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ORIGINAL ARTICLE

Thermal performance evaluation of half effect Li/Br-H2O vapour absorption refrigeration system with single & multi cascaded vapour compression refrigeration systems using HFO refrigerants for replacing HFC-134a

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Abstract

In the present scenario, the energy, exergy, economy, environment and safety strategies are the major issues which are being considered for evaluating thermodynamic performances of vapour compression and absorption refrigeration cycles both having higher as well as lower evaporator temperatures. The technologies of mechanical refrigeration systems are consistently working in thermodynamic processes which also contribute electricity consumption and environmental impact having low thermodynamic performances. These processes also include vapour compression refrigeration with vapour absorption refrigeration systems using half, single, double and triple effect. To improve thermodynamic first (energy) and second law(exergy) performances, the cascading of these refrigeration cycles are essential

In this paper, half effect Li/Br-H_2O absorption-compression systems using ecofriendly eight HFO ultra low GWP refrigerants for evaporator temperature of -75ºC in single cascading and -150ºC in multi-cascading have been compared with HFC-134a for reducing global warming and it was found that the optimum exergetic efficiency is 33.55% low temperature evaporator temperature ranging from -60ºC to -63ºC and for HFO-1336mzz(Z) is 32.51% of the optimum low temperature evaporator is-58º C and -59º C and 32.32% using R1225ye(Z) of the optimum low temperature evaporator -57º C and -58º C respectively. ©2021 ijrei.com. All rights reserved

1. Introduction

The first law (energy) and second law (exergetic) efficiency in particular, are very important to be considered for designing of refrigeration systems by considering global warming and ozone depletion potentials in general. The concepts of Global Warming Potential (GWP) and ozone depletion potential (ODP) are also be important for consideration in environmental impact particularly in HFO refrigerants. However, GWP is an index which allows a simple comparison to be make between the with warming effects of different gases on a kg to kg basis relative to carbon. Therefore, GWP depends on the lifetime of a substance in the atmosphere and its infra-red absorption capacity. Chlorofluorocarbons (CFCs) which have been widely used as refrigerants are powerful greenhouse gases producer with high GWPs due to the bank of CFCs in refrigerating systems, and their levels in the atmosphere are still increasing and it will be some time before refrigerant changes will be effective in reducing the global warming effects of refrigerant releases [1].

The Hydrocarbons(HC) are in limited use due to its flammable nature. However, hydroflourocarbons (HFC) are also to be limited due to its higher GWP. Similarly, ammonia (R-717) all

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have a part to play as substitute refrigerants but due to its toxic nature and not used for domestic applications but can easily be used in industrial refrigeration and air conditioning systems. For analyzing vapour compression and absorption refrigeration systems, the evaluation of energetic and exergetic efficiencies are very important for reducing CO_2 emissions. The exergetic efficiency is defined in terms exergy of product to exergy of fuel. Therefore, ultra-low GWP ecofriendly HFO refrigerants can solve such problems due to its similar to thermodynamic performances for replacing CFC, HCFC and HFC refrigerants in vapour compression systems. The main drawback is in VCRS is higher compressor work which can be reduced by using vapour absorption refrigeration systems. The thermodynamic performances of Li/Br-H_2O and NH_3H_2O VARS are lower and its capacity size is larger. By using compression-absorption system can have reduced the compressor work in VCRS and overall system performances increased [2].

In this paper, half effect Li/Br-H_2O absorption-compression systems using ecofriendly eight HFO ultra low GWP refrigerants for evaporator temperature of -75ºC in single cascading and -150ºC in multi-cascading have been compared with HFC-134a for reducing global warming have been considered.

2. Thermodynamic Performances of Vapour compression absorption refrigeration systems

Exergy is commonly considered to be the measure of work potential or maximum work that can be obtained from a system with respect to its environment or the quality of a heat source. Exergy, unlike energy, is a non-conserved quantity, and exergy balances account for inputs, losses and wastes of a process. Exergy input and destruction rates provide an accounting of the efficiency of resources used. Dincer and Rosen [3,4,5] have developed the relationship between energy, exergy and sustainable development and have shown that exergy might allow for measuring impacts on the environment. Mishra et al. [6] suggested that exergy methods should be considered to better realize increased efficiencies and environmental impacts.

Several investigators [7-8] have reported that the consumption of electricity in the cascade refrigeration system is lower in comparison to the conventional vapour compression refrigeration system. Lithium bromide (Li/Br-H_2O) absorption refrigeration systems have been evaluated based on their exergy computation [8]. Colorado and Rivera [9] compared the thermodynamic performances of a conventional vapour compression system with compression-absorption cascaded refrigeration systems and found 45% lower electrical energy consumption in cascaded compression-absorption refrigeration system than using conventional vapour compression refrigeration system.

Gebreslassie et al [10], presented at detailed analysis of exergy for half to triple effect absorption. chillers Bereche et al. [11] analyzed single and double-effect Li/Br-H_2O absorption systems using a thermo-economic analysis and exergy. They were able to conclude that 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 absorption systems. The double-effect Li/Br-H_2O absorption systems chillers have also been internally analyzed, Morosuk and Tsatsaronis[12] presented an exergy analysis of the internal components of absorption refrigeration machines. They were able to conclude that the absorber and generator destroy 40% of their exergy and are primary candidates for improvement.

Cimsit andOzturk [13] performed thermodynamic analysis of compression-absorption cascaded refrigeration systems by using H_2O-Li/Br and NH_3-H_2O pairs in vapour absorption refrigeration system and R134a, R410a and NH3 in vapour compression refrigeration system and found 48–51% less electrical energy consumption in cascade refrigeration system as compared with conventional vapour compression refrigeration system. Garimella et al. [14] proposed absorption-vapour compression cascade refrigeration system using waste heat and found 30% less electricity consumption than conventional vapour compression refrigeration system. Wang et al. [16] studied solar assisted cascade refrigeration system and found 50% less power consumption than conventional system. Chinnappa et al. [15] analyzed solar energy operated vapour compression-NH_3H_2O absorption cascade refrigeration system using R22 in vapour compression refrigeration cycle and found significant electrical energy saving than vapour compression system.

The application of optimization has been applied to absorption chillers; Gebreslassie et al. [16], assessed the relationship between heat exchange area and exergy. They used a structural method to obtain a simplified equation to estimate the optimum heat exchanger area for absorption chillers. Their analysis also concluded that in the optimum case the highest exergy destruction sources were in the solution heat exchanger and the condenser with all components decreasing their destruction rates as the heat exchange area increased. Optimization of a double effect absorption chiller by Ghani et al [17], showed that there was a relationship between temperatures, COP and exergy. They were able to conclude that an increase in temperature in the generator yielded an increase in exergy efficiency.

A second law-based thermodynamic analysis of water and lithium bromide absorption refrigeration by Kilic and Kaynakli [18] showed exergy loss rates for the major components of the absorption chiller. They were able to conclude that the generator, absorber and evaporator were the largest sources of exergy destruction. They also showed good agreement with Ghani et al. [17] in by increasing the heat source temperatures in the generator resulted in an increase in COP and exergy efficiency of the system.

Osta-Omar and Micallef [19] created a mathematical model of a Li/Br water absorption refrigeration system. Their model incorporated an adiabatic absorber with the goal of identifying key parameters that influence Li/Br-H_2O mass concentrations for both strong and weak solutions. By plotting generator temperatures vs. COP, they showed that increasing temperatures in the generator resulted in a diminishing increase in COP.

3. Importance of HFO refrigerants using Energy-exergy Analysis

The first law (energy) and second law (exergetic) efficiency in particular, are very important to be considered for designing of refrigeration systems by considering global warming and ozone depletion potentials in general. The concepts of Global Warming Potential (GWP) and ozone depletion potential (ODP) are also be important for consideration in environmental impact particularly in HFO refrigerants. However, GWP is an index which allows a simple comparison to be make between the with warming effects of different gases on a kg to kg basis relative to carbon. Therefore, GWP depends on the lifetime of a substance in the atmosphere and its infra-red absorption capacity. Chloro-flouro-carbons (CFCs) which have been widely used as refrigerants are powerful greenhouse gases producer with high GWPs due to the bank of CFCs in refrigerating systems, and their levels in the atmosphere are still increasing and it will be some time before refrigerant changes will be effective in reducing the global warming effects of refrigerant releases.

The Hydrocarbons(HC) are in limited use due to its flammable nature. However, hydroflourocarbons (HFC) are also to be limited due to its higher GWP. Similarly, ammonia (R-717) all have a part to play as substitute refrigerants but due to its toxic nature and not used for domestic applications but can easily be used in industrial refrigeration and air conditioning systems. For analyzing vapour compression and absorption refrigeration systems, the evaluation of energetic and exergetic efficiencies are very important for reducing CO_2 emissions. The exergetic efficiency is defined in terms exergy of product to exergy of fuel. Therefore, ultra-low GWP ecofriendly HFO refrigerants can solve such problems due to its similar to thermodynamic performances for replacing CFC, HCFC and HFC refrigerants in vapour compression systems. The main drawback is in VCRS is higher compressor work which can be reduced by using vapour absorption refrigeration systems. The thermodynamic performances of Li/Br-H_2O and NH_3H_2O VARS are lower and its capacity size is larger. By using compression-absorption system can have reduced the compressor work in VCRS and overall system performances increased [20].

In this paper, half effect Li/Br-H_2O absorption-compression systems using ecofriendly eight HFO ultra low GWP refrigerants for evaporator temperature of -75ºC in single cascading and -150ºC in multi-cascading have been compared with HFC-134a for reducing global warming and it was found that the optimum exergetic efficiency is 33.55% low temperature evaporator temperature ranging from -60ºC to -63ºC and for HFO-1336mzz(Z) is 32.51% of the optimum low temperature evaporator is-58 ºC and -59º C and 32.32% using R1225ye(Z) of the optimum low temperature evaporator -57 ºC and -58 ºC respectively.

4. Results and Discussion

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

- Generator temperature= 80ºC
- Absorber temperature=35ºC
- Condenser temperature =35ºC
- VARS evaporator temperature=5ºC
- load on VARS Evaporator= 35.167 kW
- Ambient (dead state) temperature=25ºC
- Temperature overlapping in MTC = 10ºC
- VCR evaporator temperature of MTC=-75ºC
- VCR compressor efficiency of MTC= 80%

Table-1(a) shows the Thermodynamic first law (energetic) and second law (exergetic) Performances comparison of following ecofriendly refrigerants with using R134a in the Integrated half effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature of -75º C and found that the thermodynamic first law (energy) performance using HFO-1233zd(E) is highest and exergetic second law performance is also highest and first law (energy) improvement is 29.22% while improvement in the second law (exergetic) performances using R1233zd(E) in the cascaded VCRS is 82.03%.

Similarly, percentage improvement first law energy performance (COP) of cascaded system using R1225ye(Z) and HFO-1336mzz(Z) is 0.57% lower as compared by using R134a in the low temperature VCRS cycle. Similarly, second law (exergetic) performance is 2.5% lower than using R134a in VCRS section. It was also found that the thermodynamic first law (energy) and second law (exergetic) performances using R1225ye(Z) is nearly same in VCRS section up to -75ºC of evaporator in VCRS section. Similarly, improvement in first law (energetic) performance using R245fa in VCRS section is 28.94% higher and exergetic second law performance is 80.83% higher. The percentage improvement using other refrigerants in VCRS section is also shown in table-1(a) respectively.

Table-1(a): Thermodynamic first law (energetic) performances of Integrated half effect Li/Br-H2O VARS using ecofriendly refrigerants at evaporator temperature -75ºC

Refrigerants in the Integrated VARS system	COP_Cascade	EDR_Cascade	Cascade Exergetic Efficiency	%Improvement in COP_Cascade	% Decrement in EDR_Cascade	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
R1233zd(E)	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
HFO1336mzz(Z)	0.5377	2.156	0.3169	27.39	-52.09	74.28	0.4221	4.50	0.1818
R1225ye(Z)	0.5377	2.156	0.3169	27.40	-52.10	74.30	0.4221	4.50	0.1818
R134a	0.5401	2.112	0.3213	27.97	-53.06	76.72	0.4221	4.50	0.1818
R32	0.5383	2.146	0.3179	27.53	-52.32	74.84	0.4221	4.50	0.1818
R245fa	0.5442	2.042	0.3288	28.94	-54.42	80.83	0.4221	4.50	0.1818

Table-1(b): Thermodynamic first law (energetic) and second law (exergetic) performances of following ecofriendly refrigerants with comparison with using R134a in the Integrated half effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature -75ºC

Refrigerants in the Integrated VARS system	%Improvement in COP_MTC	%Improvement in COP_cascade with respect to R134a
R1233zd(E)	0.9813	3.09
HFO-1336mzz(Z)	0.4444	-1.3694
R1225ye(Z)	0.4444	-1.369
R32	-0.3333	-1.0582
R245fa	0.759	2.334
R134a	0.0	0.0

Table-1(b) shows the Thermodynamic first law (energetic) and second law (exergetic) Performances comparison of following ecofriendly refrigerants with using R134a in the Integrated half effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature of -75º C and found that the thermodynamic first law (energy) performance using HFO-1233zd(E) is 0.98% higher than using R134a and exergetic second law performance is 3.09% higher. Similarly, first law energy performance (COP) of cascaded system is 0.44% higher but second law exergetic performance is 1.67% lower. Similarly, first law(energy) performance R245fa is 0.76% higher and exergetic second law performance is 2.334% higher than using R134a in integrated system. However, R32 is 0.33% lower and exergetic second law performance is 1.058% lower than using R134a in integrated system. Although thermodynamic performances using R236fa is nearly same but it has ultra-higher global warming potential as compared to R134a.

Table-2(a): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	COP_Cascade	EDR_Cascade	Cascade Exergetic Efficiency	%Improvement in COP_Cascade	% Decrement in EDR_Cascade	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-75	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
-70	0.5608	1.997	0.3337	32.87	-55.63	83.54	0.4221	4.50	0.1818
-65	0.5764	1.983	0.3352	36.57	-55.93	84.38	0.4221	4.50	0.1818
-64	0.5796	1.982	0.3354	37.37	-55.96	84.46	0.4221	4.50	0.1818
-63	0.5828	1.981	0.3355	38.07	55.98	84.52	0.4221	4.50	0.1818
-62	0.5859	1.981	0.3355	38.82	-55.99	84.54	0.4221	4.50	0.1818
-61	0.5891	1.981	0.3355	39.58	-55.99	84.54	0.4221	4.50	0.1818
-60	0.5923	1.981	0.3355	40.33	-55.98	84.51	0.4221	4.50	0.1818
-59	0.5955	1.982	0.3353	41.09	55.96	84.45	0.4221	4.50	0.1818
-58	0.5987	1.984	0.3352	41.85	55.92	84.35	0.4221	4.50	0.1818
-57	0.6019	1.986	0.3349	42.61	55.88	84.23	0.4221	4.50	0.1818
-56	0.6052	1.988	0.3347	43.38	55.82	84.08	0.4221	4.50	0.1818
-55	0.6084	1.991	0.3343	44.14	-55.76	83.89	0.4221	4.50	0.1818
-50	0.6246	2.014	0.3317	47.99	-55.24	82.47	0.4221	4.50	0.1818
-45	0.6411	2.052	0.3276	51.88	-54.39	80.20	0.4221	4.50	0.1818
-40	0.6576	2.107	0.3218	55.81	-53.17	77.01	0.4221	4.50	0.1818
-35	0.6743	2.182	0.3142	59.76	-51.50	7.83	0.4221	4.50	0.1818
-30	0.6901	2.282	0.3047	63.74	-49.29	67.59	0.4221	4.50	0.1818
-25	0.7080	2.412	0.2930	67.74	-46.39	61.19	0.4221	4.50	0.1818
-20	0.7249	2.583	0.2791	71.76	-42.61	53.52	0.4221	4.50	0.1818
-15	0.7419	2.807	0.2627	75.78	-37.63	44.48	0.4221	4.50	0.1818

Table-2(b): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using HFO1336mzz(Z) ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	COP_Cascade	EDR_Cascade	Cascade Exergetic Efficiency	% Improvement in COP_Cascade	% Decrement in EDR_Cascade	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-75	0.5377	2.156	0.3169	27.39	-52.09	74.28	0.4221	4.5	0.1818
-70	0.5535	2.118	0.3207	31.14	-52.94	76.41	0.4221	4.5	0.1818
-65	0.5696	2.092	0.3234	34.96	-53.52	77.90	0.4221	4.5	0.1818
-64	0.5729	2.088	0.3238	35.73	-53.60	78.11	0.4221	4.5	0.1818
-63	0.5762	2.085	0.3242	36.51	-53.67	78.30	0.4221	4.5	0.1818
-62	0.5794	2.082	0.3245	37.29	-53.73	78.46	0.4221	4.5	0.1818
-61	0.5827	2.080	0.3247	38.06	-53.78	78.59	0.4221	4.5	0.1818
-60	0.5860	2.078	0.3249	38.85	-53.82	78.69	0.4221	4.5	0.1818
-59	0.5893	2.077	0.3250	39.63	-53.85	78.76	0.4221	4.5	0.1818
58 (optimum)	0.5927	2.076	0.3251	40.41	-53.86	78.80	0.4221	4.5	0.1818
57 (optimum)	0.5960	2.076	0.3251	41.20	-53.87	78.80	0.4221	4.5	0.1818
-56	0.5993	2.077	0.3250	41.99	-53.86	78.78	0.4221	4.5	0.1818
-55	0.6027	2.078	0.3249	42.78	-53.84	78.73	0.4221	4.5	0.1818
-50	0.6195	2.091	0.3235	46.77	-53.54	77.96	0.4221	4.5	0.1818
-45	0.6365	2.12	0.3206	50.80	-52.90	76.32	0.4221	4.5	0.1818
-40	0.6536	2.166	0.3159	54.87	-51.88	73.75	0.4221	4.5	0.1818
-35	0.6709	2.232	0.3094	58.96	-50.40	70.16	0.4221	4.5	0.1818
-30	0.6883	2.324	0.3008	63.08	-48.36	65.47	0.4221	4.5	0.1818
-25	0.7058	2.447	0.2901	67.21	-45.62	59.56	0.4221	4.5	0.1818
-20	0.7232	2.611	0.277	71.35	-41.99	52.34	0.4221	4.5	0.1818
-15	0.7409	2.829	0.2612	75.48	-37.15	43.66	0.4221	4.5	0.1818

Table-2(c): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) performances of Integrated halfeffect Li/Br-H_2O VARS using R1225ye(Z) ecofriendly refrigerant at evaporator temperature=75ºC

Evaporator temperature in VCRS section (ºC)	COP_Cascade	EDR_Cascade	Cascade Exergetic Efficiency	% Improvement in COP_Cascade	% Decrement in EDR_Cascade	% Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-75	0.5377	2.156	0.3169	27.40	-52.10	74.30	0.4221	4.5	0.1818
-70	0.5531	2.124	0.3201	31.05	-52.80	76.05	0.4221	4.5	0.1818
-65	0.5689	2.104	0.3222	34.79	-53.25	77.21	0.4221	4.5	0.1818
-64	0.5721	2.101	0.3225	35.55	-53.31	77.37	0.4221	4.5	0.1818
-63	0.5753	2.099	0.3237	36.31	-53.37	77.50	0.4221	4.5	0.1818
-62	0.5785	2.097	0.3229	37.07	-53.41	77.61	0.4221	4.5	0.1818
-61	0.5818	2.095	0.3231	37.87	-53.44	77.69	0.4221	4.5	0.1818
-60(optimum)	0.5850	2.094	0.3232	38.60	-53.46	77.75	0.4221	4.5	0.1818
-59 (optimum)	0.5883	2.094	0.3232	39.37	-53.47	77.77	0.4221	4.5	0.1818
-58 (optimum)	0.5915	2.094	0.3232	40.15	-53.47	77.77	0.4221	4.5	0.1818
-57	0.5948	2.095	0.3231	40.92	-53.46	77.74	0.4221	4.5	0.1818
-56	0.5981	2.096	0.3230	41.70	-53.43	77.68	0.4221	4.5	0.1818
-55	0.6014	2.097	0.3229	42.48	-53.40	77.59	0.4221	4.5	0.1818
-50	0.618	2.113	0.3212	46.42	-53.05	76.69	0.4221	4.5	0.1818
-45	0.6349	2.143	0.3181	50.42	-52.37	74.97	0.4221	4.5	0.1818
-40	0.6519	2.194	0.3134	54.46	-51.31	72.37	0.4221	4.5	0.1818
-35	0.6692	2.259	0.3069	58.55	-49.81	68.79	0.4221	4.5	0.1818
-30	0.6866	2.351	0.2984	62.66	-47.76	64.15	0.4221	4.5	0.1818
-25	0.7040	2.474	0.2879	66.80	-45.03	58.33	0.4221	4.5	0.1818
-20	0.7216	2.637	0.2750	70.96	-41.40	51.23	0.4221	4.5	0.1818
-15	0.7392	2.854	0.2595	75.14	-36.58	42.71	0.4221	4.5	0.1818

Table-2(a) to Table-2(g) shows the Thermodynamic first law (energetic) and second law (exergetic) performances comparison of following ecofriendly refrigerants with using ecofriendly HFO refrigerants in the low temperature vapour compression cycle in the Integrated half effect Li/Br-H_2O VARS at VCRS evaporator temperature of -75º C and found that the thermodynamic first law (energy) performance and second law(exergetic) performance is using HFO-1233zd(E) is highest and using R1234yf in VCRS circuit is lowest. The thermodynamic performances using HFO-1336mzz(z) and R1225ye(Z) is nearly similar. Similarly, and first law (energy) improvement is 29.22% while improvement in the second law (exergetic) performance using R1233zd(E) in the cascaded VCRS is 82.03%. It was found by increasing evaporator temperature, the first law (energy) performance is increasing while second(exergetic) law performance is increasing and reached to an optimum value and then decreasing. The optimum values of exergetic efficiency is 33.55% for optimum temperature obtained for R1233zd(E) is from -60ºC to -63ºC HFO-1336mzz(Z) is 32.51% from evaporator temperature range from -58 ºC to -59ºC of cooling evaporator temperature while for R1225yez(Z), the exergetic efficiency is 32.32% for -58ºC to -60ºC. Table-3 shows the Thermodynamic first law (energetic) and second law (exergetic) performances with varying condenser temperature in the half effect Li/Br-H_2O VARS for R1233zd(E) in VCRS at evaporator temperature of -75º C and found that by increasing condenser temperature.

Table-2(d): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated half effect Li/Br-H_2O VARS using HFO1234ze(Z) ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	%Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	% Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-30	0.6925	2.262	0.3066	64.06	-49.74	68.63	0.4221	4.5	0.1818
-25	0.7090	2.396	0.2945	67.99	-46.76	61.96	0.4221	4.5	0.1818
-20	0.7257	2.570	0.2801	71.94	-42.90	54.07	0.4221	4.5	0.1818
-15	0.7425	2.797	0.2633	75.92	-37.84	44.85	0.4221	4.5	0.1818

Table-2(e): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated half effect Li/Br-H_2O VARS using HFO1234ze(E) ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	%Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	% Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-30	0.6871	2.342	0.2992	62.80	-47.95	64.57	0.4221	4.5	0.1818
-25	0.7047	2.464	0.2887	66.96	-45.26	58.80	0.4221	4.5	0.1818
-20	0.7223	2.626	0.2758	71.13	-41.66	51.70	0.4221	4.5	0.1818
-15	0.7399	2.842	0.2603	75.30	-36.84	43.15	0.4221	4.5	0.1818

Table-2(f): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated half effect Li/Br-H_2O VARS using HFO1243zf ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	%Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-30	0.6874	2.338	0.2996	62.86	-48.05	64.79	0.4221	4.5	0.1818
-25	0.7047	2.463	0.2887	66.97	-45.27	58.82	0.4221	4.5	0.1818
-20	0.7221	2.628	0.2756	71.09	-41.59	51.59	0.4221	4.5	0.1818
-15	0.7396	2.848	0.2599	75.22	-36.72	42.95	0.4221	4.5	0.1818

Table-2(g): Effect of low temperature VCRS evaporator on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated half effect Li/Br-H_2O VARS using HFO1234yf ecofriendly refrigerant at evaporator temperature=-75ºC

Evaporator temperature in VCRS section (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	% Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
-50	0.6123	2.201	0.3124	45.07	-51.08	71.81	0.4221	4.5	0.1818
-45	0.6298	2.220	0.3105	49.22	-50.66	70.80	0.4221	4.5	0.1818
-40	0.6476	2.258	0.3070	53.42	-49.83	68.84	0.4221	4.5	0.1818
-35	0.6672	2.323	0.3009	58.08	-48.37	65.51	0.4221	4.5	0.1818
-30	0.6834	2.40	0.2941	61.91	-46.67	61.77	0.4221	4.5	0.1818
-25	0.7014	2.516	0.2844	66.18	-44.10	56.45	0.4221	4.5	0.1818
-20	0.7195	2.672	0.2723	70.46	-40.63	49.79	0.4221	4.5	0.1818
-15	0.7375	2.883	0.2575	74.74	-35.94	41.65	0.4221	4.5	0.1818

Table-3: Effect of VARS condenser temperature on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C

Condenser temperature in VARS section (°C)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	% Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
30	0.5471	2.017	0.3315	29.14	-54.98	81.65	0.4237	4.480	0.1825
32	0.5464	2.019	0.3313	29.17	-55.02	81.81	0.4230	4.488	0.1822
34	0.5458	2.021	0.3311	29.21	-55.06	81.96	0.4224	4.496	0.1819
35	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
36	0.5451	2.023	0.3308	29.24	-55.10	82.11	0.4218	4.504	0.1817
38	0.5444	2.025	0.3306	29.27	-55.13	82.26	0.4211	4.513	0.1814
40	0.5437	2.027	0.3304	29.30	-55.17	82.41	0.4205	4.521	0.1811
42	0.5430	2.029	0.3302	29.33	-55.20	82.56	0.4199	4.529	0.1809
44	0.5424	2.031	0.3300	29.36	-55.21	82.71	0.4193	4.537	0.1806
45	0.5420	2.032	0.3299	29.38	-55.26	82.78	0.4189	4.541	0.1805

Table-4: Effect of VARS evaporator temperature on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C

Evaporator temperature in VARS section (°C)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	%Improvement in $COP\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
3	0.5479	1.948	0.3392	30.48	-51.61	70.47	0.4199	4.026	0.1990
4	0.5467	1.986	0.3351	29.86	-53.32	75.97	0.4210	4.252	0.1904
5	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
6	0.5442	2.059	0.3269	28.60	-56.87	88.77	0.4232	4.775	0.1732
7	0.5430	2.097	0.3299	27.97	-58.71	96.28	0.4243	5.079	0.1645
8	0.5418	2.136	0.3189	27.34	-60.59	104.70	0.4255	5.42	0.1558
9	0.5404	2.175	0.3149	26.72	-62.51	114.2	0.4266	5.802	0.1470
10	0.5395	2.215	0.3110	26.09	-64.47	125.0	0.4278	6.235	0.1382

Table-4 shows the Thermodynamic first law (energetic) and second law (exergetic) performances with varying evaporator temperature in the half effect Li/Br-H_2O VARS for R1233zd(E) in VCRS at evaporator temperature of -75° C and found that by increasing evaporator temperature, the first law (energy) performance is increasing while second(exergetic) law performance is decreasing and exergy destruction ratio is increasing.

Table-5(a): Effect of absorber temperature in VARS *on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C*

High pressure Absorber and low pressure Absorber temperature in VARS section (°C)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascade Exergetic Efficiency	% Improvement in $EDR\_{Cascade}$	% Decrement in $EDR\_{Cascade}$	% Improvement in Exergetic Eff	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
30	0.5580	1.985	0.3350	28.65	-54.38	79.29	0.4338	4.352	0.1868
32	0.5525	2.001	0.3332	28.90	-54.69	80.48	0.4286	4.416	0.1846
34	0.5476	2.015	0.3317	29.12	-54.96	81.54	0.4241	4.474	0.1827
35	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
36	0.5454	2.028	0.3303	29.32	-55.19	82.50	0.4201	4.526	0.1810
38	0.5454	2.040	0.3290	29.50	-55.41	83.37	0.4165	4.574	0.1794
40	0.5454	2.051	0.3278	29.66	-55.60	84.18	0.4132	4.616	0.1780
42	0.5454	2.061	0.3267	29.82	-55.78	84.93	0.4102	4.66	0.1767
44	0.5454	2.070	0.3257	29.96	-55.94	85.63	0.4073	4.70	0.1755
45	0.5454	2.075	0.3252	30.03	-56.02	85.96	0.4060	4.718	0.1749

Table-5(a) shows the Thermodynamic first law (energetic) and second law (exergetic) performances with varying absorber temperature in the half effect Li/Br-H_2O VARS for R1233zd(E) in VCRS at absorber temperature of -75° C and found that by increasing evaporator temperature, the first law (energy) performance is increasing while second(exergetic) law performance is decreasing and exergy destruction ratio is increasing. To see effect of low pressure and high absorber temperature with thermodynamic performances, it is found that high pressure absorber temperature is significantly effecting thermodynamic performances as compared to low pressure absorber temperature of half effect Li/Br-H_2O vapour absorption refrigeration system. Similarly, thermodynamic performances also significantly effecting by varying generator temperature.

Table-5(b): Effect of high pressure absorber temperature VARS on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C

High pressure Absorber temperature in VCRS section (°C)	COP_ Cascade	EDR_ Cascade	Cascade Exergetic Efficiency	%Improve ment in COP_ Cascade	% Decri ment in EDR_ Cascade	%Improve ment in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
30	0.5540	1.977	0.3337	28.83	-54.61	80.16	0.430	4.399	0.1852
35	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.50	0.1818
40	0.5390	2.041	0.3289	29.51	-55.43	83.45	0.4162	4.578	0.1793
45	0.5338	2.057	0.3272	29.75	-55.71	84.62	0.4114	4.643	0.1772

Table-5(c): Effect of low pressure absorber temperature VARS on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated halfeffect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C

Low pressure Absorber temperature in VCRS section (°C)	COP_ Cascade	EDR_ Cascade	Cascade Exergetic Efficiency	%Improve ment in EDR_ Cascade	% Decri ment in EDR_ Cascade	%Improve ment in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
30	0.5493	2.01	0.3322	29.04	-54.87	81.18	0.4257	4.454	0.1834
35	0.5493	2.01	0.3322	29.22	-55.08	82.03	0.4221	4.50	0.1818
40	0.5493	2.01	0.3322	29.37	-55.26	82.77	0.4190	4.541	0.1805
45	0.5493	2.01	0.3322	29.51	-55.42	83.41	0.4164	4.576	0.1793

Table-6: Effect of Generator temperature of VARS on the thermodynamic first law (energetic) and second law (exergetic) Performances of Integrated half effect Li/Br-H_2O VARS using R1233zd(E) ecofriendly refrigerant at evaporator temperature=-75°C

Generator temperature in VARS section (°C)	COP_ Cascade	EDR_ Cascade	Cascade Exergetic Efficiency	% Improvement in COP_ Cascade	% Decrement in EDR_ Cascade	%Improvement in Exergetic Efficiency	Half Effect VARS COP	Half Effect VARS EDR	Half Effect VARS Exergetic Efficiency
70	0.5522	1.792	0.3582	28.91	-49.72	63.46	0.4283	3.564	0.2191
75	0.5486	1.908	0.3439	29.08	-52.74	73.21	0.4250	4.037	0.1985
80	0.5454	2.022	0.3310	29.22	-55.08	82.03	0.4221	4.500	0.1818
85	0.5426	2.133	0.3192	29.35	-56.95	90.04	0.4195	4.954	0.1680
90	0.5401	2.241	0.3085	29.47	-58.47	97.34	0.4171	5.396	0.1563

5. Performance of Integrated Half effect VARS with Multi Cascading with VCRS

The following cascaded absorption-compression refrigeration systems have been considered in present investigation.

System-1

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

System-2

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

System-3

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

System-4

Li/Br-H_2O half effect vapour absorption refrigeration system at 10°C 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 half effect Li/Br-H_2O VARS using ecofriendly refrigerants.

- Generator temperature= 80ºC
- 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 LTC= 80%
- Ambient (dead state) temperature=25ºC

Thermodynamic first law energy performances of integrated half effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table 7(a) respectively. It was observed that system-2 has lowest thermodynamic performances than system-1, however first law thermodynamic performance improvement is less. Similarly, Thermodynamic second tlaw exergy performances of cascaded half effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table-7(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.

Table-7(a): Thermodynamic first law (energetic) Performances of Integrated half effect Li/Br-H2O VARS using ecofriendly refrigerants at evaporator temperature -150ºC

Integrated system	$COP\__{VARS}$	$COP\__{MTC}$	$COP\__{ITC}$	$COP\__{L\,TC}$	% Improvement in $COP\__{MTC}$	% Improvement in $COP\__{TC}$	% Improvement in $COP\__{LTC}$
System-1	0.4278	0.6183	0.7776	0.8034	44.52	81.75	87.78
System-2	0.4278	0.6183	0.7745	0.8073	44.52	81.02	88.69
System-3	0.4278	0.6029	0.7625	0.7903	40.92	78.22	84.72
System-4	0.4278	0.6029	0.7594	0.7942	40.92	77.5	85.62

Table-7(b:) Thermodynamic second law (exergetic) Performances of Integrated hal feffect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-150ºC

Integrated system	Exergetic Efficiency ($ETA\__{VARS}$)	Exergetic Efficiency ($ETA\__{MTC}$)	Exergetic Efficiency ($ETA\__{ITC}$)	Exergetic Efficiency ($ETA\__{L\,TC}$)	% Improvement in Exergetic Efficiency ($ETA\__{MTC}$)	%Improvement in Exergetic Efficiency ($ETA\__{ITC}$)	%Improve ment in Exergetic Efficiency ($ETA\__{LTC}$)
System-1	0.1382	0.3126	0.4438	0.4510	126.2	221.1	226.3
System-2	0.1382	0.3126	0.4380	0.4652	126.2	216.9	236.6
System-3	0.1382	0.2898	0.4330	0.4436	109.7	213.2	221.2
System-4	0.1382	0.2896	0.4274	0.4576	109.7	209.0	231.0

Table-7(c): Thermodynamic exergy destruction ratio of Integrated halfeffect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-150ºC

Integrated system	$EDR\__{VARS}$	$EDR\__{MTC}$	$EDR\__{ITC}$	$ED\,R\__{L\,TC}$	% decrement in $EDR\__{MTC}$	% decrement in $EDR\__{ITC}$	% decrement in $EDR\__{LTC}$
System-1	6.235	2.199	1.253	1.217	-64.73	-79.9	-80.48
System-2	6.235	2.199	1.283	1.150	-64.73	-79.42	-81.56
System-3	6.235	2.450	1.31	1.254	-60.7	-79.0	-79.88
System-4	6.235	2.450	1.34	1.186	-60.7	-78.51	-80.96

System-5

Li/Br-H_2O half 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, R1233zd(E) 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 half 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 R-1225ye(Z) in lower temperature cycle at evaporator temperature = -135ºC.

System-7

Li/Br-H_2O half 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-8

Li/Br-H_2O half 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-9

Li/Br-H_2O half 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-10

Li/Br-H_2O half 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-11

Li/Br-H_2O half 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-12

Li/Br-H_2O half 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.

System13

Li/Br-H_2O half 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-14

Li/Br-H_2O half 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.

System-15

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

- Generator temperature= 80ºC
- 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=-135°C
- VCR compressor efficiency of MTC= 80%
- VCR compressor efficiency of ITC= 80%
- VCR compressor efficiency of MTC= 80%
- Ambient (dead state) temperature=25°C

Thermodynamic first law energy performances of integrated half effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table 8(a) respectively. It was observed that system-6 has highest thermodynamic performances than other integrated systems. However, first law thermodynamic performance improvement is higher of system-5 and lowest for system-7. Similarly, Thermodynamic first law exergy performances of integrated half effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table-8(b) respectively. It was observed that system-8 has lowest thermodynamic exergetic performances. Similarly, second law thermodynamic exergetic performance improvement is less of system-8 as compared to other systems at -75°C of evaporator temperature. The exergy destruction ratio in these systems are presented in table-8(c). It is seen that system 5 has maximum percentage in the exergy decrement

Table-8(a): Thermodynamic first law (energetic) Performances of Integrated half effect Li/Br-H2O VARS using ecofriendly refrigerants at evaporator temperature=135°C

Integrated system	COP_{VARS}	COP_{MTC}	COP_{ITC}	COP_{LTC}	%Improvement in COP_{MTC}	%Improvement in COP_{ITC}	%Improvement in COP_{LTC}
System-1	0.4278	0.6865	0.8586	0.8871	60.45	100.7	107.3
System-2	0.4278	0.6865	0.8568	0.8927	60.45	100.2	108.6
System-3	0.4278	0.6848	0.8569	0.8857	60.06	100.3	107.0
System-4	0.4278	0.6848	0.8551	0.8912	60.06	99.86	108.30
System-5	0.4278	0.6794	0.8516	0.8811	58.80	99.05	105.9
System-6	0.4278	0.6794	0.8498	0.8866	58.80	98.63	107.2
System-7	0.4278	0.6794	0.8516	0.8811	58.80	99.05	105.9
System-8	0.4278	0.6794	0.8498	0.8866	58.80	98.6	107.2
System-9	0.4278	0.6747	0.8470	0.877	57.70	97.96	105.0
System-10	0.4278	0.6747	0.8452	0.8825	57.70	97.54	106.3

Table-8(b): Thermodynamic second law (exergetic) Performances of Integrated half effect Li/Br-H2O VARS using ecofriendly refrigerants at evaporator temperature=-135°C

Integrated system	Exergetic Efficiency (ETA_{VARS})	Exergetic Efficiency (ETA_{MTC})	Exergetic Efficiency (ETA_{ITC})	Exergetic Efficiency (ETA_{LTC})	%Improvement in Exergetic Eff. (ETA_{MTC})	%Improvement in Exergetic Efficiency (ETA_{ITC})	%Improvement in Exergetic Efficiency (ETA_{LTC})
System-1	0.1382	0.2894	0.3935	0.4298	109.4	184.7	211.0
System-2	0.1382	0.2894	0.3907	0.4436	109.4	182.7	220.9
System-3	0.1382	0.2872	0.3924	0.4290	107.8	183.9	210.4
System-4	0.1382	0.2872	0.3896	0.4428	107.8	181.9	220.3
System-5	0.1382	0.2803	0.3888	0.4265	102.8	181.3	208.6
System-6	0.1382	0.2803	0.3861	0.4402	102.8	179.3	218.4
System-7	0.1382	0.2803	0.3888	0.4265	102.8	181.3	208.6
System-8	0.1382	0.2803	0.3861	0.4402	102.8	179.3	218.4
System-9	0.1382	0.2743	0.3857	0.4243	98.43	179.10	207.0
System-10	0.1382	0.2743	0.3830	0.4378	98.43	177.10	216.8

Table-8(c): Thermodynamic exergy destruction ratio of Integrated half effect Li/Br-H2O VARS at evaporator temperature=-135°C

Integrated system	EDR_{VARS}	EDR_{MTC}	EDR_{ITC}	EDR_{LTC}	% decrement in EDR_{MTC}	% decrement in EDR_{ITC}	% decrement in EDR_{LTC}
System-1	6.235	2.455	1.541	1.327	-60.62	-75.28	-78.72
System-2	6.235	2.455	1.56	1.254	-60.62	-74.99	-79.88
System-3	6.235	2.482	1.549	1.331	-60.20	-75.16	-78.66
System-4	6.235	2.482	1.567	1.258	-60.70	-74.87	-79.82
System-5	6.235	2.568	1.572	1.345	-58.81	-74.79	-78.43
System-6	6.235	2.568	1.590	1.272	-58.81	-74.49	-79.60
System-7	6.235	2.568	1.572	1.345	-58.81	-74.79	-78.43
System-8	6.235	2.568	1.59	1.272	-58.81	-74.49	-79.6
System-9	6.235	2.646	1.593	1.357	-57.56	-74.46	-78.24
System-10	6.235	2.646	1.611	1.284	-57.56	-74.16	-79.41

Table-9: Thermodynamic energy efficiency (COP) and exergetic efficiency of halfeffect Li/Br-H_2O VARS

Generator temp(°C)	VAR COP	EDR	Exergetic Efficiency
65	0.4380	4.367	0.1186
70	0.4343	5.0	0.1666
75	0.4309	5.624	0.1510
80	0.4278	6.235	0.1382
85	0.4251	6.832	0.1277
90	0.4227	7.416	0.1188

The effect of generator temperature with first law (energy) efficiency (COP) and second law (exergetic) efficiency is shown in table-9. It is seen from table as generator temperature is increasing first law(energy) efficiency and second law (exergetic) efficiency is decreasing while exergy destruction ratio is increasing.

The effect of generator temperature with first law (energy) efficiency (COP) and second law (exergetic) efficiency is shown in table-10. It is seen that as condenser temperature is increasing first law(energy) efficiency and second law (exergetic) efficiency is decreasing while exergy destruction ratio is increasing.

Table-10: Effect of condenser temperature on thermodynamic energy efficiency (COP) and exergetic efficiency of half effect Li/Br-H_2O VARS

Condenser Temp (°C)	VAR COP	EDR	Exergetic Efficiency
25	0.4380	4.367	0.1186
30	0.4343	5.0	0.1666
35	0.4309	5.624	0.1510
40	0.4278	6.235	0.1382
45	0.4251	6.832	0.1277
50	0.4227	7.416	0.1188

Table-11: Effect of evaporator temperature on thermodynamic energy efficiency (COP) and exergetic efficiency of half effect Li/Br-H_2O VARS

Evaporator temp(°C)	VAR COP	EDR	Exergetic Efficiency
2	0.4380	4.367	0.1186
4	0.4343	5.0	0.1666
5	0.4309	5.624	0.1510
6	0.4278	6.235	0.1382
8	0.4251	6.832	0.1277
10	0.4227	7.416	0.1188

Similarly, the effect of VARS evaporator temperature with first law (energy) efficiency (COP) and second law (exergetic) efficiency is shown in table-11. It is seen that as evaporator temperature is increasing first law(energy) efficiency is increasing and second law (exergetic) efficiency is decreasing while exergy destruction ratio is increasing. Similarly, the effect of VARS evaporator temperature with first law (energy) efficiency (COP) and second law (exergetic) efficiency is shown in table-12. It is seen that as absorber temperature is increasing first law(energy) efficiency is decreasing and second law (exergetic) efficiency is also decreasing while exergy destruction ratio is increasing.

Table-12: Effect of absorber temperature on thermodynamic energy efficiency (COP) and exergetic efficiency of half effect Li/Br-H_2O VARS

Absorber temp (°C)	VAR COP	EDR	Exergetic Efficiency
25	0.4380	4.367	0.1186
30	0.4343	5.0	0.1666
35	0.4309	5.624	0.1510
40	0.4278	6.235	0.1382
45	0.4251	6.832	0.1277
50	0.4227	7.416	0.1188

6. Conclusions

A theoretical analysis has been presented to predict the performance of cascaded half effect Li/Br-H_2O using energy and exergy principles. A half effect H_2O-LiBr VARS is coupled to the VCRS using HFO refrigerant through the cascade heat-exchanger by the three times time. These systems have its utilities in ultra-low evaporator temperatures ranging from ice manufacturing to frozen food and ultra-low temperature applications. Following conclusions were drawn from present investigation

- 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 R32, R245fa and 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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