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THERMODYNAMIC ANALYSIS OF DI METHYL ETHER AND ITS BLENDS AS ALTERNATIVE REFRIGERANTS TO R134A IN A VAPOUR COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT:- *In this study, the first and second law analysis of Dimethyl ether (DME) and its blend refrigerants (R429A, R435A, R 510A) is presented as an alternatives to R134a. A computational model, developed in cycle_D software, is employed for comparing the performance of these refrigerants in vapour compression refrigeration cycle. The thermodynamic properties of the DME and its blend refrigerants are computed using Refprop version 9.0. The parameters computed are volumetric refrigerating capacity, compressor discharge temperature, Co efficient of performance and exergy efficiency in system. The results indicate that VRC, COP and exergy efficiency for R134a are lower in comparison with R429A, R435A, R510A.*

Key words: *RE170, R429A, R435A, R510A, COP, Exergy efficiency*

1. INTRODUCTION

R134a has been developed and adopted in domestic refrigerators due to the phase out of CFCs which have high ODP [1]. The Global warming potential of R134a is 1370 as compared to that of CO_2 [2]. As per Kyoto Protocol 1997, it is considered as greenhouse gas and hence the production and use of same will be completed in few years. Hence it is to be replaced by eco-friendly refrigerants [3, 4]. Now it is imperative to identify the alternative refrigerant with low GWP in accordance with the limit fixed by EU Regulations [5]. The thermo-physical and environmental properties of investigated refrigerants are shown in Table1 [6].

Table: 1.1Properties of Investigated Refrigerants

S.No	Refrigerant mixture	Composition (% mass f.)	NBP (C)	GWP	Molecular Mass	Critical Temperature	Critical Pressure
1	R134a	--------	-26.1	1430	102.3	101.1	4.06
2	RE170	-------	-24.8	10	46.07	127.2	5.34
3	R 429A	RE170/R600a/R152a	-26.0	14	50.76	123.5	4.86
4	R 435A	DME/R 152a (80/20)	-26.1	<31	49.04	125.2	5.39
5	R 510A	DME/R 600a (88/12)	-25.2	<3	47.24	127.9	5.33

Nicholas Cox [7] reported that the Di methyl ether (RE170, DME) makes a better refrigerant than R290 / R600a blends as it has no temperature glide and doesn't separate during leakage. Valentinapostol et al [8] conducted a comparative thermodynamic study considering a single-stage vapour compression refrigeration system (VCRS) using as working fluids DME,R717, R12, R134A, R22 (pure substances) and R404A , R407C (zoetrope mixtures), respectively. The result of this study is that DME could be used as a refrigerant and, more, that DME could be a good substitution alternative for R12 and R134a.

B.M. Adamson [9] reported that the Di methyl ether (DME, C2H6O) possesses a range of desirable properties as a replacement for R-134a. These include better heat transfer characteristics than R-134a, a pressure/temperature relationship very close to R134a, compatibility with mineral oils, low cost and ready availability. It is also highly environmentally friendly. (ODP =0; GWP =1; atmospheric lifetime = 6 days) DME is compatible with most materials commonly found in refrigeration systems.

Baskaran et al. [10-18] analyzed the performance of a vapor compression refrigeration system with DME and its blends. The results were compared with R134a as a possible alternative refrigerant. Ki-Jung Park, Dong Gyu Kang and

Dongsoo Jung C, S. investigated both numerically and experimentally in an effort to replace HFC134a used in the refrigeration system of domestic water purifiers. Test results show that the energy consumption and the compressor discharge temperature of R429A (mixture of DME, R600a and R152a)is 28.9% and 13.4^0 C lower than that of HFC134a with50% of the refrigerant charge , Overall,R429Ais a new long term environmentally safe refrigerant, is a good alternative for HFC134a requiring little change in the refrigeration system of the domestic water purifiers. [19]

Choedaeseong, Dangsoo Jung (2010) presented an experimental study on the application of R435A (mixture of DME and R152a) to replace HFC134a in domestic water purifiers. Test results show that the energy consumption and discharge temperature was 12.7% and 3.7°C lower than that of HFC 134a [20]. Ki-Jung Park/Yohan Lee/Dongsoo Jung investigated both numerically and experimentally in an effort to replace HFC134a used in the refrigeration system of domestic water purifiers. Test results show that the energy consumption and the compressor discharge temperature of R510A is 22.3% and 3.7^0 C lower than that of HFC134a with 50% of the refrigerant charge. Overall, R510A is a good alternative for HFC134a requiring little change in the refrigeration system of the domestic water purifiers. [21]

The present study mostly concentrates on a theoretical investigation on the first and second law performance of the vapour compression refrigeration cycle .The refrigerants RE170 and their blends R429A, R435A, and R510A are used as the working fluid for the comparison with the conventional refrigerant R134a.

2. MATERIALS AND METHODS

Schematic diagram of vapor compression refrigeration system is shown in Figure 1 and the relevant P-h diagram of the system is shown in Figure 2. States 1-2 represent isentropic compression in the compressor, states 2-3 represent the condensation i.e. heat rejection in the condenser, states 3-4 represent the throttling in the expansion valve and states 4-1 represent the evaporation in evaporator i.e. heat addition.

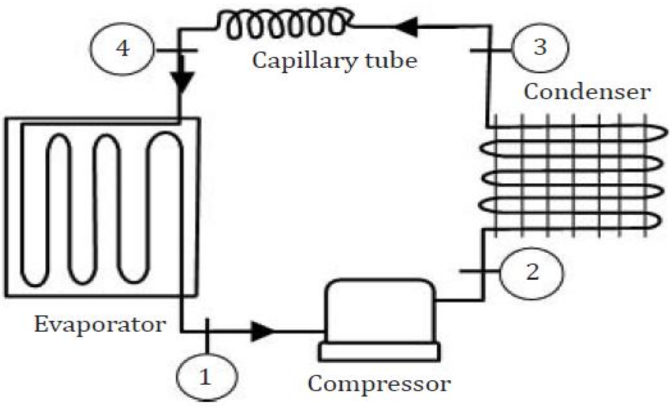


Figure 2.1Schematic Diagram of a Simple Vapour Compression Refrigeration System

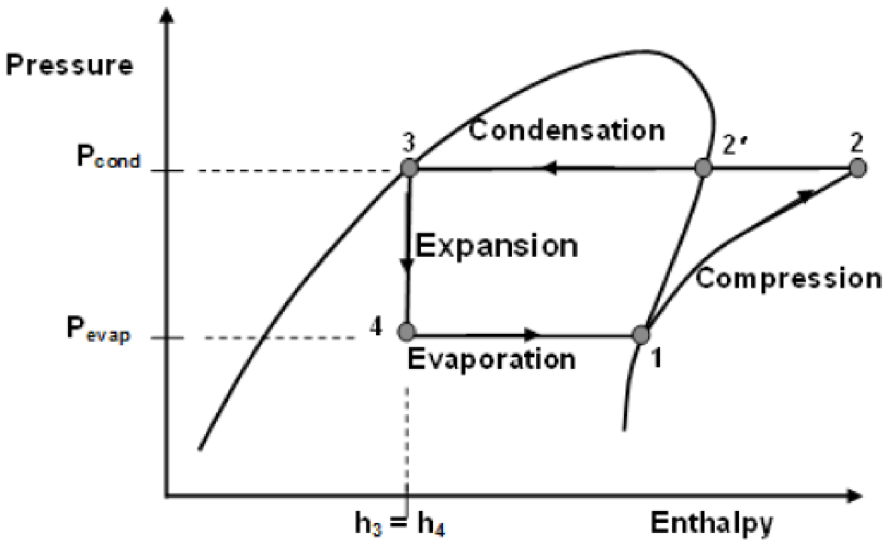


Figure 2.2 Vapour Compression Refrigeration Cycle on P-H Diagram

Mathematical formulation for Exergy analysis in different components can be arranged in the following way

Specific Exergy in any state

$$\psi = (h-h_0)-T_0(s-s_0) \qquad (1)$$

For Evaporator:

Heat addition in evaporator

$$Q = m\ (h_1-h_4) \qquad (2)$$

Exergy losses,

$$I_{ev} = m\ (\psi_4-\psi_1)+Q(1-\frac{T0}{Tev})$$
$$= m[(h_4-h_1)-T_0(s_4-s_1)]+ Q(1-\frac{T0}{Tev}) \qquad (3)$$

For Compressor,

exergy loss,

$$I_{comp} = m\ (\psi_1-\psi_2)+ W_{el}$$
$$= m[(h_1-h_2)-T_0(s_1-s_2)]+ W_{el} \qquad (4)$$

For Condenser,

$$Q_{cond} = m\ (h_2 - h_3) \qquad (5)$$

Exergy loss,

$$I_{cond} = m\ (\psi_2-\psi_3) - Q_{cond}\ (1-\frac{T0}{Tcond})$$
$$= m[(h_2-h_3)-T_0(s_2-s_3)] - Q_{cond}\ (1-\frac{T0}{Tcond}) \qquad (6)$$

For Expansion Valve,

Exergy destruction,

$$I_{exp} = m\ (\psi_4-\psi_3)$$
$$= m\ (s_4-s_3)\ [\text{Thorttling, } h_4 = h_3] \qquad (7)$$

Coefficient of performance,

$$COP = \frac{Q_{ev}}{W_{el}} \qquad (8)$$

Total destruction,

$$I_{total} = I_{cond} + I_{exp}+ I_{comp}+ I_{ev} \qquad (9)$$

A theoretical analysis was implemented for the use of R134a, Di methyl ether (RE170) and the following selected mixtures.

1. R 429A- Mixture of RE170, R600a and R152a in the proportion 60%, 30% and10%.
2. R435A- Mixture of RE170 and R152a in the proportion 80% and20%.
3. R510A- Mixture of RE170 and R600a in the proportion 88% and12%.

The software CYCLE_D 4.0 vapour compression cycle design program [23] 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 = 0.75
Compressor volumetric efficiency = 0.75
Electric motor efficiency = 0.75
Effectiveness of suction line heat exchanger = 0.80
Pressure drop in the suction line = 0.0
Pressure drop in the discharge line = 0.0
Evaporator: Average sat.Temp = -50^0C to $+20^0C$
Condenser: Average sat. Temp = 45^0C
Super heat = 10^0C
Sub cooling = 5^0C

All the enthalpy and entropy values needed for the analysis are obtained from the Software REFPROP 9.0[22].

The analysis of the variation of performance parameters of selected refrigerants such as Volumetric refrigeration capacity (VRC), Discharge temperature, Compressor power (CP), mass flow rate (MFR), Coefficient of performance (COP) and Exergetic efficiency (Ex.eff) in system are investigated in this theoretical study and they are plotted against the evaporating temperature (Tevap) as shown in figures from 3.1 to 3.6.. Table 1 and 2 show the operation results and deviation of alternative refrigerants from the values of R134a.

Table: 2.1
Operation on a standard vapour-compression cycle using R134a and various refrigerants at Tcod=45°C and Tevap=-10°C with super heating 10°C and sub cooling 5°C

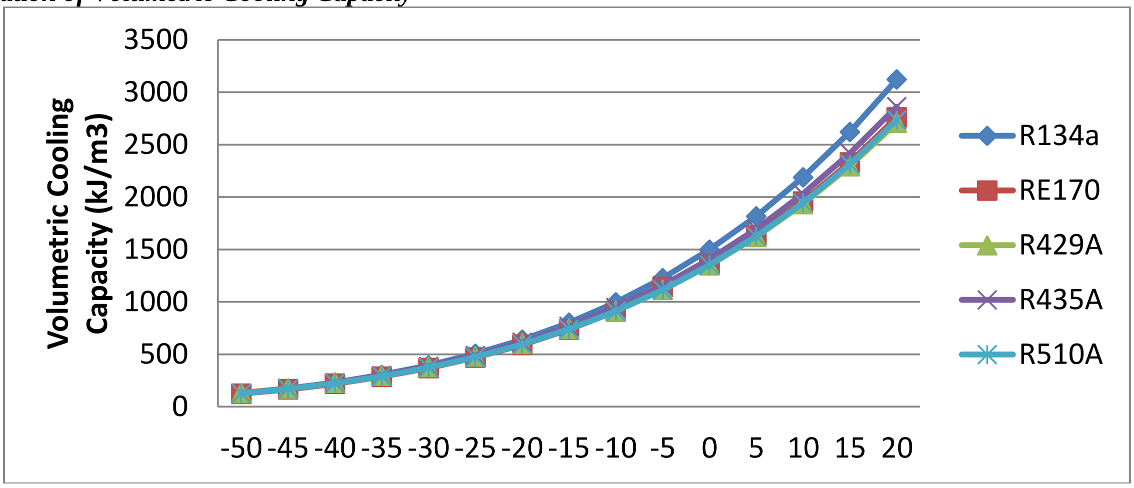
S.NO	Performance parameters	R134a	RE170	R429A	R435A	R510A
1	Discharge Temperature (^{0}C)	131.6	155.7	138	154.8	148.5
2	Volumetric cooling capacity(kJ/m^3)	995.5	909.9	914.8	945.6	911.2
3	Coefficient of performance	2.003	2.001	2.04	1.995	2.017
4	Compressor power (kW)	0.499	0.5	0.49	0.501	0.496
5	Mass flow rate (gram/sec)	5.7958	2.5726	2.9339	2.7646	2.6742
6	Exergy efficiency (%)	24.39	24.30	24.89	24.28	24.49

Table: 2.2
Some deviation values of alternative refrigerants from R134a at Tcod = 45°C and Tevap = -10°C with super heating 10°C and sub cooling 5°C (values are in percentage)

S.NO	Performance parameters	RE170	R429A	R435A	R510A
1	Discharge Temperature	18.31	4.86	17.63	12.84
2	Volumetric cooling capacity	-8.60	-8.11	-5.01	-8.47
3	Coefficient of performance	-0.10	1.85	-0.40	0.70
4	Compressor power	0.20	-1.80	0.40	-0.60
5	Mass flow rate	-55.61	-49.38	-52.30	-53.86
6	Exergy efficiency	-0.33	2.08	-0.45	0.43

3. RESULT AND DISCUSSIONS

3.1Variation of Volumetric Cooling Capacity

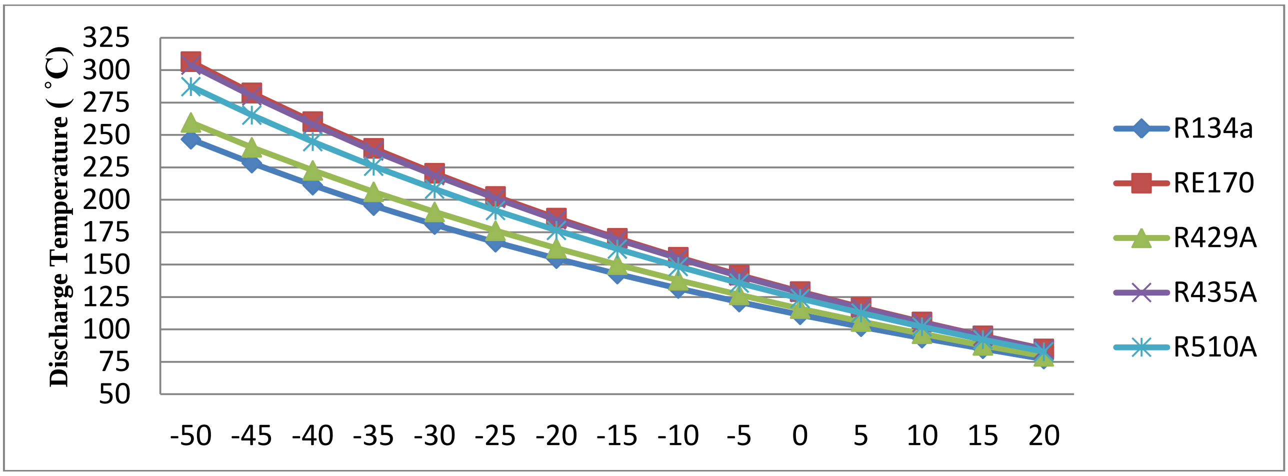


Evaporating Temperature (˚C)
Fig.3.1 Variation of Volumetric Cooling Capacity with Evaporating Temperature

The figure 3.1shows the variation of volumetric cooling capacity with varying evaporating temperature at 45°C condenser temperature for R134a, RE170, R429A, R435A and R510A. The figure shows that the volumetric cooling capacity increases with increase in evaporating temperature. The VRC for RE170, R429A, R435A and R510A are lower than R134a.

3.2 Variation of Discharge Temperature

The figure 3.2 shows the variation of discharge temperature with varying evaporator temperature at 45°C condenser temperature for R134a, RE170, R429A, R435A and R510A. The figures show that discharge temperature decreases with increase in evaporator temperature. Results show that the discharge temperature of all the investigated refrigerants is higher than that of R134a

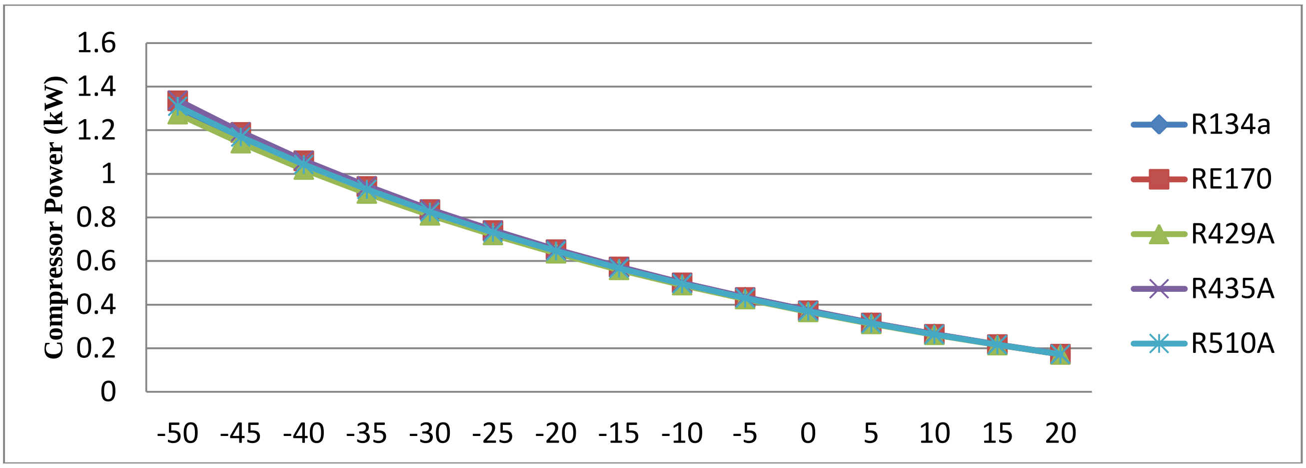


Evaporating Temperature (˚C)

Fig.3.2 Variation of Discharge Temperature with Evaporating Temperature

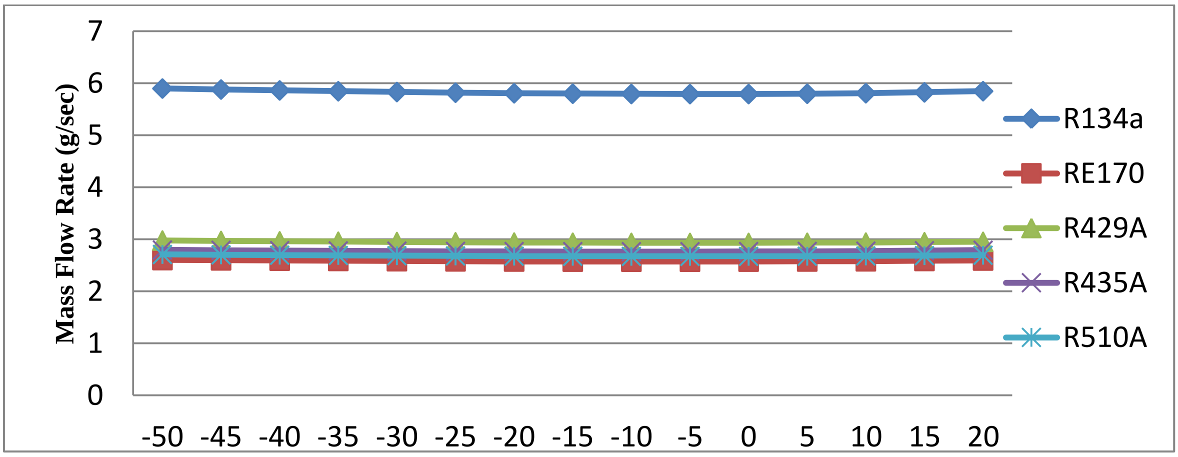
3.3 Variation of Compressor Power

The figure 3.3 shows the variation of compressor power with varying evaporator temperature at 45°C condenser temperature for R134a, RE170, R429A, R435A and R510A. The figures show that compressor power decreases with increase in evaporator temperature. Among the all refrigerants, R429Aand R510A consumes less compressor power than R134a and all other refrigerants consume slightly more power.



Evaporating Temperature (˚C)

Fig.3.3 Variation of Compressor power with Evaporating Temperature

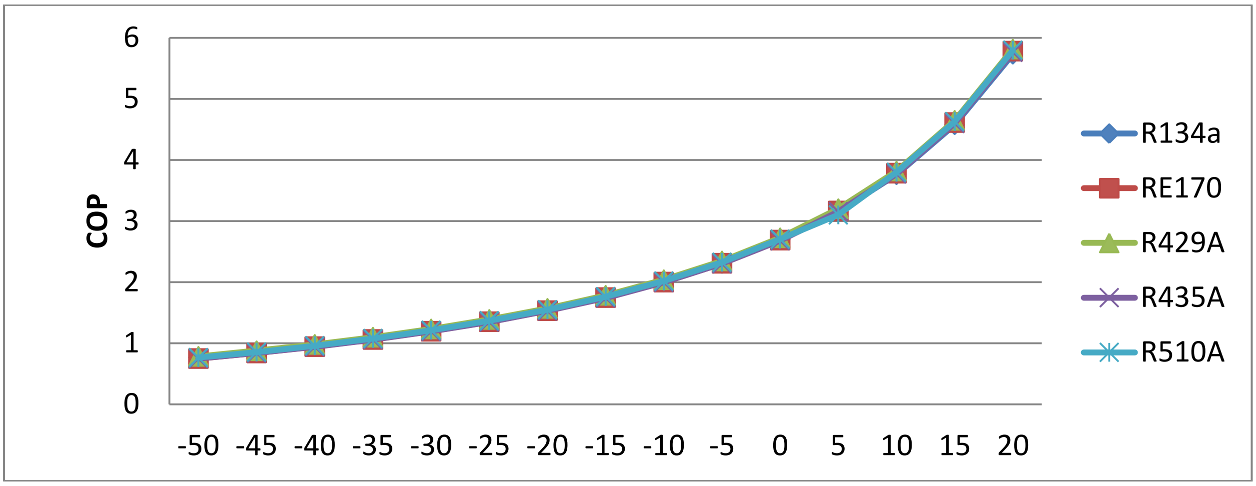


Evaporating Temperature (˚C)

Fig.3.4 Variation of Mass floe rate with Evaporating Temperature

3.4 Variation of Mass flow rate

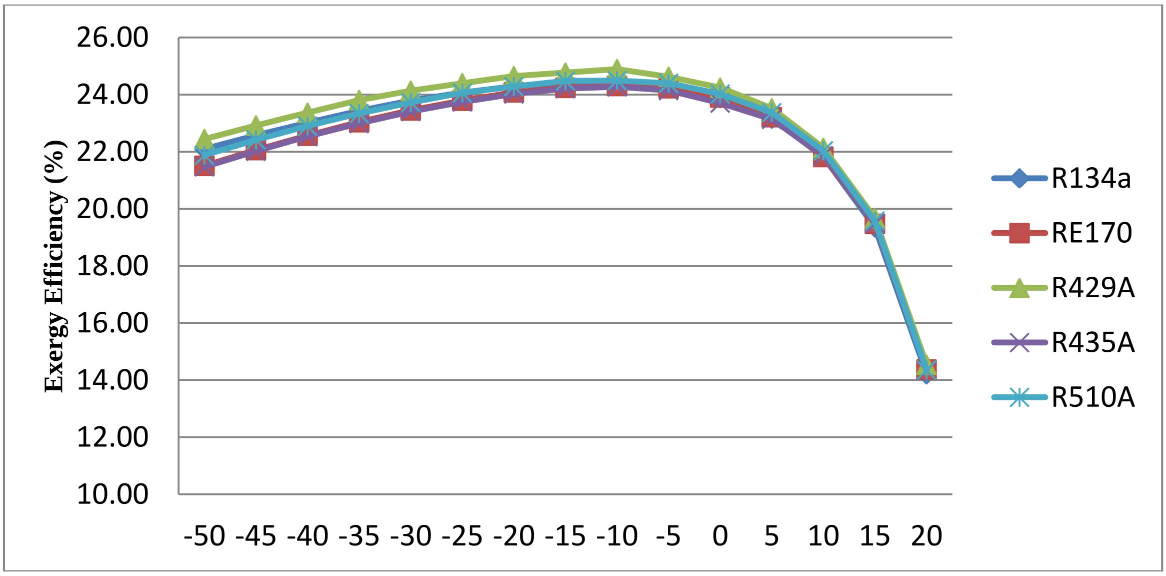
The figure 3.4 shows the variation of refrigerant mass flow with varying evaporator temperature at 45^{0}C condenser temperature for R134a, RE170, R429A, R435A and R510A. The figures show that refrigerant mass flow decreases with increase in evaporator temperature. Results show that at condenser temperature 45^{0}C and evaporator temperature -10^{0}C refrigerant mass flow for RE170, R429A, R435A and R510A are lower than R134a.



Evaporating Temperature (˚C)
Fig.3.5 Variation of COP with Evaporating Temperature

3.5 Variation of Coefficient of performance

Figure 3.5 shows the effects of evaporator temperatures on coefficient of performance. The pressure ratio across the compressor decreases, with increase in evaporator temperature causing work required by the compressor decrease and cooling capacity increases due to increase in refrigerating effect. Hence, the combined effects of these two factors increase the coefficient of performance (COP).At lower evaporating temperature, the Refrigerants R429A and R510A are having higher COP value than R134a.At higher evaporating temperature, all selected refrigerants are having higher COP. In general R429A and R510A are having more COP value than R134a over the range of evaporating temperatures.



Evaporating Temperature (˚C)
Fig.3.6 Variation of Exergy efficiency with Evaporating Temperature

3.6 Variation of Exergy Efficiency

Figure 3.6 shows the effect of evaporating temperatures on exergetic efficiency (η_{ex}). With increase in evaporator temperatures exergetic efficiency increases till the optimum evaporator temperature and beyond the optimum temperature it decrease. The optimum evaporator temperature is the temperature at which maximum exergetic efficiency is achieved. The increasing and decreasing of exergetic efficiency depends upon the two factors, first factor is the exergy. Second factor is compressor work required by compressor W which decreases with increase in evaporator temperature. The combined effect of these two factors, increases exergetic efficiency increases till the optimum evaporator temperature and beyond the optimum temperature decrease. At lower evaporating temperature, the Refrigerant R429A is having higher exergetic efficiency than R134a. At higher evaporating temperature, all selected refrigerants are having higher exergetic efficiency. In general, R429A is having more exergetic efficiency value than R134a over the range of evaporating temperatures. The exergetic efficiency of R429A is 1.6-2.3% higher than R134a.

4. CONCLUSIONS

A computational model based on first and second law analysis is presented for the investigation of the effects of evaporating temperature on the Discharge temperature, Coefficient of performance, Volumetric refrigeration capacity, Mass flow rate Compressor power and Exergetic efficiency in system of the vapour compression refrigeration cycle for the refrigerants R134a, RE170, R429A, R435A and R510A.
The conclusions present in this analysis are given as follows

- The refrigerants R429A and R510A are having more COP and exergy efficiency than R134a over the range of condensing temperatures from 30°C to 55^{o}C at -10^{o}C evaporation temperature. The COP of R429Aand R510A is 0.8-2.69% and 0.07-1.57% higher than R134a.The exergetic efficiency of R429Aand R510A is 0.31-2.46% and 0.37-1.29% higher than R134a.
- The refrigerants R429A and R510A are having less consumption of compressor power and mass flow rate than R134a. The average compressor power for R429A and R510A is 1.8% and 0.6% lower than that of R134a.The average mass flow rate of R429Aand R510A is 49.38 % and 53.86 % lower than that of R134a.
- The use of Di-methyl ether and mixtures provides a doubling of the latent heat of vaporization compared to R134a. This factor leads to a reduction of about 50% of the charge of refrigerant in the cooling system for a same capacity.
- The coefficient of performance of the system with Dimethyl ether and mixtures (R429A and R510A) are similar and higher values compared to R134a.
- The discharge temperature for the investigated refrigerants is higher than the refrigerant R134a
- Generally, the Vapour Compression Refrigeration System performed better using RE170 and its blend than using R134a as working fluids.

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