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ORIGNAL ARTICLE

Performance evaluation of single effect Li/Br-H_2O vapour absorption refrigeration system with three cascaded vapour compression refrigeration systems using HFO refrigerants for ultra-low temperature applications

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Abstract

The potential alternative absorption refrigeration technology is due to the utilization of renewable and nonrenewable energy resources through vapour compression–absorption refrigeration systems for ultra-low temperature applications. The main issues observed with the vapour absorption refrigeration systems are low overall COP and large size of system which is mainly due to the reduced thermodynamic performance.
This paper mainly deals with the utility of HFO refrigerants in cascaded vapour compression cycles for low temperature and ultra-low temperature applications using single effect Li/Br-H_2O absorption unit. The percentage improvement in overall first law (energy) performance of cascaded system is 7.88% to 8.67% using R1233zd(E), 3.36% to 4.15% by using R1225ye(Z) and 4.66% to 5.45% using HFO-1336mzz(Z) by increasing the generator temperature from 90oC to 120oC, and percentage improvement in exergetic efficiency. from 26.1% to 55.67% by using R1233zd(E) and 17.43% to45.5 % by using R1225ye(Z) and17.4% to 45.49% by using HFO-1336mzz(Z) for low evaporator temperature of -65oC respectively. However, the performances decrease by increasing condenser and absorber temperatures.

1. Introduction

For reducing global warming and ozone depletion and maximizing the use of natural and renewable energy resources with minimal environmental impacts is key building of an energy efficient sustainable system. Although completely sustainable energy efficient system would require a fully reversible process, exploits the second law of thermodynamics which proves is not possible, which indicating that all real processes are irreversible and impact on the environment. Approaching sustainability can yield greater benefits both the current and future environment. The utilization of natural and renewable resources in a responsible fashion and by using efficient methods is important aspect when developing new technologies and analyzing current refrigeration and air conditioning systems. The conventional vapour compression refrigeration systems and vapour absorption systems utilize different working fluids. Many of the vapour compression systems use the ozone depleting chloro-fluoro-carbon refrigerants (CFCs), Hydro-chloro-fluoro-carbon refrigerants (HCFCs), Hydro-fluoro-carbon refrigerants (CFCs), because of the thermo-physical properties obtainable by them. Many industrial processes frequently produce a significant amount of thermal energy; regularly by burning fossil fuels for heat or

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steam. The opportunities to convert wastes or excess heat into useful cooling can be done by integration of absorption refrigeration systems into these systems. Szargut et al [1]. suggested that exergy methods should be considered to better realize increased efficiencies and environmental impacts because exergy is normally considered to be the measure of work potential (i.e. maximum work) that can be obtained from a system with respect to its environment. The exergy, is a non-conserved quantity, and exergy balances account for inputs, losses and wastes of a process. the exergy input and destruction rates provide an accounting of the utilized efficiency of resources used. Rosen and Dincer [2] have given links between energy, exergy and sustainable development, which shows that exergy may allow for measuring impacts on the environment

Gebreslassie et al [3] had evaluated exergy in Lithium bromide (Li/Br) absorption systems by using structural method to obtain a simplified equation to estimate the optimum heat exchanger area for absorption cooling system and assessed the relationship between heat exchange area and exergy. Also concluded that in the optimum case, the maximum exergy destruction was in the solution heat exchanger and the condenser while in all other components, the destruction rates decreasing as increased heat exchange area and presented at detailed analysis of exergy for half to triple effect absorption chillers. Bereche et al [4] analyzed single and double-effect LiBr systems using a thermo-economic analysis and exergy and concluded that the single-effect absorption refrigeration systems are suitable utilizing waste heat or operating in cogeneration systems because of their operation at lower temperatures compared to double-effect chillers, Morosuk and Tsatsaron [5] is presented an exergy analysis of the internal components of absorption refrigeration machines. And concluded that the absorber and generator destroyed about 40% of their exergy and are main (primary) candidates for improvement. Kilic and Kaynakli [6] carried out a second law(exergy) thermodynamic analysis of water and lithium bromide absorption refrigeration and found the evaporator is a major component for the exergy loss rates and concluded that the generator, absorber and evaporator were the largest sources of exergy destruction. Garimella et al [7] proposed absorption/vapour compression cascade refrigeration system driven by waste heat used in naval ship and concluded that electricity consumption is reduced by 31% than that of conventional vapour compression refrigeration system.

The large number of research studies on cascade refrigeration systems have been done. These research studies provide valuable insights about energy and exergy analysis of VCR, VAR cycles in the single, double and triple stage and compression-absorption in the form of cascade cycles. Most of the research studies considered till date emphasize on VCR and VAR cycles (single and double effect, triple and half effect in Li/Br-H_2O and NH_3H_2O). Mishra [8] carried out exergy- energy analysis of compression-absorption (combined) or cascade cycles. Though, exhaustive research has been carried out on cascade cycles, but very less consideration has been given to explore the thermodynamic performance using HFO refrigerants in the range from -30ºC to -150ºC and none of the research work is available on performance analysis of compression-absorption cascade refrigeration system using HFO refrigerants. Radhey Shyam Mishra [9-10] carried out thermodynamic performance of the HFO refrigerants in the medium temperature compression stage between 5ºC to -50ºC and NH_3H_2O, Li/Br-H_2O refrigerants in the absorption stage and its overall effect on the cascade system. The effect of these HFO refrigerants on the intermediate temperature in the range of (-50ºC to 95ºC) using R245fa of medium temperature cycle cascade system using R32 refrigerant/ hydrocarbons in ultra-low evaporator temperature first and second law performances using the pair of NH_3–H_2O in the high temperature absorption stage and HFO refrigerants at the evaporator temperature of 223K (-50ºC) and R245fa in the medium temperature compression cycle for evaporator temperature of -95ºC evaluated the effect of various performance parameters of multi cascade refrigeration system in which a compression system at the low temperature stage using R32 in low temperature cycle at evaporator temperature of -130ºC . It is found that R1233zd (E), R1225ye(Z) and HFO-1336mzz(z) gives better thermodynamic performances than using R1243yf. The studies carried out so far on the double and triple effect cycles in the use of HFO refrigerants up to evaporator temperature of -50ºC in cascaded vapour compression refrigeration systems. to some extent, the effect of HFO refrigerants in the intermediate temperature cycle at -75ºC and -95ºC is missing. Also the effect of HFO –refrigerants in ultra-low temperature cycle of compression –absorption refrigeration systems have not been investigated so far. The present study has therefore been carried out the effect of HFO refrigerants in intermediate temperature cycle(ITC) up to -95ºC and LTC evaporator of -135ºC and -150ºC.

2. Results and Discussion

Following systems have been taken for performance evaluations.

System-1

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1233zd(E) in medium temperature cycle at evaporator temperature =-50ºC, R-1225ye(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -150ºC.

System-2

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1233zd(E) in medium temperature cycle at evaporator temperature =-50ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -150ºC.

System-3

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234yf in medium temperature cycle at evaporator temperature =-50ºC, R-1225ye(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -150ºC.

System-4

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234yf) in medium temperature cycle at evaporator temperature =-50ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -150ºC.
Following numerical values have been used for validation of code developed for Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants.

- Generator temperature= 110ºC
- Absorber temperature=35ºC
- Condenser temperature =35ºC
- VARS evaporator temperature=10ºC
- load on VARS Evaporator= 175 kW
- Ambient (dead state) temperature=25ºC
- Temperature overlapping in MTC = 10ºC
- VCR evaporator temperature of MTC=-50ºC
- VCR evaporator temperature of ITC=-95ºC
- VCR evaporator temperature of LTC=-150ºC
- VCR compressor efficiency of MTC= 80%
- VCR compressor efficiency of ITC= 80%
- VCR compressor efficiency of MTC= 80%
- Ambient (dead state) temperature=25ºC

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table 2(a) respectively. It was observed that system-6 has lowest thermodynamic performances than system-5, however first law thermodynamic performance improvement is less. Similarly, Thermodynamic second law exergy performances of cascaded single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table-2(b) respectively. It was observed that system-6 has higher thermodynamic exergetic performances than system-5.

Table-1(a) Thermodynamic first law (energetic) Performances of Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-150ºC

Integrate system	COP_{VARS}	$COP\ \_{MTC}$	$COP\ \_{ITC}$	$COP\ \_{LTC}$	% Improvement in $COP\ \_{MTC}$	% Improvement in $COP\ \_{ITC}$	% Improvement in $COP\ \_{LTC}$
System-1	0.7560	0.8759	0.9847	0.9236	15.86	30.65	22.17
System-2	0.7560	0.8759	0.9847	0.9282	15.86	30.26	22.79
System-3	0.7560	0.8102	0.9120	0.8634	7.168	20.64	14.22
System-4	0.7560	0.8102	0.9120	0.8674	7.168	20.31	14.74

Table-1(b) Thermodynamic second law (exergetic) Performances of Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-150ºC

Integrate system	ETA_{VARS}	ETA_{MTC}	ETA_{ITC}	ETA_{LTC}	% Improvement in ETA_{MTC}	% Improvement in ETA_{ITC}	% Improvement in ETA_{LTC}
System-1	0.1564	0.321	0.5331	0.5539	77.98	195.3	206.8
System-2	0.1564	0.321	0.5293	0.5639	77.98	193.1	212.3
System-3	0.1564	0.2680	0.4561	0.4890	48.94	152.6	170.9
System-4	0.1564	0.2689	0.4530	0.4974	48.94	150.9	175..5

Table-1(c) Thermodynamic exergy destruction ratio of Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature= -150ºC

Integrate system	EDR_{VARS}	EDR_{MTC}	EDR_{ITC}	EDR_{LTC}	% Improvement in EDR_{MTC}	% Improvement in EDR_{ITC}	% Improvement in EDR_{LTC}
System-1	4.539	2.112	0.8754	0.8053	-53.47	-80.7	-82.26
System-2	4.539	2.112	0.8894	0.7735	-53.47	-80.4	-82.96
System-3	4.539	2.719	0.8754	0.8053	-40.10	-73.72	-76.98
System-4	4.539	2.719	0.8754	0.8053	40.10	-73.40	-77.74

However, second law thermodynamic exergetic performance improvement for -150ºC evaporator temperature is less. It means by putting HFO-1336mzz(Z) in lower temperature cycle in system-5 gives lower first and second law thermodynamic performances than using R-1225ye(Z) in low temperature cycle. However, first law(energy) and second law exegetic performances of double stage cascaded integrated system-5 is higher than double stage cascaded integrated system-6 at evaporator temperature of -95ºC.It means by putting HFO-1336mzz(Z) in intermediate temperature cycle gives lower first and second law thermodynamic performances than using R-1225ye(Z). The exergy destruction ratio of whole cascaded system is shown in Table-2(c) respectively.

System-5

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234ze(Z) in medium temperature cycle at evaporator temperature =-30ºC, R1225ye(Z) in intermediate temperature cycle at evaporator temperature = -75ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-6

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234ze(Z) in medium temperature cycle at evaporator temperature =-30ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -75ºC and using R1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-7

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234ze(E) in medium temperature cycle at evaporator temperature =-30ºC, R1225ye(Z) in intermediate temperature cycle at evaporator temperature = -75ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-8

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234ze(E) in medium temperature cycle at evaporator temperature =-30ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -75ºC and using R1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-9

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1243zf in medium temperature cycle at evaporator temperature =-50ºC, R-1225ye(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-10

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1243zf in medium temperature cycle at evaporator temperature =-30ºC, HFO-1336mzz(Z)in intermediate temperature cycle at evaporator temperature = -75ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-11

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1233zd(E) in medium temperature cycle at evaporator temperature =-50ºC, R-1225ye(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-12

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1233zd(E) in medium temperature cycle at evaporator temperature =-50ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -150ºC.

System-13

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234yf in medium temperature cycle at evaporator temperature =-50ºC, R-1225ye(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System14

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234yf in medium temperature cycle at evaporator temperature =-50ºC, HFO-1336mzz(Z) in intermediate temperature cycle at evaporator temperature = -95ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-15

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R-1225ye(Z) in medium temperature cycle at evaporator temperature =-50ºC, R1233zd(E) in intermediate temperature cycle at evaporator temperature = -95ºC and using HFO-1336mzz(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-16

Li/Br-H_2O single effect vapour absorption refrigeration system at 10ºC of evaporator temperature cascaded with three stages vapour compression refrigeration system using R1234yf in medium temperature cycle at evaporator temperature =-50ºC, R1233zd(E) in intermediate temperature cycle at evaporator temperature = -95ºC and using R-1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

Following numerical values have been used for validation of code developed for Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants

- Generator temperature= 110ºC
- Absorber temperature=35ºC
- Condenser temperature =35ºC
- VARS evaporator temperature=10ºC
- load on VARS Evaporator= 175 kW
- Ambient (dead state) temperature=25ºC
- Temperature overlapping in MTC = 10ºC
- VCR evaporator temperature of MTC=-30ºC
- VCR evaporator temperature of ITC=-75ºC
- VCR evaporator temperature of LTC=-135ºC
- VCR compressor efficiency of MTC= 80%
- VCR compressor efficiency of ITC= 80%
- VCR compressor efficiency of MTC= 80%
- Ambient (dead state) temperature=25ºC

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table 2(a) respectively. It was observed that system-2 has lowest thermodynamic performances than system-1, however first law thermodynamic performance improvement is less

Table-2(a) Thermodynamic first law (energetic) Performances of Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-135ºC

Integrate system	COP_{VARS}	$COP\_{\_MTC}$	$COP\_{\_ITC}$	$COP\_{\_LTC}$	%Improvement in $COP\_{\_MTC}$	%Improvement in $COP\_{\_ITC}$	% Improvement in $COP\_{\_LTC}$
System-5	0.7560	1.002	1.145	1.05	32.56	51.44	38.96
System-6	0.7560	1.002	1.143	1.057	32.58	51.15	39.82
System-7	0.7560	0.9662	1.104	1.020	27.81	46.032	34.92
System-8	0.7560	0.9662	1.102	1.057	27.81	45.82	35.75
System-9	0.7560	0.9698	1.108	1.057	28.29	46.62	35.35
System-10	0.7560	0.9698	1.106	1.057	28.29	46.36	36.16
System-11	0.7560	0.9961	1.138	1.057	31.76	50.53	38.28
System-12	0.7560	0.9961	1.138	1.045	31.76	50.53	38.28
System-13	0.7560	0.9431	1.078	1.0	24.76	42.62	32.31
System-14	0.7560	0.9431	1.076	1.006	24.76	42.37	32.08
System-15	0.7560	0.9634	1.102	1.018	2744	45.74	34.68
System-16	0.7560	0.9794	1.120	1.039	29.56	48.13	37.5

Table-2(b) Thermodynamic second law (exergetic) Performances of Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-135ºC

Integrate system	ETA_{VARS}	ETA_{MTC}	ETA_{ITC}	$ETA\_{\_LTC}$	%Improvement in ETA_{MTC}	% Improvement in ETA_{ITC}	%Improvement in $ETA\_{\_LTC}$
System-5	0.1560	0.322	0.5278	0.5383	78.49	192.3	198.1
System-6	0.1560	0.3223	0.5255	0.5491	78.49	191.0	204.1
System-7	0.1560	0.2970	0.4936	0.5126	64.50	173.5	183.5
System-8	0.1560	0.2970	0.4917	0.5227	64.5	172.3	189.5
System-9	0.1560	0.2992	0.4972	0.5152	65.86	175.4	185.3
System-10	0.1560	0.2995	0.4951	0.5253	65.86	174.5	191.0
System-11	0.1560	0.3170	0.5219	0.5339	76.04	189.1	195.7
System-12	0.1560	0.3170	0.5219	0.5339	76.04	189.1	195.7
System-13	0.1560	0.2817	0.4723	0.4958	55.96	161.6	174.6
System-14	0.1560	0.2816	0.4704	0.5054	55.96	160.5	179.9
System-15	0.1560	0.2950	0.4918	0.5110	55.96	172.4	183.0
System-16	0.1560	0.3061	0.5068	0.5347	69.54	180.7	196.1

Table-2(c) Thermodynamic exergy destruction ratio of Integrated single effect Li/Br-H_2O VARS at evaporator temperature=-135ºC

Integrate system	EDR_VARS	EDR_MTC	EDR_ITC	ED R_ L TC	% Improve in EDR_MTC	%Improvement in EDR_ITC	%Improvement in EDR_ LTC
System-5	4.539	2.103	0.9031	0.8212	-53.66	-80.10	-81.91
System-6	4.539	2.103	0.8947	0.8577	-53.66	-80.29	-81.1
System-7	4.539	2.367	1.025	0.9529	-47.85	-77.41	-79.05
System-8	4.539	2.367	1.034	0.9133	-47.82	-77.23	-79.88
System-9	4.539	2.339	1.011	0.9410	-48.46	-77.72	-79.23
System-10	4.539	2.339	1.02	0.9036	-48.46	-77.53	-80.09
System-11	4.539	2.146	0.916	0.8729	-52.71	-79.82	-80.77
System-12	4.539	2.146	0.916	0.8729	-52.71	-79.82	-80.77
System-13	4.539	2.551	1.117	1.017	-43.79	-75.39	-77.6
System-14	4.539	2.551	1.126	0.9785	-47.37	-77.23	-78.92
System-15	4.389	2.551	1.033	0.9569	-43.79	-75.19	-78.44
System-16	4.539	2.267	0.9730	0.8703	-50.06	-78.56	-80.83

Similarly, Thermodynamic second tlaw exergy performances of cascaded single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table-2(b) respectively. It was observed that system-2 has higher thermodynamic exergetic performances than system-1. However, second law thermodynamic exergetic performance improvement for -150ºC evaporator temperature is less. It means by putting HFO-1336mzz(Z) in lower temperature cycle in system-1 gives lower first and second law thermodynamic performances than using R-1225ye(Z) in low temperature cycle. However, first law(energy) and second law exegetic performances of double stage cascaded integrated system-1 is higher than double stage cascaded integrated system-2 at evaporator temperature of -95ºC.It means by putting HFO-1336mzz(Z) in intermediate temperature cycle gives lower first and second law thermodynamic performances than using R-1225ye(Z). The exergy destruction ratio of whole cascaded system is shown in Table-2(c) respectively.

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with varying evaporator temperature is shown in table -3 respectively. It was observed that by increasing VAR evaporator temperature, the thermodynamic first law (energy) performance is increases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases. Similarly, Thermodynamic second law exergy performances of cascaded single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with variation of absorber temperature is shown in table-4 respectively. It was observed thermodynamic performances
is decreases, by increasing absorber temperature.

Table-3 Thermodynamic (exergy) performances of Integrated single effect Li/Br-H2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Evaporator temperature of VARS (ºC)	COP_VARS	EDR	Exergetic Efficiency	COP_ cascade	EDR_ cascade	Exergetic Efficiency_ cascade	% Improvement in COP _ cascade	% Decrement in EDR _ cascade	%Improv-ment in Exergetic Efficiency _ cascade
3	0.7360	2.783	0.2643	0.7789	1.933	0.3410	5.03	-30.56	29.0
4	0.7410	2.964	0.2523	0.7808	1.970	0.3367	5.03	-33.55	33.48
5	0.7560	3.163	0.2402	0.7827	2.008	0.3325	5.03	-36.52	38.41
6	0.7438	3.382	0.2282	0.7848	2.046	0.3283	5.03	-39.49	43.84
7	0.7466	3.624	0.2163	0.7869	2.085	0.3241	5.03	-42.46	49.87
8	0.7496	3.894	0.2043	0.7892	2.125	0.320	5.03	-45.42	56.60
9	0.7525	4.197	0.1924	0.7916	2.166	0.3159	5.16	-48.40	64.16
10	0.7560	4.539	0.1805	0.7940	2.207	0.3119	5.03	-51.38	72.73

Table-4 Effect of Absorber temperature on thermodynamic performances of Integrated single effect Li/Br-H2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Absorber temperature of VARS (ºC)	COP_VARS	EDR	Exergetic Efficiency	COP _ cascade	EDR_ cascade	Exergetic Efficiency_ cascade	% Improvement in COP _ cascade	% Decrement in EDR _ cascade	% Improvement in Exergetic Efficiency _ cascade
30	0.7486	3.121	0.2427	0.7885	1.997	0.3337	5.323	-36.02	37.51
35	0.7410	3.163	0.2402	0.7827	2.008	0.3325	5.627	-36.52	38.41
40	0.7353	3.195	0.2384	0.7784	2.016	0.3315	5.856	-36.90	39.09
45	0.7312	3.219	0.2370	0.7752	2.022	0.3309	6.023	-37.17	39.59

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with varying Condenser temperature is shown in table -5 respectively. It was observed that by increasing VARS Condenser temperature, the thermodynamic first law (energy) performance is decreases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases. Similarly, Thermodynamic performances of cascaded single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with variation of generator temperature is shown in table-6 respectively. It was observed thermodynamic performances is decreases, by increasing generator temperature.

Table-5 Effect of condenser temperature on thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Condenser temperature of VARS (ºC)	COP_VARS	EDR	Exergetic Efficiency	COP _cascade	EDR_cascade	Exergetic Efficiency_cascade	% Improvement in COP _cascade	% Decrement in EDR _cascade	%Improv-ment in Exergetic Efficiency _cascade
30	0.7472	3.129	0.2422	0.7874	2.003	0.3330	5.38	-36.11	37.61
32	0.7449	3.141	0.2415	0.7857	2.004	0.3328	5.470	-36.26	37.94
34	0.7423	3.156	0.2406	0.7837	2.006	0.3327	5.574	-36.44	38.25
35	0.7410	3.163	0.2402	0.7827	2.008	0.3325	5.627	-36.52	38.41
36	0.7398	3.170	0.2398	0.7818	2.070	0.3323	5.678	-36.61	38.56
38	0.7374	3.183	0.2390	0.780	2.013	0.3319	5.773	-36.76	38.84
40	0.7353	3.195	0.2384	0.7784	2.016	0.3315	5.856	-36.90	39.09
42	0.7336	3.205	0.2378	0.7771	2.019	0.3313	5.925	-37.01	39.30
44	0.7322	3.213	0.2373	0.7760	2.021	0.3310	5.983	-37.11	39.47
45	0.7315	3.217	0.2371	0.7755	2.022	0.3309	6.009	-37.15	39.55

Table-6 Effect of generator temperature on thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Generator temperature of VARS (ºC)	COP_VARS	EDR_VARS	Exergetic Efficiency_VARS	COP _MTC	EDR _MTC	Exergetic Efficiency _ M TC	%Improve-ment in COP _MTC	%Improve-ment in COP _ITC	%Improv-ment in COP _ LTC
90	0.7596	2.277	0.3052	0.8194	1.599	0.3849	7.881	-29.79	26.10
95	0.7532	2.510	0.2849	0.8145	1.657	0.3761	8.132	-33.98	32.10
100	0.7478	2.737	0.2676	0.8103	1.715	0.3684	8.346	-37.37	37.67
105	0.7437	2.955	0.2528	0.8070	1.770	0.3611	8.509	-40.13	42.82
110	0.7410	3.163	0.2402	0.8049	1.822	0.3544	8.618	-42.40	47.53
115	0.7388	3.364	0.2291	0.8031	1.873	0.3481	8.709	-44.34	51.93
120	0.7399	3.541	0.2202	0.8040	1.917	0.3428	8.665	-45.87	55.68

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with varying generator temperature for constant evaporator temperature of -75ºC in lower vapour compression cycle is shown in tables -7 for R1233zd(E), R1225ye(Z) and HFO-1336mzz(Z) respectively. It was observed that by increasing VARS Condenser temperature, the thermodynamic first law (energy) performance is decreases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases. Similarly, Thermodynamic performances of cascaded single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems with variation of generator temperature is shown in table-6 respectively. It was observed thermodynamic performances

Table-7(a) Effect of generator temperature on thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-75ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Generator temperature of VARS (ºC)	COP_Cascade	EDR_ Cascade	Exergetic Efficiency_ Cascade
90	0.8194	1.599	0.3849
95	0.8145	1.657	0.3761
100	0.8103	1.715	0.3684
105	0.8070	1.770	0.3611
110	0.8049	1.822	0.3544
115	0.8031	1.873	0.3481
120	0.8040	1.917	0.3428

Table-7(b) Effect of generator temperature on improvement in thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-75°C, T_Eva_VARS= 5°C, Approach=, 5°C

Generator temperature of VARS (°C)	% improve-ment in $COP_{Cascade}$	% decre-ment in $EDR_{Cascade}$	% improvement in Exergetic $Eff_{Cascade}$
90	7.881	-29.79	26.10
95	8.132	-33.98	32.10
100	8.346	-37.36	37.67
105	8.509	-40.13	42.82
110	8.618	-42.40	47.53
115	8.709	-44.34	51.93
120	8.665	-45.87	55.68

Table-7(c) Effect of generator temperature on thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using HFO1336mzz(Z) ecofriendly refrigerants at MTC evaporator temperature=-75°C, T_Eva_VARS= 5°C, Approach=, 5°C

Generator temperature of VARS (°C)	$COP_{cascade}$	$EDR_{cascade}$	Exergetic $Efficiency_{cascade}$
90	0.7950	1.790	0.3594
95	0.7902	1.852	0.3507
100	0.7478	1.911	0.3435
105	0.7437	1.968	0.3369
110	0.7410	2.022	0.3309
115	0.7388	2.075	0.3252
120	0.7399	2.122	0.3204

Table-7(d) Effect of generator temperature on percentage improvement in thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using HFO1336mzz(Z) ecofriendly refrigerants at MTC evaporator temperature=-65°C, T_Eva_VARS= 5°C, Approach=, 5°C

Generator temperature of VARS (°C)	% improvement in $COP_{cascade}$	% decrement in $EDR_{cascade}$	% improvement in Exergetic $Efficiency_{cascade}$
90	4.662	-21.36	17.43
95	4.914	-26.26	23.10
100	5.129	-30.18	28.38
105	5.293	-33.41	33.26
110	5.402	-36.06	37.73
115	5.493	-38.32	41.92
120	5.449	-40.09	45.49

Table-7(e) Effect of generator temperature on thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1225ye(Z) ecofriendly refrigerants at MTC evaporator temperature=-65°C, T_Eva_VARS= 5°C, Approach=, 5°C

Generator temperature of VARS (°C)	$COP_{cascade}$	$EDR_{cascade}$	Exergetic $Efficiency_{cascade}$
90	0.7851	1.874	0.3479
95	0.7532	1.936	0.3406
100	0.7478	1.997	0.3337
105	0.7437	2.055	0.3274
110	0.7410	2.11	0.3216
115	0.7388	2.163	0.3161
120	0.7399	2.211	0.3115

Table-7(f) Effect of generator temperature on percentage improvement thermodynamic performances of Integrated single effect Li/Br-H_2O VARS using R1225ye(Z) ecofriendly refrigerants at MTC evaporator temperature=-75°C, T_Eva_VARS= 5°C, Approach=, 5°C

Generator temperature of VARS (°C)	% improve-ment in $COP_{cascade}$	% decre-ment in $EDR_{cascade}$	% improvement in Exergetic $Efficiency_{cascade}$
90	3.359	-17.69	17.43
95	3.612	-22.87	23.10
100	3.827	-27.06	28.38
105	3.991	-30.48	33.26
110	4.10	-33.29	37.73
115	4.192	-35.70	41.92
120	4.148	-37.58	45.49

3. Conclusions

Following conclusions were drawn from present investigations

- By reducing the exergy destruction rate by using HFO refrigerants therefore, sustainability improved.
- The best thermodynamic performances were observed by using R1234ze(Z) and R1233zd(E), HFO-1336mzz(Z), and R1225ye(Z) and R1234ze(E) and R1243zf performance
- The lowest thermodynamic performances were fund by using R1234yf in cascaded system in lower circuit up to a VCR evaporator temperature
- In single cascading with VARS, at low temperature applications up to -30°C evaporator temperature, HFO ecofriendly refrigerants (R-1234ze(Z), R-1234ze(E), R1233zd(E), R-1243zf, R1225ye(Z), HFO-1336mzz(Z) and R1234yf will be certainly useful for replacing HFC, HCFC and CFC refrigerants, while R1224yd(Z) will be suitable for -10°C above evaporator temperature for replacing R134a.
- In single cascading with VARS, at low temperature applications up to -50°C evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), R1233zd(E), HFO-1336mzz(Z) and R1234yf will be certainly useful for replacing HFC, HCFC and CFC refrigerants.
- In the double cascading with VARS, at low temperature applications up to -75°C evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), R1233zd(E), HFO-1336mzz(Z) will be certainly useful for replacing HFC, HCFC and CFC refrigerants and can be better than replacing R134a
- In the triple cascading with VARS, at ultra-low temperature applications up to -150°C evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), HFO-1336mzz(Z) will be certainly useful for replacingR32, and, HCFC and CFC refrigerants.

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