condensing temperature 55^{o}C. Decreasing the compressor power requirement is associated with a great increase in specific cooling capacity. So, that the compressor power should be as low as possible, this increases the refrigeration cycle efficiency. The compressor power requirement is higher for R-22 varying from 2.925 to 1.707 kw at different evaporating temperature throughout the range. The lower requirement of compressor power is for R-600a varying from 2.449 kw to 1.474 kw at different evaporating temperature throughout the range. R-134a is higher compressor power than R-290/R-600a (30/70) and R-290/R-600a (50/50) and lower compressor power than R-32/R-134a (30/70) and R-290.

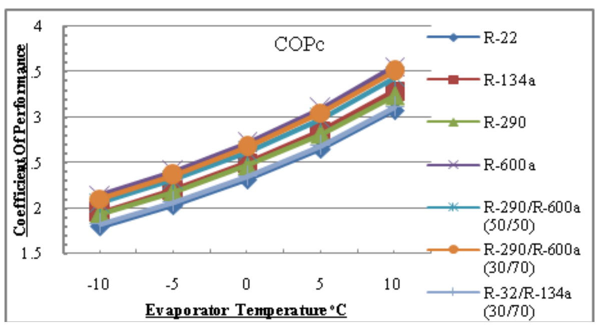

Fig.1.2. Variation of Coefficient of Performance of cooling (COPc) with evaporating temperature (oC).

Figure 1.2 shows the variation of Coefficient of Performance of cooling (COP_c) with evaporating temperature (T_{evap}). For a given combinations of T_{evap} = -10 to 10^{o}C and T_{cond} = 55^{o}C, the lower coefficient of performance of cooling capacity varying from 1.795 to 3.075 for R-22 and the higher to R-600a varying from 2.144 to 3.561 at different evaporating temperature range, it is higher throughout the range. Coefficient of performance of cooling (COP_c) of all refrigerants (which are studied in this project) increases when evaporating temperature varying from -10^{o}C to 10^{o}C throughout the range. R-134a higher Coefficient of Performance than R-32/R-134a (30/70) and R-290 and lower Coefficient of Performance than R-290/R-600a (30/70) and R-290/R-600a (50/50).

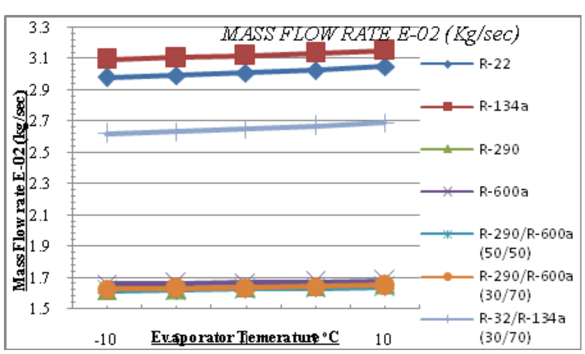

Fig. 1.3. Variation of Mass Flow Rate of Refrigerants (kg/sec) with Evaporating Temperature (oC).

The third graph gives the effect of change of Evaporating Temperature on the performance of the refrigeration cycle. Figure 1.3 shows that the variation of mass flow requirement of refrigerants with evaporating temperature varying from -10 to 10^{o}C and T_{cond} = 55^{o}C condensing temperature. The mass flow requirement increases gradually with increase in evaporating temperature. When mass flow rate is higher its means more refrigerant is required to produce same cooling capacity for evaporator, refrigerant which have lower mass flow rate of refrigerants are more suitable as alternative refrigerant. The Mass Flow requirement is higher for R-134a varying from 3.090 E-02 kg/sec to 3.149 E-02 kg/sec for all the range of evaporating temperature. The lower mass flow rate for R-290/R-600a (50/50) varying from 1.615 E-02 kg/sec to 1.642 E-02 kg/sec for all the range of evaporating temperature. R-290/R-600a (30/70), R-600a, R-290 refrigerants considered require very smaller charge of refrigerants as compare to R-22, R-134a, R-32/R-134a (30/70) and these refrigerants are very near to the smaller charged refrigerant. R-32/134a (30/70) require comparatively low Mass flow requirement of refrigerant compared to R-22, R-134a and much higher than R-290/R-600a (30/70), R-290/R-600a (50/50), R- 600a, R-290.

Fig. 1.4. Variation of Pressure Ratio with Evaporating Temperature (oc).

The changes in the value of pressure ratio required for the low and medium temperature refrigeration cycle for all refrigerants (which are studied in this project) is shown in the figure 1.4. The pressure ratio reduces with increasing evaporating temperature. The rate reduction is more for the change in evaporating temperature from -10^{o}C to 10^{o}C and condensing temperature 55^{o}C. The pressure ratio should be as low as possible; this increases the refrigeration cycle efficiency. The pressure ratio is higher for R-134a varying from 7.44 to 3.6 at different evaporating temperature throughout the range. Lower pressure ratio for R-290 varying from 5.52 to 3.00 at different evaporating temperature throughout the range. R-290/600a (30/70 higher pressure ratio than R-22 and R-290/600a (50/50) and lower pressure ratio than R-32/R-134a (30/70) and R-600a. All the refrigerants are decrease at a constant rate. At -10^{o}C all refrigerants have more difference in the pressure ratio but coming to 10^{o}C all refrigerants have not more difference in the pressure ratio.

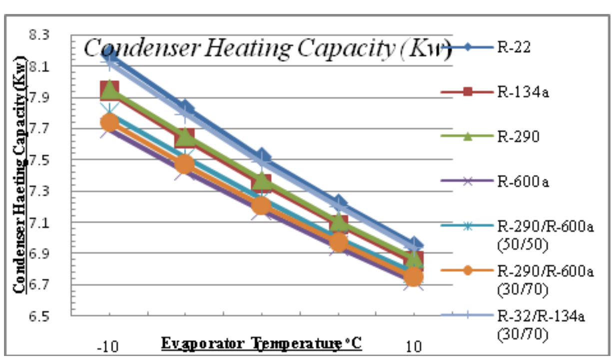

Fig. 1.5. Variation of Condensing Heating Capacity (KW) with Evaporating Temperature (oc).

Figure 1.5 shows that the variation of Condenser Heating Capacity with Evaporating Temperature, for condition T_{evap}. = -10^{o}C to 10^{o}C and condensing temperature (T_{cond}.) = 55^{o}C. Condenser lower heating capacity varying from 7.699 kw to 6.724 kw for R-600a and the higher to R-22 varying from 8.175 kw to 6.957 kw. Condenser heating capacity of all refrigerants (are studied in this project) is decreases when Evaporating Temperature varying from -10 to 10^{o}C. R-290/R-600a (30/70) is comparatively high but lower than remaining refrigerants. R-134a and R-290 are comparatively same condensing heating capacity. R-22 and R-32/134a (30/70) comparatively same condensing heating and also high throughout the range of evaporating temperature. The refrigerant R-600a and R-290/R-600a (30/70) are more suitable as alternative refrigerants.

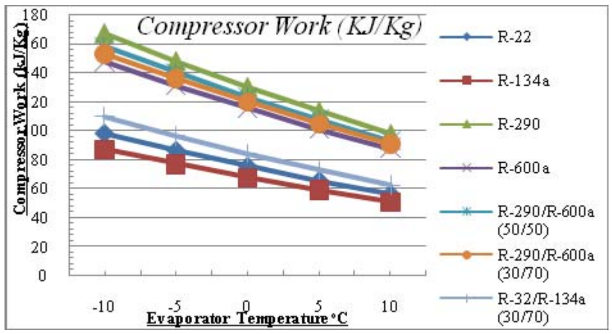

Fig. 1.6. Variation of Compressor Work (kj/kg) with Evaporating Temperature (oc).

Figure 1.6 shows that the variation of Compressor works with Evaporating Temperature for condition T_{evap}. = -10^{o}C to 10^{o}C and condensing temperature (T_{cond}.) = 55^{o}C. Compressors work varying from 86.91 kJ/kg to 50.68 kJ/kg lower work capacities for R-134a and the higher to R-290 varying from 166.99 kJ/kg to 97.80 kJ/kg. Compressor working capacities for all refrigerants (which are studied in this project) decrease when Evaporating Temperature varying from -10^{o}C to 10^{o}C. R-290/R-600a (30/70) is comparatively high but lower than R-290and R-290/600a (50/50) and higher than R-600a. R-22 are comparatively low compressor work than R-32/134a (30/70) and comparatively higher than R-134a (which has low compressor working capacity) and these three refrigerants also low throughout the range of evaporating temperature. The refrigerant R-600a, R-290/R-600a (50/50) and R-290/R-600a (30/70) are comparatively same but higher than HFC and HCFC refrigerant and low compressor work than R-290.

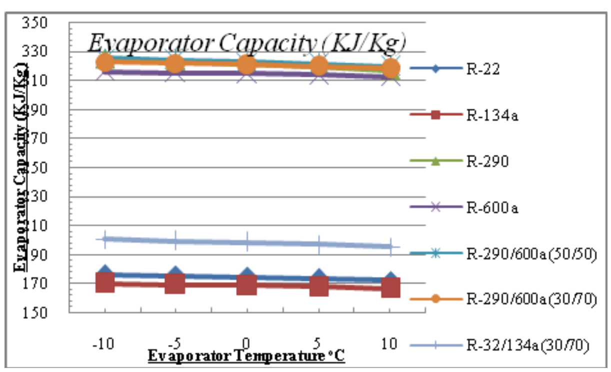

Fig. 1.7. Variation of Evaporator capacity (kJ/kg) and Evaporating Temperature (oC).

Figure 1.7 shows the Variation of Evaporator capacity (kJ/kg) and Evaporating Temperature (^{o}C), for condition T_{evap} = -10^{o}C to 10^{o}C and Condensing temperature T_{cond} = 55^{o}C, Evaporating capacity of all refrigerants (which are studied in this project) decreases when Evaporating Temperature increases. All evaporating capacities decrease constantly throughout the range of evaporating temperature. R-290/R-600a (50/50) has higher evaporating capacity than all refrigerants varying from 325.07 kJ/kg to 319.67 kJ/kg throughout the evaporating temperature range and R-290/R-600a (30/70) is almost same evaporating capacity varying from 322.59 kJ/kg to 317.97 kJ/kg. R-600a has lower evaporating capacity than R-290, and Hydrocarbon mixtures. R-32/134a, R22 and R134a have very low evaporating capacities is in the range of 200 to 165 as compared to hydrocarbon and Hydrocarbon mixtures.

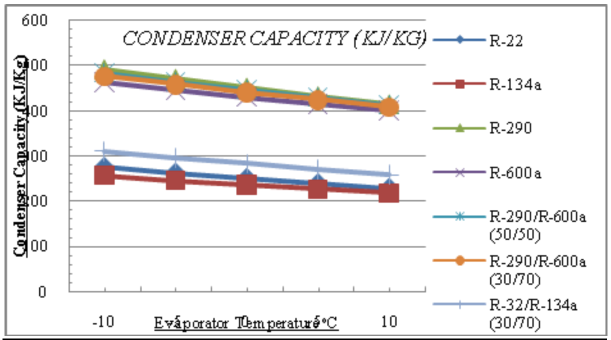

Fig. 1.8. Variation of Condenser capacity (kJ/kg) and Evaporating Temperature (oC).

Figure 1.8 shows the Variation of Condenser capacity (kJ/kg) with Evaporating Temperature (^{o}C) for condition T_{evap} = -10^{o}C to 10^{o}C and Condensing temperature T_{cond} = 55^{o}C.The Evaporating capacities of all refrigerants (which are studied in this project) decrease with increase Evaporating Temperature throughout the range. R-134a has the lower condenser capacity varying from 256.74 kJ/kg to 217.40 kJ/kg. R-290 has the higher condenser capacity among all the refrigerants varying from 491.21 kJ/kg to 414.53 kJ/kg and R-290/R-600a mixtures have almost same evaporating capacity as compared to R-290. It is in the range of 482.91 kJ/kg to 408.63 kJ/kg. R-600a has condenser capacities values from 463.21 kJ/kg to 400.25 kJ/kg it is lower than hydrocarbon mixtures and R-290 and higher than R-134a, R-22 and R-32/R-134a.

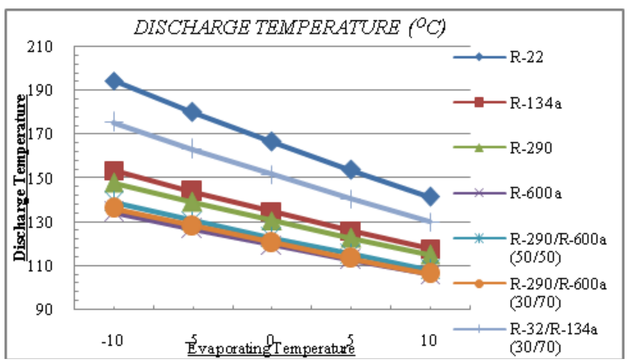

Fig. 1.9. Variation of Discharge Temperature (oC) and Evaporating Temperature (oC).

The changes in the value of Discharge temperature required for the low and medium temperature refrigeration cycle for all refrigerants (which are studied in this project) is shown in figure 1.9. Discharge temperature reduces with increasing evaporating temperature. The rate of reduction is more for the change in evaporating temperature from -10^{o}C to 10^{o}C and condensing temperature 55^{o}C. The Discharge temperature should be as low as possible; this increases the refrigeration cycle efficiency. The Discharge temperature is higher for R-22 varying from 194.5^{o}C to 141.6^{o}C at different evaporating temperature throughout the range. The lower discharge temperature is for R-600a varying from 134.4^{o}C to 106^{o}C at different evaporating temperature throughout the range. R-290 is higher discharge temperature than R-290/R-600a (30/70) and R-290/R-600a (50/50) and lower discharge temperature than R-32/R-134a (30/70) and R-134a.

On the basis of all performance results R-600a consume low power, high COP, low condenser heating capacity, discharge temperature but R-600a require higher mass flow of refrigerant, and gives low evaporating capacity, higher pressure ratio than R-290/600a (30/70), its performances are not constant as compare to R-290/R600a (30/70). R-290/R-600a (30/70) gives constant performance, gives higher COP, consume low power, lower requirement of refrigerant, higher evaporating capacity, discharge temperature and low pressure ratio which increase volumetric efficiency and required low power consumption and gives constant performance compared to R-600a and other refrigerants. So R-290/600a is more suitable as an alternative refrigerant for HCFC R-22. Also, R-

290/600a (30/70) is ozone friendly, low Global warming, non-toxic, low cost, more efficient, compatible with all types of mineral oils and synthetic oils and materials and has so many advantages.

IV.CONCLUSION

On the basis of all above results and conclusions, finally conclude that R-290/R-600a ratio of 30/70 is found to a more suitable as an alternative refrigerant in low and medium temperature refrigeration system at Evaporating temperature -10^{o}C to 10^{o}C and Condensing temperatures 55^{o}C for 1.5 Ton of refrigeration system.

R-290/R-600a has zero Ozone Layer Depletion Potentials, lower Global Warming potential , Higher efficient, low power consumption, low Mass Flow Rate, high Evaporating capacity, low pressure ratio, Higher COP, lower discharge pressure and compatible with oils and materials. So, R-290/600a (30/70) is found to be more suitable as an alternative refrigerant in low and medium temperature refrigeration system at evaporating temperature -10^{o}C to 10^{o}C and Condensing temperatures 55^{o}C for 1.5 Ton of refrigeration system.

REFERENCES

[1] A. S. Dalkilic , S.Wongwises, A performance comparison of vapour- compression refrigeration system using various alternative refrigerants, International Communication in Heat and Mass Transfer 37 (2010) 1340 – 1349.

[2] Mark W. Spatz, Samuel F. Yana Motta, An evaluation of option for replacing HCFC-22 in medium temperature refrigeration systems, International Journal of Refrigeration 27 (2004) 475-483.

[3] S. Devotta, A. S. Padalkar, N. K. Sane, Performance analysis of window Air-conditioner with alternatives to HCFC-22, ACRECONF 26 September (2001) 481-487.

[4] Samuel F. Yana Motta, Piotr A. Domanski, Performance of R-22 and its alternatives working at high outdoor temperatures, National Institute of Standard and Technology, International National Conference at Purudue University, West Lafayette, In U.S.A. July 25-28 (2000) 47-54.

[5] M. Mohanraj, S. Jayaraj, C. Muraleedharan, Improved energy efficiency for HFC-134a domestic refrigerator retrofitted with hydrocarbon mixture (R-290/R-600a) as drop-in substitute, Energy For Sustainable Development, Volume xi No.4, December (2007) 29-32.

[6] A. K. Ahluwalia, A. K. Saluja, Thermo-physical properties of HC-290 and HC- 600a A Promising substitute to CFC-12, ACRECONF, September 26-28 (2001) New Delhi, 488-497.

[7] Eric W. Lemmon, Marcia L. Huber, Mark O. McLinden, 2007, NIST Reference Fluids Thermodynamic Properties - REFPROP, Ver. 8.0, NIST Standard Reference Database 23, National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A. http://www.nist.gov/srd/nist23.htm.

[8] Performance Rating of Positive Displacement Refrigerant Compressors and Compressor Units, Standard ANSI/ARI 540-2004, Air-Conditioning and Refrigeration Institute, Arlington, VA, 2004, http://www.ahrinet.org/Content/FindaStandard_218.aspx.

[9] ISHRAE Hand book, Refrigerants, page- 2.1 -2.5.

[10] R.S. Agarwal, Impact of Montreal Protocol on refrigeration and Air Conditioning industries, ACRECONF, 26-28 September (2001) New Delhi, 3-12

[11] Alka Bani Agarwal and Vipin Shrivastava, Retrofitting of Compression refrigeration trainer by an eco- friendly refrigerant, Indian Journal of Science and Technology, Vol. No. 4 (April 2010) 455-458