International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Effect of performance parameters on thermodynamic performances of triple effect Li/Br H_2O VARS cascaded with VCRS using ecofriendly HFC-134a and HFO refrigerants

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Abstract

Vapour Absorption system is an attractive method for using the low grade energy directly for cooling simple vapour absorption system consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. In this paper the effect of performance parameters on the thermodynamic performances of triple effect Li/Br H_2O system cascaded by vapour compression refrigeration cycle at -53^{o}C of evaporator temperature have been studied in detailed and it is found that performance of triple effect vapour absorption refrigeration system cascaded with vapour compression system using HFO-1234yf and HFC-1234yf ecofriendly refrigerants have been compared and it is also found that cascade system using HFO-1234yf has 1,5% to 2% lower thermodynamic performances in terms of overall coefficient of performances, and exergetic efficiency has 3% to 3.7% lower than tripple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC-134a ecofriendly refrigerant. The effect of various thermodynamic parameters (such as effect of temperature overlapping i.e. approach , generator temperature, absorber temperature, evaporator temperature of VCRS cycle, Evaporator temperature of triple effect Li/Br VARS cycle, heat exchanger effectiveness, etc. on first law efficiency ($COP\_{Cascade}$) and exergetic efficiency of overall system have been presented and found that there are significant effect of performance parameters on overall coefficient of performance and exergetic efficiency of cascade system.

Keywords: Thermodynamic performance Comparison, Ecofriendly refrigerants, Cascaded System,

1. Introduction

Vapour Absorption system is an attractive method for using the low grade energy directly for cooling. This is an important advantage as compared to the conventional vapour compression system which operates on high grade energy. Another important feature of these systems is that they do not use any moving component except for a very small liquid pump. Vapour absorption system consists of four basic components viz. an evaporator, an absorber (located on low pressure side), a generator and a compressor (located on high pressure side). Refrigerant flows from the condenser to the evaporator, then through absorber to the generator and back to condenser, while the absorbent passes from absorber to the generator and back to absorber. For maximum efficiency, the pressure difference between the low pressure side and high pressure side is maintained as small as possible. In some places there is a fluctuation in the amount of heat availability which generates cyclic temperature changes in the cooling volume. This change alters the quality of the stored materials like fruits, meat, bakery products etc. So maintaining this temperature is an issue faced by absorption system.

The simple vapour absorption system consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system. In Lithium bromide absorption system, a solution of lithium bromide and water is used. Water is being used as the refrigerant and Lithium bromide acts as an absorbent. Lithium bromide is a hydroscopic salt with high affinity for water vapour due to its very low vapour pressure. This system is

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generally used in air conditioning systems due to not very low temperature (above 0˚C) requirements.

In a Li/Br-H_2O bromide vapour absorption system, the absorber and the evaporator are placed in one compartment which operates at the same low pressure of the system. The generator and condenser are placed together in another chamber that operates at the same high pressure of the system. In the absorber, the lithium bromide solution absorbs the water refrigerant, which creates a weak solution of water and lithium bromide. This weak solution is pumped by the pump to the generator where the solution is heated by the available waste heat. The water refrigerant gets vapourized and flows to the condenser where it is cooled while the strong solution of lithium bromide flows back to the absorber where it further absorbs water coming from the Evaporator. In condenser, water refrigerant loses heat and changes its phase into liquid. Then it passes to the evaporator through an expansion valve where pressure is reduced drastically. In evaporator water is sprayed at low pressure which absorbs the heat from the area to be cooled and gets converted into vapour state.

Kilic and Kaynakli [2] carried out energy analysis for finding the performance of a single stage water lithium bromide absorption refrigeration system by varying inputs parameters and found that that the maximum energy loss occurs in generator of the system. Lee et al. [3] studied carbon dioxide and ammonia as refrigerants in the cascade refrigeration system and carried out thermodynamic analysis to determine the optimal condensing temperature of the cascade condenser to maximize the COP and minimize the exergy destruction of the system

Gomri [4] developed the thermal models of single effect and double effect absorption refrigeration systems and found the best possible generator temperature and also observed that the first law efficiency (COP) of double effect system is around twice the first law efficiency (COP) of single effect system.

Chinnappa et al. [5] developed a compression- absorption cascaded refrigeration system which consist a conventional refrigerants with a solar operated, NH_3-H_2O, VARS for air conditioning application. Cimsit and Ozturk [6] carried out thermodynamic analysis of vapour compression absorption cascaded refrigeration system (VCACRS) with H_2O-LiBr and NH_3-H_2O and improved the system performances with lesser amount of energy input. S.B. Riffat N. Shankland [7] designed the different types of absorption systems integration with vapour-compression systems. The double-effect parallel continuous absorption systems and their integration with vapour compression systems have been carried out. Garimella and Brown [8] studied a NH_3/H_2O cascaded absorption–compression system coupled with subcritical CO_2 vapor–compression cycle to breed low-temperature refrigerant. Rogdakis and Antonopoulos [9] carried out absorption refrigeration system NH_3/H_2O running by waste heat and found COP lower as compared LiBr absorption refrigeration system. Fernández-Seara et al. [10] proposed a cascaded vapor NH_3/H_2O absorption refrigeration system with a CO_2 compression vapour refrigeration system at an evaporation temperature of -45°C and found its COP using energy and exergy analysis. Kaushik and Arora [11-13] developed then energy and exergy analysis of single effect and series flow double effect water– lithium bromide absorption system and found that the irreversibility is highest in the absorber in both systems as compared to other systems.

Mishra [14-16] used the cascaded half effect vapour absorption refrigeration cycle coupled with vapour compression cycle. He has improved COP by 40% using the half effect LiBr/H_2O vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a. Apart from this, he also carried out Thermodynamic analysis of cascade single effect ammonia-water (NH_3-H_20) vapour absorption refrigeration system coupled with vapour compression refrigeration using ecofriendly refrigerants in the low temperature cycle of VCRS system and found that dichloro-1 -fluoroethane and Pentafluoropropane gives better performance. Kilicarslan [17] did the theoretical and experimental investigation of a two-stage vapor compression cascade refrigeration system using R-134a as the refrigerant. Getu and Bansal [18] did the thermodynamic analysis of carbon dioxide–ammonia (R744–R717) cascade refrigeration system to optimize the design and operating parameters of the system. The above investigators have not gone through detailed analysis for finding performance improvement and the effect of performance parameters using HFC/ 134A and HFO/1234yf refrigerants in vapour compression refrigeration cycle cascaded with double effect LiBr/ H_2O vapour absorption system.

2. Results and Discussion

Following input data have been taken for numerical computation of triple effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration systems using HFC-134a and HFO-1234yf refrigerants.

(i) Effect of temperature overlapping (Approach= Temperature of cascade condenser vapour compression refrigeration cycle- cascade evaporator temperature of vapour absorption refrigeration cycle) variation from 0 to 16 using HFC-134a and HFO-1234yf refrigerants
(ii) Compressor efficiency= 0.80
(iii) Generator temperature variation double effect Li/Br vapour absorption refrigeration from 170 ºC to 200 ºC,
(iv) Evaporator temperature vapour compression refrigeration system from $T_{\_EVA\_VCRS}$ = - 53ºC.
(v) Evaporator temperature vapour absorption refrigeration system $T_{\_EVA\_VARS}$= 05ºC,
(vi) Refrigeration effect of vapour absorption refrigeration system =35.167 "kW'.

2.1 Effect of temperature overlapping(approach =$T_{\_Cond\_VCRS}$ -$T_{\_Eva\_VARS}$)

Table-1 (a) shows the variation of approach with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when temperature overlapping in terms of approach (means condenser temperature of vapour compression refrigeration minus evaporator temperature of vapour absorption refrigeration system) is increasing, the thermodynamic performances in terms of ($COP\_{Cascade}$, Exergetic $efficiency\_{Cascade\ System}$) is decreasing and $EDR\_{Rational}$ is increasing. Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing as shown in table-1(b) respectively. Table-1 (c) shows the variation of approach with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded triple effect vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of triple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when temperature overlapping in terms of approach (means condenser temperature of vapour compression refrigeration minus evaporator temperature of vapour absorption refrigeration system) is increasing , the thermodynamic performances in terms of ($COP\_{Cascade}$, Exergetic efficiency $_{Cascade\ System}$) is decreasing and $EDR\_{Rational}$ is increasing. Similarly exergy destruction ratio based on the exergy of product ($EDR\_{Cascade}$) is also decreasing as shown in table-1(d) respectively.

The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53°C and generator temperature at 180°C have been compared and also shown in Tables-1 to Tables-2 respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643% lower and exergetic efficiency is 3.20% lower than using HFC-134a For both type of EDRs 6.26% decreasing as temperature overlapping approach is increasing.

(A) Input Parameters for vapour triple effect Li/Br-H_2O refrigeration system

- Generator temperature= 180 °C,
- T_{EVA_VARS}= 5°C,
- Refrigerating Effect=35.167 "kW'
- Condenser temperature (T_{Cond})=35°C
- Absorber temperature (T_{Cond})=35°C

(B) Performance of Triple effect Vapour Absorption System

- First law Efficiency (COP_VARS) =1.121,
- Exergy Destruction Ratio (EDR)=3.2412, ,
- Exergetic Efficiency_VARS=0.2358.

(C) Input Parameters for vapour compression refrigeration system using HFC-134a

- Compressor efficiency= 0.80
- T_{EVA_VCRS} = - 53°C.
- Effect of Approach; 0 to 20

Table-1(a) Effect of approach on exergy destruction ratio ($EDR\_{Rational}$) of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(°C)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency
0	1.435	0.8697	0.5348
2	1.415	0.9201	0.5208
4	1.396	0.9717	0.5072
6	1.377	1.025	0.4939
8	1.358	1.079	0.4811
10	1.339	1.134	0.4686
12	1.321	1.191	0.4564
14	1.303	1.25	0.4445
16	1.285	1.31	0.4329
18	1.267	1.372	0.4212
20	1.250	1.436	0.4105

(A) Input Parameters for vapour Double effect Li/Br-H_2O refrigeration system:

- Generator temperature= 180 °C,
- T_{EVA_VARS}= 5°C,
- RE=35.167 "kW'
- Condenser temperature (T_ Cond)=35°C
- Absorber temperature ($T\_{Absorber}$)=35°C

(B) Performance of Tripple effect Vapour Absorption System

- COP_VARS=1.121,
- EDR=3.2412,
- Exergetic Efficiency_VARS=0.2358.

(C) Input Parameters for vapour compression refrigeration system

- Effect of Approach; 0 to 20 using HFO-1234yf,
- Compressor efficiency= 0.80
- T_{EVA_VCRS} = - 53°C.

Table-1(b) Effect of approach on exergy destruction ratio ($EDR\_{Rational}$) of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(°C)	COP_{VCRS}	EDR_{VCRS}	VCRS Second Law Efficiency
0	2.378	0.1882	0.8431
2	2.271	0.2418	0.8053
4	2.171	0.2991	0.7698
6	2.077	0.3581	0.7363
8	1.988	0.4190	0.7040
10	1.903	0.4819	0.6747
12	1.823	0.5470	0.6464
14	1.747	0.6143	0.6195
16	1.675	0.6841	0.5938
18	1.606	0.7566	0.5693
20	1.54	0.8319	0.5459

Effect of Approach; 0 to 20 using HFO-1234yf, Compressor efficiency= 0.80

- Generator temperature= 180 °C, $T_{\_EVA\_VCRS}$ = - 53°C. $T_{\_EVA\_VARS}$= 5°C, RE=35.167 "kW'
- Performance of Vapour Absorption System: COP_VARS =1.121, EDR=3.241,
- Exergetic Efficiency_VARS=0.2358.

Table-1(c) Effect of Approach on exergy Destruction Ratio (EDR) of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(°C)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
0	1.420	0.907	0.5244
2	1.399	0.962	0.5095
4	1.378	1.02	0.4950
6	1.357	1.08	0.4809
8	1.339	1.141	0.4671
10	1.317	1.205	0.4536
12	1.297	1.271	0.4404
14	1.276	1.339	0.4275
16	1.256	1.411	0.4149
18	1.237	1.489	0.4021
20	1.217	1.563	0.3902

- Effect of Approach; 0 to 20 using HFO-1234yf, Compressor efficiency= 0.80
- Generator temperature= 180 °C, $T_{\_EVA\_VCRS}$ = - 53°C. $T_{\_EVA\_VARS}$= 5°C, RE=35.167 "kW'
- Performance of Vapour Absorption System: $COP_{\_VARS}$=1.121, EDR_{VARS} =3.241,
- Exergetic $Efficiency_{\_VARS}$=0.2358

Table-1(d) Effect of Approach on exergy Destruction Ratio (EDR) of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping/ Approach(°C)	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Second Law Efficiency
0	2.298	0.2273	0.8148
2	2.188	0.2891	0.7758
4	2.084	0.3533	0.7390
6	1.986	0.420	0.7042
8	1.893	0.4897	0.6710
10	1.805	0.5624	0.6401
12	1.722	0.6384	0.6104
14	1.642	0.7181	0.5821
16	1.565	0.8017	0.5550
18	1.493	0.8898	0.5292
20	1.423	0.9827	0.5044

2.2 Effect of low temperature evaporator temperature of vapour compression refrigeration cycle

Table-2 (a) shows the variation of low temperature evaporator circuit temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of triple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when low temperature evaporator circuit temperature of vapour absorption refrigeration system is increasing, the thermodynamic performances in terms of ($COP_{\_Cascad}$,) is decreasing and exergetic $efficiency_{\_Cascade\ System}$ is also decreasing and $EDR_{\_Rational}$ is increasing . Similarly exergy destruction ratio based on the exergy of product ($EDR_{\_Cascade}$) is also decreasing and exergetic efficiency is increasing as shown in table-2(b) respectively. The optimum values of triple effect vapour absorption refrigeration cycle cascaded with vapour compression cycle for generator temperature of 180°C and condenser temperature and 35°C of absorber temperature using HFC-134a refrigerant comes to be -36°C, -37°C and -38°C and the optimum value of exergetic efficiency is 47.54% with exergy destruction ratio based on exergy of product is 1.104 and rational EDR=0.5246.

(A) Input Parameters for vapour Double effect Li/Br-H_2O refrigeration system

- Generator temperature= 180 °C,
- $T_{\_EVA\_VARS}$= 5°C,
- RE=35.167 "kW'
- Condenser temperature (T_ Cond)=35°C
- Absorber temperature ($T_{\_ Absorber}$)=35°C

(B) Performance of Tripple effect Vapour Absorption System

- COP_VARS=1.121, (vii) EDR=3.24,
- Exergetic Efficiency_VARS=0.2358.

(C) Input Parameters for vapour compression refrigeration system:
(ix)Effect of Approach; 10 using HFC-134a,

- Compressor efficiency= 0.80
- $T_{\_EVA\_VCRS}$ = - 53°C.

Table-2(a) Effect of evaporator Temperature VCRS Evaporator on thermal performances of triple effect vapor absorption refrigeration cascaded with vapor compression refrigeration system

Temperature VCRS Evaporator $T_{\_Evaporator}$(°C)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded System 2nd Law Efficiency
-25	1.665	1.125	0.4706
-29	1.615	1.113	0.4730
-30	1.602	1.111	0.4738
-31	1.59	1.109	0.4742
-32	1.578	1.107	0.4746
-33	1.585	1.106	0.4749
-34	1.553	1.105	0.4751
-35	1.541	1.104	0.4753
-36	1.529	1.104	0.4754
-37	1.518	1.104	0.4754
-38	1.506	1.104	0.4754
-39	1.494	1.104	0.4753

- 40	1.483	1.105	0.4751
- 45	1.426	1.111	0.4736
-50	1.371	1.124	0.4708
-51	1.36	1.127	0.4701
-52	1.35	1.131	0.4694
-53	1.339	1.134	0.4686

(A) Input Parame0ters for vapour Double effect Li/Br-H_2O refrigeration system:

- Generator temperature= 180 ^oC,
- $T_{\_EVA\_VARS}$= 5^{o}C,
- RE=35.167 "kW'
- Condenser temperature (T_ Cond)=35^{o}C
- Absorber temperature ($T_{\_ Absorber}$)=35^{o}C

(B) Performance of Triple effect Vapour Absorption System

- COP_VARS=1.121, (vii) EDR=3.24,
- Exergetic Efficiency_VARS=0.2358

(C) Input Parameters for vapour compression refrigeration system

- Effect of Approach; 10 using HFC-134a,
- Compressor efficiency= 0.80
- $T_{\_EVA\_VCRS}$ = - 53^{o}C.

Table-2(b) Effect of evaporator Temperature VCRS Evaporator on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature VCRS Evaporator $T_{\_Evaporator}$(^{o}C)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
-25	1.654	1.151	0.4648
-29	1.602	1.144	0.4664
-30	1.589	1.143	0.4666
-31	1.577	1.143	0.4667
-32	1.564	1.143	0.4667
-33	1.555	1.143	0.4667
-34	1.539	1.143	0.4666
-34.5	1.533	1.134	0.4665
-34.6	1.531	1.144	0.4665
-36	1.541	1.145	0.4662
-37	1.502	1.146	0.4659
-38	1.49	1.148	0.4756
-39	1.477	1.15	0.4752
- 40	1.465	1.152	0.4647
- 45	1.407	1.167	0.4615
-50	1.35	1.189	0.4569
-51	1.339	1.194	0.4559
-52	1.328	1.199	0.4548
-53	1.317	1.205	0.4536

The optimum value of second law efficiency of triple effect Li/Br H_2O vapour absorption refrigeration system at 5^{o}C of VARS evaporator temperature using HFO-1234yf occurred between VCRS evaporator temperature -30^{o}C to -34^{o}C (i.e. -31^{o}C, -32^{o}C and -33^{o}C. The optimum exergetic efficiency is 46.67% with exergy destruction ratio is 1.143 and rational exergy destruction ratio is 0.5333) and similar second law performance (exergetic efficiency= 46.66%) which is less than optimum exergetic efficiency occurred at -30^{o}C and -34^{o}C.

Table-2 (b) shows the variation of low temperature evaporator circuit temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when low temperature evaporator circuit temperature of tripple effect Li/Br H_2O vapour absorption is increasing , the thermodynamic performances in terms of ($COP_{\_Cascade}$) & Exergetic $efficiency_{\_Cascade\ System}$ is decreasing and $EDR_{\_Rational}$ is increasing. Similarly exergy destruction ratio based on the exergy of product ($EDR_{\_Cascade}$) is also decreasing and low temperature evaporator circuit temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-2(b) respectively. The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53^{o}C have been compared and also shown in Table-2(a) & Table-2(b) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643 % and exergetic efficiency is 3.201% lower than using HFC-134a.

2.3 Comparison between VCRS performance using HFC-134a and HFO-1234yf refrigerants at $T_{\_Evaporator}$ = -30 (^{o}C)

(A) Input Parameters for vapour Double effect Li/Br-H_2O refrigeration system

- Generator temperature= 180 ^oC,
- $T_{\_EVA\_VARS}$= 5^{o}C,
- RE=35.167 "kW'
- Condenser temperature (T_ Cond)=35^{o}C
- Absorber temperature ($T_{\_ Absorber}$)=35^{o}C

(B) Performance of Tripple effect Vapour Absorption System

- COP_VARS=1.121
- EDR=3.24,
- Exergetic Efficiency_VARS=0.2358

(C) Input Parameters for vapour compression refrigeration system

- Using HFC-134a, R1234ze and R-1234yf
- Effect of Approach; 10
- Compressor efficiency= 0.80
- $T_{\_EVA\_VCRS}$ = - 30^{o}C.

Table-3(a) Effect of ecofriendly refrigerants in the VCRS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Ecofriendly Refrigerants	$COP_{Cascade}$	Rational $EDR_{\_Cascade}$	Cascaded System 2nd Law Efficiency
R134a	1.602	1.111	0.4738
R1234ze	1.60	1.116	0.4725
R1234yf	1.589	1.143	0.4666

(A) Input Parameters for vapour Double effect Li/Br-H_2O refrigeration system:

- Generator temperature= 180 °C,
- $T_{\_EVA\_VARS}$= 5°C,
- RE=35.167 "kW'
- Condenser temperature (T_ Cond)=35°C
- Absorber temperature ($T_{\_ Absorber}$)=35°C

(B) Performance of Tripple effect Vapour Absorption System

- COP_VARS=1.121
- EDR=3.24,
- Exergetic Efficiency_VARS=0.2358.

(C) Input Parameters for vapour compression refrigeration system

- Using HFC-134a, R1234ze and R-1234yf
- Effect of Approach; 10
- Compressor efficiency= 0.80
- $T_{\_EVA\_VCRS}$ = - 30°C.

Table-3(b) Effect of ecofriendly refrigerants in the VCRS on VCRS thermal performances of vapour compression refrigeration system cascaded with tripple effect vapour absorption refrigeration system.

Ecofriendly Refrigerants	COP_{VCRS}	Rational $EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
R134a	3.444	0.2829	0.8046
R1234ze	3.535	0.2499	0.8001
R1234yf	3.444	0.2829	0.7795

Table-3(a) and Table-3(b) show, the effect of ecofriendly HFC-134a and HFO refrigerants in low temperature circuit with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration at -30°C and it is found that the performance of HFC-134a refrigerant and HFO-1234ze are nearly similar with the variation of 0.125% in first law efficiency and 0.2744% in second law efficiency while the performance of HFC-134a is superior than HFO- 1234yf refrigerant. Therefore both HFO refrigerants can replace HFC-134a refrigerant in near future due to its very low global warming potential (i.e. GWP of R1234ze is 6 and GWP of R1234yf is 4 respectively as compared to GWP of HFC-134a is 1360).

2.4 Effect of heat exchanger effectiveness on thermal performances

- Evaporator temperature of VCRS using HFC-134a = - 53 °C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Performance of Vapour compression System: COP_VCRS=1.903, EDR= 0.4819
- Exergetic Efficiency_VCRS= 0.6748.

Table-4(a) Effect of heat exchanger effectiveness of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Heat exchanger effectiveness of VARS	$COP_{\_VARS}$	$EDR_{\_ VARS}$	VARS Second Law Efficiency
0.40	1.250	1.233	0.4479
0.45	1.293	1.183	0.4580
0.50	1.339	1.134	0.4686
0.55	1.388	1.085	0.4796
0.60	1.441	1.036	0.4911
0.65	1.497	0.9873	0.5032
0.70	1.558	0.9388	0.5158
0.75	1.624	0.8909	0.5289
0.80	1.695	0.8426	0.5427

- Evaporator temperature of VCRS using HFC-134a = - 53 °C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T_{\_generator}$= 180°C. $T_{\_EVA\_VARS}$= 05°C, RE=35.167 "kW', T_Cond=35°C
- Performance of Vapour compression System: COP_VCRS=1.903, EDR= 0.4819
- Exergetic Efficiency_VCRS= 0.6748,

Table-4(b) Effect of heat exchanger effectiveness of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Heat exchanger effectiveness of VARS	COP_VARS	$EDR_{\_VARS}$	Tripple effect VARS Second Law Efficiency
0.40	1.021	3.659	0.2146
0.45	1.069	3.45	0.2247
0.50	1.121	3.241	0.2358
0.55	1.179	3.033	0.2479
0.60	1.243	2.826	0.2613
0.65	1.314	2.620	0.2762
0.70	1.393	2.415	0.2928
0.75	1.481	2.211	0.3115
0.80	1.581	2.008	0.3325

- Evaporator temperature of VCRS using HFO-1234yf = - 53 °C, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T_{\_generator}$= 180°C. $T_{\_EVA\_VARS}$= 5°C, RE=35.167 "kW', T_Cond=35°C

- Performance of Vapour compression System:
- COP_{VCRS}=1.805, EDR= 0.5624, Exergetic Efficiency_$_{VCRS}$ = 0.6401.

Table-4(c) Effect of heat exchanger effectiveness of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Heat exchanger effectiveness of VARS	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency
0.40	1.23	1.305	0.4339
0.45	1.272	1.255	0.4436
0.50	1.317	1.205	0.4536
0.55	1.364	1.155	0.4641
0.60	1.416	1.105	0.4750
0.65	1.471	1.056	0.4865
0.70	1.530	1.006	0.4984
0.75	1.593	0.9575	0.5109
0.80	1.662	0.9089	0.5239

- Evaporator temperature of VCRS using HFO-1234yf = -53 ^{o}C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 180^{o}C. T_{EVA_VARS}= 5^{o}C, RE=35.167 "kW', T_Cond=35^{o}C
- COP_{VCRS}=1.805, EDR= 0.5624, Exergetic Efficiency_$_{VCRS}$ = 0.6401.

Table-4(d) Effect of heat exchanger effectiveness of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

heat exchanger effectiveness of VARS	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency
0.40	1.021	3.659	0.2146
0.45	1.069	3.450	0.2247
0.50	1.121	3.241	0.2358
0.55	1.179	3.033	0.2479
0.60	1.243	2.826	0.2613
0.65	1.314	2.620	0.2762
0.70	1.393	2.415	0.2928
0.75	1.481	2.211	0.3115
0.80	1.581	2.008	0.3325

Table-4 (a) shows the variation of heat exchanger effectiveness with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when heat exchanger effectiveness of vapour absorption refrigeration system) is increasing, the thermodynamic performances in terms of ($COP\_{Cascade}$) & exergetic efficiency_$_{Cascade\ System}$) is increasing and $EDR\_{cascade}$ is decreasing when heat exchanger effectiveness is increasing.

Similarly exergy destruction ratio based on the exergy of product ($EDR\_{Cascade}$) is also decreasing as exergetic efficiency is increasing shown in table-4(b) respectively.

Table-4 (c) shows the variation of heat exchanger effectiveness of VARS with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded triple effect vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of triple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when heat exchanger effectiveness of VARS is increasing, the thermodynamic performances in terms of ($COP\_{Cascade}$, Exergetic efficiency_$_{Cascade\ System}$) is decreasing and $EDR\_{Rational}$ is increasing. Similarly exergy destruction ratio based on the exergy of product ($EDR\_{Cascade}$) is also decreasing as shown in table-4(d) respectively. The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53^{o}C and generator temperature at 180^{o}C have been compared and also shown in Tables-4(a) to Tables-4(d) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643 % and exergetic efficiency is 3.201% lower than using HFC-134a For both type of EDRs 6.261% decreasing as heat exchanger effectiveness is increasing.

2.5 Variation of vapour absorption refrigeration system evaporator temperature of vapour absorption system, when absorber temperature is same as condenser temperature

- Evaporator temperature (T_{EVA_VARS}) varying from 5^{0}C to 10^{0}C
- Generator temperature =180 ^{0}C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = - 53^{o}C. RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS=1.828, EDR=,1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{Rational}$ =0.5276 .Solar collector Area= 38.2 m^{2}

Table-5(a) Effect of vapour absorption refrigeration system evaporator temperature on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Vapour absorption system evaporator temperature ($T\_{evaporator}$) (^{o}C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency
05	1.339	1.134	0.4686
06	1.452	1.07	0.4828
07	1.529	1.051	0.4877
908	1.585	1.052	0.4873
09	1.626	1.069	0.4834
10	1.651	1.095	0.4774

- Evaporator temperature ($T_{\_EVA\_VARS}$) varying from 5^0C to 10^0C
- Generator temperature =180 ^{o}C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53^{o}C. $T_{\_EVA\_VARS}$= 5^{o}C, RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS=1.903, EDR=0.4819
- Exergetic Efficiency_VCRS=0.6748.

Table-5(b) Effect of Vapour absorption system evaporator temperature ($T_{\_evaporator}$) *on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system*

Vapour absorption system evaporator temperature ($T_{\_evaporator}$)	$COP_{\_VARS}$	Rational $EDR_{\_VARS}$	VARS 2nd Law Efficiency
05	1.121	3.241	0.2358
06	1.269	2.958	0.2527
07	1.384	2.844	0.2601
08	1.479	2.825	0.2614
09	1.557	2.874	0.2581
10	1.624	2.976	0.2515

- Evaporator temperature ($T_{\_EVA\_VARS}$) varying from 5^0C to 10 ^{0}C
- Generator temperature =180 ^{o}C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53^{o}C. $T_{\_EVA\_VARS}$= 5^{o}C, RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS = 1.828, EDR=,1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{\_Rational}$ =0.5276 .Solar collector Area= 38.2 m^2

Table-5(c) Effect of Vapour absorption system evaporator temperature ($T_{\_evaporator}$) on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Vapour absorption system evaporator temperature ($T_{\_evaporator}$) (^{o}C)	$COP_{\_Cascade}$	Rational $EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
05	1.317	1.205	0.4536
06	1.425	1.146	0.4661
07	1.498	1.13	0.4695
08	1.551	1.137	0.4679
09	1.588	1.16	0.4631
10	1.616	1.192	0.4561

- Evaporator temperature ($T_{\_EVA\_VARS}$) varying from 5^0C to 10^0C
- Generator temperature =180 ^{o}C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53^{o}C. $T_{\_EVA\_VARS}$= 5^{o}C, RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS=1.828, EDR= 1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{\_Rational}$ =0.5276 .Solar collector Area= 38.2 m^2

Table-5(d) Effect of generator temperature on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Vapour absorption system evaporator temperature ($T_{\_evaporator}$)	$COP_{\_VARS}$	Rational $EDR_{\_VARS}$	VARS Second Law Efficiency
05	1.121	3.241	0.2358
06	1.269	2.958	0.2527
07	1.384	2.844	0.2601
08	1.471	2.825	0.2614
09	1.557	2.874	0.2581
10	1.624	2.976	0.2515

Table-5 (a) shows the variation of Vapour absorption system evaporator temperature ($T_{\_evaporator}$) with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when Vapour absorption system evaporator temperature ($T_{\_evaporator}$) of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of ($COP_{\_Cascad}$,) is decreasing and Exergetic efficiency$_{_Cascade\ System}$ is increasing and $EDR_{\_Rational}$ is decreasing . Similarly exergy destruction ratio based on the exergy of product ($EDR_{\_Cascade}$) is also decreasing and exergetic efficiency is increasing.as shown in table-5(b) respectively. Table-5 (c) shows the variation of generator temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of double effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf, the thermodynamic performances in terms of ($COP_{\_Cascade}$) & $EDR_{\_Rational}$ is decreasing and Exergetic efficiency$_{_Cascade\ System}$) is increasing. Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing and generator temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-5(d) respectively.

The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53^{o}C and Vapour absorption system evaporator temperature at 5^{o}C have been compared and also shown in Table-5(a) to Tables-5(d) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643% and exergetic efficiency is 3.201 % lower than using HFC-134a.

2.6 Variation of generator temperature of vapour absorption system, when absorber temperature is same as condenser temperature

Table-6 (a) shows the variation of generator temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when generator temperature of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of ($COP_{\_Cascad}$,) is decreasing and Exergetic $efficiency_{\_Cascade\ System}$ is increasing and $EDR_{\_Rational}$ is decreasing . Similarly exergy destruction ratio based on the exergy of product ($EDR_{\_Cascade}$) is also decreasing and exergetic efficiency is increasing.as shown in table-6(b) respectively. Table-6 (c) shows the variation of generator temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of double effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when generator temperature of tripple effect Li/Br H_2O vapour absorption is increasing , the thermodynamic performances in terms of ($COP_{\_Cascade}$) & $EDR_{\_Rational}$ is decreasing and Exergetic $efficiency_{\_Cascade\ System}$) is increasing. Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing and generator temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-4(b) respectively. The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53ºC and generator temperature at 180ºC have been compared and also shown in Table-6(a) to Tables-6(d) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is1.643% lower and exergetic efficiency is 3.201 % lower than using HFC-134a.

- Generator temperature varing from 170 to 205^{0}C
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53ºC. $T_{\_EVA\_VARS}$= 5ºC, RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS=1.828, EDR= 1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{\_Rational}$ =0.5276 .Solar collector Area= 38.2 m^2

Table-6(a) Effect of generator temperature on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T_{\_generator}$ (ºC)	$COP_{\_Cascade}$	Rational $EDR_{\_Cascade}$	Cascaded System 2nd Law Efficiency
170	0.8735	1.80	0.3572
175	1.176	1.301	0.4346
180	1.339	1.134	0.4686
185	0.4861	1.057	0.4861
190	1.504	1.017	0.4958
195	1.550	0.9950	0.5012
200	1.583	0.9842	0.5040
205	1.608	0.9797	0.5051

- Generator temperature varing from 170 to 200ºC
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53ºC. $T_{\_EVA\_VARS}$= 5ºC, RE=35.167 "kW'
- Performance of Vapour compression System: COP_VCRS=1.828, EDR= 1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{\_Rational}$ =0.5276 .Solar collector Area= 38.2 m^2

Table-6(b) Effect of generator temperature on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T_{\_generator}$ (ºC)	$COP_{\_VARS}$	Rational $EDR_{\_VARS}$	VARS Second Law Efficiency
170	0.6448	6.056	0.1427
175	0.9406	3.948	0.2021
180	1.121	3.241	0.2358
185	1.24	2.916	0.2554
190	1.323	2.746	0.2670
195	1.382	2.654	0.2737
200	1.426	2.607	0.2772
205	1.459	2.588	0.2787

- Generator temperature varying from 170 to 205ºC
- VCRS using HFO-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_EVA\_VCRS}$ = - 53ºC. $T_{\_EVA\_VARS}$= 5ºC, RE=35.167 "kW'
- Performance of Vapour compression System: COP_ VCRS=1.828, EDR=,1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR_{\_Rational}$ =0.5276 Solar collector Area= 38.2 m^2

Table-6(c) Effect of generator temperature on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T_{\_generator}$ (ºC)	$COP_{\_Cascade}$	Rational $EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
170	0.8617	1.879	0.3473
175	1.158	1.374	0.4212
180	1.317	1.206	0.4536
185	1.413	1.126	0.4703
190	1.477	1.086	0.4794
195	1.522	1.064	0.4846
200	1.554	1.053	0.4872
205	1.577	1.048	0.4883

- Generator temperature varing from 170 to 200 ^oC
- VCRS using HFO-1234yf , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = - 53ºC. T_{EVA_VARS}= 5ºC, RE=35.167 "kW'
- Performance of Vapour compression System: COP_ VCRS=1.828, EDR=,1.117
- Exergetic Efficiency_VCRS=0.4724, $EDR\_{Rational}$ =0.5276 .Solar collector Area= 38.2 m^2

Table-6(d) Effect of generator temperature on thermal performances of tripleeffect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T\_{generator}$ (ºC)	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency
170	0.6448	6.056	0.1417
175	0.9406	3.948	0.2021
180	1.121	3.241	0.2358
185	1.240	2.916	0.2554
190	1.323	2.746	0.2670
195	1.382	2.654	0.2737
200	1.426	2.607	0.2772
205	1.459	2.588	0.2787

2.7 Variation of condenser temperature of vapour absorption system, when absorber temperature is same as condenser temperature

- Evaporator temperature of VARS using HFC-134a = - 53 ºC, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 180ºC. T_{EVA_VARS}= 05ºC, RE=35.167 "kW', T_Absorber=T_Cond
- Performance of Vapour compression System: COP_VCRS=1.201, EDR= 2.802
- Exergetic Efficiency_VCRS= 0.2630, $EDR\_{Rational}$ =0.7370. Solar collector Area= 38.2 7m^2

Table-7(a) Effect of condenser temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system when T_{Cond}=$T\_{Absorber}$

T_Cond	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency
30	1.738	0.8138	0.5509
31	1.695	0.8427	0.5427
32	1.641	0.8787	0.5323
33	1.571	0.9291	0.5184
34	1.477	1.005	0.4988
35	1.339	1.134	0.4686
36	1.112	1.407	0.4155

- Evaporator temperature of VARS using HFC-134a = - 53 ºC, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 180ºC. T_{EVA_VARS}= 05ºC, RE=35.167 "kW', T_Absorber=T_Cond
- Performance of Vapour compression System: COP_VCRS=1.201, EDR= 2.802
- Exergetic Efficiency_VCRS= 0.2630, $EDR\_{Rational}$ = 0.7370. Solar collector Area= 38.2 7m^2

Table-7(b) Effect of condenser temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system when T_{Cond}=$T\_{Absorber}$

T_Cond	COP_{VARS}	EDR_{VARS}	VARS Second Law Efficiency
30	1.644	1.892	0.3458
31	1.581	2.008	0.3324
32	1.505	2.161	0.3164
33	1.41	2.374	0.2964
34	1.287	2.694	0.2707
35	1.121	3.241	0.2358
36	0.8816	4.395	0.1854

- Evaporator temperature of VARS using HFO-1234yf = - 53 ºC, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 180ºC. T_{EVA_VARS}= 05ºC, RE=35.167 "kW', T_Absorber=T_Cond
- Performance of Vapour compression System: COP_VCRS=1.201, EDR= 2.802
- Exergetic Efficiency_VCRS= 0.2630, $EDR\_{Rational}$ =0.7370. Solar collector Area= 38.2 7m^2

Table-7(c) Effect of condenser temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system when T_{Cond}=$T\_{Absorber}$

T_Cond	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency
30	1.704	0.8811	0.5316
31	1.662	0.9089	0.5239
32	1.610	0.9455	0.5140
33	1.542	0.9966	0.5008
34	1.45	1.073	0.4823
35	1.317	1.205	0.4536
36	1.102	1.481	0.4031

- Evaporator temperature of VARS using HFO-1234yf = - 53 ºC, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 180ºC. T_{EVA_VARS}= 05ºC, RE=35.167 "kW', T_Absorber=T_Cond
- Performance of Vapour compression System: COP_VCRS=1.201, EDR= 2.802
- Exergetic Efficiency_VCRS=, 0.2630, $EDR\_{Rational}$ =0.7370. Solar collector Area= 38.2 7m^2

Table-7(d) Effect of condenser temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system when T_{Cond}=$T\_{Absorber}$

T_Cond	COP_{VARS}	EDR_{VARS}	VARS Second Law Efficiency
30	1.644	1.892	0.3458
31	1.581	2.008	0.3324

32	1.505	2.161	0.3164
33	1.410	2.374	0.2964
34	1.287	2.694	0.2707
35	1.121	3.241	0.2358
36	0.8816	4.395	0.1854

Table-7 (a) shows the variation of condenser temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when condenser temperature of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of ($COP\_{_{Cascad}}$,) and Exergetic efficiency$_{_{Cascade\ System}}$ both are decreasing and $EDR\_{_{Rational}}$ is increasing . Similarly exergy destruction ratio based on the exergy of product ($EDR\_{_{Cascade}}$) is also increasing as exergetic efficiency is decreasing. Table-7 (b) shows the variation of low temperature evaporator circuit temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when absorber temperature of double effect Li/Br H_2O vapour absorption is increasing , the thermodynamic performances in terms of ($COP\_{_{Cascade}}$) & Exergetic efficiency $_{Cascade\ System}$ is decreasing and $EDR\_{_{Rational}}$ is increasing. Similarly exergy destruction ratio based on the exergy of product ($EDR\_{_{Cascade}}$) is also increasing. Table-7 (c) shows the variation of condenser temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when condenser temperature of vapour absorption refrigeration system is increasing, the thermodynamic performances in terms of ($COP\_{_{Cascad}}$,) and Exergetic efficiency$_{_{Cascade\ System}}$ both are decreasing and $EDR\_{_{Rational}}$ is increasing . Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also increasing and exergetic efficiency is decreasing. The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53°C and generator temperature at 130°C have been compared and also shown in Table-7(a) to Table7(d) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP, is 1.9563 % lower than using HFC-134a at 30°C of condenser temperature and 1.643% lower than using HFC-134a at 35°C of condenser temperature respectively. Similarly the exergetic efficiency using HFO-1234yf is 3.5033% lower than R134a at 30°C and 3.20% lower than HFC-134a at 35°C respectively.

2.8 Effect of absorber temperature of triple effect vapour absorption cascaded vapour absorption refrigeration system on thermal performances

- Evaporator temperature of VCRS using HFC-134a = -53°C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T\_{_{generator}}$= 180°C. $T\_{_{EVA\_VARS}}$= 05°C, RE=35.167 "kW', T_Cond=35°C
- Performance of Vapour compression System: Performance of Vapour compression System:
- COP_VCRS=1.805, EDR= 0.5624, Exergetic Efficiency_VCRS= 0.6401, $EDR_{\_Rational}$ =0.3599.

Table-8(a) Effect of absorber temperature of VARS on thermal performances of triple-effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber (°C)	$COP\_{_{Cascade}}$	Rational $EDR\_{_{Cascade}}$	Cascaded System Second Law Efficiency
25	1.265	1.215	0.4514
30	1.301	1.175	0.4598
35	1.339	1.135	0.4686
40	1.380	1.094	0.4777
45	1.422	1.053	0.4871

- Evaporator temperature of VCRS using HFC-134a = -53°C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T\_{_{generator}}$= 180°C. $T\_{_{EVA\_VARS}}$= 05°C, RE=35.167 "kW', T_Cond=35°C
- Performance of Vapour compression System: Performance of Vapour compression System: COP_VCRS=1.805, EDR= 0.5624, Exergetic Efficiency_VCRS= 0.6401, $EDR_{\_Rational}$ =0.3599.

Table-8(b) Effect of absorber temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber (°C)	$COP\_{_{VARS}}$	Rational $EDR\_{_{VARS}}$	VARS Second Law Efficiency
25	1.037	3.584	0.2181
30	1.078	3.413	0.2266
35	1.121	3.241	0.2358
40	1.169	3.07	0.2457
45	1.22	2.898	0.2566

Table-8 (a) shows the variation of absorber temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when absorber temperature of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of ($COP_{\_Cascad}$,) is decreasing and Exergetic efficiency$_{_Cascade\ System}$ is increasing and $EDR_{\_Rational}$ is decreasing . Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing and exergetic efficiency is increasing.as shown in table-8(b) respectively.Table-8 (c) shows the variation of low temperature evaporator circuit temperature with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of tripple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf refrigerant and it is found that when absorber temperature of triple effect Li/Br H_2O vapour absorption is increasing , the thermodynamic performances in terms of ($COP_{\_Cascade}$) & Exergetic efficiency$_{_Cascade\ System}$ is decreasing and $EDR_{\_Rational}$ is increasing. Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing and absorber temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-8(d) respectively.

The performance of tripple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for absorber temperature at 40°C have been compared and also shown in Tables-7 to Tables-8 respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643 % lower and, exergetic efficiency is 3.201 % lower than using HFC-134a at 35°C of vapour compression absorber temperature. .

- Evaporator temperature of VCRS using HFO-1234yf = -53 °C, Compressor efficiency= 0.80
- Triple effect Li/Br-H_2O VARS
- Approach=10, $T_{\_generator}$= 180°C. $T_{\_EVA\_VARS}$= 05°C, RE=35.167 "kW', T_Cond=35°C
- Performance of Vapour compression System: Performance of Vapour compression System:
- COP_VCRS=1.805, EDR= 0.5624, Exergetic Efficiency_ VCRS= 0.6401, $EDR_{\_Rational}$ =0.3599.

Table-8(c) Effect of absorber temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber (°C)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded System Second Law Efficiency
25	1.245	1.287	0.4378
30	1.28	1.246	0.4450
35	1.317	1.205	0.4536
40	1.356	1.163	0.4622
45	1.398	1.122	0.4712

- Evaporator temperature of VCRS using HFO-1234yf = -53 °C, Compressor efficiency= 0.80
- Tripple effect Li/Br-H_2O VARS
- Approach=10, $T_{\_generator}$= 180°C. $T_{\_EVA\_VARS}$= 05°C, RE=35.167 "kW', T_Cond=35°C
- Performance of Vapour compression System:
- COP_VCRS=1.805, EDR= 0.5624,
- Exergetic Efficiency_VCRS= 0.6401, $EDR_{\_Rational}$ =0.3599.

Table-8(d) Effect of absorber temperature of VARS on thermal performances of triple effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber (°C)	$COP_{\_VARS}$	$EDR_{\_VARS}$	VARS Second Law Efficiency
25	1.037	3.584	0.2181
30	1.078	3.413	0.2266
35	1.121	3.241	0.2358
40	1.169	3.07	0.2457
45	1.22	2.898	0.2566

3. Conclusions and Recommendations

The following conclusions were drawn from present investigations.

- The thermodynamic performances of triple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC-134a and HFO-1234yf refrigerants in terms of COP is 1.643% lower and exergetic efficiency is 3.20% lower than using HFC-134a For both type of EDRs 6.25% and also decreases as temperature overlapping (approach) is increasing.
- The thermal performance of triple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is always than the triple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants. The thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643 % lower and exergetic efficiency is 3.201% lower than using HFC-134a in the vapour compression refrigeration system.
- The variation of low temperature evaporator circuit temperature in triple effect Li/Br vapour absorption refrigeration system on thermal performance of triple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO - 1234yf refrigerant when low temperature evaporator circuit temperature of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of ($COP_{\_Cascad}$,) is decreasing and Exergetic efficiency$_{_Cascade\ System}$ is also decreasing and $EDR_{\_Rational}$ is increasing . Similarly exergy destruction ratio based on the exergy of product (EDR_Cascade) is also decreasing and exergetic efficiency is increasing.as shown in table-

2(b) respectively. The optimum values of triple effect vapour absorption refrigeration cycle cascaded with vapour compression cycle for generator temperature of 180ºC and condenser temperature and 35ºC of absorber temperature using HFC-134a refrigerant comes to be -36ºC, -37ºC and -38ºC and the optimum value of exergetic efficiency is 47.54% with exergy destruction ratio based on exergy of product is 1.104 and rational EDR=0.5246.

- The variation of temperature of generator in double effect Li/Br vapour absorption refrigeration system on thermal performance of double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is 6.0 % to 7% lower than the triple effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.
- For tripple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration at -30ºC , the performance of HFC-134a refrigerant and HFO-1234ze are nearly similar with the variation of 0.125% in first law efficiency and 0.2744% in second law efficiency while the performance of HFC-134a is superior than HFO- 1234yf refrigerant. Therefore both HFO refrigerants can replace HFC-134a refrigerant in near future due to its very low global warming potential (i.e. GWP of R1234ze is 6 and GWP of R1234yf is 4 respectively as compared to GWP of HFC-134a is 1360)
- Thermodynamic performances of triple effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643 % lower and exergetic efficiency is 3.201% lower than using HFC-134a. For both type of EDRs 6.261% decreasing as heat exchanger effectiveness is increasing.
- The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53ºC and generator temperature at 180ºC thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is1.643% lower and exergetic efficiency is 3.201 % lower than using HFC-134a in the vapour compression refrigeration cycle.
- The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53ºC and Vapour absorption system evaporator temperature at 5ºC have been compared and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is 1.643% and exergetic efficiency is 3.201 % lower than using HFC-134a.
- The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for low temperature circuit evaporator at -53ºC and generator temperature at 130ºC have been compared and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP, is 1.9563 % lower than using HFC-134a at 30ºC of condenser temperature and 1.643% lower than using HFC-134a at 35ºC of condenser temperature respectively. Similarly. The exergetic efficiency using HFO-1234yf is 3.5033% lower than R134a at 30ºC and 3.20% lower than HFC-134a at 35ºC respectively.
- The performance of triple effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for absorber temperature at 40ºC have been compared and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP is1.643 % lower and exergetic efficiency is 3.201 % lower than using HFC-134a at 35ºC of vapour compression absorber temperature.
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that absorber temperature of Tripple effect Li/Br vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of (COP_{Cascad},) is decreasing and Exergetic efficiency$_{Cascade\ System}$ is increasing and $EDR\_{Rational}$ is decreasing
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when condenser temperature of vapour absorption refrigeration system is increasing, the thermodynamic performances in terms of (COP_{Cascad},) and Exergetic efficiency$_{Cascade\ System}$ both are decreasing and $EDR\_{Rational}$ is increasing.
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when generator temperature of vapour absorption refrigeration system is increasing , the thermodynamic performances in terms of (COP_{Cascad},) is decreasing and Exergetic efficiency$_{Cascade\ System}$ is increasing and $EDR\_{Rational}$ is decreasing
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when Vapour absorption system evaporator temperature ($T\_{evaporator}$) of vapour absorption refrigeration system is increasing, the thermodynamic performances in terms of (COP_{Cascad},) is decreasing and Exergetic efficiency$_{Cascade\ System}$ is increasing and $EDR\_{Rational}$ is decreasing. Similarly exergy destruction ratio based on the exergy of product ($EDR\_{Cascade}$) is also decreasing and exergetic efficiency is increasing
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression

refrigeration using HFC-134a refrigerant and it is found that when heat exchanger effectiveness of vapour absorption refrigeration system) is increasing , the thermodynamic performances in terms of ($COP\_{Cascade}$) & exergetic efficiency_$_{Cascade\ System}$) is increasing and EDR_$_{cascade}$ is decreasing when heat exchanger effectiveness is increasing

- The optimum value of second law efficiency of triple effect Li/Br H_2O vapour absorption refrigeration system at 5ºC of VARS evaporator temperature using HFO-1234yf occurred between VCRS evaporator temperature -30ºC to -34ºC (i.e. -31ºC, -32ºC and -33ºC. The optimum exergetic efficiency is 46.67% with exergy destruction ratio is 1.143 and rational exergy destruction ratio is 0.5333) and similar second law performance (exergetic efficiency= 46.66%) which is less than optimum exergetic efficiency occurred at -30ºC and -34ºC.
- In the triple effect Li/Br-H_2Ovapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant and it is found that when temperature overlapping in terms of approach (means condenser temperature of vapour compression refrigeration minus evaporator temperature of vapour absorption refrigeration system) is increasing, the thermodynamic performances in terms of (COP_$_{Cascade}$, Exergetic efficiency_$_{Cascade\ System}$) is decreasing and EDR_$_{Rational}$ is increasing.

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Cite this article as: R.S. Mishra, Effect of performance parameters on thermodynamic performances of triple effect Li/Br H_2O VARS cascaded with VCRS using ecofriendly HFC-134a and HFO refrigerants, International Journal of Research in Engineering and Innovation Vol-3, Issue-2 (2019), 109-122.