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Thermal analysis of vapour compression refrigeration system with R152a and its blends R429A, R430A, R431A and R435A

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Abstract —This paper presents the analysis results of R429A, R430A, R431A and R435A as drop in substitute for R152a at various evaporating temperature with condenser temperature 30°C, 40°C and 50°C. A theoretical study of thermodynamic properties such as pressure, density, and specific volume, latent heat of vaporization compression index, and critical values are done. The theoretical performance of vapour compression refrigeration system with R152a, R429A, R430A, R431A and R435A was done and their results are compared. The effects of the main parameters of performance analysis such as refrigerating effect, compressor work, coefficient of performance, volumetric refrigerating capacity, discharge temperature, pressure ratio, condenser duty, compressor power, refrigerating mass flow are analyzed for various evaporating temperatures. The compressor power required for the refrigeration during analysis with R152a and its blends were observed. The results shows that the refrigerants R435A consumes 1.098% less compressor power than that of R152a.The COP, Refrigerating effect for R435A is 1.229%,32.198% higher than R152a respectively . The refrigerant mass flow is decreased by 24.353% while using R435A substitute to R152a. Other results obtained in the analysis show a positive indication of using R435A as refrigerant in vapour compression refrigeration system substitute to R152a.

Index Terms —R152a, R429A, R430A, R431A, R435A, vapour compression Refrigeration

1 Introduction

For the past half century, chlorofluorocarbons (CFCs) have been used extensively in the field of refrigeration due to their favorable characteristics. In particular, CFC12 has been predominantly used for small refrigeration units including domestic refrigerator/freezers. Since the advent of the Montreal Protocol, however, the refrigeration industry has been trying to find out the best substitutes for ozone depleting substances [1]. For the past decade, HFC134a has been used to replace CFC12 used in refrigerators and automobile air conditioners. HFC134a has such favorable characteristics as zero ozone depleting potential (ODP), non-flammability, stability, and similar vapor pressure to that of CFC12. A recent survey, however, showed that the performance of HFC134a in refrigerators with a proper compressor and lubricant is quite comparable to that of CFC12 [2]. In 1997 the Kyoto protocol was agreed by many nations calling for the reduction in emissions of greenhouse gases including HFCs [3].Since the Global warming potential (GWP) of HFC134a is relatively high (GWP1300)and also expensive, the production and use of HFC134a will be terminated in the near future. In an effort to reduce greenhouse gas emissions, R152a (difluoroethane) is being considered as a replacement for R134a. It has an average GWP of just 130, which in comparison has roughly ten times less GWP than R134a. B.O.Bolagi, M.A .Akintunde, and T.O Falade investigated experimentally the performance of three ozone friends HFC refrigerants (R32, R134a and R152a) in a vapour compression refrigerator and compared the results obtained. The result shows that the COP of R152a was 2.5% higher than that of R134a and 14.7% higher than that of R32 [4]. Hydrocarbons are free from ozone depletion potential and have negligible global warming potential. Wongwise et al (2006) presented an experimental study on the application of HC mixture to replace HFC -134a in automotive air-conditioner. They found that propane /butane/isobutene 50%/40%/10 % was the best alternative refrigerant to replace HFC-134a having the best performance of all other mixture being investigated [5]. Wongwise and chimres presented an experimental study on the application of a mixture of propane, butane and isobutene to replace HFC134a in domestic refrigerators. The results showed that a 60%/40% propane/butane mixture was the most appropriate alternative refrigerant [6]. Dimethyl ether (RE170) makes a better refrigerant than R290 / R600a blends as it has no temperature glide and doesn’t separate during leakage. It has been extensively adopted by the aerosol industry as the most cost effective replacement for R134a in propellant applications. [7]. R432A(mixture of DME and propylene) is a good long term ‘drop-in’ environment friendly alternative refrigerant to replace CFC12 and HFC134a in automobile air-conditioners due to its excellent thermo dynamic and environment properties. Test results show that the COP of these refrigerants is up to 21.55 % higher than that of R12 in all temperature conditions [8] R435A(mixture of DME and R152a) is a good long term ‘drop-in’ environment friendly alternative safe refrigerant to replace HFC134a in domestic water purifiers due to its excellent thermo dynamic and environment properties . Test results show that the energy consumption and discharge temperature was 12.7% and 3.7°C lower than HFC 134a [9]. In this study, the thermal analysis using the environment-friendly refrigerant R152a and its blends with R290, R600a and RE170 (Di-methyl Ether) were investigated. The composition of the Refriger-

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ant blends are designated as R429A(R-152a-10%, RE-170-60%, R-600a-30%), R430A (R152a-76%, R-600a-24%), R431A(R-152a-29%, R-290-71%) and R435A(R-152a-20%, RE-170-80%) The Thermodynamic properties and thermal performance of the above Refrigerants were compared with R152a.

2 Method of Analysis

The software CYCLE_D 4.0 vapour compression cycle design program was used for the analysis to find the performance of the system. The ideal refrigeration cycle is considered with the following conditions.

System cooling capacity (kW) = 1.00
Compressor isentropic efficiency = 1.00
Compressor volumetric efficiency = 1.00
Electric motor efficiency = 1.00
Pressure drop in suction line = 0.00
Pressure drop in the discharge line = 0.00
Evaporator: average sat.Temp. (^{0}C) =-30 to +30
Condensor: average sat.Temp (^{0}C) = 30, 40, 50
Super heat (^{0}C) = 10
Sub cooling (^{0}C) = 5

The analysis of the variation of physical properties and performance parameters of R152 a and its blend refrigerants such as evaporation pressure (Pevap), Pressure ratio (PR), Refrigerating effect (RE), Compressor work (CW), Volumetric refrigeration capacity (VRC), Discharge temperature (TDis), Compressor power(CP), Condenser duty (CD), Mass flow rate (MFR) and Coefficient of performance (COP) are investigated in this theoretical study and they are plotted against the evaporating temperature (Tevap) as shown in figures from 1 to 10.

3 Thermo Physical Properties

Table 1: Physical and Thermal Properties of Refrigerants

Working substances	R-152a	R-429A	R-430A	R-431A	R-435A
Composition		R-152a-10% RE-170-60% R-600a-30%	R-152a-76% R-600a-24%	R-152a-29% R-290-71%	R-152a-20% RE-170-80%
Molecular Mass (kg/kg mole)	66.05	50.7	63.9	48.8	49.0
Critical Temperature(^{0}C)	113	127	107	100	125
Critical Pressure(kPa)	4516	5213	4091	4898	5401
Critical Density(kg/m^3)	368.00	262.0	314.2	249.4	286.0
ODP	0	0	0	0	0
GWP	120.00	20	20	20	20
Latent Heat of Evaporation(kJ/kg) At -10^{0}C	317.00	392.2	310.3	350.2	414.5

3.1 Specific Volume

The specific volume of the refrigerant should be low in the vapour state. The figure 3.1 shows that the refrigerant R431A is having low specific volume in vapour state.

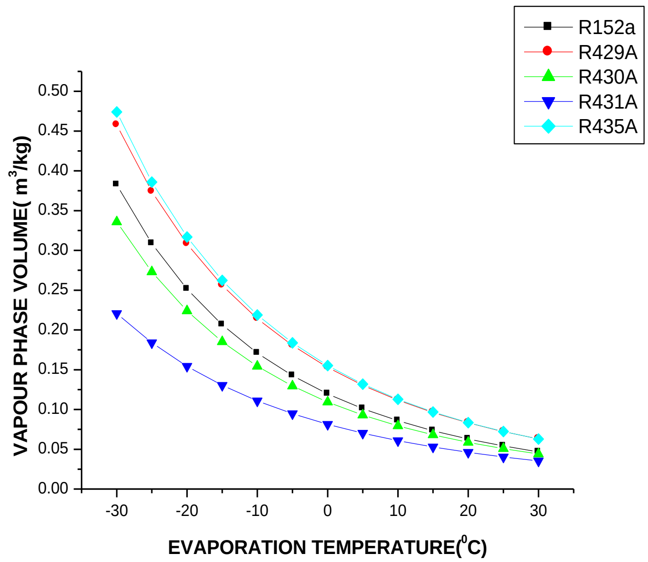

Fig: 3.1 Variation of Vapour phase volume

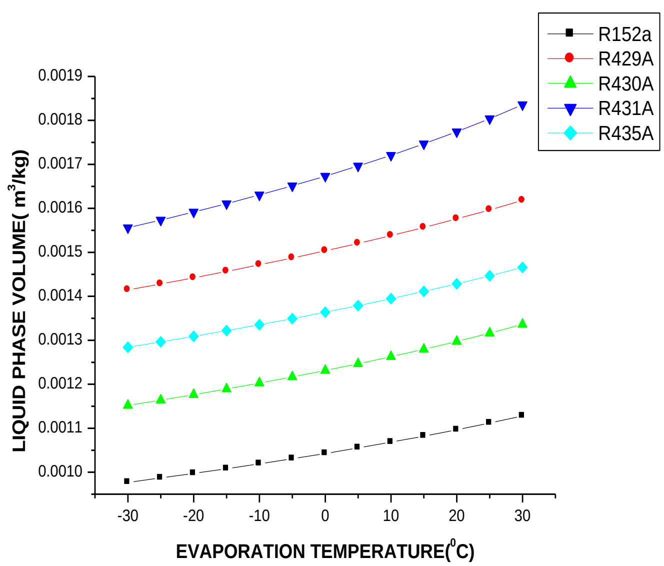

Fig: 3.2 Variation of Liquid phase volume

3.2 Density

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The figure 3.3 and 3.4 shows the variation of density of refrigerants in liquid and vapour phase. The vaue of liquid density decreases with increase in saturation temperature. The value of vapour density increases with increase in evaporation temperature. The refrigerant R431A has lower density at liquid phase. The refrigerant R435A has lower density at vapour phase.

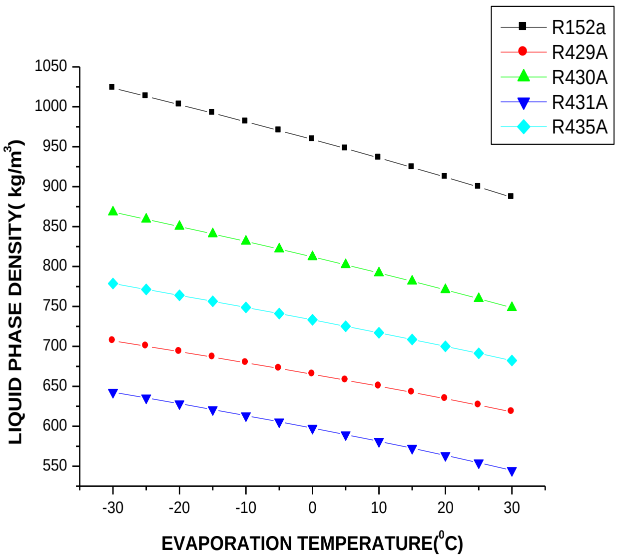


Fig: 3.3 Variation of liquid phase density

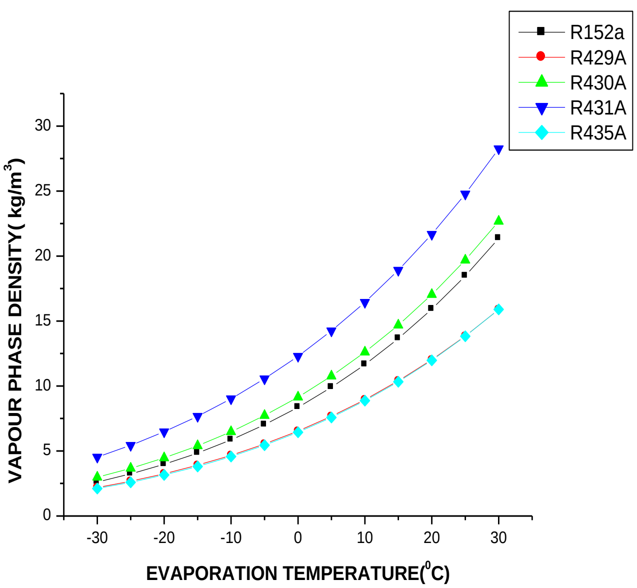


Fig: 3.4 Variation of Vapour phase density

3.3 Index of Compression

The work of compression per unit mass dpends on the isentropic index (γ). The smaller the index, the smaller will be the work of compression. The figure 3.5 & 3.6 shows that the refrigerant R435A is having smaller value of index whereas R431A is having higher value. Evaporating pressure should be just above the atmosphere pressure. If too low, it would result in a large volume of suction vapour. If high, the condenser pressure and the overall pressure will be greater. A refrigerant should have low condensing pressure to avoid robust construction and to reduce the tendency of leakages. Figure 3.7 & 3.8 show that the refrigerants R152a, R429A and R435A are having optimum values of pressure.

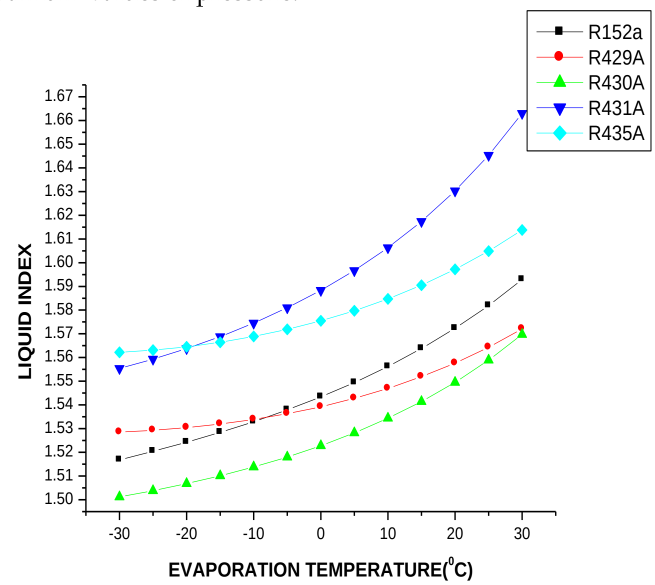


Fig: 3.5 Variation of liquid index

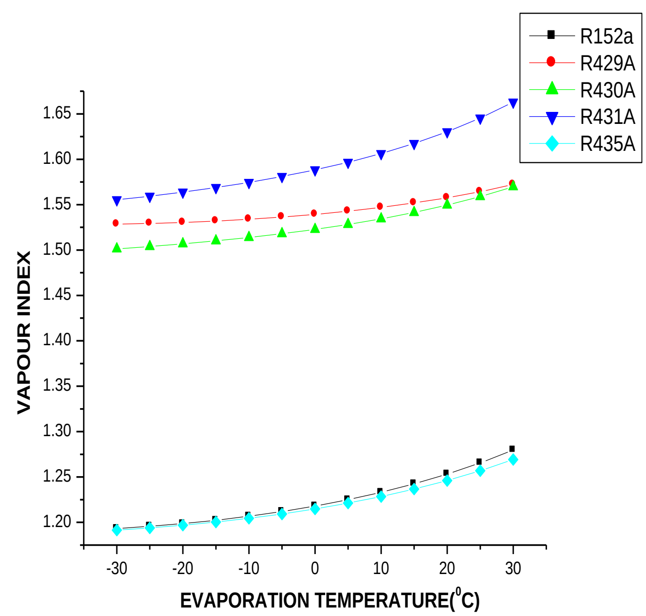


Fig: 3.6 Variation of Vapour index

3.4 Evaporating Pressure and Condensing

PRESSURE

Evaporating pressure should be just above the atmosphere pressure. If too low, it would result in a large volume of suction vapour. If high, the condenser pressure and the overall pressure will be greater. A refrigerant should have low condensing pressure to avoid robust construction and to reduce the tendency of leakages. Figure 3.7 & 3.8 show that the refrigerants R152a, R429A and R435A are having optimum values of pressure.

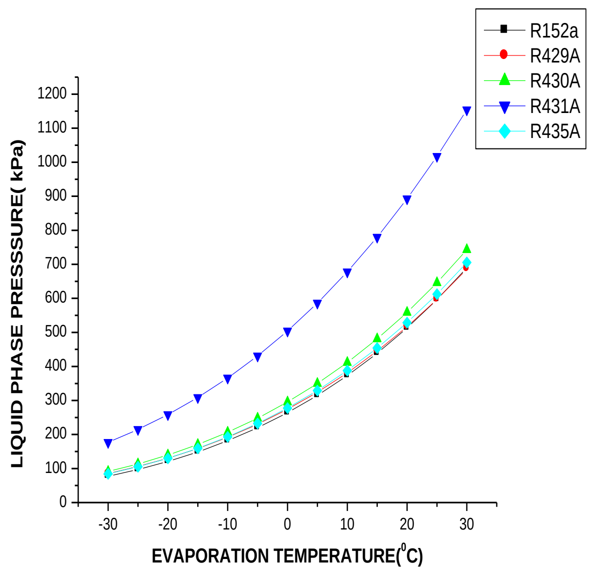


Fig: 3.7 Variation of liquid phase pressure

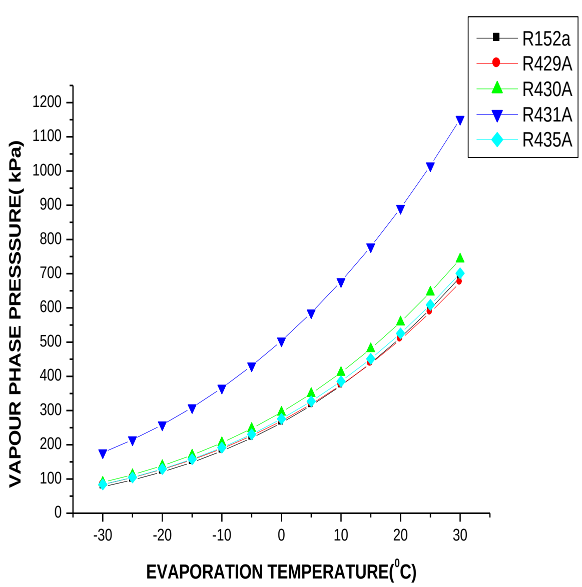


Fig: 3.8 Variation of Vapour phase pressure

4. RESULT AND DISCUSSIONS

4.1 PRESSURE RATIO

The figure 4.1 shows the variation of pressure ratio with varying evaporator temperature at 50°C condenser temperature for R-152a, R429A, R430A, R431A and R435A.The figure 4.1 shows that the pressure ratio decreases with increase in evaporator temperature . The pressure ratio required for these refrigent blends at evaporating temperature of -30^{0}C and 5^{0}C are lower than R152a. The trends are similar for condenser temperature 30^{0}C and 40^{0}C. Hence small size compressor will be required while using these blends.

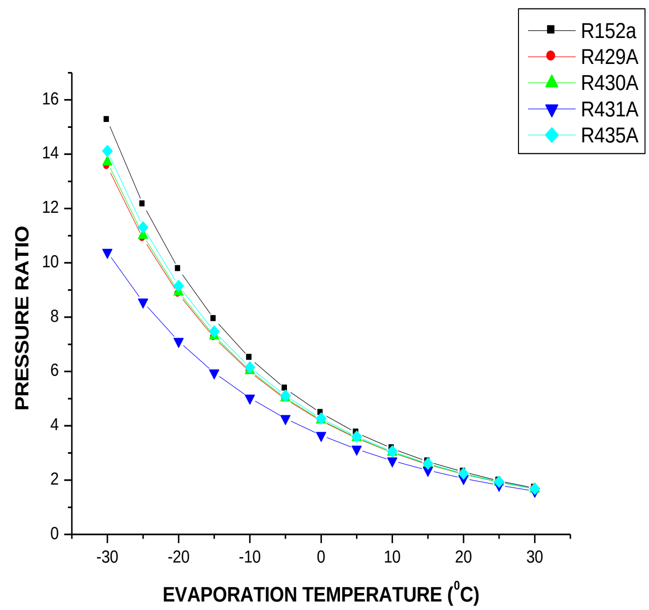
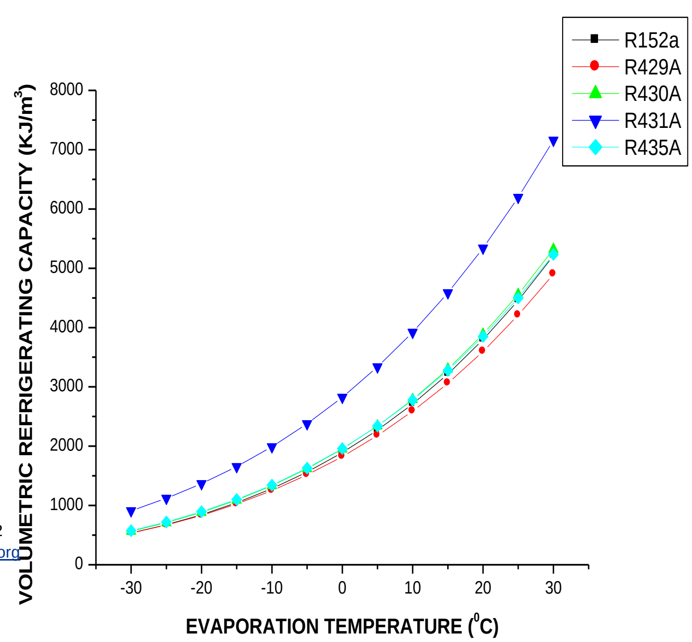


Fig: 4.1 Variation of Pressure Ratio at T_c=50^{0}C



4.2 Volumetric Refrigerating Capacity

The figure 4.2 shows the variation of volumetric rfrigerating capacity with varying evaporator temperature at 50°C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figures show that the volumetric refrigerating capacity increases with increase in evaporator temperature.TheVRCfor R429A at evaporating temperature of -30^{0}C and 5^{0}C are lower than R152a and other blends have higher value. The trends are similar for condenser temperature 30^{0}C and 40^{0}C. Hence smaller size compressor can be used for R430A, R431A and R435A.

Fig: 4.2 Variation of volumetric refrigeration capacity

4.3 Coefficient of performance

Fig 4.3 shows the variation of COP with varying evaporator temperature at 50°C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figure shows that the COP increases with increase in evaporator temperature. Results show that the COP for R435A at -30^{0}C evaporating temperature is 1.23% higher than R152a. At 5^{0}C evaporating temperature, the COP for R435A and R429A is 0.847% and 0.1925% higher than R152a respectively. The other blends have lesser COP than R152a at both conditions.

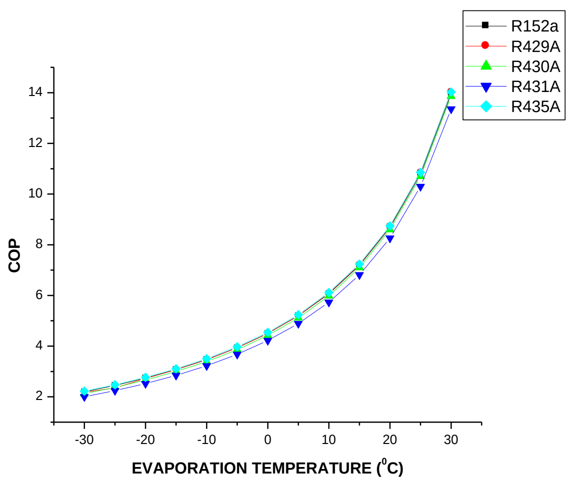
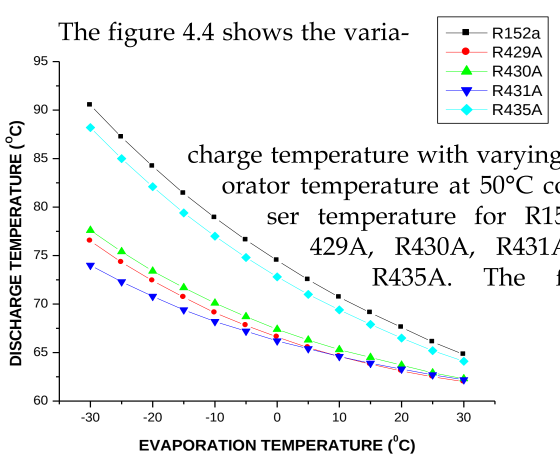


Fig: 4.3 Variation of COP at T_c=50^{0}C

4.4 Discharge Temperature



The figure 4.4 shows the variation of discharge temperature with varying evaporator temperature at 50°C condenser temperature for R152a, R 429A, R430A, R431A and R435A. The figures show that discharge temperature decreases with increase in evaporator temperature. Results show that the discharge temperature decreases for all these refrigerant blends which means compressor life is increased while using these blends for substitute to R152a. The trends are similar for condenser temperature 30^{0}C and 40^{0}C.

Fig: 4.4 Variation of Discharge Temperature at T_c=50^{0}C

4.5 Compressor Power

The figure 4.5 shows the variation of compressor power with varying evaporator temperature at 50°C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figures show that compressor power decreases with increase in evaporator temperature. Among the all refrigerant blends, R435A consumes less compressor power than R152a and all other blends consume more power. The trends are similar for condenser temperature 30^{0}C and 40^{0}C.

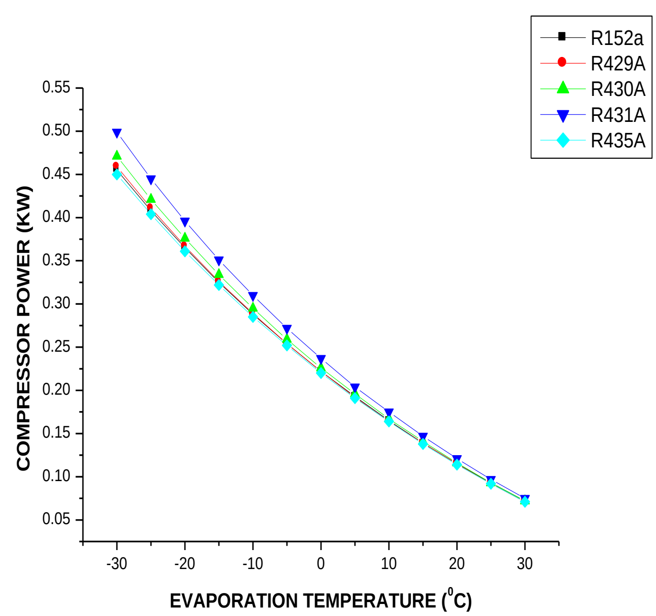


Fig: 4.5 Variation of Compressor Power at T_c=50^0C

4.6 Refrigeration Effect

The figure 4.6 shows the variation of refrigeration effect with varying evaporator temperature at 50°Ccondenser temperature for R152a, R429A, R430A, R431A and R435A.The figures show that refrigeration effect increases with increase in evaporator temperature. Results show that at condenser temperature 50^0C and evaporator temperature -30^0C refrigeration effect or R429A, R435A are 20.056%, 32.198 % higher than R152a but for R430A, R431A are7.639%, 1.764%lower than R152a. At 5^0C evaporator temperature and condenser temperature 50^0C refrigeration effect for R429A, R431A, R435Aare 23.286%, 2.582%, 32.470% higher than R152a but for R430A is 5.115% lower than R152a which means more refrigeration effect is obtained while using R435A for substitute to R152a. The trends are similar for condenser temperature 30^0C and 40^0C.

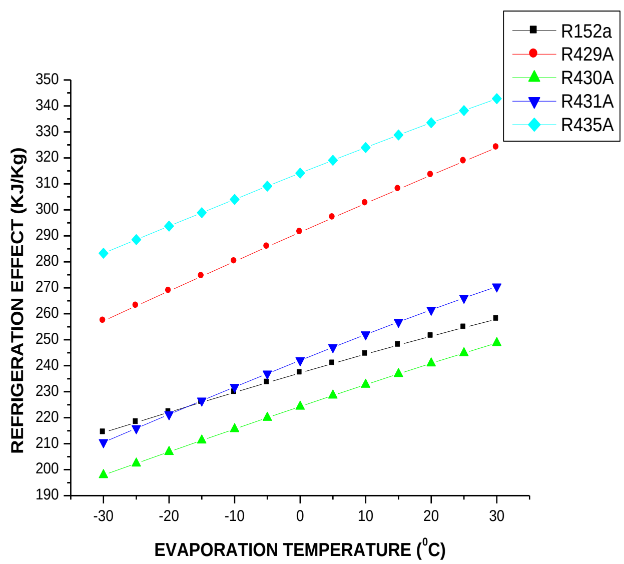


Fig: 4.6 Variation of Refrigeration Effect at T_c=50^0C

4.7 Compressor Work

The figure 4.7 shows the variation of compressor work with varying evaporator temperature at 50^0C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figures show that compressor work decreases with increase in evaporator temperature. Results show that at condenser temperature 50^0C and evaporator temperature -30^0C compressor work for R429, R431A, R435A are 20.761%, 7.576%, 30.477% higher than R152abut for R430A is 4.556% lower than R152a. At 5^0C evaporator temperature and condenser temperature 50^0C compressor work for R-429A, R431A, R435Aare 23.032%, 8.950%, 31.335% higher than R152a but for R430A is 3.601% lower than R-152a which means less compressor work is required while using R430A for substitute to R152a. The trends are similar for condenser temperature 30^0C and 40^0C.

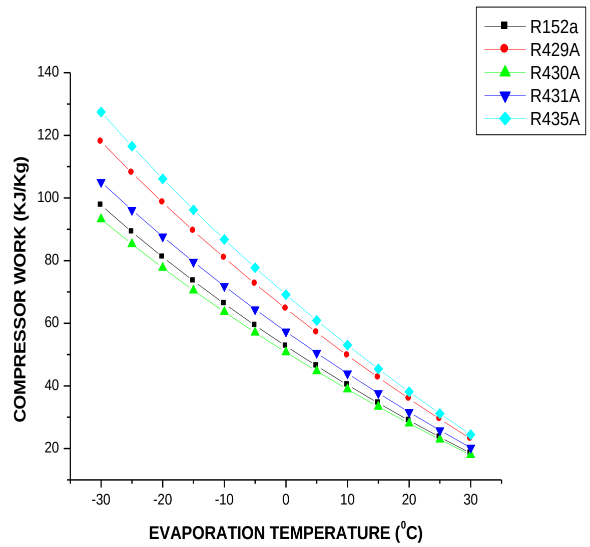
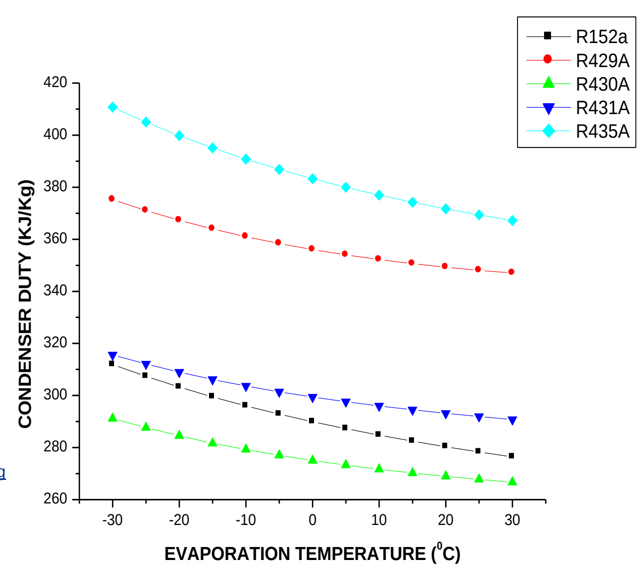


Fig: 4.7 Variation of Compressor Work at T_c=50^0c

4.8 Condensor Duty

The figure 4.8 shows the variation of Condensor duty with varying evaporator temperature at 50^0C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figures show that Condensor duty decreases with increase in evaporator temperature. Results show that at condenser temperature 50^0C and evaporator temperature -30^0C Condensor duty for R429, R431A, R435A are 20.312 % 1.189 %, 31.697%, higher than R152a but for R430A is 6.646% lower than R152a. At 5^0C evaporator temperature and condenser temperature 50^0C Condensor duty for



R429A, R431A, R435Aare 23.245%, 3.610%, 32.286% higher than R152a but for R430A is 4.867% lower than R152a which means more Condensor duty is required while using R429A, R431A, R435A and less Condensor duty is required while using R430A for substitute to R152a. The trends are similar for condenser temperature 30^{0}C and 40^{0}C.

Fig: 4.8 Variation of Condensor Duty at T_c=50^{0}C

4.9 Refrigerant Mass Flow

The figure 4.9 shows the variation of refrigerant mass flow with varying evaporator temperature at 50^{0}C condenser temperature for R152a, R429A, R430A, R431A and R435A. The figures show that refrigerant mass flow decreases with increase in evaporator temperature. Results show that at condenser temperature 50^{0}C and evaporator temperature -30^{0}C refrigerant mass flow for R430A, R431A are 8.274%, 1.798% higher than R152a but for R429A, R435A are 16.705%, 24.353% lower than R152a. At 5^{0}C evaporator temperature and condenser temperature 50^{0}C refrigerant mass flow for R430A is 5.388% higher than R152a but for R429A, R431A, R435A are 18.887%, 2.515%, 24.511% lower than R152a which means refrigerant mass flow is decreased while using R429A, R435A for substitute to R152a. The trends are similar for condenser temperature 30^{0}C and 40^{0}C.

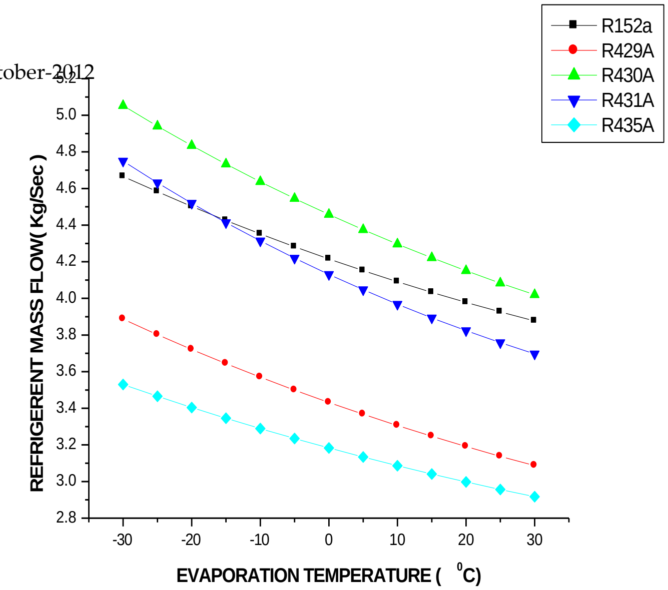


Fig: 4.9 Variation of Refrigerant mass flow at T_c=50^{0}C

5. Conclusions

In present work the comparative performance analysis of R152a and its blends R429A, R430A, R431A and R435A have been discussed. The results obtained permit the following remarks:

- Coefficient of Performance for R429A, R430A, R431A are 0.683%, 3.324% 8.789%lower and it is higher for R435A by 1.229% in comparison to R152a .
- Pressure ratio required for R430A, R431A and R435A are 10.098%, 31.869%, 7.409%
  Lower than R152a. So thus the size of compressor required for R152a is higher.
- Volumetric Refrigerating capacity for R429A is 0.112% lower and 5.548%, 69.979% 7.398% higher for R430A, R431A R435Ain comparison to R152a. Hence, while using the above blends small size compressor is sufficient.
- Discharge temperature for R429A, R430A, R431A and R435A are 15.469%, 14.254%, 18.232%, and 2.541% lower than R152a. Hence, compressor life is increased while using above blends for substitute to R152a.
- Compressor power required for R429A, R430A, R431A are 0.879%, 3.516 %, 9.67% higher and 1.098% lower for R435A. Hence, less compressor power is required while using R435A for substitute to R152a.
- Refrigeration effect for R429A, R435A is 20.056%, 32.198 % higher and 7.639%, 1.764% lower for R430A R431A .Hence, and more refrigeration effect is obtained while using R-435A for substitute to R-152a.
- Compressor work for R429, R431A and R435A are 20.76%, 7.576 %, 30.477% higher and 4.556% lower for R430A.Hence, less compressor work is required while using R430A for substitute to R152a.
- Condensor duty for R429, R431A, and R435A are 20.312 %, 1.189 %, 31.697% higher and 6.646% lower for R430A. Hence, less Condensor duty while using R430A for substitute to R152a.
- Refrigerant mass flows for R430A, R431A are 8.274%, 1.798% higher and 16.705%, 24.353% lower for R429A, R435A. Hence, and refrigerant mass flow is decreased while using R429A, R435A for substitute to R152a.

6. Acknowledgment

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