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Analysis of Vapour Compression Refrigeration System with Refrigerants R134a, R143a, R152a, R290 and R32

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Abstract:
This paper pressents analysis of vapour compression refrigeration cycle with refrigerantsR134a, R143a, R152a, R290 and R32. A computational model has been developed for comparision of COP, power required for compressor, refrigerating effect, pressure ratio and discharge temperature for refrigerants R134a, R143a, R152a, R290 and R32. This investigation is based on evaporating temperatures and condensing tempeartures in the range of -10 to 4°C and 40 to 54°C respectively.

Keywords*: Refrigerant,COP,Cooling Capacity, Discharge temperature, R134a, R290*

1. Introduction

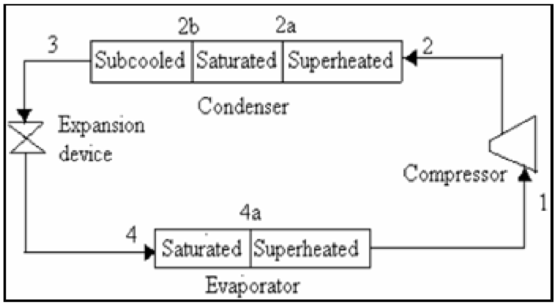
R134a has been used widely but the global warming potential (GWP) of R134a is 1430 over 100 years which is much more than that of other refrigerants. In this paper refrigerants like R143a, R152, R290 and R32 having lower global warming potentials have been introduced. A simple vapour compresson refrigeration system has been studied with refrigerantsR134a, R143a, R152a, R290 and R32. In this study, COP, power required for compressor, refrigerating effect, pressure ratio and discharge temperature have been analysed with these refrigerants.

Refrigerants	Molecular Weight (gm/mol)	NBP(°C)	Critical Temperature (°C)	Critical Pressure (kPa)	ODP	GWP (100 Years)
R134a	102.03	-26.3	101.86	4059	0	1430
R143a	80.04	-47.6	72.89	3776	0	
R152a	66.05	-25	113.26	4517	0	124
R290	44.09	-42.1	96.8	4254	0	20
R32	52.02	-52	78.11	5782	0	675

Table 1: Properties of Refrigerants

1.1. Principle of Vapour Compression Cycle

The vapour compression refrigeration cycle modeled for this study is shown in Fig.1. Superheated refrigerant vapor from the evaporator entrs the compressor (state 1) and leaves as high pressure superheated vapor(state 2). This vapor enters the condenser where heat is rejected to atmospere . The refrigerant vapor is cooled to saturation temperature (state 2b), and then cooled to below the saturation temperature (state 3).The high pressure liquid then flows through the expansion valve into the evaporator (state 4)where it enters as a low pressure saturated mixture. The refrigerant then absorbs heat from the refrigerated space and gets completely evaporated at saturation temperature (state 4a). The refrigerant gets superheated above the saturation temperature and enters the compressor (state 1). Thus, the cycle is completed. The vapour compression refrigeration cycle is shown on T-s diagram in the Fig.2.



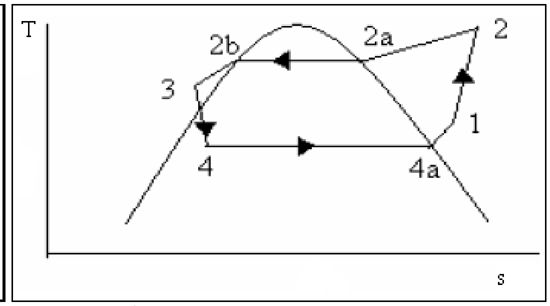


Figure 1: Simple Vapour Compression Refrigeration Cycle

Figure 2: T-s diagram

2. Results and Discussion

A computational model is develoved for carrying out the energy analysis of the system using Engineerig Equation Sover software (Klein and Alvarado,2005).

The input data assumed for the computation of results are furnished below:

- Mass flow rate of refrigerant: 0.05 kg/s
- Degree of subcooling: 5^{o}C
- Degree of superheat:5^{o}C
- Isentroic efficiency of compressor: 75%
- Evaporator temperature: -10 to 4^{o}C
- Condenser temperature: 40 to 54^{o}C
- Pressure drop in evaporator and condenser is negligible.

Fig. 3 shows the pressure ratios for R134a and alternate refrigerants for various evaporating temperatures at condensing temperature 45^{o}C. The pressure ratio is the highest for R134a and the lowest for R290 for the entire range of evaporating temperatue in this study.

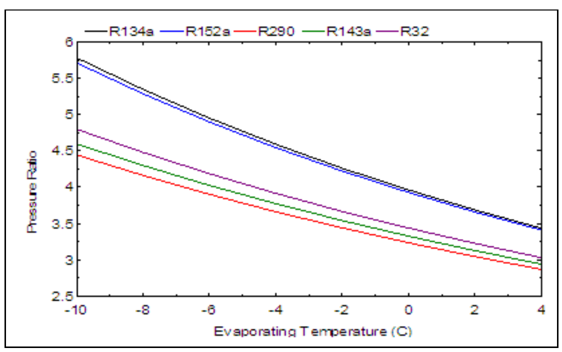


Figure 3: Variation of Pressure Ratio with Evaporating Temperature

This study shows that there is 40% reduction in pressure ratio for R134a while 35% reduction in pressure ratio for R290 during evaporating temperature ranging from -10 to 4^o C at condensing temperature 45^{o}C. If the pressure ratio is lower, the compressor efficiency is higher. It is recognized that compressor efficiency can have significant effect on the system energy efficiency.

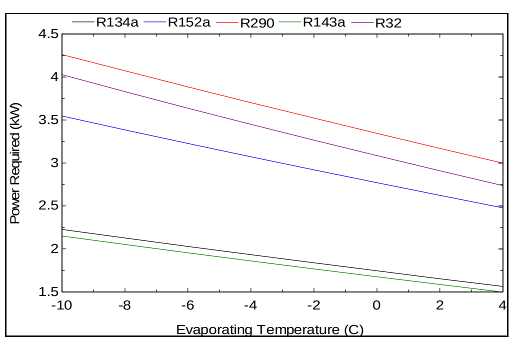


Figure 4. Variation of Compressor Power With Evaporating Temperature

Fig. 4 shows compressor power for R134a and alternate refrigerants for various evaporating temperatures at condensing temperature 45^oC. R290 requires the highest compressor power and R143a requires the lowest compressor power. With increase in evaporating temperature, there is 29.6% reduction in power requirement of compressor for R290 while 29.98% reduction in case of R143a. The descending order of refrigerants for compressor power is R290, R32, R152a, R134a and R143a.

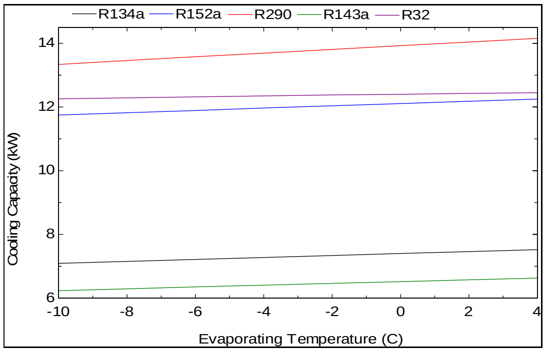


Figure 5: Variation of Cooling Capacity With Evaporating Temperature

Fig. 5shows cooling capacity for R134a and alternate refrigerants for various evaporating temperatures at condensing temperature 45^oC. R290 has the highest cooling capacity and R143a has the lowest cooling capacity during the evaporating temperature range of -10 to 4^oC.With increase in evaporating temperature, there is 6.14% increase in cooling capacity for R290 while there is 6.08% increase in cooling capacity for R143a.

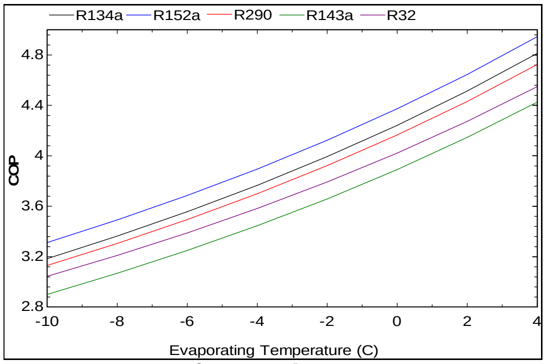


Figure 6: Variation of COP with Evaporating Temperature

Fig.6 shows the variation of coefficient of performance with different evaporating temperatures for R134a and alternate refrigerants at condensing temperature 45^oC. With increase in evaporating temperature, the pressure ratio across the compressor reduces causing compressor work to reduce and cooling capacity increases because of increase in specific refrigerating effect. The combined effect of these two actors is to enhance the overall COP. The COP of R152a increases by 49.3% while that of R143a increases by 52.6% when the evaporating temperature increases from -10 to 4^o C.

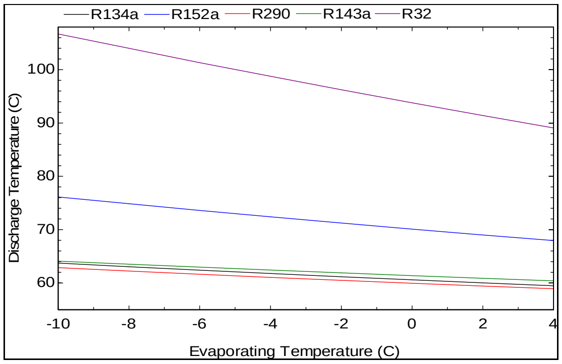


Figure 7: Variation of Discharge Temperature With Evaporating Temperature

Fig. 7 shows discharge temperatures for R134a and alternate refrigerants for various evaporating temperatures at condinesing temperature 45^oC. R32 has the highest discharge temperature and R290 has the least. The discharge temperature of R134a is in between those of R290 and R143a. Lower dischage temperature is useful for better lubricant and refrigerant stabilty. At lower temmperatures, any reactions initiated due to the compatibility problems refrigerant, lubricant and system materials is likely to be slower. This means that the reliable life of the compressor is likely to be longer.

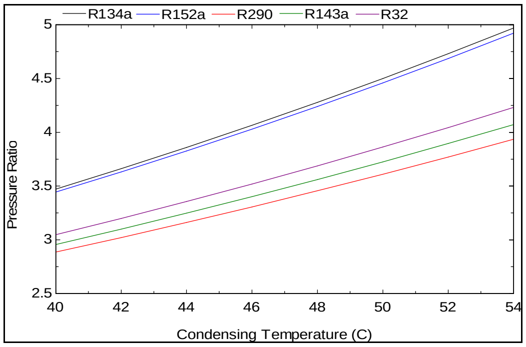


Figure 8: Variation of Pressure Ratio With Condensing Temperature

Fig. 8 shows the pressure ratios for R134a and alternative refrigerants for various condensing temperatures at fixed evaporating temperature 0^oC.The pressure ratios are the highest for R134a and the lowest for R290 for entire range of condensing temperatures from 40 to 54^oC. This study shows that there is increase in pressure ratio with increase in condensing temperature. With increase in condensing temperature, there is 43.18% increase in pressure ratio for R134a while 36.34% increase for R290. If the pressure ratio is higher, then the compressor efficiency is lower.

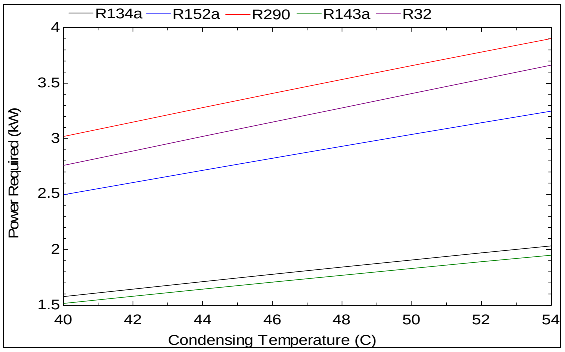


Figure 9: Variation of Compressor Power With Condensing Temperature

Fig. 9 shows compressor power for R134a and alternate refrigerants for various condensing temperatures at evaporating temperature 0^oC. R290 requires the highest compressor power and R143a requires the lowest compressor power. With increase in condensing temperature, there is 29.24% increase in power requirement of compressor for R290 while 28.71% increase in case of R143a. The descending order of refrigerants for compressor power is R290, R32, R152a, R134a and R143a.

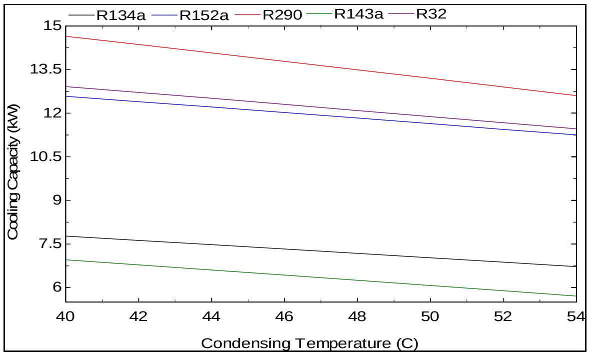


Figure 10: Variation ofCooling Capacity With Condensing Temperature

Fig. 10 shows cooling capacity for R134a and alternate refrigerants for various condensing temperatures at evaporating temperature 0^oC. R290 has the highest cooling capacity and R143a has the lowest cooling capacity during the condensing temperature range of 40 to 54^oC. With increase in condensing temperature, there is 13.93% decrease in cooling capacity for R290 while there is 17.91% increase in cooling capacity for R143a.

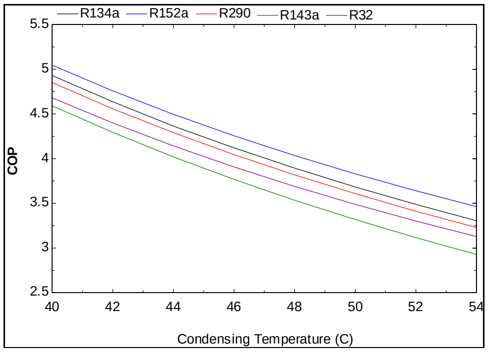


Figure 11: Variation of COP With Condensing Temperature

Fig. 11 shows the variation of coefficient of performance with different condensing temperatures for R134a and alternate refrigerants at evaporating temperature 0^{o}C. With increase in condensing temperature, the pressure ratio across the compressor increases causing compressor work to increase and cooling capacity decreases because of decrease in specific refrigerating effect. The combined effect of these two actors is to decrease the overall COP. The COP of R152a reduces by 31.35% while that of R143a reduces by 36.24% when the condensing temperature increases from 40 to 54^o C.

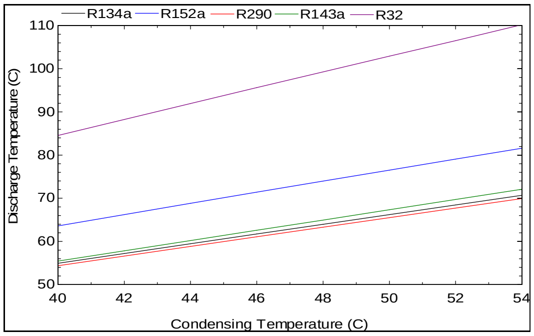


Figure 12: Variation of Discharge Temperature With Condensing Temperature

Fig. 12 shows discharge temperatures for R134a and alternative refrigerants for various condensing temperatures at evaporating temperature 0^{o}C. R32 has the highest discharge temperature and R290 has the lowest. With increase in condensing temperature, the discharge temperature of R32 increases by 30.35% while there is 28.62% increase in discharge temperature for R290.

3. Conclusion

- R290 has the lowest pressure ratio for entire range of evaporating temperatures from -10 to 4 ^{o}C and condensing temperatures from 40 to 54^{o}C.
- R143a requires the lowest compressor power for entire range of evaporating temperatures from -10 to 4 ^{o}C and condensing temperatures from 40 to 54^{o}C.
- R290 has highest cooling capacity for entire range of evaporating temperatures from -10 to 4 ^{o}C and condensing temperatures from 40 to 54^{o}C.
- R152 has the highest COP for entire range of evaporating temperatures from -10 to 4 ^{o}C and condensing temperatures from 40 to 54^{o}C.
- R32 has the highest discharge temperature for entire range of evaporating temperatures from -10 to 4 ^{o}C and condensing temperatures from 40 to 54^{o}C.

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