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Single and multiple cascading of VCRS in NH_3H_2O vapour absorption refrigeration systems for improving thermodynamic (energy-exergy) performances using five ecofriendly new HFOs and other low GWP refrigerants for replacing R134a

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Abstract

In this paper, the performance of the HFO refrigerants in the medium temperature compression stage between 5°C to -50°C and NH_3H_2O refrigerants in the absorption stage and its overall effect on the cascade system is presented. The effect of these HFO refrigerant on the intermediate temperature in the range of (-50°C to 95°c) using R245fa of multiple stage cascade system is also investigated. For ultra-low evaporator temperature using R32 refrigerant/ hydrocarbon effects its first and second law performances using the pair of NH_3–H_2O in the high temperature absorption stage. Effect of various performance parameters of multi cascade refrigeration system in which a compression system at the low temperature stage and an absorption system at the high temperature stage are cascaded to generate cooling at low temperatures have been investigated. These cycles were analyzed thermodynamically and were compared with each other using different HFO refrigerants in the medium temperature compression cycle at the evaporator temperature of 223K (-50°C) and vapor evaporator temperature of 273K. The multi cascading effect is also been carried out for evaporator temperature of -95°C using R245fa refrigerants and also using R32 at evaporator temperature of -130°C. It is found that R1233zd (E) and HFO-1336mzz(z) gives better thermodynamic performances than using R1243zf and R1224yd (Z) and R1225ye(Z) and worst performances was found using R1234yf. For evaporator temperature of 243K the thermodynamic performances of R1234yf is lower than R134a and R1234ze(E), However R1234ze (Z) can gives better performance than other HFO refrigerants for above evaporator temperature of 273K.The effect of Hydrocarbon on low temperature is also investigated and also compared with R32.

Keywords: HFO refrigerants in MTC, R245fa in ITC, R32 in LTC, Multi cascade-compression-absorption System

1. Introduction

Vapour-compression refrigeration cycle with only one stage of compression is called a single-stage refrigeration system. A cascade refrigeration system, on the other hand, employs two or more individual refrigeration cycles operating at different pressure and temperature levels. The duty of the lower temperature cycle is to provide the desired refrigeration effect at a relatively low temperature. The condenser in the lower-temperature cycle is thermally coupled to the evaporator in the higher-temperature cycle. Thus, the evaporator in the higher cycle only serves to extract the heat released by the condenser in the lower cycle. Then this heat is rejected into the ambient air or a water stream in the condenser of the higher cycle. Since high ratios of pressure across the compressor cause undesirably high discharge temperatures, low volumetric efficiencies and excessive stresses on compressor parts, the maximum allowable pressure ratio for reciprocating compressors is limited to about nine. When pressure ratio exceeds to nine for a specific application requiring a relatively low refrigeration temperature, it can be decreased using a cascade refrigeration system instead of a single-stage one. HFO-1234yf is not considered to be a viable alternative for these refrigerants because of its significantly lower volumetric capacity. HFO-1233zd, refrigerant with a GWP value of less than seven used in the centrifugal chiller in Europe R1234ze(E) is sometimes referred to as a R134a substitute, but its volumetric refrigerating capacity is more than 20% lower than that of R134a or R1234yf. The boiling point (-19°C) also greatly restricts the application at lower evaporation temperatures. Its preferred use is therefore in liquid chillers and high temperature applications. The ten HFO refrigerants that met the requirements in terms of thermodynamic properties, flammability, toxicity,

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chemical stability, compatibility with materials and lubricants. These include e.g. the non-flammable (safety group A1) low-pressure refrigerants R1336mzz(Z), R1233zd(E) and R1224yd(Z). These are primarily an option for liquid chillers with large turbo-compressors, and can be used with positive displacement compressors in high-temperature applications. R1233zd(E) and R1224yd(Z) belong to the group of HCFO (hydro-chloro-fluoro-olefins); they have a (very) low ozone depletion potential (ODP). Upon release into the atmosphere, however, the molecule rapidly disintegrates [14].

2. System Description

The thermodynamic analyses of total six cycles were done using the same methodology as explained in previous section. For medium temperature vapour compression stage of the cascade cycle ten HFO refrigerants were chosen; R1234yf, R1234ze(Z), R1234ze(E), HFO-1336mzz(Z), R1243zf, R1224yd(Z), R1225ye(Z), R-1233zd(E),R124 and R-1336mzz(E) and R152a for replacing R134a in the evaporator temperature of 225K. In the intermediate temperature stage R245fa refrigerants was chosen in the evaporator range of 187K and in the low temperature range of 143K R32 refrigerants was used and results were compared with hydrocarbons R600a and R290 and ethylene as refrigerants for ultra-low temperature applications. Thermodynamic performance analysis of a vapour compression absorption cascaded refrigeration system and concluded that electric power requirement in vapour compression refrigeration system is reduced substantially by cascading it with absorption system. However, the total size of the vapour compression refrigeration system will increase when it is cascaded the running cost is probable to decrease due to the utilization of waste heat available at lower cost, but. the COP of vapour compression system will also increase because of low electric power requirement and also found that the larger the temperature difference in the cascade heat exchanger, the lower the COP of the system; however, a lower temperature difference will direct to increased heat exchanger size and cost [1-3]. Similarly by increasing the size of heat exchanger also increases the overall performance of system, hence also also increases the system cost. L. Kairouani& E. Nehdi [4] computed cooling performance and energy saving of a compression absorption refrigeration system assisted by geothermal energy and concluded that the proposed absorption/compression refrigeration system is to improve the overall cycle efficiency under the same operating conditions (evaporation temperature at 263 K and condensation temperature at 308 K). This system presents an opportunity to reduce the continuously increasing electrical energy consumption. H.M. Getu et al [5] carried out thermodynamic analysis of an R744–R717 cascade refrigeration system and concluded that by increasing the condenser temperature which increases refrigerant mass flow rates and also the decreasing COP. Similarly by increasing evaporating temperature increased COP of the system and decreases mass flow ratios. By increasing temperature difference in cascade condenser reduced both COP and mass flow ratios and by increasing isentropic efficiency of compressors also increases COP linearly. Srinivas Garimella et.al. [6] found that when the cascading of vapour compression cycle and vapour absorption cycle has been done which gives more energy efficient because the high temperature stage of the system uses low grade heat energy instead of high grade electrical energy which is much more expensive. CananCimsit et al. [7] analyzed the compression absorption cascade refrigeration cycles and found that the using the absorption and vapour compression cascade refrigeration cycle have the advantage that cooling can be done by using less electric energy consumption than classical vapour compression cycle for low temperature cooling applications. When the compression absorption cascade refrigeration cycles and the classic vapour compression refrigeration cycles are compared for sample application at the same conditions for the same cooling capacity, depending on absorption fluid pairs such as LiBr-H_2O and NH_3-H_2O and found that around 48-51% less electric energy is consumed in the cascade systems, The coefficient of performance of the cascade cycle using LiBr-H_2O and NH_3-H_2O fluid pairs in absorption cycle increases by increasing the generator and evaporator temperatures, but reduces by increasing the condenser temperatures [10-11]. Jose´Fernandez-Seara et. al. [8-9] obtained results for Compression absorption cascade refrigeration system; by carrying out complete analysis about the compression absorption cascade refrigeration system and found that the intermediate temperature level is an important design parameter that causes an opposite effect on the COP of the compression and absorption systems. Therefore, the cascade system COP is a maximum when the intermediate temperature is varied. Dixit Manoj et.al [12] developed mathematical model of vapour absorption compression cascaded refrigeration system, comprising of a vapour compression refrigeration system in low temperature stage using CO_2, NH_3 and R134a as ecofriendly refrigerants and H_2O-LiBr VARS at the high temperature stage and found that the cascade condenser, compressor and refrigerant throttle valve are the major source of exergy destruction. A.K. Prithar, et.al. [13] Carried out the Simulation of an Ammonia water compression absorption refrigeration system and found that 16% enhancement of COP by increasing 30% of solution heat exchanger area using R22 in the VARS.

3. Results & Discussion

3.1 NH_3-H_2O VARS with cascading (two stages) VCRS using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Following input data have been chosen for numerical computations are

System-1: NH_3-H_2O vapour absorption refrigeration system.
System-2: NH_3H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration system using new HFO ecofriendly refrigerant for evaporator temperature of 50^{o}C for reducing global warming and ozone depletion.
System-3: NH_3H_2O vapour absorption refrigeration system multi cascaded with vapour compression refrigeration systems using new HFO ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle of evaporator temperature of -95^{o}C for reducing global warming and ozone depletion.

System-4: NH_3H_2O vapour absorption refrigeration system multi cascaded with vapour compression refrigeration systems using new HFO ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle and R32 in low temperature cycle of evaporator temperature of -130°C for reducing global warming and ozone depletion as given below.

- Temperature of low temperature evaporator using hydrocarbon R-32 = -130°C.
- Compressor efficiency of low temperature cycle compressor =80%
- Temperature overlapping between low temperature condenser and intermediate temperature evaporator =10°C
- Load on low temperature evaporator = 175 "kW"
- Temperature of intermediate temperature evaporator using R-245fa = -95°C,
- Compressor efficiency of intermediate temperature cycle compressor =80%
- Temperature overlapping between intermediate temperature condenser and medium temperature evaporator =10°C
- Compressor efficiency of medium temperature cycle compressor =80%
- Temperature of intermediate temperature evaporator using following refrigerants = -50°C
- Temperature overlapping between medium temperature condenser and NH_3-H_2O Vapour absorption evaporator temperature =10°C

The thermodynamic performances in terms of first law fficiency (COP) and second law efficiency along with exergy destruction ratio have been computed by developed program for NH_3-H_2O vapour absorption-compression systems (system-1) as given below.

- First law efficiency of vapour absorption system ($COP_{\_VARS}$) = 0.322 ,
- VARS exergy destruction ratio ($EDR_{\_VARS}$)= 3.041 ,
- Second law efficiency (i.e. Exergetic $Efficiency_{\_VARS}$) =0.2475

The overall thermodynamic performances of simple and cascade system, multi cascaded systems have been computed and results are shown in Tables-1-10 respectively.

Table-1(a) & Table-1(b) shows the First law performance simple NH_3-H_2O vapour absorption refrigeration system (system-1) and Simple NH_3H_2O Vapour absorption Refrigeration system with cascading of vapour compression refrigeration system (system-2) using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion and it was found that Cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-2) gives better thermodynamic first law performance (COP) than system-1 and the performance improvement using ten ecofriendly refrigerants are shown in table 1.

Table- 1(a) : First law performance parameters on simple NH_3-H_2O vapour absorption refrigeration system (system-1) and Simple NH_3H_2O Vapour absorption Refrigeration system*with cascading of vapour compression refrigeration system (system-2) using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

First Law Efficiency	HFO-1336mzz(Z)	R1243zf	R1233zd(E)	R1244yd(z)	R1225ye(z)
$COP_{\_VARS}$ (System-1:)	0.322	0.322	0.322	0.322	0.322
$COP_{\_MTC}$(System-2)	0.4993	0.4958	0.5022	0.5018	0.4987
First law performance improvement (%)	55.062	53.9752	55.963	55.8385	54.8758

Table- 1(b) : First law performance Parameters on NH_3-H_2O Vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

First Law Efficiency	R134a	R1234yf	R1234ze(E)	R1234ze(z)	R124
$COP_{\_VARS}$ (System-1)	0.322	0.322	0.322	0.322	0.322
$COP_{\_MTC}$(System-2)	0.4996	0.4960	0.4983	0.5015	0.5103
First law performance improvement (%)	55.1553	54.0373	54.752	55.7453	58.4783

Table- 2(a) : Thermodynamic (energy-exergy) performance parameters on NH_3-H_2O vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Performance Parameters	HFO-1336mzz(Z)	R1243zf	R1233zd(E)	R1244yd(z)	R1225ye(z)
$COP_{\_MTC}$(System-2)	0.4993	0.4958	0.5022	0.5018	0.4987
$EDR_{\_MTC}$(System-2)	0.8953	0.9267	0.8690	0.8729	0.90
Exergetic $Efficiency_{\_MTC}$ (System-2)	0.5276	0.5190	0.5351	0.5339	0.5261

Table- 2(b): Thermodynamic (energy-exergy) performance Parameters on NH_3-H_2O vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Performance Parameters	R134a	R1234yf	R1234ze(E)	R1234ze(Z)	R124
$COP_{\_MTC}$ (System-2)	0.4996	0.4960	0.4983	0.5105	0.5033
$EDR_{\_MTC}$ (System-2)	0.8924	0.9248	0.9038	0.7977	0.8859
Exergetic $Efficiency_{\_MTC}$ (System-2)	0.5284	0.5195	0.5253	0.5563	0.5303

Table-2(a) & Table-2(b) shows the thermodynamic first and second law performances of Simple NH_3H_2O Vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) using ten new HFO ecofriendly refrigeranst for reducing global warming and ozone depletion and it was found that Cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-2) gives better thermodynamic first and second law performances using R1234ze(Z) than using R1234ze(E) and worst thermodynamic first and second law performances using R1234yf was found. Although thermodynamic first and second law performances using R124 are better than R134a. The thermodynamic first and second law performances using HFO-1336mzz(Z) are nearly approaching to the performance using R134a in the cascade system. The performance improvement using ten ecofriendly refrigerants using cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion are shown in Table-3(a) and Table-3(b) respectively. It was found that HFO-1336mzz (Z) gives similar thermodynamic performance improvement can easily replace R134a in the near future.

The maximum thermodynamic performances improvement (first law performance improvement was 58.54% with reduction of system exergy destruction ratio of 70.28%) with improvement in second law efficiency is 124.8% by using R1234ze(Z) and 116.2% by using R1233zd(E) and R115.8% by using R1244yd(Z) in the low temperature cycle up to evaporator temperature of -50%. It was also observed that R1234ze(E) can be used up to evaporator temperature of -30^{o}C and R1234ze(Z) will be used in high temperature cycle up to evaporator temperature of 0^{o}C.

Table 3(a) : % improvement in thermodynamic (energy-exergy) performance Parameters on NH_3-H_2O VARS with multi cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	HFO-1336mzz(Z)	R1243zf	R1233zd(E)	R1244yd(z)	R1225ye(z)
$COP_{\_MTC}$(System-2)	55.07	53.99	55.98	55.85	54.87
$EDR_{\_MTC}$(System-2)	-70.56	-69.53	-71.43	-71.29	-70.38
$ExergeticEfficiency_{\_MTC}$(System-2)	113.2	109.7	116.2	115.8	112.6

Table 3(b) : % improvement in thermodynamic (energy-exergy) performance parameters on Single effect Li/Br-H_2OVARS with multi cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	*R134a*	*R1234yf*	*R1234ze(E)*	*R1234ze(Z)*	*R124*
$COP_{\_MTC}$(System-2)	55.17	54.05	54.77	58.54	55.39
$EDR_{\_MTC}$(System-2)	-70.65	-69.59	-70.28	-73.77	-70.87
Exergetic $Efficiency_{\_MTC}$	113.5	109.9	112.3	124.8	114.3

3.2 NH3-H_2O vapour absorption refrigeration system with cascading (two stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Table-4 shows the overall first law performance simple NH_3-H_2O vapour absorption refrigeration system (system-1) and simple NH_3H_2O vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) simple NH_3H_2O vapour absorption refrigeration system with multi cascading of vapour compression refrigeration systems (system-3) using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion and it was found that multi cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-3) gives better thermodynamic first law performance (COP) than cascade system (system-2) and system-1 respectively and the performance improvement using ten ecofriendly refrigerants are shown in Tables-4 respectively.

Table 4: First law performance parameters on NH_3-H_2O vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

First Law Efficiency	R124	R1233yd(E)	R1234yf	R1233zd(E)	HFO1336mzz(Z)	R1243zf	R1234ze(E)	R1234ze(Z)
$COP_{\_VARS}$ (System-1)	0.322	0.322	0.322	0.322	0.322	0.322	0.322	0.322
$COP_{\_MTC}$ (System-2)	0.5003	0.5022	0.4954	0.5022	0.4993	0.4958	0.4983	0.5105
$COP_{\_ITC}$ (System-3)	0.5998	0.6023	0.5934	0.6023	0.5984	0.5939	0.5972	0.6129

Table 5(a) : Thermodynamic (Energy-Exergy) performance parameters on NH_3-H_2O vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Performance Parameters	R124	R1233yd(E)	R1234yf	R1233zd(E)	HFO-1336mzz(z)	R1243zf	R1234ze(E)	R1234ze(Z)
$COP_{\_MTC}$ (System-2)	0.5003	0.5022	0.4954	0.5022	0.4993	0.4958	0.4983	0.5105
$EDR_{\_MTC}$ (System-2)	0.8859	0.8690	0.9306	0.869	0.8953	0.9267	0.9038	0.7977
Exergetic $Eff_{\_MTC}$ (System-2)	0.5303	0.5351	0.5180	0.5351	0.5276	0.5190	0.5253	0.5563

Table 5(b): Thermodynamic (energy-exergy) performance Parameters on NH_3-H_2O vapour absorption refrigeration system with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Performance Parameters	R124	R1233yd(E)	R1234yf	R1233zd(E)	HFO-1336mzz(z)	R1243zf	R1234ze(E)	R1234ze(Z)
COP_{ITC} (System-3)	0.5998	0.6023	0.5934	0.6023	0.5984	0.5939	0.5972	0.6129
EDR_{ITC} (System-3)	0.3739	0.3636	0.4013	0.3636	0.3797	0.3989	0.3849	0.3205
Exergetic Eff_{ITC} (System-3)	0.7278	0.7333	0.7136	0.7336	0.7248	0.7149	0.7221	0.7573

Table-5(a) & Table-5(b) shows the thermodynamic first and second law performances of cascaded NH_3H_2O vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) using ten new HFO ecofriendly refrigerants and multi- cascaded NH_3H_2O Vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) using ten new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that Cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-2) gives better thermodynamic first and second law performances using R1234ze(Z) than using R1234ze(E) and worst thermodynamic first and second law performances using R1234yf was found. Although thermodynamic first and second law performances using R124 are better than R134a. The thermodynamic first and second law performances using HFO-1336mzz(Z) are nearly approaching to the performance using R134a in the cascade system.

The performance improvement using ten ecofriendly refrigerants using cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion are shown in Table-6(a) and Table-6(b) respectively. It was found that HFO-1336mzz(Z) gives similar thermodynamic performance improvement can easily replace R134a in the near future.

The maximum % thermodynamic performances improvement of system-3 in terms of first law performance improvement was 90.4% with reduction of system exergy destruction ratio of (89.5%) with improvement in second law efficiency is 206% by using R1234ze(Z) and 196.3% by using R1233yd(E) and 188.4% by usingR1234yf, 194.1% by using R124, 188.9% by using R1243zf and 192.9% by using HFO-1336mzz(Z) in the low temperature cycle up to evaporator temperature of -50%. It was also observed that R1234ze(E) can be used up to evaporator temperature of -30^{o}C and R1234ze(Z) will be used in high temperature cycle up to evaporator temperature of 0^{o}C.

Table 6(a) : % improvement in thermodynamic (energy-exergy) performance parameters on NH_3-H_2O VARS with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	R124	R1233yd(E)	R1234yf	R1233zd(E)	HFO-1336mzz(z)	R1243zf	R1234ze(E)	R1234ze(Z)
COP_{MTC} (System-2)	55.39	55.98	53.86	55.98	55.07	53.99	54.77	58.54
EDR_{MTC} (System-2)	-70.87	-71.43	-69.4	-71.43	-70.56	-69.53	-70.28	-79.71
Exergetic Eff_{MTC} (System-2)	114.3	116.2	109.3	116.2	113.2	109.7	112.3	124.8

Table 6(b): % improvement in thermodynamic (energy-exergy) performance parameters on NH_3-H_2O VARS with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	R124	R1233yd(E)	R1234yf	R1233zd(E)	HFO- 336mzz(z)	R1243zf	R1234ze(E)	R1234ze(Z)
COP_{ITC}(System-3)	86.29	87.06	84.29	87.06	85.86	84.46	85.48	90.37
EDR_{ITC}(System-3)	-87.7	-88.04	-86.8	-88.04	-87.51	-86.88	-87.34	-89.46
Exergetic Eff_{ITC} (System-3)	194.1	196.3	188.4	196.3	192.9	188.9	191.8	206.0

3.3 NH_3-H_2O Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Table-7(a-b) are showing the First law performance simple NH_3-H_2O vapour absorption refrigeration system (system-1) and simple NH_3H_2O vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) for lower evaporator temperature of -50^{o}C using HFO ecofriendly refrigerants for reducing global warming and ozone depletion , simple NH_3H_2O vapour absorption refrigeration system with multi cascading of vapour compression refrigeration systems (system-3) for lower evaporator temperature of -95^{o}C using R245fa ecofriendly refrigerant for reducing global warming and ozone depletion and simple NH_3H_2O vapour absorption refrigeration system with multi cascading of vapour compression refrigeration systems (system-3) for lower evaporator temperature of -130^{o}C using new R32 ecofriendly refrigerant for reducing global warming and ozone depletion and it was found that multi cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-4) gives better thermodynamic first law performance (COP) than cascade system (system-3) and cascade system-2 respectively and the performance improvement using ten ecofriendly refrigerants are shown in Table-7(a) respectively.

Table 7(a): First law performance Parameters on NH_3-H_2O Vapour absorption refrigeration system with multi cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

First Law Efficiency	*R1234yf*	*HFO1336mzz(Z)*	*R1233zd(E)*	*R1225ye(z)*	*R134a*
$COP_{\_VARS}$(NH_3-H_2O VARS System_1)	0.322	0.322	0.322	0.322	0.322
$COP_{\_MTC}$(Cascade System_2)	0.4954	0.4993	0.5022	0.4987	0.4996
$COP_{\_ITC}$(Multi cascade System_3)	0.5934	0.5984	0.6023	0.5976	0.5986
$COP_{\_LTC}$(Multi cascade System_4)	0.6433	0.6489	0.6531	0.6480	0.6493

Table 7(b): First law performance Parameters on NH_3-H_2O *Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

First Law Efficiency	*R1243zf*	R1234ze(E)	R1234ze(Z)
$COP_{\_VARS}$	0.322	0.322	0.322
$COP_{\_MTC}$	0.4958	0.4983	0.5105
$COP_{\_ITC}$	0.5339	0.5979	0.6129
$COP_{\_LTC}$	0.6439	0.6475	0.6646

Table 7(c): First law performance Parameters on NH_3-H_2O *Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

First Law Efficiency	*R1234yf*	HFO-1336mzz(Z)	R1234zd(E)	R1225ye(z)	R134a
$COP_{\_VARS}$	0.322	0.322	0.322	0.322	0.322
$COP_{\_MTC}$	0.4954	0.4993	0.5022	0.4987	0.4996
$COP_{\_ITC}$	0.5934	0.5984	0.6023	0.5976	0.5986
$COP_{\_LTC}$	0.6433	0.6489	0.6531	0.6480	0.6493

Table-8(a) to Table-8(c) are showing the thermodynamic first and second law performances of cascaded NH_3H_2O Vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) using ten new HFO ecofriendly refrigerants and multi- cascaded NH_3H_2O Vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-2) using ten new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that Cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-2) gives better thermodynamic first and second law performances using R1234ze(Z) than using R1234ze(E) and worst thermodynamic first and second law performances using R1234yf was found. Although thermodynamic first and second law performances using R124 are better than R134a. The thermodynamic first and second law performances using HFO-1336mzz(Z) are nearly approaching to the performance using R134a in the cascade system.The performance improvement using ten ecofriendly refrigerants using cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system using new HFO ecofriendly refrigerant at -50ºC of VCRS evaporator temperature for reducing global warming and ozone depletion are shown in Table-8(d-f) respectively. It was found that HFO-1336mzz(Z) gives similar thermodynamic performance improvement can easily replace R134a in the near future. Fig-9(b) shows the percentage thermodynamic performances improvement of system-2 in terms of first law performance improvement was 55.07% with reduction of system exergy destruction ratio of (70.56%) with improvement in second law efficiency is 113.2 using HFO-1333mzz(Z). The % improvement in first law efficiency in cascade system-2 is by using R1233zd(E) and 55.9% with reduction of system exergy destruction ratio of (71.43%) with improvement in second law efficiency is 116.2% . Similarly the % improvement in first law efficiency in cascade system-2 is by using R1225ye(Z) is 54.8% with reduction in cascade System EDR is 70.65% with increase in second law efficiency of 113.5%.

Table 8(a):Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O *Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

Performance Parameters	R-1234yf	HFO1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
$COP_{\_MTC}$ (Cascaded VARS-VCRS System_2)	0.4954	0.4993	0.5022	0.4954	0.4993
$EDR_{\_MTC}$ (Cascade VARS-VCRS System_2)	1.044	1.095	0.869	0.9009	0.8926
$ExergeticEfficiency_{\_MTC}$ (Cascade VARS-VCRS System_2)	0.5180	0.5276	0.5351	0.5261	0.5284

Table 8(b): Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O *Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

Performance Parameters	*R1243zf*	R1234ze(E)	R1234ze(Z)
$COP_{\_MTC}$	0.4958	0.4983	0.5105
$EDR_{\_MTC}$	0.9267	0.9038	0.7977
$ExergeticEfficiency_{\_MTC}$	0.5190	0.5253	0.5563

Table 8(c): Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O *Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

Performance Parameters	*R1234yf*	HFO-1336mzz(Z)	R1234zd(E)	R1225ye(z)	R134a
COP_{MTC}	0.4954	0.4993	0.5022	0.4987	0.4996
EDR_{MTC}	0.9306	0.8953	0.8690	0.9009	0.8926
Exergetic $Efficiency_{MTC}$	0.5180	0.5276	0.5351	0.5261	0.5284

Table 8 (d) : % improvement in thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O VARS *with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

% improvement in performance Parameters	R-1234yf	HFO1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
COP_{MTC}(Cascade VARS-VCRS System_2)	53.86	55.07	55.9	54.8	55.16
EDR_{MTC}(Cascade VARS-VCRS System_2)	-69.4	-70.56	-71.43	-70.38	-70.65
Exergetic $Efficiency_{MTC}$(Cascade VARS-VCRS System_2)	109.3	113.20	116.2	112.6	113.5

Table 8(e) : Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O*Vapour absorption refrigeration system with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

% improvement in Performance Parameters	*R1234yf*	HFO-1336mzz(Z)	R1234zd(E)	R1225ye(z)	R134a
COP_{MTC}	53.86	55.07	55.9	54.87	55.16
EDR_{MTC}	-69.40	-70.54	-71.43	-70.38	-70.65
Exergetic$Efficiency_{MTC}$	109.3	113.2	116.2	112.6	113.5

Table 8(f) : % improvement in thermodynamic (energy-exergy) performance parameters on NH_3-H_2O *VARS with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion*

% improvement in performance Parameters	*R1243zf*	R1234ze(E)	R1234ze(Z)
COP_{MTC}	53.99	54.77	58.54
EDR_{MTC}	-69.53	-70.28	-73.77
Exergetic $Efficiency_{MTC}$	109.7	112.3	124.8

Table 9 (a) :Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O *VARS with multi cascading (four stages)VCRS using new HFO ecofriendly refrigerant in medium cycle and R245fa in intermediate temperature cycle and R32 in low temperature cycle*

Performance Parameters	R-1234yf	HFO-1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
COP_{ITC} (multi Cascade VARS-VCRS System_3)	0.5934	0.5984	0.6023	0.5976	0.5986
EDR_{ITC}(multi Cascade VARS-VCRS System_3)	0.4073	0.3797	0.3636	0.3831	0.3780
Exergetic $Efficiency_{ITC}$(multi Cascade VARS-VCRS System_3)	0.7131	0.7248	0.7333	0.7230	0.7257

Table-9(a) shows the thermodynamic first and second law performances of cascaded NH_3H_2O Vapour absorption refrigeration system with multi-cascading of vapour compression refrigeration system (system-3) using ten new HFO ecofriendly refrigerants and multi- cascaded NH_3H_2O Vapour absorption refrigeration system with cascading of vapour compression refrigeration system (system-3) using ten new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that Cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-3) gives better thermodynamic first and second law performances using R1234ze(Z) than using R1234ze(E) and worst thermodynamic first and second law performances using R1234yf was found. Although thermodynamic first and second law performances using R124 are better than R134a. The thermodynamic first and second law performances using HFO-1336mzz(Z) are nearly approaching to the performance using R134a in the cascade system.The performance improvement using ten ecofriendly refrigerants using cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system using new R245fa ecofriendly refrigerant at -95^{o}C of VCRS evaporator temperature for reducing global warming and ozone depletion are shown in Table-9(b) respectively. It was found that HFO-1336mzz(Z) gives similar thermodynamic performance improvement can easily replace R134a in the near future.

Table 9(a-b) are showing the percentage thermodynamic performances improvement of system-3 in terms of first law performance improvement was 85.86% with reduction of system exergy destruction ratio of (87.51%) with improvement in second law efficiency is 192.90 % using HFO-1333mzz(Z) . The % improvement in first law efficiency in cascade system-3 is by using R1233zd(E) is 87.06% with reduction of system exergy destruction ratio of (88.0 %) with improvement in second law efficiency is 196.3% . Similarly the % improvement in first law efficiency in cascade system-3 is by using R1225ye(Z) is 85.6 % with reduction in cascade System EDR is 87.4 % with increase in second law efficiency of 192.2%. It is to be noted that R1234ze(z) gives best thermodynamic first and second law performance but it cannot be used evaporator temperator below 273K .However R1234ze(e) can be used up to evaporator of 243K.

Table 9(b) : % improvement in thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O VARS with multi – cascading (four stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	R-1234yf	HFO-1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
COP_ITC ITC (multi Cascade VARS-VCRS System-3)	84.29	85.86	87.06	85.61	85.98
EDR_ITC ITC (multi Cascade VARS-VCRS System-3)	-86.8	-87.51	-88.04	-87.4	-87.51
ExergeticEfficiency_ITC ITC (multi Cascade VARS-VCRS Sys-3)	188.4	192.9	196.3	192.2	193.2

Table 9(c) : % improvement in thermodynamic (energy-exergy) performance parameters on triple effect NH_3-H_2O VARS with multi cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	*R1243zf*	R1234ze(E)	R1234ze(Z)
COP_ITC multi Cascade VARS-VCRS System_3)	84.48	85.48	90.37
EDR_ITC multi Cascade VARS-VCRS System_3)	-86.88	-87.34	-89.46
Exergetic Efficiency_ITC multi Cascade VARS-VCRS System_3)	188.9	191.8	206.0

Table 10(a) : Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O Vapour absorption refrigeration system with multi cascading (fourstages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

Performance Parameters	R-1234yf	HFO-1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
COP_LTC	0.6433	0.6489	0.6531	0.6480	0.6493
EDR_LTC	0.1407	0.1251	0.1136	0.1276	0.1239
Exergetic Efficiency_LTC	0.8767	0.8888	0.8980	0.8869	0.8897

Table-10(a) shows the thermodynamic first and second law performances of cascaded NH_3H_2O Vapour absorption refrigeration system with multi-cascading of vapour compression refrigeration system (system-4) using ten new ten new HFO ecofriendly refrigerants in medium temperature cycle and R245fa in intermediate temperature cycle and R32 in lower temperature cycle of evaporator temperature of -130ºC for reducing global warming and ozone depletion and it was found that multi cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system (system-4) gives better thermodynamic first and second law performances using R1234ze(Z) than using R1234ze(E) and worst thermodynamic first and second law performances using R1234yf was found. Although thermodynamic first and second law performances using R124 are better than R134a. The thermodynamic first and second law performances using HFO-1336mzz(Z) are nearly approaching to the performance using R134a in the cascade system.The performance improvement using ten ecofriendly refrigerants using cascaded NH_3-H_2O vapour absorption refrigeration system with vapour compression refrigeration system using new R32 ecofriendly refrigerant at -130ºC of VCRS evaporator temperature for reducing global warming and ozone depletion are shown in Table-10(b) respectively. It was found that HFO-1336mzz(Z) gives similar thermodynamic performance improvement can easily replace R134a in the near future.

Fig-11(b) shows the percentage thermodynamic performances improvement of system-3 in terms of first law performance improvement was 101.5% with reduction of system exergy destruction ratio of (95.89 %) with improvement in second law efficiency is 259.2% using HFO-1333mzz(Z). The % improvement in first law efficiency in cascade system-4 is by using R1233zd(E) is 102.8% with reduction of system exergy destruction ratio of (96.27%) with improvement in second law efficiency is 262.9% . Similarly the % improvement in first law efficiency in cascade system-4 is by using R1225ye(Z) is 101.3% with reduction in cascade System EDR is 95.81% with increase in second law efficiency of 258.4%. The second law performance using following refrigerants nearly similar improvement as HFC-134a. Therefore these rHFO refrigerants can replace R134a in near future. For evaporator temperature up to 243K, the R1234ze(Z) and can replace R134a in near future. However R1234zf can be used up to evaporator temperature of 263K and the performance is nearly similar to R1234yf.

Table 10 (b): Thermodynamic (Energy-Exergy) performance Parameters on NH_3-H_2O VARS with multi cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in Performance Parameters	*R1234yf*	HFO-1336mzz(Z)	R1233zd(E)	R1225ye(z)	R134a
COP_LTC	99.81	101.5	102.8	101.3	101.7
EDR_LTC	95.37	-95.89	-96.27	-95.81	-95.92
ExergeticEfficiency_LTC	254.3	259.2	262.9	258.4	259.5

Table 10 (c): % improvement in thermodynamic (energy-exergy) performance parameters on NH_3-H_2O VARS with multi – cascading (three stages) vapour compression refrigeration system using new HFO ecofriendly refrigerant for reducing global warming and ozone depletion

% improvement in performance Parameters	R1243zf	R1234ze(E)	R1234ze(Z)
COP_LTC	100%	101.1	106.4
EDR_LTC	-95.43	-95.76	-97.28
Exergetic Efficiency_LTC	254.8	258.0	273.3

4. Conclusions

The following conclusions were drawn from present investigation.

- Single cascading of vapour compression refrigeration with NH_3H_2O vapour absorption refrigeration systems improves thermodynamic first and second law performance using ten ecofriendly HFO refrigerants in the medium temperature cycle up to evaporator temperature of VCRS -50ºC
- Double cascading of vapour compression refrigeration with NH_3H_2O vapour absorption refrigeration systems improves thermodynamic first and second law performance significantly using ten ecofriendly HFO refrigerants medium temperature cycle up to evaporator temperature of VCRS -50ºC and R245fa in intermediate temperature cycle up to -95ºC.
- Triple cascading of vapour compression refrigeration with NH_3H_2O vapour absorption refrigeration systems improves thermodynamic first and second law performance significantly using ten ecofriendly HFO refrigerants medium temperature cycle up to evaporator temperature of VCRS-50ºC and R245fa in intermediate temperature cycle up to-95ºC and R32 in lower temperature cycle up to -130 ºC
- Triple cascading of vapour compression refrigeration with NH_3H_2O vapour absorption refrigeration systems improves thermodynamic first and second law performance significantly using ten ecofriendly HFO refrigerants medium temperature cycle up to evaporator temperature of VCRS-50ºC and R245fa in intermediate temperature cycle up to -95ºC and R600a in lower temperature cycle up to -150 ºC
- R1233zd(E) gives best thermodynamic first and second law as compared to HFO13336mzz(Z)
- R1234yf gives worst /lowest performance as compared to R1233zd(E) and HFO13336mzz(Z).

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