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Experimental Performance Analysis ofVCR System Using Mixture of Hydrocarbon (R134a/R600a) with Different Concentrations

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ABSTRACT
In this research work, an experimental performance study on a VCR system with refrigerant mixtures based on HFC 134a and HC 600a is done for various composition ratios and loading conditions. This paper provides experimental results of R134a and the mixtures of R600a with R134a used in the experimentation. The tests are conducted at 0W, 50 Watt, 100 Watt and 150 Watt load with different mass concentrations (40/60, 50/50, 60/40, 70/30 and 80/20 mass %). Experimental results showed that all of the alternative refrigerants investigated in the analysis have a higher performance coefficient (COP) than HFC134a for evaporating temperatures ranging between −30 °C to 12 °C. Refrigerant blends of HFC134/HC600a (50/ 50 by wt. %) instead of HFC134a are found to be replacement refrigerants among other alternatives as a result of the analysis. After the experimentation and analysis, it is found that the mixture of R134a/R600a (50/50 wt %) has improved the performance of the system by 4.10 % than R134a with 3.73% less power consumption.

Keywords: Refrigerant blends, Hydrocarbon, COP, Exergy loss, etc.

1. Introduction

Vapor compression refrigeration (VCRS) in which the refrigerant goes through phase change process called VCR system. Chloro-fluro-carbon (CFCs) and hydro- cholro-fluro-carbon (HCSCs) have many suitable properties like non-flammability, low toxicity, and material compatibility that have led to their common widespread use by consumer and industries.

Air, ammonia, carbon dioxide and water and HC are the only refrigerants with zero ODP and negligible GWP and low environmental impact. Compared to HFCs and CFCs hydrocarbon have low viscosity and high thermal conductivity. Thermal properties of HCs are similar to that of refrigerants, like propane and R-12 & R-22. Since the discovery of the depletion of the earth ozone layer cause by CFCs and HCFCs and as the result of the 1992 united nation environmental program meeting, the out of CFCs- 11 and CFCs- 12 use mainly in conventional refrigeration and air conditioning equipment was expected by 1996 (Lee And Su, 2002). This article provides experimental results of R134a and data regarding the hydrocarbon used in experimentation. The test will be done on No Load, 50 Watt, 100 Watt and 150 Watt load. The tests will be conducted at three different mass % (60/40, 70/30, & 80/20 mass %) for each load.Jose V. H. D'Angelo, et. al. [1], studied with the mixture of R290/ R600a in vapour injection system. The performance of the vapor injection cycle achieved 16- 32 % higher than that of vapor compression cycle. A. S. Dalkilic, et. al. [2], deals with the VCR system using various alternative refrigerants. The mixture of R290/ R600a (40/ 60 wt. %) gives better performance instead of CFC 12. S. Wongwises, et. al. [5], presents an experimental analysis of hydrocarbon mixtures to replace R134a. The energy consumption was reduced by 4.86% in the mixture of propane/butane (60/40 %) compared to R134a. J. N. Esbriet. al. [6], works on the drop in replacement of R134a by using R1234yf. The values of the COP obtained using R1234yf are between 5% and 30% lower than those obtained with R134a. M. Joybariet. al. [7], works on the exergy analysis and optimization of R600a as a replacement. By using Taguchi method, the amount of total exergy destruction in optimal condition is 45.05% of the base refrigerant and which confirms the enhancement of the cycle for 54.95%. M. Rasti, et. al. [8], works on the exergy efficiency enhancement by using R436A and R600a as alternative refrigerants to R134a. The total exergy destruction is found to be 0.0292 for R600a with HC type compressor. H. C. Bayrackci, et. al [9], studied and deals with energy and exergy analysis using pure hydrocarbon. Among the all working refrigerants considered, the system with R1270 gives better performance.

2. Experimental Set Up

This experimental work with blends of single Hydrocarbon (R600a) with base refrigerant (R134a) which is used as refrigerant in 165 liter gross capacity refrigerator design by Godrej, from which we can find and study the refrigerator performance and exergy loss parameter. The selected experimental system is already designed for gross capacity of 165 liter by Godrej Pvt. Ltd. The performance of the system at ideal condition is given to be 1.2. This experiment is retrofitted only with the charge of refrigerants. The kind of refrigerant mixture is used for different concentrations for the performance improvement.

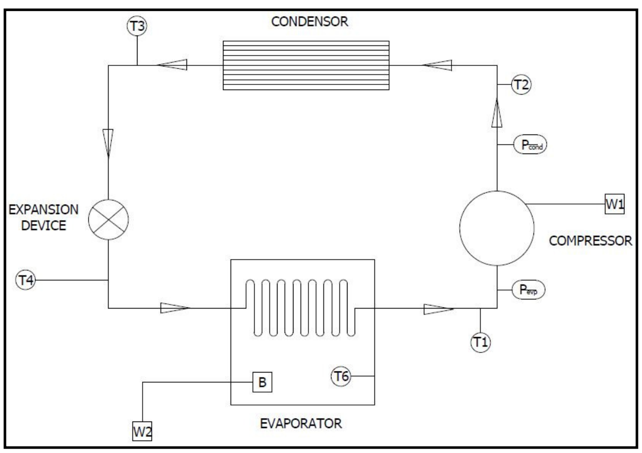

Figure 2.1: Experimental schematic of VCR system.

Figure 2.1 depict the experimental schematic of VCR system. The setup consists of single stage VCR system with hermetically sealed compressor. Set up is provided with necessary instruments for suction pressure, compressor pressure, Wattmeter for power supply measurement to the compressor and load and multi-point temperature indicator to record temperatures at different sections.

Figure 2.2: Control panel of system

Figure 2.2 shows the control panel of the system on which all the necessary instruments are mounted for the data measurement. The instruments used in the experimentation are all calibrated by the manufacturer. The compound and simple pressure gauges are mounted on the control panel to measure suction and compression pressure respectively.

The compound and simple type pressure gauges are used with the accuracy of (+-) 1 Psi and the wattmeter is used for the measurement of power supplied to the compressor and to control the load power given to the system which is also capable to capture the data of voltage and current supplied to the system.

The pin and pencil type thermocouples is used to measure the temperature at different sections of the system with the accuracy of (+-) 1^{0}C. Total 7 thermocouples are used for temperature measurement at different sections. The 4 thermocouple are mounted on the inlet and outlet of compressor and evaporator and one is for atmospheric temperature measurement, and two for freezer and cabinet temperature measurement.

3. Results And Discussion

The dependency on the composition of refrigerant mixtures makes the pressure–temperature relationship in the cycle significant for condensers and evaporators. Cycle performance is affected by the pressure alterations while the ratios of the blend vary at the given temperature. For that reason, the proportion of the components in the mixture is one of the significant factors in the cycle. For comparison of the theoretical data, R134a is chosen in this paper as reference fluids due to their common usage in cooling systems and prohibition by the Montreal Protocol.

The experiment was conducted on the variable refrigerant mixture at different load conditions to evaluate the performance and exergy destruction of R134a and different mixture of R134a with hydrocarbon. The performance of the system is discussed by considering the effect of refrigerating effect, pressure ratio, power consumption per ton of refrigeration, variation of evaporator and condenser temperature, etc. By studying the all these parameters, following results were obtained_

3.1. Performance Analysis

Figure 3.1 shows the increment in condenser temperature of the system with respect to time. The increase or decrease in the condenser temperature is directly or indirectly related to the system performance. As the condenser temperature increases the performance of the system decreases. The result of R134a/R600a (40/60 wt %) proves the theoretical principle behind the increasing power consumption and lowering the performance of the system.

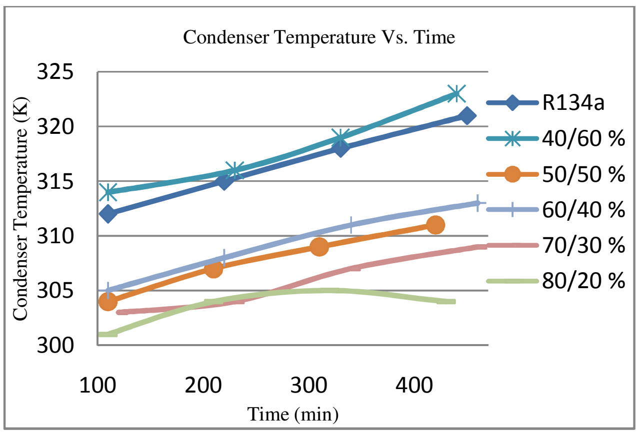

Figure 3.1: Variation of Condenser temperature with time

The system performance is increasing in this research work because of the lowering condensing temperature than R134a. The mixture of R600a using 40/60 wt % concentration in the system gives the highest value of condensing temperature which causes reduction in the performance of the system.

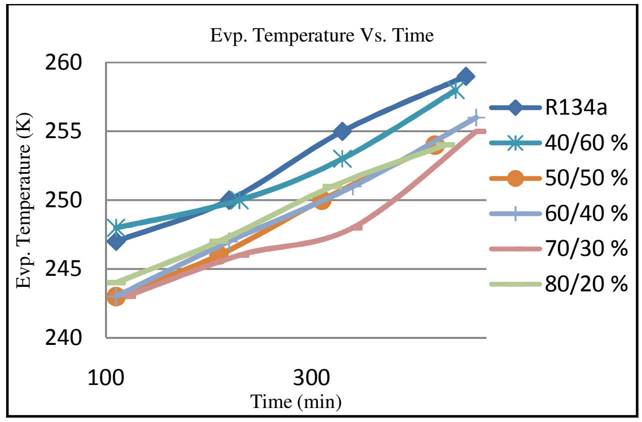

Figure 3.2: Variation of evaporator temperature with time

The improvement in the evaporator temperature is directly related to the refrigeration effect which helps to improve the performance of the system. Figure 3.2 shows the variation in the evaporator temperature with respect to time. The system using R134a gives the highest evaporator temperature at 150 W load conditions but as the load increases the power consumption is also increases which reduce the performance of the system. The thermo- physical properties of the mixture gives the better performance of the system at lower evaporator temperature. The percentage decrease in the evaporator temperature in the mixture using 50/50 of R600a are 1.77%.

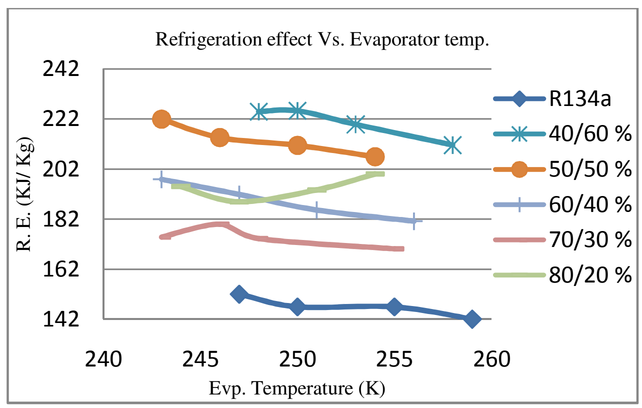

Figure 3.3: Effect of Evp. Temp. on RE

Figure 3.3 shows the variation of the refrigerating effect with respect to evaporator temperature. The refrigeration effect is directly related to the pressure drop in the system. As the pressure of the system increases with load and time the effect of refrigeration or the system is also an increase. The refrigerating effect of the system at each condition is decreases with respect to increase in the evaporating temperature. The mixture of R134a/600a (40/60 wt %) provides average maximum refrigerating effect up to 220.37 Kj/ Kg. The avg. percentage increase in the refrigerating effect in refrigerant mixture of R134a/R600a (40/60 wt %)

and R134a/R600a (50/50 wt %) compared to pure R134a are 49.92 % and 45.36 % respectively.

Figure 3.4 and figure 3.5 shows the dependency of power consumption of compressor with time and evaporator temperature, for the evaporator temperature ranging from - 30 ^{0}C to 12 ^{0}C. Tested refrigerants at various concentrations R134a and R134a/R600a (40/60 wt %) have much higher values of compression work than R134a/R600a (50/50 wt %) and others respectively. The power consumption in compressor using R134a/600a (40/60 wt %) is 13.91% and 18.65% higher than R134a, R134a/R600a (50/50 wt %) respectively.

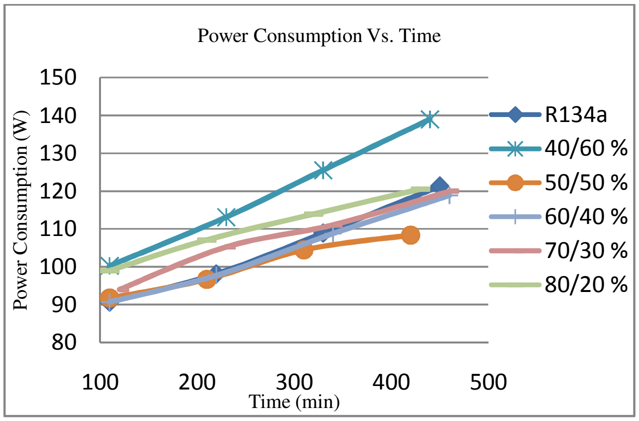

Figure 3.4: Power consumption with respect to time

That means the charge required to the system with R600a should not exceed than the 50%. The average power consumption of compressor is reduced by 3.73 % in R134a/R600a (50/50 wt %) than R134a. The major cause of increasing power consumption of compressor in all the cases (Figure 3.4 and 3.5) is the increase in load given to the system with respect to time.

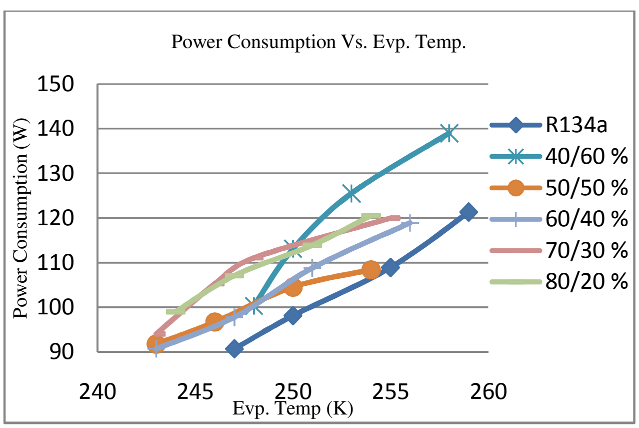

Figure 3.5: Dependency of power consumption on Evp. Temperature

Figure 3.6 shows the variation of pressure ratio with respect to evaporator temperature. The drops in pressure cause reduction in the refrigeration effect which is directly related to the system performance. The trend of the pressure ratio of the system shown in below figure is decreasing as a results increase in the pressure at both sides.

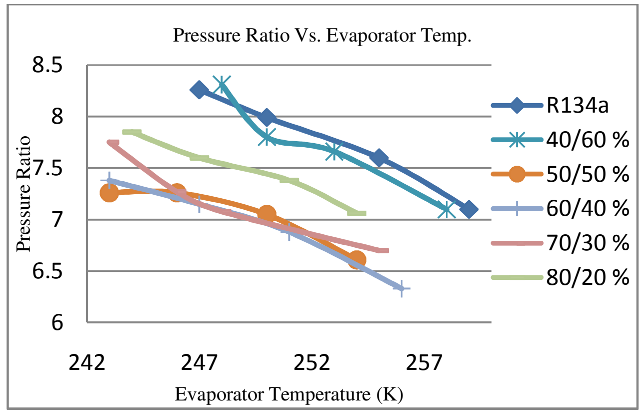

Figure 3.6: Variation in pressure ratio

The mixture of R134a/R600a (60/40 wt %) provides the minimum pressure ratio but the system performance is not that much improved because of the low grade of thermo-physical properties of the mixture. The mixture of R134a/R600a (50/50) gives the satisfactory pressure increment in both side of the system (condenser side and evaporator side) which helps in the increment of system performance.

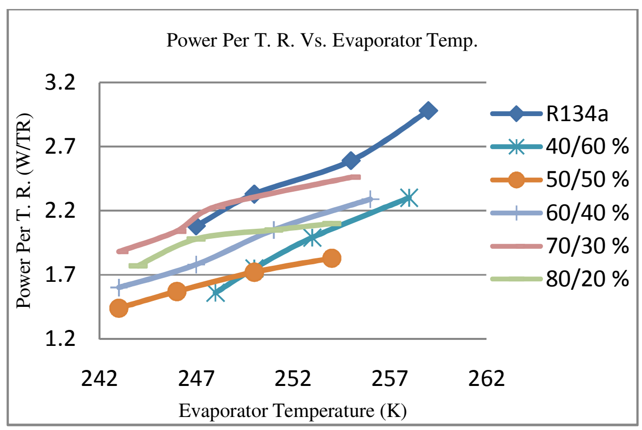

Figure 3.7: Power per ton vs. evaporator temperature

The changes in power needed for refrigeration with evaporation temperature is shown in figure 3.7. It is the power required to extract the heat to achieve 1 ton of refrigeration effect. The Power consumption per ton of refrigeration of each mixture shows in increasing order as evaporator temperature increases. Thermo-physical properties are also one of the major causes of reduction in power consumption per T. R. in case of mixtures than R134a. The avg. minimum power consumption per T. R. is 1.64 W/TR which is 33.88% lower than pure R134a.

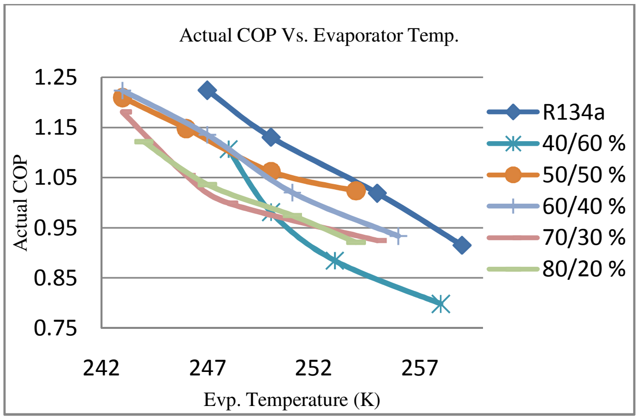

Figure 3.8: Variation of COP with Evaporator temperature

The variation of performance coefficient (COP) with evaporation temperature (Tevp) is illustrated in Figure 3.8. From this figure, the coefficient of performance (COP) decreases as the evaporation temperature (Tevp) increases as evaporation temperatures ranging from −30 °C to 10 °C, considering an increase in refrigerating effect (RE) and a decrease in compressor power (Wc). Each mixture at the no load condition provides the maximum performance of the system as 1.2 which is provided by the manufacturer. All the performance coefficients (COP) of the alternative refrigerants tested are found to be higher than those of R134a with the exception of R134a/R600a (40/60 wt %) for the final steady state conditions. The average coefficient of performance of the mixture R134a/R600a (50/50 wt %) is found to be 4.10% higher than R134a.

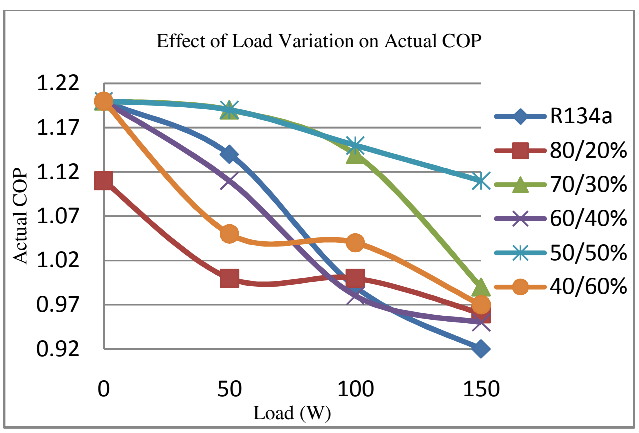

Figure 3.9: Variation of COP along with Load

Figure 3.9 shows the variation of the COP along with the variation of load using R600a in the mixture at 5 different concentrations. From the graph we can directly predict the best refrigerant mixture suitable for the replacement of R134a. The mixture of R600a using 50/50 wt % of refrigerant in the mixture gives the highest value of performance at each load condition. At the no load condition each mixture of R600a provides the maximum performance of about 1.2 with the exception of 40/60 wt % of mixture. The percentage increase in the performance of the system using R600a is 4.10% higher than R134a.

3.2. Exergy Analysis

In case of evaporator (Figure 3.10), R134a gives the best results of exergy destruction among all the refrigerants used. Alternately R134a/R600a (50/50 wt %) gives the better performance but provides an implementation in exergy destruction at the final steady state condition. The average exergy destruction in the evaporator using R134a/R600a (50/50 wt %) as compared to the pure R134a are 57.4% higher respectively.

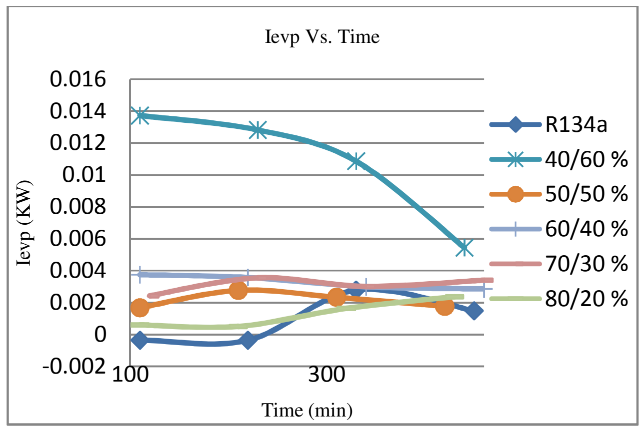

Figure 3.10: Exergy destruction in evaporator with respect to time

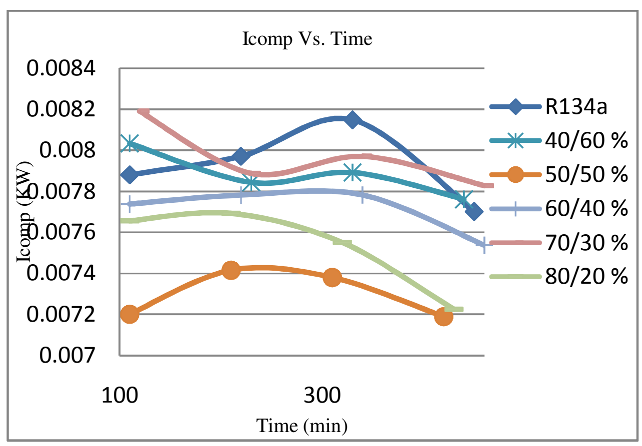

Figure 3.11: Exergy destruction in compressor with respect to time

In case of compressor (Figure 3.11), R134aa/R600a (50/50 wt %) gives the best performance compared to R134a and other refrigerant mixture which is 7.91 % lower than R134a. The performance of the pure R134a refrigerant trends the up and down as the load changes gradually. The exergy destruction in the compressor using the mixture of R600a with R134a is gradually in decreasing order.

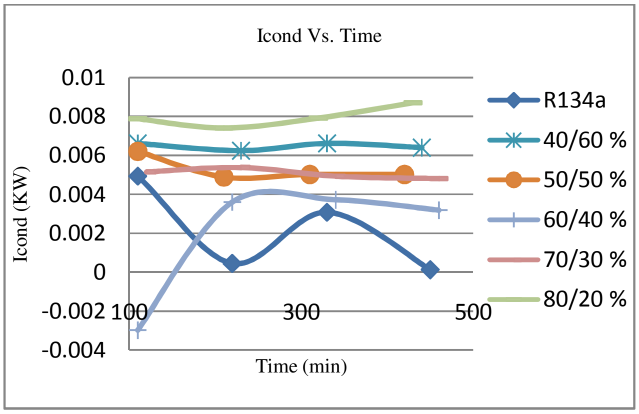

Figure 3.12: Exergy destruction in condenser with respect to time

In condenser (figure 3.12) R134a performs better than other refrigerant mixture then after R134a/R600a (60/40 wt %). Some alterations are occurred in the values of destruction of exergy in each refrigerant mixture. The mixture of R134a/R600a (80/20 wt %) gives the highest value of destruction of about 0.0087 KW which is 72.67% higher than R134a. The destruction in exergy in case of R134a/R600a (50/50 wt %) is near about stable in whole run time and loading conditions of the system.

Expansion device has found to be lowest exergy destructive component of the system among all the other components (Figure 3.13). The range of the destruction for the expansion device changes from 1.1*E-5 to 3.42*E-5. R134a/R600a (80/20 wt %) and R134a/R600a (50/50 wt %) provides best performance of expansion device with reduction in the destruction average percentage of about 46.1 % and 48. 55% than R134a respectively.

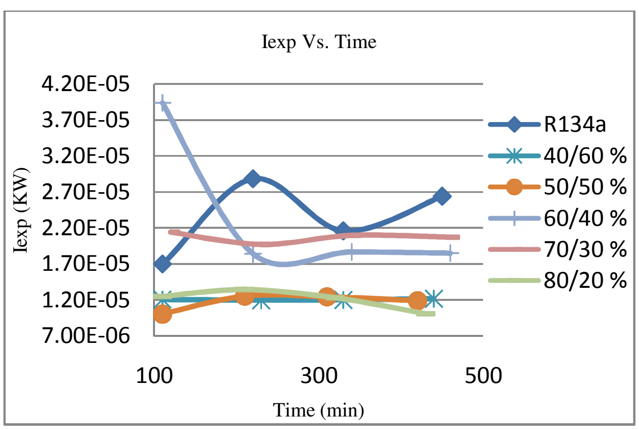

Figure 3.13: Exergy destruction in expansion device with respect to time

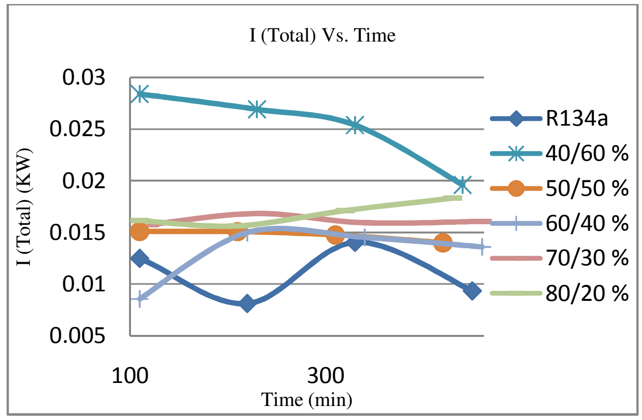

Figure 3.14: Time dependency of total exergy loss

Figure 3.14 and figure 3.15 provides a good sight to compare results and enables extraction of two important points. First, the amount of total exergy destruction of all runs is distinguishable and it is clear that the R134a has the minimum amount of total exergy destruction among all the mixtures. Second, the time required for the refrigerator to reach the desired conditions (according to ISIRI 13700) and to stop the compressor is clear. For example, the second run finished after 110 min, while the fourth completed after 120 min.

The importance of this time is due to compressor ON time ratio and its work percent. Therefore, the second and forth runs in results are the best ones in this regard. The trend of the results are same in both the cases (figure 3.14 and figure 3.15) and these results are concluded without statistical analysis and, for that reason, are just among the conditions which were investigated. The maximum exergy destruction is found in the mixture of R600a in the ratio of 40/60 wt %. The average exergy destruction increased in the system by 55.72% and 25.39% using R134a/R600a (40/60 wt %) and R134a/R600a (50/50 wt %) respectively than R134a.

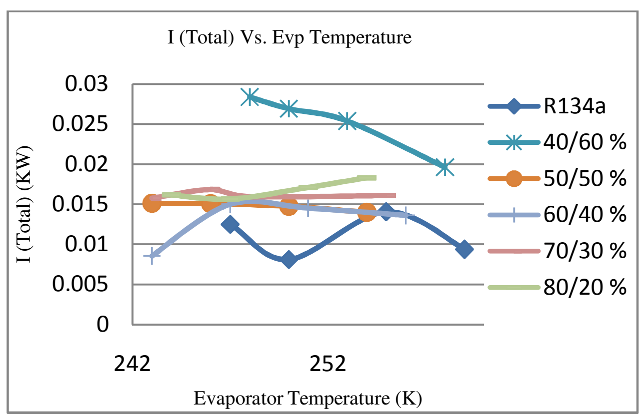

Figure 3.15: Effect of temperature on total exergy loss

4. Conclusions

In this study, a vapor-compression refrigeration system is used for the performance analysis of alternative new refrigerant mixtures of hydrocarbons (R134a/R600a) as substitutes for HFC134a.

After the experimentation and analysis, it can be concluded that-

1. The performance of the system decreases along with increase in evaporator temperature with respect to time change and load means the variation of evaporator temperature impacts on the all performance data (Refrigeration effect, COP, power consumption, ect.).
2. Refrigeration effect, condenser and evaporator temperature, power consumption, power per TR of the system using mixture of R600a is improved as compared to the results of R134a. Refrigeration effect has improved by 45.36% as compared to R134a using R600a in the ratio of 50/50 wt %.
3. The mixture of R134a/R600a (50/50 wt %) has given the maximum average performance coefficient of the system of about 4.10% higher than R134a.
4. The average power consumption of the system using R134a/R600a (50/50 wt %) has found to be lower than R134a of about 3.73 %.
5. The mixture using R600a (50/50 wt %) achieves 33.88% less power consumption per TR as compared to R134a.
6. Compressor has found to be the highest exegy destructive component of the system. The mixture of R134a/R600a (50/50 wt %) gives 7.91% lower exergy destruction in compressor as compared to R134a.
7. Using R134a/R600a (40/60 wt %) has highest increment in average total exergy destruction of about 55.72% as compared to the results of R134a. The average exergy destruction in R134a/R600a (50/50 wt %) has found to be 25.39 % higher than R134a which is satisfactory.

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