NUMERICAL SIMULATION OF VAPOUR COMPRESSION REFRIGERATION SYSTEM USING REFRIGERANT R152A, R404A AND R600A

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ABSTRACT

A numerical simulation of vapour compression refrigeration system has been carried out using different refrigerants such as R152a, R404A and R600a. A computational simulation model is developed and simulation is carried out using CoolPack software for analyzing the vapour compression refrigeration system performances. Simulation is done within the condenser temperature range of 25°C to 45°C and evaporator temperature range of 0°C to -20°C. Effect of compressor isentropic efficiency and degree of subcooling is also taken into consideration for the simulation model. The parameters that are computed in this study are required compressor power, coefficient of performance (COP) and required mass flow rate of refrigerants. Effect of degree of subcooling on these computed parameters are also computed in this present work. The performances of the different refrigerants mentioned have been compared and R-152a is found to be the most efficient one.

KEYWORDS: Alternative Refrigerants, COP, GWP, ODP R152a, R600a, Sub-cooling, VCRS

Refrigerant is a substance that is used as a primary working fluid in a refrigeration system. It absorbs heat from a lower temperature and release it to higher temperature along with the compressor work to get cooling effect. The halogen derivatives of hydrocarbon discovered by Midgley were used as excellent refrigerants having favorable thermodynamic properties. But these halogenated hydrocarbon refrigerants have a tendency to destroy ozone layer and warm the environment due to their higher ozone depletion potential (ODP) and higher global warming potential (GWP). Molina and Rowland [1] first discovered ozone holes in the stratosphere. For this reason, now-a-days, ODP and GWP play a significant role for searching alternative refrigerants to CFC and HCFC refrigerants. The discovery of ozone depletion properties of CFC and HCFC refrigerants leads to phase out of these refrigerants through Montreal protocol (1987), London amendments (1990), Copenhagen amendments (1992) and Kyoto protocol (1997) [2] and finally ban of these refrigerants by the end of 2030 throughout the world. So it is necessary to find out environment friendly alternative to these refrigerants with zero ODP and low GWP. Different researchers suggested few HFC and HC refrigerants as suitable alternative to these CFC and HCFC refrigerants. Properties of some HFC and HC refrigerants with zero ODP and relatively less GWP as compared to CFC and HCFC refrigerants are shown in table I [3]. Bolaji [4] experimentally investigated the exergetic performance of a domestic refrigeration system using R 12 and two environment-friendly alternative refrigerants R134a and R152a. Author concluded that refrigerant R152a gave better performance than refrigerant R 12 and R134a as working fluids in the experimental domestic refrigeration system. Bolaji et al. [5] in another study experimentally investigated the performance of vapour compression refrigeration system using three environment friendly refrigerants R152a, R134a and R32 and compared with the theoretical analysis. They observed that R32 had the most undesirable performance characteristics among the refrigerants and R152a showed the most desirable property on the basis of operating pressure and temperature, VCC and COP. Mohanraj et al. [6] numerically investigated on a domestic refrigerator using R152a, R290, R1270, R600a and R600. They found that except for flammability, R152a, R600a and R600 were best alternative option. They also stated that R290 and R1270 could not be used as alternatives due to their high operating pressures. They found that R152a offer many desirable characteristics such as low operating pressure, mass flow rate, higher COP and approximately the same volumetric cooling capacity (VCC). Arora and Kaushik [7] made an energy and exergy analysis of an actual vapour compression cycle using R502, R404A and R507A as refrigerants. They observed that the COP and the exergetic efficiency for R507A were better than that for R404A. It was also noted that the increase in dead state temperature had a positive effect on exergetic efficiency. COP and exergetic efficiency of both R404A and R507A improved by subcooling of refrigerant and the reversed happened when effectiveness of liquid vapour heat exchanger was increased.

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Table I: Properties of Refrigerants

Refrigerant	Molecular weight(gm)	Critical Temperature (°C)	Boiling Point (°C)	ODP	GWP
R134a	102.03	101.1	-26.5	0	1300
R152a	66.05	113.3	-24	0	120
R600a	58.12	134.7	-11.6	0	~20
R600	58.12	152	-0.5	0	~20
R404A	97.60	72.1	-46.6	0	3800
R507	98.9	70.9	-47.1	0	3900
R12	120.93	112	-29.79	0.82	10600
R22	86.47	96.2	-40.8	0.034	1700
R11	137.37	23.7	198	1	4600

So, an attempt has been made to simulate vapour compression refrigeration system with some HFC and HC environment friendly refrigerants. Few HFC and HC refrigerants are taken to simulate vapour compression refrigeration system for this work.

SIMULATION USING COOLPACK SOFTWARE

A simulation of an actual vapour compression refrigeration system is done using CoolPack software. A computational model has been developed in this software to simulate the cycle with refrigerants R152a, R404A and R600a. Various parameters such as compressor power requirement, COP of the system, mass flow rate of refrigerants are calculated. The effect of subcooling on the above said parameters is also investigated in the study. The computed results have been plotted and the variation has been shown in figure 1 – 8. In this simulation work few assumptions are made. These are:

Evaporator temperature, T_E = 0°C – -20°C

Condenser temperature, T_C = 25°C – 45°C

Compressor isentropic efficiency, $\eta_S = 0.7$

Degree of subcool, ΔT_{sb} = 10K

Refrigeration effect = 1 TR

Volumetric efficiency, $\eta_V = 1$

VALIDATION OF THE SIMULATED RESULTS

In this section, simulated results obtained from CoolPack software validated with the numerical work of Chen and Prasad [8] for the same working working conditions. Validation has been carried out for different system performance of the system using R134a as refrigerant. The comparison of the simulated results and the work of Chen and Prasad have been shown in figures 1 and 2. From fig. 1, it is observed that CoolPack predicts slightly higher COP. At higher evaporator temperature (0°C), the COP values obtained from the simulation and the work of Chen and Prasad are found to be 3.81 and 3.84 respectively. However, at lower evaporator temperature (- 20°C) the coresponding values are noted to be 2.08 and 2.14 respectively. Simulated results also predicts same value (0.26 kW) of compressor power at higher evaporator temperature (at 0°C) as shown in fig. 2, whereas, simulated result decreases at lower evaporator temperature than the work of Chen and Prasad. The corresponding values of the simulated work and the work of Chen and Prasad is found to be 0.47 kW and 0.48 kW respectively. The simulated results match well qualitatively with the numerical results of Chen and Prasad for all the parameters. The predicted results from this software have also been validated with the numerical work of Roy and Mandal [9]. The next section deals with the analysis of different parameters including subcooling effect using various refrigerants by utilizing the simulated data obtained using CoolPack software.

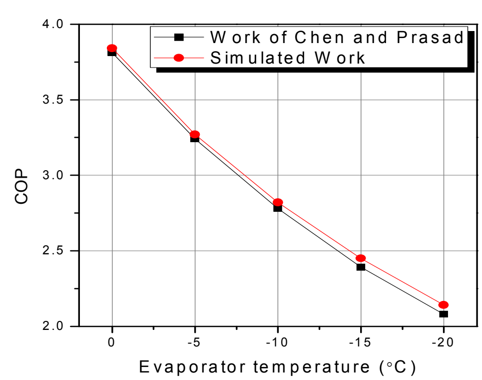


Figure 1:

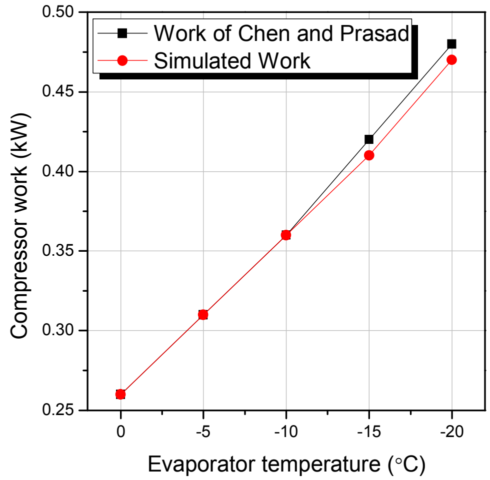
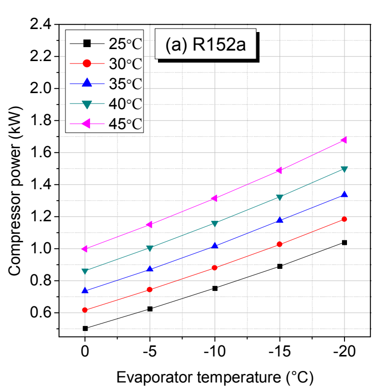


Figure 2: Validation of Compressor work with evaporator temperature

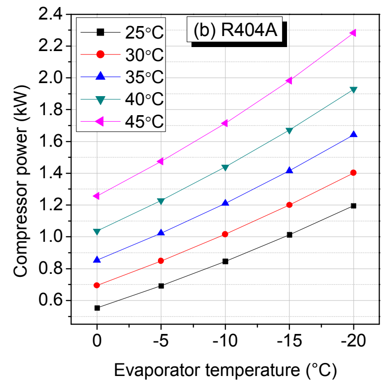
RESULTS AND DISCUSSION

Variation of Compressor Power with Evaporator Temperature

Fig. 3(a) – (c) show the effect of evaporator temperature on compressor power at different condenser temperature between 25°C to 45°C for four refrigerants, namely R152a, R404A and R600a respectively. The figures show that with the decrease in evaporator temperature required compressor power changes and similar trends are seen for all the refrigerants considered here. It is seen from the figures that with the decrease in evaporator temperature, compressor power increases. It is also noted from the figures that compressor power requirement for R152a is less and that for R404A is maximum for all evaporator temperature and condenser temperature range. This is because of the different specific volume of different refrigerants used in the work. Power requirement for refrigerant R600a is slightly higher than R152a and lower than R404A.



(a)



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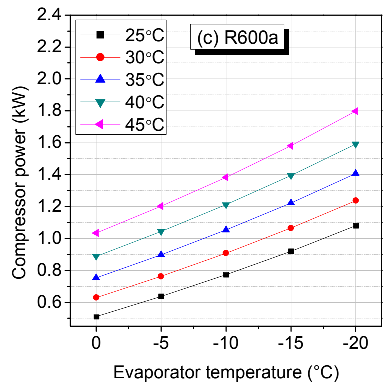
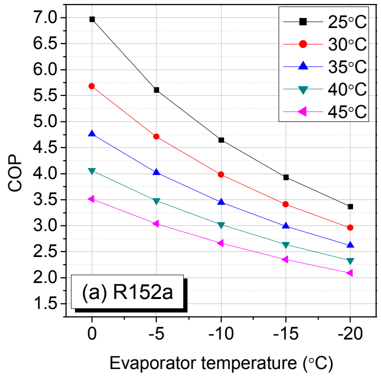


(c)

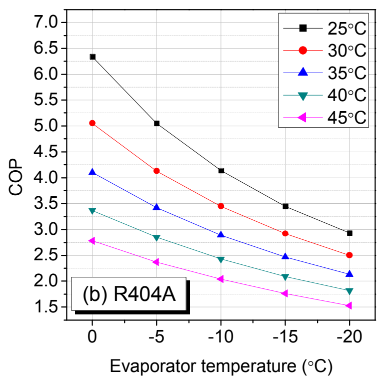
Figure 3: Variation of required compressor power with evaporator temperature for refrigerants (a) R152a, (b) R404A and (c) R600a

Variation of Coefficient of Performance of the System with Evaporator Temperature

Fig. 4(a) – (c) show the effect of evaporator temperature on COP of the system for refrigerants R152a, R404A and R600a with varying condenser temperature from 25°C to 45°C. It is seen from the figures that the COP of the system decreases with the decrease in evaporator temperature and increases when condenser temperature decreases. This is because as the evaporator temperature decreases, compressor power increases. As a result, overall COP decreases for all the investigated refrigerants. Similarly, when condenser temperature decreases, compressor power decreases that leads to increase in COP of the system. All investigated refrigerants are showing the similar trends. It is seen from the figure that maximum COP of the system is obtained when R152a is used as the working fluid in the system and minimum value of COP is achieved when R404A is used as refrigerant, where both R600a and R152a gives almost similar result with R152a. The difference in the COP of the system while using R600a and R152a as refrigerants in the system is calculated and it is found to be 1.6% while the maximum difference is obtained while using R404A as refrigerant which is about 10% at higher condenser temperature.



(a)



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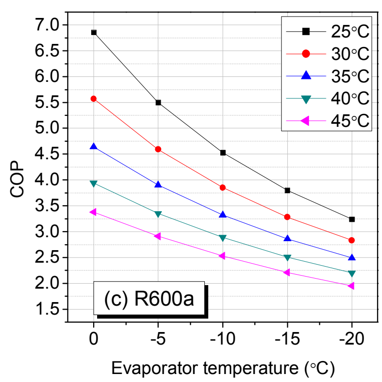
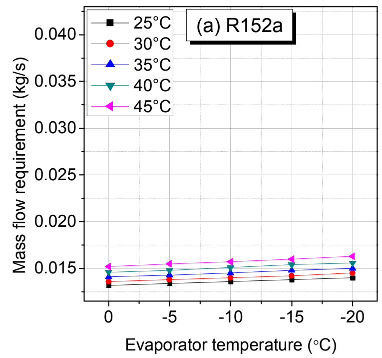


(c)

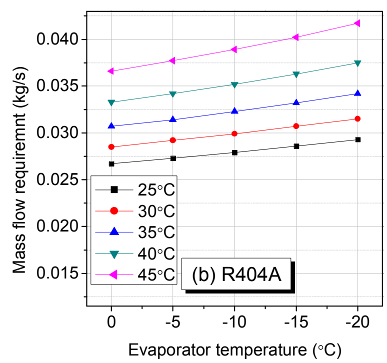
Figure 4: Effect of evaporator temperature on COP of the system for refrigerant (a) R152a, (b) R404A and (c) R600a

Effect of Evaporator Temperature on Mass Flow Rate

The variations of mass flow rate of different refrigerants with evaporator temperature have been shown in fig. 5(a) - (c) at varying condenser temperature range of 25°C to 45°C respectively. It is seen from the figures that required mass flow rate of refrigerant to achieve same refrigeration effect increases as the evaporator temperature decreases and increases when condenser temperature increases. Similar trends are found for all the investigated refrigerants. It is seen from the figures that minimum mass flow rate is required when R600a is used as the working fluid in the system and maximum mass flow is required when R404A is used as refrigerant. The required mass flow rate of R600a differ from that of R152a is 3% lower while the maximum difference obtain while using R404A which is about 62% lower at higher condenser temperature.



(a)



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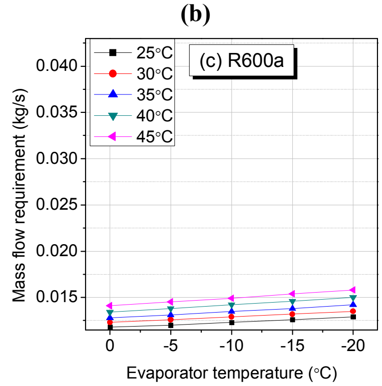

(c)

Figure 5: Variation of required mass flow rate with evaporator temperature for refrigerant (a) R152a, (b) R404A and (c) R600a

Effect of Subcooling Temperature

Fig. 6 shows the effect of degree of subcooling on refrigerant flow rate for investigated refrigerants with fixed evaporator and condenser temperature of 0°C and 40°C respectively. It is seen from the figure that refrigerant flow rate decreases with the increase in degree of subcool to achieve a desirable cooling effect. As the degree of subcool increases, refrigerating effect increases and it leads to a decrease in refrigerant flow rate. All four refrigerants show the similar trend. It is interesting to note that the mass flow rates of refrigerants R600a and R152a are much lower than the corresponding value of R404A.

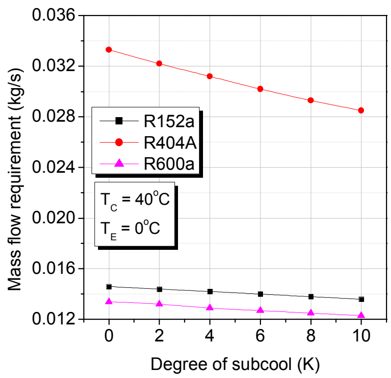

Figure 6: Effect of degree of subcooling on mass flow rate of refrigerant

The effect of degree of subcooling on compressor power requirement for various refrigerants with fixed evaporator and condenser temperature of 0°C and 40°C respectively has been shown in fig. 7. It is seen from the figure that compressor power requirement decreases with the increase in subcool temperature to achieve a desirable cooling effect. This is because the specific compressor work does not change with subcool temperature, but as the mass flow rate of refrigerant decreases with the increase in subcooling, compressor power requirement also decreases because compressor power is the product of specific compressor power and mass flow rate of refrigerant. All four refrigerants show the similar trend.

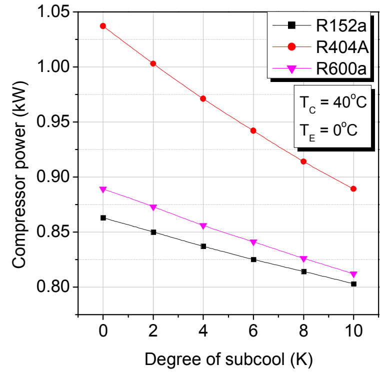

Figure 7: Effect of degree of subcooling on compressor power

The variations of COP of the system with degree of subcooling for various refrigerants with fixed evaporator and condenser temperature of 0°C and 40°C respectively have been shown in fig. 8. It is seen from the figure that COP of the system increases with the increase in degree of subcooling to achieve a desirable cooling effect. With the increase in degree of subcool temperature the refrigeration effect increase but degree of subcooling has no effect on specific compressor work. For this reason the ratio of these two also increases, i.e., COP of the system increases with the increase in subcool temperature. It is found from the figure that, COP of the system is obtained maximum while R152a is used as refrigerant whereas, minimum COP obtained for R404A when degree of subcooling is 10 K.

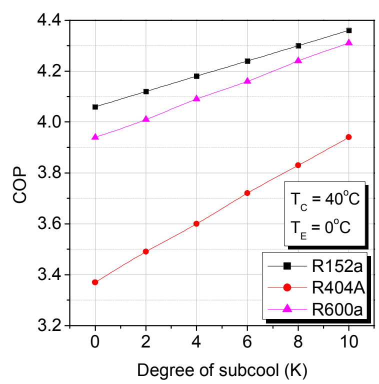

Figure 8: Variations of COP of the system with degree of subcooling

CONCLUSION

The following conclusions can be drawn from the above mentioned work where simulation has been carried using CoolPack software.

1)Compressor power requirement increases with the decrease in evaporator temperature and increases with the increase in condenser temperature for all four investigated refrigerants.

2) The compressor power requirement is maximum for R152a and minimum for R404A among the refrigerants for all the condenser temperature within same evaporator temperature range.

3) Coefficient of performance of the system decreases with decrease in evaporator temperature and also decreases with the increase in condenser temperature for all the refrigerants.

4) Maximum COP is achieved when R152a is used and minimum COP is achieved when R404A is used as refrigerant.

5) Mass flow rate increases with the decrease in evaporator temperature and it also increases when condenser temperature increases.

6) Mass flow rate of R404A is maximum and minimum for R600a.

7) COP, mass flow rate and required compressor power of all four investigated refrigerants improve with the subcooling of condensed liquid refrigerants.

8) R152a shows a better performance than the other investigated refrigerants.

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