Evaluation of Green Refrigerant Performance for VCR

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Abstract: A refrigerator is a common household appliance. It is used for storage of food. CFCs and HCFCs were used as refrigerants for the refrigerator in the earlier days. They are now replaced by HFCs like R134a because of the ozone layer depletion and global warming potential of CFCs and HCFCs. HFCs don't have ozone layer depletion potential but, has a global warming potential. So, it is important to find an environment friendly alternative of R134a. This work deals with the same. Simulation of the vapour compression refrigeration cycle is carried out and the results for refrigeration capacity, specific refrigeration effect and COP for the system running with the refrigerants namely, R134a, R22, nitrogen, hydrocarbons and nitrogen-hydrocarbon mixture are compared.

Keywords: hydrocarbons,R134a, refrigerant mixture, refrigeration.

I. INTRODUCTION

A refrigerator is a device that transfers heat from inside to the outside environment. Heat is rejected to the surroundings at ambient temperature and absorbed at a temperature less than ambient. For this heat transfer, work is done on the system. Refrigeration is essential for storing food items.

A. Vapour compression cycle

The household refrigerators uses vapour compression refrigeration (VCR) cycle (Fig.1) [1]. In this cycle, the refrigerant enters the compressor in saturated vapour phase and is compressed to a higher pressure, resulting in higher temperature as well. The hot compressed vapour which is in super-heatedvapour state enters the condenser in which it is condensed with either cooling water or cooling air flowing across the coil or tubes. The heat is rejected in the condenser and the refrigerant exits in saturated liquid state from the condenser. The condensed liquid refrigerant is next routed to an expansion valve where it undergoes reduction in pressure, which in turn, reduces the temperature. The refrigerant exits the expansion valve in the mixed state. The cold mixture is then routed through the coils and tubes in the evaporator. A fan circulates the warm air. That warm air evaporates the liquid part of the cold refrigerant. To complete the refrigeration cycle, the refrigerant vapour from the evaporator is again a saturated vapour fed to the compressor.

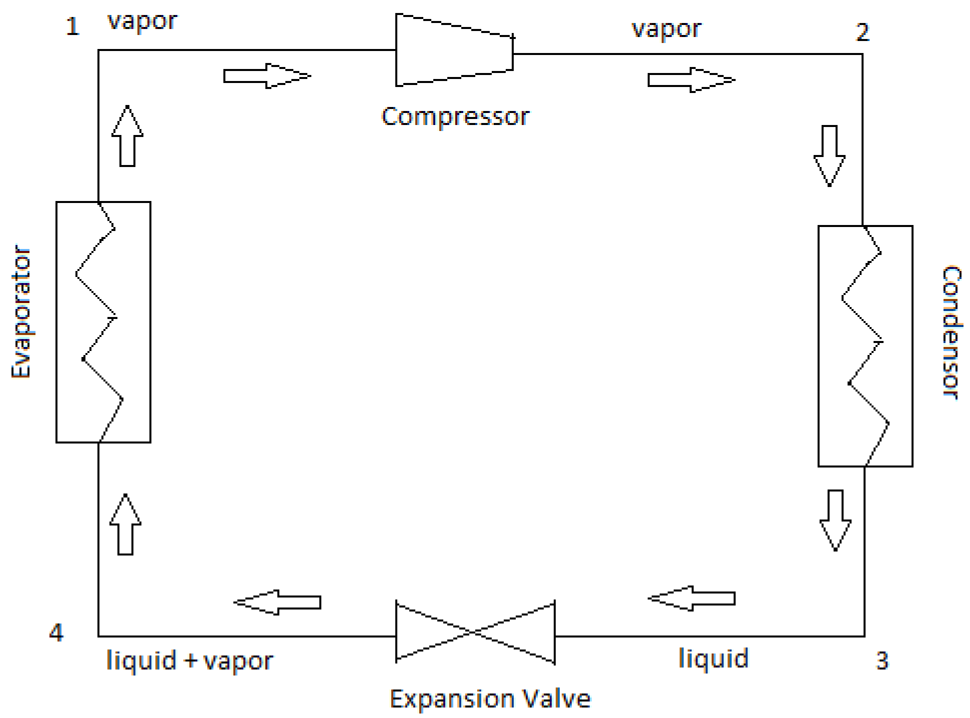


Fig.1- Vapour compression refrigeration cycle

B. Refrigerants

There are a large number of refrigerants available. The Chlorofluorocarbons (CFCs) were the most commonly used refrigerant. But, the CFCs break up when coming in contact with UV rays releasing chlorine free radicals. The chlorine free radicals cause ozone layer depletion.Therefore, the CFCs got replaced by HCFCs (hydro chlorofluorocarbons). One such HCFC is R22 (Chlorodifluoromethane) which was used as refrigerant for household refrigerators [2]. This has low ozone layer depletion potential but high global warming potential [2]. So,the use of this refrigerant was phased out.Nowadays the refrigerant used is R134a (1,1,1,2-tetrafluoroethane), which is a hydroflurocarbon [3]. HFCs also have global warming potential [3]. So, it is important to find an environment friendly alternative for the refrigerant. The mixed refrigerants can be used as an alternative. Boyarsky,Mogorychny, and Klusmiersuggested a mixture for operation within temperature ranges 80 K-100 K [4]. They suggested a refrigerant mixture consisting of nitrogen between 30-50 mole percent, methane less than 20 mole percent, and propane more than 30 mole percent and ethane the balance. Bonaquist,Prosser and Arman described the advantages using a mixed refrigerant cycle [5]. They suggested that the efficiency can be improved and cost can be reduced using mixed refrigerants. Venkatarathnamstudied the specific refrigeration effect and exergy efficiency of a Linde-Hampson cryogenic refrigeration process using refrigerant mixtures and pure fluid [6]. Oruc, Deveciollu,Berk and Vuraldid the experimental comparison of the energy parameters of HFC that can be used as an alternative to R22 or HCFC-22 for a split air conditioner [7]. Sunardi, Martin, Sumeru, Nasutionsuggested that the performance of a refrigerator can be increase by using subcooling [8]. They used R22 and R 290 as refrigerant. Dreepaul suggested that hydrocarbons can be used as an alternative refrigerant [9]. He took two blends of hydrocarbons i.e., (95% propane and 5% ethane) and (50% propane and 50%

isobutene). He used the replacement refrigerant in a bench type window air conditioner. The results suggested that the COP was higher than the system using R22 and R134a and also the discharge pressure was low for the hydrocarbon blends.

The current work deals with mixed refrigerant systems. Three nitrogen-hydrocarbon mixtures are considered. Simulation is carried out using ASPEN PLUS for vapor compression cycle using R134a and R22. Also same is done for pure fluid refrigerants namely nitrogen, methane, ethane, propane and for refrigerant mixtures with different compositions for nitrogen and hydrocarbons. The COP, specific refrigeration effect, refrigeration capacity for each of the above refrigerant is compared with operating pressure.

II. THERMODYNAMICS OF THE SYSTEM

A. Pressure-Enthalpy diagram

The refrigerant enters the compressor in saturated vapour phase and exits at an elevated pressure. This step is indicated by the line 1-2 in Fig. 2 (a). From the exit of the compressor, the high pressure refrigerant is fed to a condenser. There is no pressure change in the condenser, so 2-3 is isobaric condensation. The refrigerant exits in saturated liquid state from the condenser. The saturated liquid is then fed to an expansion valve and exits as a mixture of liquid and vapour. Thus, 3-4 is the isenthalpic expansion. Then, the liquid formed is converted to vapour in the evaporator. There is no change in pressure in evaporator also. So, 4-1 is the isobaric evaporation. The vapour is in the saturated state in the exit of the evaporator. It is again fed back to the compressor thus, completing the cycle.

B. Temperature-Entropy diagram

In Fig.2 (b), 1-2 is the isentropic compression, from the compressor, the refrigerant exits at an elevated pressure thus, causing an elevation in temperature also. So, 2-3 is the superheat removal from the refrigerant mixture. 3-4 is the isobaric condensation. 4-5 is the isenthalpic expansion and 5-1 is the isobaric evaporation.

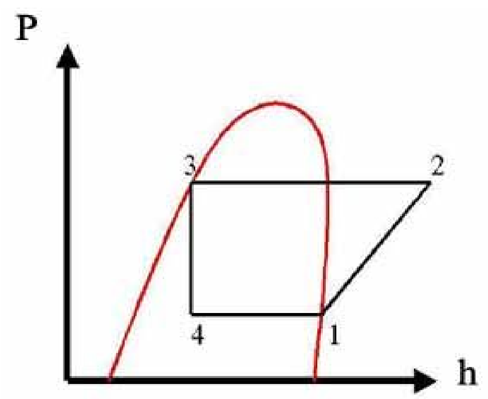
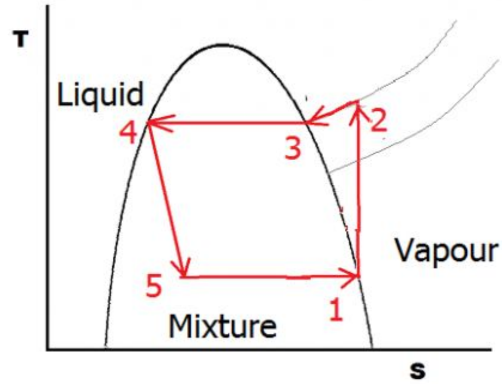


Fig. 2- (a) P-h curve for the VCR



(b) T-s curve for the VCR

C. Specific Refrigeration Effect:

Specific refrigeration effect (SRE) can be defined as the difference in the enthalpy between the stream that exits the evaporator and the stream that enters the evaporator. It is in terms of KJ/mol.

From Fig. 1,

$$SRE = h_4 - h_3 \qquad (1)$$

Where h_4 is the specific molar enthalpy of the stream leaving the evaporator and h_3 is the specific molar enthalpy of the stream entering the evaporator.

D. **Refrigeration Capacity:**

Refrigeration Capacity (RC) is the effective cooling power of a refrigerator. It can be formulated as the product of the molar flow rate of the refrigerant and the specific refrigeration effect. It is in terms of KJ/sec or KW.

$$RC = SRE \times \dot{m} \qquad (2)$$

Where, SRE is the specific refrigeration effect and $\dot{m}$ is the molar flow rate of the refrigerant.

E. Coefficient of Performance:

Coefficient of performance (COP) is the ratio of energy output to energy input. For a refrigerator it is the ratio of the amount of refrigeration produced to the work required by the compressor.

$$COP = \frac{RC}{Compressor\ work} \qquad (3)$$

III. SIMULATION

A. Conditions for the simulation

Ambient temperature = 25^{0}C.

Ambient pressure = 1 bar.

Compressor type = isentropic compressor.

Compressor efficiency = 100%

Outlet pressure of the expansion valve = 1 bar.

Molar flow rate of refrigerant = 10 kmol/hr.

No pressure drop in evaporator and condenser.

B. Refrigerants used for simulation

R134a, R22, nitrogen, methane, ethane, propane, mixture M1, mixture M2, mixture M3and M4 (Table I). Compositions of mixtures are as follows:

Table I- Mixture Compositions

Mixture	Components	Mole Fraction	Source
M1	Nitrogen	0.3	[4]
	Methane	0.15	
	Ethane	0.5	
	Propane	0.3	
M2	Nitrogen	0.5	Simulation based
	Methane	0.3	
	Ethane	0.2	
M3	Nitrogen	0.4	Simulation based
	Methane	0.3	
	Ethane	0.2	
	Propane	0.1	
M4	Nitrogen	0.5	Simulation based
	Methane	0.3	
	Propane	0.2	

C. Flowsheet

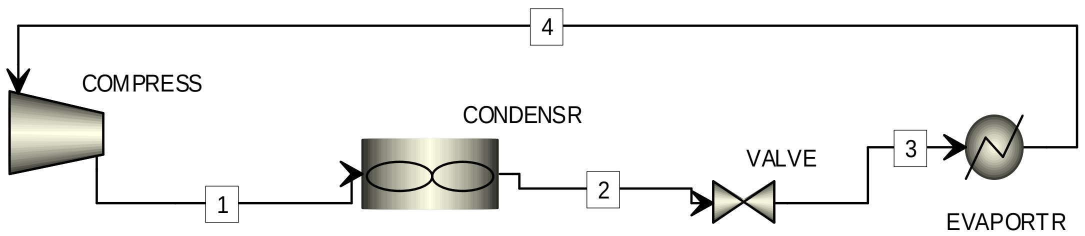


Fig. 3- Flowsheet of the simulated process

D. Description

The isentropic compression is taken care of by the COMPRESS block. Stream 1 is the high pressure refrigerant stream. The CONDENSR block decreases temperature of the high pressure stream and saturated liquid exits from the block as stream 2. The VALVE block reduces the pressure and the stream exits in the mixed state(stream 3). Then, the stream goes to the EVAPORTR block where, the liquid part of the stream is converted to vapour. Stream 4 is in the saturated vapour state which again goes to the COMPRESS block thus completing the cycle.

IV. RESULTS &DISCUSSIONS

A. Effect on Specific Refrigeration effect

The SRE can be calculated from Fig. 3 as

$$SRE = h_4 - h_3$$

Fig. 4 shows the variation of the SRE with operating pressure for different types of refrigerants. From the graph, we can say that the specific refrigeration effect decreases with increase in operating pressure. SRE for R134a is higher for very low operating pressure as compared to other refrigerants except for mixture M1 for which it is almost equal. But, as the operating pressure increases, the SRE for R134a decreases rapidly as compared to the mixtures, which is the trend prevailing for R22. Although for very low operating pressure the SRE for R134a and mixture M1 is higher than R22.

B. Effect on Refrigeration Capacity

Fig. 5 shows the variation of refrigeration capacity with operating pressure for the refrigerants. From the graph, it is evident that refrigeration capacity also decreases with increase in operating pressure. For very low operating pressure, refrigeration capacity of R134a is higher than other refrigerants except for M1. Similarly for R22, refrigeration capacity is higher than other refrigerants for very low operating pressure except forR134a and M1.

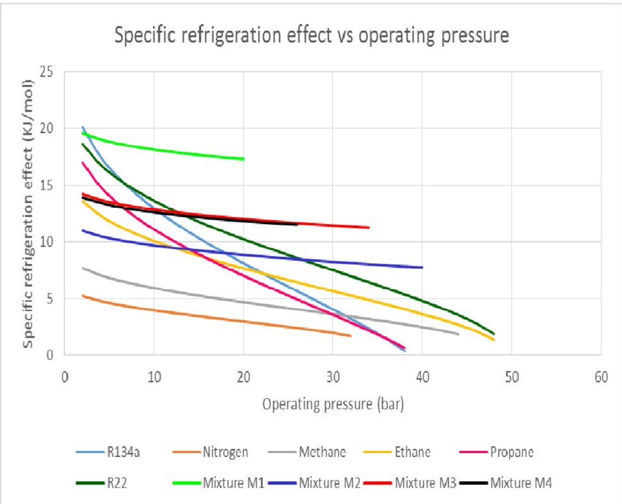


Fig. 4- Plot of specific refrigeration effect vs operating pressure for the refrigerants

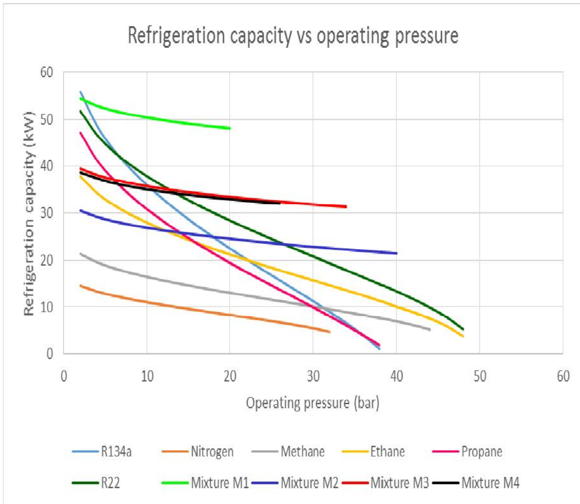
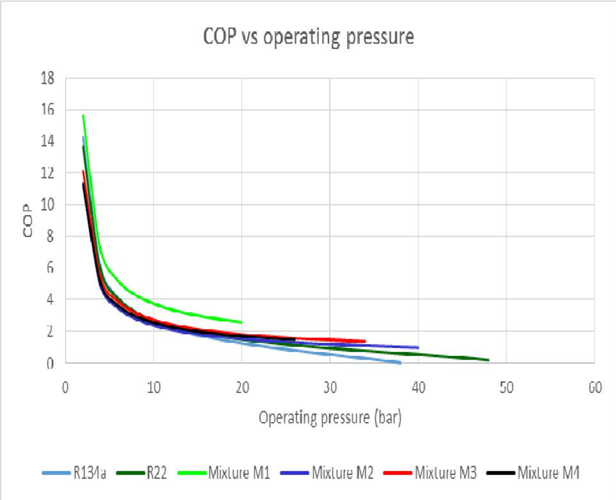
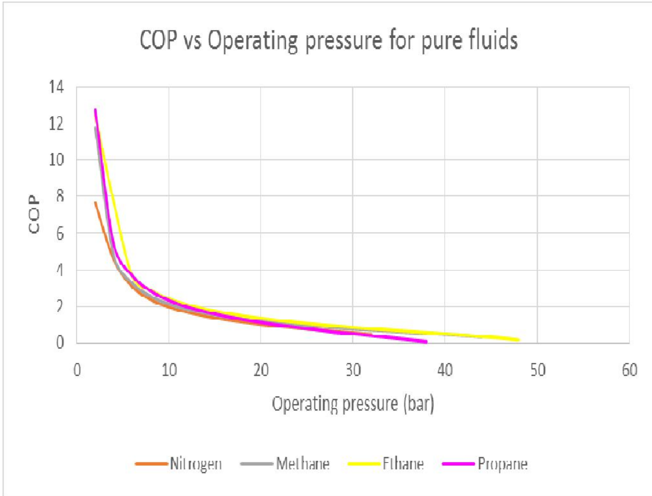


Fig. 5- Plot of refrigeration capacity vs operating pressure for the refrigerants.

C. Effect on COP

Fig.7 shows the variation of COP with operating pressure for different refrigerants. From the graph, it is revealed that the COP for the system running with mixture M1 is highest. For very low operating pressure, COP for the system running with R134a and R22 is higher than other mixtures and pure fluids. But, as the operating pressure increases, the COP for the system that runs using mixture M2, M3 and M4 becomes higher.





(a) (b)

Fig.6- (a) Plot of COP vs operating pressure for R134a, R22 and mixtures.

(b) Plot of COP vs operating pressure for pure fluids.

A household refrigerator works between 1 and 11 bar pressure. FromFigs. 4 & 5, the SRE, the refrigeration capacity and COP for the mixture M1 at 11 bar is much higher than R134a.From Fig. 6 (a), at 11 bar, the COP is also higher for mixture M1. Hence, we can conclude that mixture M1 can be used as an alternative to R134a in VCR. The refrigerator needs to maintain a refrigeration temperature, which is taken as 1.6^{0}C. The flow rate of the refrigerant will depend on the volume of the refrigerator. Since, the SRE and refrigeration capacity is higher for mixture M1 than R134a, we can decrease the flow rate of refrigerant mixture to maintain the same refrigeration temperature, which in turn will decrease the compressor power input. For mixture M2, at 11 bar, the SRE and refrigeration capacity is lower than R134a. This mixture can be used as an alternative but, we have to increase the refrigerant flow rate to ascertain the same refrigeration temperature of 1.6^{0}C. For mixture M3 and M4, at 11 bar, the SRE and refrigeration capacity is almost equal with R134a. The COP is higher for both the refrigerants. Hence, there is no need to change the refrigerant flow rate.

For a refrigerator to work, it is very important to check the temperature at the inlet of the condenser. The condenser uses ambient air to exchange the heat of the superheated refrigerant vapour. So, the temperature at the inlet of the condenser should be higher than ambient air temperature (42^{0}C assumed). If there prevails a temperature driving force of at least 10^{0}C with respect to the ambiance, then heat exchange is possible.Table II presents the refrigerant temperature at the inlet of condenser at 11 bar pressure. In order to keep a 10 ^{0}C temperature driving force to make the condenser heat exchange feasible, some of the refrigerant mixtures required to be kept at higher temperature than their prevailing temperature at 11 bar, hence they are needed to be kept at extended pressure than 11 bar. The present work suggests that the mixture M4 is the ideal replacement of R134a for the household refrigerators. Mixture M1 can also be used in place of R134a. For mixture M1, we need to decrease the refrigerant flowrate to maintain the temperature at 1.6^{0}C and also we have to increase the outlet pressure of the compressor to make the heat transfer feasible in the condenser. Mixture M2 can be used as a replacement of R134a, if we increase the flow rate of the refrigerant to maintain the temperature at 1.6^{0}C and also the outlet pressure of the compressor to make the heat transfer feasible in the condenser. Since the SRE and refrigeration capacity of Mixture M3 and R134a are same, M3 can be used as a replacement if we increase the outlet pressure of the compressor only. Table II also discusses the possibility and the difficulties of pure refrigerants to be used in VCR from the thermodynamic considerations.

Table II- Refrigerant temperature at 11 bar and their estimated pressure at 10 ^{0}C higher than ambient temperature.

Refrigerant	Temperature at the inlet of the condenser at 11 bar.	outlet pressure of the compressor to keep a 10 ^{0}C difference with the ambient
R134a	63.2 ^{0}C	No change required
R22	68.13 ^{0}C	No change required
Nitrogen	-116.208 ^{0}C	Not possible as the required pressure is higher than critical pressure.
Methane	-66.15 ^{0}C	Not possible as the required pressure is higher than critical pressure.
Ethane	15.41 ^{0}C	22 bar
Propane	44.2 ^{0}C	13.5 bar
Mixture M1	45.6581 ^{0}C	12.734 bar
Mixture M2	14.7334 ^{0}C	19 bar
Mixture M3	49.93 ^{0}C	11.5 bar
Mixture M4	62.74 ^{0}C	No change required

V. CONCLUSIONS

Various refrigerant mixtures were proposed and examined about their suitability to be used in VCR. Among them M4could be the ideal replacement of R134a for the household refrigerators at the prevailing compressor power input, whichis environment friendly alternative to the refrigerants R134a and R22 as well.

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