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Performance analysis of vapour compression refrigeration systems using eighteen ecofriendly and other CFC refrigerants

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Abstract

The (HFC) that is hydro fluorocarbon replaces the (CFC) that is chloro fluorocarbon and (HCFC) that is Hydro chloro fluorocarbon refrigerants. HFC is being considered because concern about depletion of the ozone layer and global warming. There are numerous research has been done which suggested various alternative of refrigerants Twenty one refrigerants (R32 as R22, R290, R502, R407C, R410A and R417a etc.) have been considered for investigating thermal performances and model was tested by for 40oC condenser temperature and - 40oC evaporator temperature for 3.5167 kW cooling capacity of system. The eco-friendly refrigerant also considered because of its zero ODP(ozone depletion potential). In case of R22 its ODP is 0.055., which have harmful effects on ozone layer. Therefore R22 will phase out form earth by 2030 in developed countries and by 2040 in developing countries. The vapour compression refrigeration system using alternate refrigerant needs to be modify or due to variation in the properties (physical and chemical) of these alternate with R22. The hydrocarbons R600 , R600a and R 290 are flammable in nature and R 502 is azeotropes refrigerants are also been considered for numerical computation at 40oC reference temperature (for typical Indian conditions). In the present work exergy analysis along with energy analysis of vapour compression refrigerant cycle for CFC refrigerants (R12, R22, R502) and its 18 alternate refrigerants (i.e.R 407C, R410A and R417A etc) has been carried out for evaporator temperature between -40℃ and condenser temperature of 40℃,. The parametric investigation such as coefficient of performance , exergy destruction in terms of lost work , exergetic efficiency, and efficiency defect in individual components for above refrigerants have been carried out theoretically and have been compared with the available data [10]. The result indicates that evaporating and condensing temperature have pronounced effect on exergy destruction in the components such as compressor, condenser and throttle valve .The exergetic efficiency and COP of the cycle change to large extent with the variation in evaporator and condenser temperatures and it was observed that eco-friendly refrigerant R152a have maximum first and second law performances.

Keywords: Thermodynamics, Ecofriendly Refrigerants, Performance Analysis, Vapour Compression Refrigeration Systems.

1. Introduction

As we know that our ozone layer is continuously depleting from the surface of earth. This ozone layer protect the earth's surface form ultra-violated rays coming directly form sun.it has resulted in gradual phase out of fluids as halogenated. The CFC and HCF have been banned from earth since 1996 and halogenated hydro chloro fluro carbon is partially banned for near future. HFC then become a good substitution for both HCF and CFC because they don't contain Cl. Depleting of ozone layer has also created the problem named as GREEN HOUSE EFFECT. It contains various gases such as (CFC,NO,CH4,CO_2,HCF) and human activities continuously increasing these gases which are effecting the normal temperature of the earth surface and it is naturally affecting the ecosystem. Over last decade the average temperature has been increased by 0.3^0C – 0.6^0C and also doubling the amount of carbon dioxide in the atmosphere which is also effecting the mean temperature of the earth surface from 1.5^0C – 4.5^0. It is also known that GHE occurring form operating plant is a second thing. Recent studies show that overall contribution whether it is direct or indirect, to the GHE of CFC and HCF increased 24 % , therefore the choice of working fluid in the vapour compression refrigeration systems should depend on

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the chlorine's absent. The phase out of fully halogenated CFC and partially HCF.

R32 is a refrigerant that has been known for years. As a component of R410A it is used in many residential refrigeration systems, but as a pure refrigerant it has not been used until recently. As many refrigerants, R32 balances between good and bad properties: It has favourable thermodynamic properties that lead to energy efficient units with smaller size; it is also flammable and forms poisonous hydrogen fluoride during combustion. In this article we will discuss R32 and its place in the future list of refrigerants for the future. R32 (Difluoromethane, HFC32, Methylene fluoride) is a single component refrigerant with critical pressure of 53.8 bar and -51.65 °C and 78.4 °C boiling point and critical temperatures respectively. As a substance, it has been studied for many decades, with the extensive research interest seen during the beginning of the 90ties, when the replacements for ozone depleting refrigerants have been searched for. In mixture with R125, R32 has been used to replace the ozone depleting R22 in small air conditioning systems and heat pumps. Considering generally better properties of R32, compared to R125, the later led to degradation of properties of the mixture while it has been used as a fire suspension agent in order to mitigate R32 flammability. The 50/50% mixture of R32 with R125 is known as R410A and become a popular refrigerant used nowadays. As global warming has raised more critical concerns in recent years, refrigerants, such as R-410A and R407C with high global warming potentials (GWP) are facing the challenges of being phased out. Hydrocarbons, such as R290 and R1270 have a zero ozone depletion potential (ODP) and an extremely low GWP, but they are not safe. R-32, the main component of R-410A, with zero ODP and a relatively low GWP (675), has similar thermodynamic properties with R-410A but is less expensive and has been recognized as an attractive short term candidate to replace R22.R-410-A (it is a zeotropic mixture of R125 in the equal ratio of 50% by wt.), R417 A (it is a zeotropic mixture of R134a /125/600 in the ratio of 50,46,3 % by weight and R 290 (its propane). However to switch to other refrigerant , the very initial step is to carry the analysis of performance for different refrigerant based on exergy and energy so as to optimisation of the refrigeration system. Thermodynamic process of the refrigeration system releases huge amount of heat to environment. This heat transfer between the surroundings and system takes place at a finite temp. And it is the major source of non-reversible cycle. This causes the degradation in the performance. This losses in the cycles need to be evaluated considering individual thermodynamic system that made the cycle. The analysis of the first laws is still the most commonly adopted method in the analysis of the system. The 1st law is concerned only with the conservation of the energy and it does not give any info on where and how much is system performance affected. Analysis of energy is the boastful tool in the optimization and evaluation of the energy system. Exergy analysis adopted methodologies that were already well established RecepYumrutas, Mehmet Kunduz, Mehmet Kanoglu [1] carried out the analysis of the exergy is usually aimed to find the maximum performance of the system and identify the sites of exergy destruction. Analyzing the components of system simultaneously can perform exergy analysis of a complex system. Finding out the main sites of exergy destruction shows the direction for potential improvements. An important object of exergy analysis is for the system that consumes work in the refrigeration and liquefaction is finding the minimum work requirement for a certain system. Syed Mohammad Said [2] assessed the theoretical performance of HCFC123, HFC134a, CFC11 and CFC12 as a coolant. It is established that for a specific amount of desired exergy, more compression work is required for HCFC123 & HFC 134a than for a CFC11 & CFC12 and found that the differences are not very sign at high evaporation temperature and hence HCFC123 and HFC134a should not be excluded as alternative coolant. There is an optimum evaporation temperature for each condensation temperature which yields the highest exergetic efficiency and found that the exergetic efficiency decreases with increasing the evaporator temperature for these coolants (including HCFC123, HFC134a, CFC11, and CFC12). The highest exergetic efficiency occurs at the optimum evaporation temperature. Exergetic efficiency was decreased by 9.24, 12.03, 5.66, 13.78, 20.92, 9.53, 11.34 and 13.04% in R-134a, R-143a, R-152a, R-404A, R-407C, R-410A, R-502 and R-507A, respectively. Probert and Nikoldas [3] used the exergy method to examine the behaviour of two stage compound compression cycle with flash inter cooling using R32. The condenser saturation temp was varied form 298K – 308K. The effect of temp changes in the condenser and evaporator on the plants irrevsibility rate was determined. Any reduction in the irreversibility rate of the condenser gives approx... 2.40 times greater reduction in the irrevsiblity rate for the whole plant and any reduction in the evaporators' non-reversible rate gives a 2.87 times greater mean reduction in the non-reversible rate of whole plant. Because changes in the temperature in the condenser and the evaporator contribute so significantly to the plants overall irreversibility. They pointed out that there is considerable scope for the optimization of conditions imposed upon the condenser and evaporator. Several studies are going on R32 and its various substitution on the basis of exergy and energy analysis of refrigerant system. The exergetic efficiency of the actual refrigeration cycle doesn't depend on the refrigeration temperature .The exergetic efficiencies decrease as the refrigeration temperature decrease. X.H. Han, Q. Wang, Z.W. Zhu, G.M. Chen. [4] evaluated first law efficiency in terms of COP for finding system behaviour for the conventional refrigerants (CFC R12, HCFC R22) and HFC -R 134a based on the thermodynamic properties and found that the system cooling COP for R134 is 8.0 % and 22.0 % higher than COP of R12 and R32, respectively. The exergy analysis is also carried out in terms of 2nd law efficiency (i.e. exergetic efficiency) and computed irreversibility of the components varies considerably, in such a way that the main source of energy loss is due to the heat transfer in the evaporator, condenser and found that the energetic efficiency in terms of of R134a is 20% and 8% higher than the COP of R12 and R32. Mishra R.S. [5] carried out detailed energy and exergy analysis of multi-evaporators at different temperatures with single compressor and single expansion valve using liquid vapour heat exchanger vapour compression refrigeration systems have been done in terms of performance parameter for R507a, R125, R134a, R290, R600, R600a, R1234ze, R1234yf, R410a, R407c, R707, R404a and R152a refrigerants. The numerical computations have been carried out for both systems. It was observed that first law and second law efficiency improved by 20% using liquid vapour heat exchanger in the vapour compression refrigeration systems. It is also found in both vapour compression refrigeration systems (with LVHE and without LVHE) that the thermal performances of both systems using R717 is higher but R600 and R152a nearly matching same values under the accuracy of 5% can be used in the above system .But difficulties using R152a, R600, R290 and R600a have flammable problems therefore safety measures are required using these refrigerants. Therefore R134a refrigerant is recommended for practical and commercial applications although it has slightly less thermal performance than R152a which is not widely used refrigerant for domestic and industrial applications. Bolaji B.O et.al. [6] presented an experimental performance of R152a and R32, environment-friendly refrigerants with zero ozone depletion potential (ODP) and low global warming potential (GWP), to replace R134a in domestic refrigerator. A refrigerator designed and developed to work with R134a was tested, and its performance using R152a and R32 was evaluated and compared with its performance when R134a was used. The average coefficient of performance (COP) obtained using R152a is 4.7% higher than that of R134a while average COP of R32 is 8.5% lower than that of R134a. The system consumed less energy when R152a was used. The performance of R152a in the domestic refrigerator was constantly better than those of R134a and R32 throughout all the operating conditions, which shows that R152a can be used as replacement for R134a domestic refrigerator. A test Rig was developed for substituting R-290 for R-22 in a KF-22GM air conditioner. The test result shows that R-290 and R-22 have almost the equal refrigerant capacity without any change of the system with proper amount of refrigerant.

Greco and Aprea [7] suggested that the substitution of R 32 in an experimental vapour compression plant with almost widely used drop in substitute that is zeotropic R-407 c. a comparative exergetic analysis was carried on both experimental test. The experimental test were performed in a vapour compression plant lay out working with water and iar secondary fluids in the condenser and in the evaporator. The overall exegertic performance of the plant working with R22 is consistently better than that of its candidate substitute R407C. The performance of the individual components of the plant had been analysed in order to pin point those contributing most to the decrease in the exergetic performance of the R407C.The parameters consider for analysis was condenser outlet temperature for working fluid. The results shows that the overall exergetic performance of the R22 is significantly better than that of R407. The difference range between a max. of 45% to min. 7% and also compared the experimental performance of R22 and R407c and suggested that R407c is a promising drop for substitute for R22 using reciprocating compressor and evaluated compressor performance using R407C in comparison to R22.

2. Thermal Performance of Ideal vapour compression refrigeration cycle using conventional and Non-conventional Refrigerants

Vapour compression refrigeration system consist of evaporator, condenser, capillary tube and compressor and R 32 is becoming a favorable refrigerant for system and it is currently adopted. R 32 is replacing R22 as its (ODP) Ozone Depletion Layer is around 0.055 which has to be phase out for reducing global warming where as R 32 has ZERO (ODP) less (GWP). R-407 C (it is a blend of R-32/ R-134A/ R-125), R-410A (mix of R-32/R-125 in equal proportion), R-417A (blend of R-134/ R-125/ R-600) has ZERO (ODP) which is best suited for replacing the R22.Table 1 shows the comparison of thermodynamics properties among various refrigerants such as R32, R22, R125, R134a, R600, R407c, R410a, and R417a as shown in table-1.

Table-1: Properties of some refrigerants [3]

Refrigerant	R32	R125	R134a	R600	R22	R407c	R410	R417a
Chem. formula	CH_2F_2	C_2HF_5	CF_3CH2_F	C_4H_{10}	$CHCLF_2$	MIX	MIX	MIX
Name	Di Fluro Methane	Penta Fluro Ethane	Tetra Fluro Ethane	Iso Butane	Di Fluoro Mono Cholor Methane	-	-	-
Molecular wt.[Kg/Kmol]	52.02	120	102	58.13	86.47	86.2	72.56	-
Normal boiling point [°C]	-51.91	-48.42	-26.37	-0.8605	-41.09	-43.6	-50.5	-43.3
Pressure critical [bar]	57.84	36.18	40.59	37.96	49.89	45.97	49.25	-
Temperature critical [°C]	78.11	66.02	101	152	96.13	86.79	72.13	90.99
Viscosity [kg/m-s]	.00001151	.0000123	0.00001113	0.00007076	0.1218	0.1147	0.1205	0.1181
Conductivity [Wm/K]	0.01311	0.1256	0.1248	0.1444	0.009895	0.0118	0.012	0.0133
Surface tension[N/m]	0.00976	0.001801	0.001058	0.01042	0.0107	0.0095	0.00825	N/A
Density [kg/m^3]	2.269	5.251	4.496	2.592	3.78	3.766	3.17	4.546
Cp [Kj/Kg-K]	0.831	0.7699	0.8248	1.666	0.6438	0.8004	0.8113	0.8342

3. Thermal Modelling of vapour compression refrigeration cycle using conventional and Non-conventional Refrigerants

Following assumptions have been taken for developing energy -exergy thermal mode for vapour compression refrigeration system

1. Compressor's isentropic efficiency is 80%.
2. Evaporator temp. is 5°C less than the room temperature.
3. Evaporator leaving the refrigerant vapour is saturated.
4. System components leaving heat to the surroundings is negligible.
5. Refrigerant coming out form condenser is saturated at its saturation temp.

Pipelines losses pressure due to friction is considered to be negligible

Energy Analysis

In each components of vapour compression refrigeration system energy changes

Evaporators: it takes out the heat (Qe) from the cold room, which is given by

$Q\_{evaporator} = m\_{Refri.}\ (h_1\text{-}h_4)$ (1)

Compressor

The isentropic work input to compressor (Wcs) is shown below

$Wcs = m\_{Refri.}\ (h_{2s}\text{-}h_1)$ (2)

Where as actual compressor work is termed as (Wc)

$W\_{Compressor} = W\_cs/\eta\_{comp}$ (3)

$W\_{Compressor} = m\_{Ref}\ (h_2\text{-}h_1)$ (4)

Throttle valve : in throttle valve the enthalpy remains constant. Form the 1st law, the measure of performance of refrigeration cycle is COP and is termed as net refrigeration effect formed per unit of work required.

$COP = Q\_{evaporator} / W\_{Compressor}$ (5)

Volumetric cooling capacity

The volumetric cooling capacity is the cooling capacity per unit vol. flow rate at the inlet to the compressor.

Vol. cooling capacity = $Q\_{evaporator} / (m\_{Ref} \times V_s)$ KJ/m^3 (6)

Where

m_{Ref} = Mass flow of refrigeration

V_s= specific vol. at the inlet to compressor.

Pressure ratio

Compressor pressure ratio (Pr) is termed as

$P\_{ratio} = P\_{condenser} / P\_{evaporator}$ (7)

$P\_{condenser}$ = pressure of condenser at stage 2 (bar)

$P\_{evaporator}$ = pressure of evaporator at stage 1 (bar)

4. Exergy Analysis

A reversible thermo process can be reversed without leaving any tracing in surroundings. That is the system and the surroundings comes to its initial stage again in the ending of the process. It is possible when heat (net) and work (net) inter change between the surrounding and system is zero. All real process are non-reversible. Some factors causing non-reversible in a refrigeration cycle including friction and transfer of heat across a finite temp. Difference in compressor. , evaporator, condenser, and refrigerant lines, sub cooling to ensure pure liquid at the throttling valve inlet, super heating to ensure pure vapour at compressor inlet, pressure drops and heat gains in refrigeration lines. The vapour at compressor inlet, pressure drop and heat gains in refrigerant lines. The VCRS cycle shown in fig. 2.

The formula for calculating the exergy destruction.

Evaporator

Exergy entering in the evaporator =

$m\_{refri}\ (h_4.T_{0s4}) + m\_{refri}\ (1\text{-}\{T_0/T_r\})$

Exergy leaving the evaporator = $m\_{refri}\ (h_1 - T_{0S1})$

Exergy destruction (Ede) in evaporator is given as :

$ED\_{evaporator} = m\_{refri.}\ (h_4.T_{0S4}) + QL\ (1\text{-}\{T_0/T_r\}) - m_R\ (h_1\text{-}T_{0S1})$ (8)

Here,

m_{refri} = mass flow of refrigerant. (kg/sec)

$Q\_{Evaporator}$ = refre. Effect (kW)

h =enthalapy (kJ/Kg)

T = temp.

S = entropy

0 = refrence state

Compressor

Exergy entering compressor = $m_R\ (h_1 - T_{0s1}) + W\_{Compressor}$

Exergy leaving compressor = $m_R\ (h_2\text{-}\ T_{0s2})$

Destruction of exergy in compressor ($ED\_{compressor}$)

$ED\_{compressor} = m_x\ (h_1 - T_{0s1}) + Wc - m_R\ (h_2 - T_{0s2})$ (9)

Where

W_comp.= compressor work

Condenser

Exergy entering the condenser = $m_R\ (h_2 - T_eS_2)$

Exergy leaving the condenser = $m_R\ (h_3 - T_eS_3)$

Exergy destruction in condenser ($ED_{cond.}$)

$ED_{condenser} = m_R\ (h_2 - T_0S_2)\text{-}\ m_R(h_3\text{-}\ T_0S_3)$ (10)

Throttle valve

As enthalpy across the throttle valve remains const. therefore destruction of exergy across the throttle valve (EDt) is given as

$ED\_{}_{Throttling\_Valve} = m_R (s_4 - s_3)$ (11)

Total energy destruction

The total energy destruction in the system is the summation of exergy destruction in the various componenets of the system and is given below as

$ED\_Total = ED\_{}_{Throttling\_Valve} + ED_{condenser}. + ED\_{}_{compressor} + ED\_{}_{evaporator}$ (12)

Exergetic efficiency

The exergetic efficiency is the ratio of exergy of product to the exergy of fuel. According to BEJAN, (1996)

ηex = Exergy equivalent of Refrigerating Effect / Exergy of fuel in terms of compressor work

Exergy destruction ratio (EDR)

It is defined as the ratio of total exergy destruction in the system to exergy in the product as defined by Said and Ismail, (1995)

EDR = [ED_ total / Exergy of Product (EP)]

Where exergy of product can be expressed by following equation

EP=Q_Evaporator*((1-(T_ambient/T_Ref.)

T_Ref= T_Eva + Super Heating temperature

Super Heating temperature is ranging from (0, 5 & 10)^oC and Condenser Subcooled temperature is ranging from (0, 5 & 10) ^oC

Therefore ηex=[1/(1+EDR)]

Defect in efficiency

The efficiency defect (kotas, 1985) is the ratio between the exergy flow destroyed in each components and the exergy flow required to sustain the process that is the electrical power supplied to the compressor:

δ = EDi / We

i= used for particular component.

The defects in efficiency in the components are linked to the exergetic efficiency of the whole plant by means of following relation.

ηex = (1 – Σ δi)

For exergetic and energetic performance of R32 and its alternatives such as R 407C, R 410A, R417A, and R11, R12 & R22. The temp of evaporator of -40^oC, with condenser temperature of 40^oC has cooling load capacity of 3.5167 kW.

5. Result and Discussion

The numerical computations have been carried out for 40 ^oC ambient condition for typical Indian conditions and at same condenser temperature. Table-(1a), shows the validation of results in terms of first law efficiency (COP) and second law efficiency, net work required to run the compressor and exergy destruction in terms of lost work It was found that the developed thermal model predict the similar behaviour with slightly 5% higher values than data given [10] as shown in table-1

Table-1(a)*: Validation of results developed by Model of Vapour compression refrigeration system*
$T\_{}_{Cond}$ =40^oC, $T\_{}_{Evaporator}$= - 40^oC, $T\_{}_{Ambient}$ =40^oC, Refrigerant= R-12, Cooling Load= 3.5167 "kW" $ETA\_{}_{Compressor}$=1.0 (Compression and expansion processes are isentropic)

S.No	COP_Ideal	COP_Carnot	ETA_Second	W_Carnot (W)	W_Comp (W)	Lost Work
Model	1.976	2.9140	0.6781	1.207	1.780	0.5729
Ref [10]	1.970	2.9125	0.6760	1.2075	1.781	0.5735

Table-1 (b) shows the validation of results in terms of first law efficiency (COP), COP of Carnot cycle and second law efficiency, net work required to run the compressor, work done by the Carnot refrigerator, and exergy destruction in terms of lost work for 21 ecofriendly refrigerants. It was found that first law efficiency of CFC is slightly higher than other eco-friendly refrigerants. The first law efficiency of R123 is higher than R134a and R1234yf has 3% to 8% lower first law efficiency in terms of COP than R134a. The COP of R245fa is slightly higher than R134a but this refrigerant has higher GWP than R134a. Therefore R1234yf and r1234ze is a good replacement for R134a. R1234ze can be used up to -30^oC which has GWP =6 and R1234yf has GWP=4 respectively. The actual performance of vapour compression refrigeration systems have been computed for compressor efficiency of 80% and exergy destruction in terms of lost work was computed. It was observed that R152a gives better first law performance in terms of coefficient of performances (COP) and second law performance in terms of exergetic efficiency. The higher value of exergetic efficiency was observed due to higher dead state temperature (i.e. ambient temperature of 313K). The highest exergy destruction in the system in terms of lost work was found by using R-125 and slightly lower was also found by using R227EA. The higher exergy destruction was observed by using R1234yf for replacing R134a.

Table-1(b): Performance of Ideal vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	$COP\_{}_{Ideal}$	$COP\_{}_{Carnot}$	$ETA\_{}_{Second}$	$W\_{}_{Carnot}$ (W)	$W\_{}_{Comp}$ (W)	Lost Work	$COP\_{}_{Actual}$	$ETA\_{}_{Second\_Actual}$
R_12	1.976	2.9140	0.6781	1.207	1.780	0.4719	1.581	0.5425
R_22	1.977	2.9140	0.6784	1.207	1.779	0.5719	1.582	0.5427

R_502	1.707	2.9140	0.5857	1.207	2.06	0.8537	1.385	0.4685
R-123	2.095	2.9140	0.7189	1.207	1.679	0.4719	1.678	0.5751
R-134a	1.881	2.9140	0.6628	1.207	1.869	0.6628	1.505	0.5164
R1234yf	1.684	2.9140	0.5779	1.207	2.088	0.8815	1.347	0.4623
R227ea	1.445	2.9140	0.4991	1.207	2.418	1.211	1.164	0.3993
R236fa	1.725	2.9140	0.5917	1.207	2.039	0.8323	1.380	0.4734
R245fa	1.988	2.9140	0.6821	1.207	1.769	0.5625	1.590	0.5457
R152a	2.047	2.9140	0.7023	1.207	1.718	0.5114	1.637	0.5619
R143a	1.647	2.9140	0.5651	1.207	2.135	0.9211	1.317	0.452
R32	1.901	2.9140	0.6523	1.207	1.850	0.6432	1.521	0.5218
R404a	1.553	2.9140	0.5330	1.207	2.264	1.057	1.243	0.4264
R410a	1.817	2.9140	0.6234	1.207	1.936	0.7291	1.453	0.4987
R-407c	1.637	2.9140	0.5618	1.207	2.148	0.9412	1.310	0.4494
R290	1.857	2.9140	0.6373	1.207	1.894	0.6869	1.486	0.5098
R600	1.994	2.9140	0.6842	1.207	1.764	0.5568	1.595	0.5474
R600a	1.860	2.9140	0.6380	1.207	1.891	0.6845	1.488	0.5104
R717	2.046	2.9140	0.702	1.207	1.719	0.5123	1.637	0.5616
R507a	1.589	2.9140	0.5453	1.207	2.213	1.006	1.271	0.4363
R125	1.382	2.9140	0.4743	1.207	2.544	1.338	1.106	0.3794

5.1 Effect of Super heating of evaporator in vapour compression refrigeration system

The maximum First law efficiency in terms of COP and second law efficiency is found by using R152a which is a higher than by using R1234yf and R134a in case of without superheating of evaporator. However the first law efficiency in terms of COP and exergetic efficiency of R245fa and R-600 is found to be similar and higher efficiency is found by using R717. In case of 5^0C super heating of evaporator, the second law efficiency of hydro carbons is also in the good range and slightly higher than by using R134a & R1234yf and R245fa. The highest exergetic efficiency is found by using R152a. in both cases of super heating of evaporator as shown in Table 2(a)-2(b) Respectively. From table2 (c) and 4(e), The maximum work required to run compressor in terms of exergy of fuel is to be found by using R227ea in case of without super heating of evaporator. It was found that maximum exergy destruction occurred in the whole system by using R717 and R125 and minimum exergy destruction in terms of lost work by using R123 in case of 10^oC super heating of evaporator and in case of 5^oC using super heating of evaporator, the maximum exergy destruction is to found by using R125 and minimum is found by using R502. Slightly higher work is required by using, R245fa and R32 in case of without super heating of evaporator. However by using 5^0C super heating in evaporator, the minimum work is required by using R123 and maximum work is required by using R125. Slightly higher work is required by using R1234yf than by using R123 and R134a

Table-2(a): Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants:$T_{\_Cond}=40^oC$, $T_{\_Evaporator}= -40^oC$, Effect of without Super Heating in Evaporator and assuming Compressor Efficiency=0.8

Refrigerant	$COP_{\_Actual}$	$COP_{\_Carnot}$	$ETA_{\_Second\_Actual}$	$W_{\_Carnot}$ (W)	$W_{\_Comp}$ (W)	Lost Work
R_12	1.581	2.9140	0.5425	1.207	1.780	0.4719
R_22	1.582	2.9140	0.5427	1.207	1.779	0.5719
R_502	1.385	2.9140	0.4685	1.207	2.06	0.8537
R-123	1.678	2.9140	0.5751	1.207	1.679	0.4719
R-134a	1.505	2.9140	0.5164	1.207	1.869	0.6628
R1234yf	1.347	2.9140	0.4623	1.207	2.088	0.8815
R227ea	1.164	2.9140	0.3993	1.207	2.418	1.211
R236fa	1.380	2.9140	0.4734	1.207	2.039	0.8323
R245fa	1.590	2.9140	0.5457	1.207	1.769	0.5625
R152a	1.637	2.9140	0.5619	1.207	1.718	0.5114
R143a	1.317	2.9140	0.452	1.207	2.135	0.9211
R32	1.521	2.9140	0.5218	1.207	1.850	0.6432
R404a	1.243	2.9140	0.4264	1.207	2.264	1.057
R410a	1.453	2.9140	0.4987	1.207	1.936	0.7291
R-407c	1.310	2.9140	0.4494	1.207	2.148	0.9412
R290	1.486	2.9140	0.5098	1.207	1.894	0.6869
R600	1.595	2.9140	0.5474	1.207	1.764	0.5568
R600a	1.488	2.9140	0.5104	1.207	1.891	0.6845
R717	1.637	2.9140	0.5616	1.207	1.719	0.5123
R507a	1.271	2.9140	0.4363	1.207	2.213	1.006
R125	1.106	2.9140	0.3794	1.207	2.544	1.338

Table-2(b): Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants:$T_{\_Cond}$=40°C, $T_{\_Evaporator}$= - 40°C, Effect of 5°C (Super Heating) in Evaporator using Compressor Efficiency=0.8

Refrigerant	$COP_{\_Ideal}$	$COP_{\_Carnot}$	$ETA_{\_Second}$	$W_{\_Carnot}$ (W)	$W_{\_Comp}$ (W)	Lost Work
R_12	1.77	2.9140	0.6075	1.207	1.986	0.7796
R_22	1.767	2.9140	0.6064	1.207	1.990	0.7832
R_502	1.541	2.9140	0.5287	1.207	2.282	1.072
R-123	1.873	2.9140	0.6428	1.207	1.679	0.4719
R-134a	1.691	2.9140	0.5804	1.207	2.079	0.8725
R1234yf	1.530	2.9140	0.5250	1.207	2.298	1.092
R227ea	1.345	2.9140	0.4616	1.207	2.614	1.408
R236fa	1.568	2.9140	0.5381	1.207	2.243	1.036
R245fa	1.785	2.9140	0.6126	1.207	1.97	0.7631
R152a	1.829	2.9140	0.6275	1.207	1.923	0.7164
R143a	1.489	2.9140	0.5109	1.207	2.362	1.155
R32	1.699	2.9140	0.5830	1.207	2.07	0.863
R404a	1.411	2.9140	0.4841	1.207	2.493	1.286
R410a	1.627	2.9140	0.5583	1.207	2.161	0.9547
R-407c	1.468	2.9140	0.5038	1.207	2.395	1.189
R290	1.668	2.9140	0.5725	1.207	2.108	0.9012
R600	1.789	2.9140	0.6137	1.207	1.966	0.7596
R600a	1.676	2.9140	0.5752	1.207	2.098	0.8913
R717	1.833	2.9140	0.6288	1.207	1.919	0.7123
R507a	1.422	2.9140	0.4949	1.207	2.438	1.231
R125	1.270	2.9140	0.4357	1.207	2.77	1.563

Table-2(c): Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants: $T_{\_Cond}$=40°C, $T_{\_Evaporator}$= - 40°C, Effect of 10°C (Super Heating) in Evaporator. Compressor Efficiency=0.8

Refrigerant	$COP_{\_Ideal}$	$COP_{\_Carnot}$	$ETA_{\_Second}$	$W_{\_Carnot}$ (W)	$W_{\_Comp}$ (W)	Lost Work
R_12	1.989	2.9140	0.6828	1.207	1.768	0.5617
R_22	1.981	2.9140	0.6797	1.207	1.775	0.5687
R_502	1.743	2.9140	0.5982	1.207	2.097	0.8105
R-123	2.10	2.9140	0.7206	1.207	1.674	0.4678
R-134a	1.907	2.9140	0.6542	1.207	1.845	0.6379
R1234yf	1.741	2.9140	0.5975	1.207	2.019	0.8128
R227ea	1.558	2.9140	0.5338	1.207	2.26	1.054
R236fa	1.786	2.9140	0.6129	1.207	1.969	0.7620
R245fa	2.01	2.9140	0.6898	1.207	1.749	0.5427
R152a	2.049	2.9140	0.7030	1.207	1.717	0.5099
R143a	1.687	2.9140	0.5789	1.207	2.084	0.8778
R32	1.904	2.9140	0.6534	1.207	1.847	0.640
R404a	1.605	2.9140	0.5508	1.207	2.191	0.9842
R410a	1.821	2.9140	0.6269	1.207	1.925	0.7881
R-407c	1.649	2.9140	0.5657	1.207	2.133	0.9263
R290	1.879	2.9140	0.6644	1.207	1.872	0.6649
R600	2.011	2.9140	0.6901	1.207	1.749	0.5419
R600a	1.894	2.9140	0.650	1.207	1.857	0.6499
R717	2.054	2.9140	0.7061	1.207	1.709	0.5023
R507a	1.989	2.9140	0.5627	1.207	2.144	0.9378
R125	1.981	2.9140	0.5009	1.207	2.409	1.202

5.2 Effect of Sub-cooling of condenser in vapour compression refrigeration system

From fig-3(a)-3(d) , the maximum First law efficiency in terms of COP and second law efficiency is found by using R152a which is a higher than by using R1234yf and R134a in case of without sub cooling of condenser. However the exergetic efficiency of R245fa and R 600 is found to be similar and higher efficiency is found by using R717. In case of 5^0C Sub-cooling in the condenser, the second law efficiency of hydro carbons is also in the good range and slightly higher than by using R134a & R1234yf and R245fa. The highest exergetic efficiency is found by using R152a. in both cases of sub cooling as shown in Table 4(a)-4(b) Respectively.

From table4 (c) and 4(d). The maximum work required to run compressor in terms of exergy of fuel is to be found by using R227ea in case of without subcooling. It was found that maximum exergy destruction occurred in the whole system by using R717 and R125 and minimum exergy destruction in terms of lost work by using R123 in case of 10°C sub cooling and in case of 5°C using subcooling , the maximum exergy destruction is to found by using R125 and minimum is found by using R502. Slightly higher work is required by using ,R245fa and R32 in case of without subcooling in condenser. However by using 5ºC subcooling in condenser, the minimum work is required by using R123 and maximum work is required by using R125. Slightly higher work is required by using R1234yf than by using R123 and R134a.

Table-2(d): Effect of superheating of evaporator on the first law thermal Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Actual COP (without Super Heating)	Actual COP (with 5ºC Super Heating)	Actual COP (with 10ºC Super Heating)
R_12	1.581	1.77	1.989
R_22	1.582	1.767	1.981
R_502	1.385	1.541	1.743
R-123	1.678	1.873	2.10
R-134a	1.505	1.691	1.907
R1234yf	1.347	1.530	1.741
R227ea	1.164	1.345	1.558
R236fa	1.380	1.568	1.786
R245fa	1.590	1.785	2.01
R152a	1.637	1.829	2.049
R143a	1.317	1.489	1.687
R32	1.521	1.699	1.904
R404a	1.243	1.411	1.605
R410a	1.453	1.627	1.821
R-407c	1.310	1.468	1.649
R290	1.486	1.668	1.879
R600	1.595	1.789	2.011
R600a	1.488	1.676	1.894
R717	1.637	1.833	2.054
R507a	1.271	1.422	1.64
R125	1.106	1.270	1.46

Table-2(e): Effect of superheating of evaporator on the second law thermal Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Second law Efficiency (without Super Heating)	Second law Efficiency (with 5ºC Super Heating)	Second law Efficiency (with 10ºC Super Heating)
R_12	0.5425	0.6075	0.6828
R_22	0.5427	0.6064	0.6797
R_502	0.4685	0.5287	0.5982
R-123	0.5751	0.6428	0.7206
R-134a	0.5164	0.5804	0.6542
R1234yf	0.4623	0.5250	0.5975
R227ea	0.3993	0.4616	0.5338
R236fa	0.4734	0.5381	0.6129
R245fa	0.5457	0.6126	0.6898
R152a	0.5619	0.6275	0.7030
R143a	0.452	0.5109	0.5789
R32	0.5218	0.5830	0.6534
R404a	0.4264	0.4841	0.5508
R410a	0.4987	0.5583	0.6269
R-407c	0.4494	0.5038	0.5657
R290	0.5098	0.5725	0.6644
R600	0.5474	0.6137	0.6901
R600a	0.5104	0.5752	0.650
R717	0.5616	0.6288	0.7061
R507a	0.4363	0.4949	0.5627
R125	0.3794	0.4357	0.5009

Table-3(a) : Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants without super heating in evaporator and also without sub-cooling in the condenser

Refrigerant	$COP_{\_Actual}$	$COP_{\_Carnot}$	$ETA_{\_Second\_Actual}$	$W_{\_Carnot}$ (W)	$W_{\_Comp}$ (W)
R_12	1.581	2.9140	0.5425	1.207	1.989
R_22	1.582	2.9140	0.5427	1.207	1.981
R_502	1.385	2.9140	0.4685	1.207	1.743
R-123	1.678	2.9140	0.5751	1.207	2.095
R-134a	1.505	2.9140	0.5164	1.207	2.337
R1234yf	1.347	2.9140	0.4623	1.207	2.610
R227ea	1.164	2.9140	0.3993	1.207	3.022
R236fa	1.380	2.9140	0.4734	1.207	2.549
R245fa	1.590	2.9140	0.5457	1.207	2.221
R152a	1.637	2.9140	0.5619	1.207	2.141
R143a	1.317	2.9140	0.452	1.207	2.669
R32	1.521	2.9140	0.5218	1.207	2.312
R404a	1.243	2.9140	0.4264	1.207	2.830
R410a	1.453	2.9140	0.4987	1.207	2.420
R-407c	1.310	2.9140	0.4494	1.207	2.685
R290	1.486	2.9140	0.5098	1.207	2.367
R600	1.595	2.9140	0.5474	1.207	2.204
R600a	1.488	2.9140	0.5104	1.207	2.364
R717	1.637	2.9140	0.5616	1.207	2.149
R507a	1.271	2.9140	0.4363	1.207	2.766
R125	1.106	2.9140	0.3794	1.207	3.18

Table-3(b) : Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants without super heating in evaporator and also with 5°C sub-cooling in the condenser

Refrigerant	COP_Actual	COP_Carnot	ETA_Second_Actual	W_Carnot (W)	W_Comp (W)	Lost Work (W)
R_12	1.753	2.9140	0.6016	1.207	2.006	0.7991
R_22	1.75	2.9140	0.6006	1.207	2.009	0.8024
R_502	1.549	2.9140	0.5314	1.207	2.271	1.064
R-123	1.844	2.9140	0.6328	1.207	1.907	0.7002
R-134a	1.682	2.9140	0.5771	1.207	2.091	0.8841
R1234yf	1.536	2.9140	0.5269	1.207	2.29	1.084
R227ea	1.358	2.9140	0.4661	1.207	2.589	1.382
R236fa	1.563	2.9140	0.5362	1.207	2.251	1.044
R245fa	1.764	2.9140	0.6053	1.207	1.994	0.7870
R152a	1.806	2.9140	0.6195	1.207	1.948	0.741
R143a	1.507	2.9140	0.5172	1.207	2.333	1.127
R32	1.687	2.9140	0.5788	1.207	2.085	0.8782
R404a	1.432	2.9140	0.4913	1.207	2.456	1.250
R410a	1.636	2.9140	0.5612	1.207	2.15	0.9434
R-407c	1.463	2.9140	0.5020	1.207	2.404	1.197
R290	1.685	2.9140	0.5713	1.207	2.112	0.9056
R600	1.769	2.9140	0.6070	1.207	1.988	0.7813
R600a	1.664	2.9140	0.5710	1.207	2.113	0.9064
R717	1.787	2.9140	0.6131	1.207	1.968	0.7616
R507a	1.466	2.9140	0.5030	1.207	2.399	1.192
R125	1.311	2.9140	0.4498	1.207	2.683	1.476

Table-3(c) : Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants without super heating in evaporator and also with 10°C sub-cooling in the condenser

Refrigerant	Actual COP (with 10°C Sub cooling)	COP_Carnot	ETA_Second_Actual	W_Carnot (W)	Actual work in VCRS W_Compressor (W)	Lost work in VCRS (Watt)
R_12	1.947	2.9140	0.6680	1.207	1.806	0.5997
R_22	1.94	2.9140	0.6656	1.207	1.813	0.6060
R_502	1.753	2.9140	0.6015	1.207	2.006	0.7995
R-123	2.035	2.9140	0.6984	1.207	1.728	0.5212
R-134a	1.88	2.9140	0.6451	1.207	1.87	0.6637
R1234yf	1.744	2.9140	0.5985	1.207	2.016	0.8094
R227ea	1.573	2.9140	0.5590	1.207	2.235	1.029
R236fa	1.767	2.9140	0.6062	1.207	1.99	0.7838
R245fa	1.959	2.9140	0.6722	1.207	1.795	0.5883
R152a	1.995	2.9140	0.6846	1.207	1.763	0.5558
R143a	1.716	2.9140	0.5890	1.207	2.049	0.8421
R32	1.873	2.9140	0.6427	1.207	1.877	0.6707
R404a	1.64	2.9140	0.5626	1.207	2.145	0.9383
R410a	1.838	2.9140	0.6307	1.207	1.913	0.7066
R-407c	1.631	2.9140	0.5597	1.207	2.156	0.9492
R290	1.865	2.9140	0.6399	1.207	1.886	0.6792
R600	1.964	2.9140	0.6739	1.207	1.791	0.5839
R600a	1.863	2.9140	0.6391	1.207	1.888	0.6814
R717	1.958	2.9140	0.5260	1.207	2.294	1.087
R507a	1.678	2.9140	0.5759	1.207	2.095	0.8887
R125	1.533	2.9140	0.5260	1.207	2.294	0.5892

Table-4(a): Effect of subcooling of condenser on the first law thermal Performance of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Actual COP (without Sub-cooling)	Actual COP (with 5°C Sub-cooling)	Actual COP (with 10°C Subcooling)
R_12	1.581	1.753	1.947
R_22	1.582	1.75	1.94
R_502	1.385	1.549	1.753
R-123	1.678	1.844	2.035
R-134a	1.505	1.682	1.88
R1234yf	1.347	1.536	1.744
R227ea	1.164	1.358	1.573
R236fa	1.380	1.563	1.767
R245fa	1.590	1.764	1.959
R152a	1.637	1.806	1.995
R143a	1.317	1.507	1.716
R32	1.521	1.687	1.873
R404a	1.243	1.432	1.64
R410a	1.453	1.636	1.838
R-407c	1.310	1.463	1.631
R290	1.486	1.685	1.865
R600	1.595	1.769	1.964
R600a	1.488	1.664	1.863
R717	1.637	1.787	1.958
R507a	1.271	1.466	1.678
R125	1.106	1.311	1.533

Table-4(b): Effect of subcooling of condenser on the Second law thermal Performance of actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Second law Efficiency (without Sub-cooling)	Second law Efficiency (with 5°C Sub-cooling)	Second law Efficiency (with 10°C Subcooling)
R_12	0.5425	0.6016	0.6680
R_22	0.5427	0.6006	0.6656
R_502	0.4685	0.5314	0.6015
R-123	0.5751	0.6328	0.6984
R-134a	0.5164	0.5771	0.6451
R1234yf	0.4623	0.5269	0.5985
R227ea	0.3993	0.4661	0.5590
R236fa	0.4734	0.5362	0.6062
R245fa	0.5457	0.6053	0.6722
R152a	0.5619	0.6195	0.6846
R143a	0.452	0.5172	0.5890
R32	0.5218	0.5788	0.6427
R404a	0.4264	0.4913	0.5626
R410a	0.4987	0.5612	0.6307
R-407c	0.4494	0.5020	0.5597
R290	0.5098	0.5713	0.6399
R600	0.5474	0.6070	0.6739
R600a	0.5104	0.5710	0.6391
R717	0.5616	0.6131	0.5260
R507a	0.4363	0.5030	0.5759
R125	0.3794	0.4498	0.5260

Table-4(c): Effect of subcooling of condenser on exergy of fuel in terms of compressor work of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Actual work in VCRS (without Sub-cooling) Watts	Actual work in VCRS at 5°C Sub-cooling . $W\_{Compressor}$ (Watts)	Actual work in VCRS at 10°C Sub-cooling . $W\_{Compressor}$ (Watts)
R_12	1.989	2.006	1.806
R_22	1.981	2.009	1.813
R_502	1.743	2.271	2.006
R-123	2.095	1.907	1.728
R-134a	2.337	2.091	1.87
R1234yf	2.610	2.29	2.016
R227ea	3.022	2.589	2.235
R236fa	2.549	2.251	1.99
R245fa	2.221	1.994	1.795
R152a	2.141	1.948	1.763
R143a	2.669	2.333	2.049
R32	2.312	2.085	1.877
R404a	2.830	2.456	2.145
R410a	2.420	2.15	1.913
R-407c	2.685	2.404	2.156
R290	2.367	2.112	1.886
R600	2.204	1.988	1.791
R600a	2.364	2.113	1.888
R717	2.149	1.968	2.294
R507a	2.766	2.399	2.095
R125	3.18	2.683	2.294

Table-4(d): Effect of subcooling of condenser on lost work of Actual vapour compression refrigeration cycle using eco-friendly Refrigerants

Refrigerant	Lost work in VCRS (without Sub-cooling) Watts	Lost work in VCRS at 5°C Sub-cooling . $W\_{Compressor}$ (Watts)	Lost work in VCRS at 10°C Sub-cooling . $W\_{Compressor}$ (Watts)
R_12	0.4719	0.7991	0.5997
R_22	0.5719	0.8024	0.6060
R_502	0.8537	1.064	0.7995
R-123	0.4719	0.7002	0.5212
R-134a	0.6628	0.8841	0.6637
R1234yf	0.8815	1.084	0.8094
R227ea	1.211	1.382	1.029
R236fa	0.8323	1.044	0.7838
R245fa	0.5625	0.7870	0.5883
R152a	0.5114	0.741	0.5558
R143a	0.9211	1.127	0.8421
R32	0.6432	0.8782	0.6707
R404a	1.057	1.250	0.9383
R410a	0.7291	0.9434	0.7066
R-407c	0.9412	1.197	0.9492
R290	0.6869	0.9056	0.6792
R600	0.5568	0.7813	0.5839
R600a	0.6845	0.9064	0.6814
R717	0.5123	0.7616	1.087
R507a	1.006	1.192	0.8887
R125	1.338	1.476	0.5892

6. Conclusion

The following conclusions were made

(1) The highest exergy destruction in the system in terms of lost work was found by using R-125 and slightly lower was also found by using R227ea.
(2) The higher exergy destruction was observed by using R1234yf for replacing R134a.
(3) Highest first law efficiency in terms of COP and second law efficiency in terms of exergetic efficiency was found by using R152a
(4) The subcooling of condenser improves first law performances as well as second law performances.
(5) The super heating of evaporator also improves first law performances as well as second law performances.
(6) The use of liquid vapour heat exchanger improves the first and second law performance.

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