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Effect of performance parameters on thermodynamic performances of double 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. 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 generally used in air conditioning systems due to not very low temperature (above 0˚C) requirements. In this paper the effect of performance parameters on the thermodynamic performances of double effect Li/Br H_2O system cascaded by vapour compression refrigeration cycle at -52ºC of evaporator temperature have been studied in detailed and it is found that performance of double effect vapour absorption refrigeration system cascaded with vapour compression system using HFO-1234yf ecofriendly refrigerant has 5% to 8% lower thermodynamic performances in terms of overall coefficient of performances, exergetic efficiency) than double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC-134a ecofriendly refrigerant.

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

1. Introduction

The waste heat going to the environment from condenser has a very savior effect to our environment, the utility of such a system that can minimize all these harmful effect and enhance the performance of the system i.e. vapor absorption system. However the several methods have been used for improving the thermodynamic performances such as use of heat pipe [1] and cascading of VARS with VCRS using ecofriendly refrigerants

Chinnappa et al. [2] proposed a compression- absorption cascaded refrigeration system which consist a conventional refrigerants with a solar operated, NH_3-H_2O, VARS for air conditioning application.

Gomri [3] developed the thermodynamic analysis between single effect and double effect absorption refrigeration systems using computer program and found the best possible generator temperature and also found that the COP of double effect system is approximately twice the COP of single effect system.

Kilic and Kaynakli [4] carried out thermodynamic 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.

Mishra [5-7] 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. It was proved that the performances of single effect cascaded vapour absorption refrigeration system coupled with vapour compression cycle significantly higher than that of existing cycle. Apart from this, he also carried out Thermodynamic analysis of cascade single effect ammonia-water (NH3-H_20) vapour absorption refrigeration system coupled with vapour compression refrigeration using ecofriendly refrigerants in the low

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temperature cycle of VCRS system and found that dichloro-1 -fluoroethane and Pentafluoropropane gives better performance. Cimsit and Ozturk [8] 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. Fernández–Seara et al. [9] proposed a cascaded vapor NH3/H2O 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. Garimella and Brown [10] studied a NH3/H2O cascaded absorption–compression system coupled with subcritical CO2 vapor–compression cycle to breed low-temperature refrigerant. Rogdakis and Antonopoulos [11] carried out absorption refrigeration system NH3/H2O running by waste heat and found COP lower as compared LiBr absorption refrigeration system. S.B. Riffat N. Shankland [12] described 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. Kaushik and Arora [13-14] 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.

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 double 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 105ºC to 140ºC,
(iv) Evaporator temperature vapour compression refrigeration system from $T_{\_EVA\_VCRS}$ = - 52ºC.
(v) Evaporator temperature vapour absorption refrigeration system $T_{\_EVA\_VARS}$= 08ºC,
(vi) Refrigeration effect of vapour absorption refrigeration system =35.167 "kW'

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 double 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-2 (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 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 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-2(b) respectively. The performance of double 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 -52ºC and generator temperature at 130ºC 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, exergetic efficiency is 5.54% to 6.2% lower than using HFC-134a For both type of EDR increasing as temperature overlapping approach is increasing.

Table-3 (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 double 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-3(b) respectively. Table-4 (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 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 double 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 double 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 -52ºC and generator temperature at 130ºC have been compared and also shown in Tables-3 to Tables-4 respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP, exergetic efficiency is 6.0 % to 7% lower than using HFC-134a. Table-5 (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 double effect Li/Br-H_2Ovapour 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-5(b) respectively.Table-6 (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 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 low temperature evaporator circuit 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 decreasing and low temperature evaporator circuit temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-6(b) respectively. The performance of double 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 -52ºC and low temperature evaporator circuit temperature at - 50ºC have been compared and also shown in Tables-5 to Tables-6 respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP, exergetic efficiency is 6.5 % to 7% lower than using HFC-134a. Table-7 (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 double 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-7(b) respectively.Table-8 (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 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 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 decreasing and absorber temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-8(b) respectively.

The performance of double 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 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, exergetic efficiency is 6.5 % to 7% lower than using HFC-134a. Table-9 (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 double 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}) 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-9(b) respectively.Table-10 (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 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 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 decreasing and absorber temperature increasing along with exergetic efficiency of cascaded system is increasing as shown in table-10(b) respectively. The performance of double 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 also shown in Tables-9 to Tables-10 respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system in terms of COP, exergetic efficiency is 7.4 % to 8% lower than using HFC-134a.

- Effect of Approach; 0 to 16 using HFC-134a, Compressor efficiency= 0.80
- Generator temperature= 130 ºC, T_{EVA_VCRS} = - 52ºC. T_{EVA_VARS}= 08ºC, RE=35.167 “kW’
- Performance of Vapour Absorption System: COP_VARS=1.201, EDR=2.802,
- Exergetic Efficiency_VARS=0.2630, $EDR_{Rational}$ =0.7370, Solar collector Area= 38.2 m^2

Table-1(a) Effect of approach on rational exergy destruction ratio ($EDR_{Rational}$) of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(ºC)	$COP_{Cascade}$	Rational $EDR_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VCRS}	Rational EDR_{VCRS}	VCRS Second Law Efficiency
0	1.955	0.2717	0.7283	2.279	0.4111	0.5889
2	1.891	0.3066	0.6939	2.178	0.4371	0.5629
4	1.828	0.3392	0.6608	2.083	0.4617	0.5383
6	1.769	0.3697	0.6303	1.994	0.4848	0.5152
8	1.712	0.3983	0.6017	1.909	0.5068	0.4932
10	1.658	0.4252	0.5748	1.828	0.5276	0.4724
12	1.603	0.4505	0.5495	1.752	0.5473	0.4527
14	1.552	0.4745	0.5255	1.679	0.5662	0.4338
16	1.503	0.4972	0.5028	1.610	0.5841	0.4159

- Effect of Approach; 0 to 16 using HFC-134a, Compressor efficiency= 0.80
- Generator temperature= 130 ºC, T_{EVA_VCRS} = - 52ºC. T_{EVA_VARS}= 08ºC, RE=35.167 “kW’
- Performance of Vapour Absorption System: COP_VARS=1.201, EDR=2.802, Exergetic
- Efficiency_VARS=0.2630, $EDR_{Rational}$ =0.7370, Solar collector Area= 38.2 m^2

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

Temperature overlapping / Approach(ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Second Law Efficiency
0	1.955	0.373	0.7283	2.279	0.6981	0.5889
2	1.891	0.4421	0.6939	2.178	0.7767	0.5629
4	1.828	0.5133	0.6608	2.083	0.8576	0.5383
6	1.769	0.5865	0.6303	1.994	0.9411	0.5152
8	1.712	0.6619	0.6017	1.909	1.027	0.4932
10	1.658	0.7397	0.5748	1.828	1.1170	0.4724
12	1.603	0.820	0.5495	1.752	1.209	0.4527
14	1.552	0.9030	0.5255	1.679	1.305	0.4338
16	1.503	0.989	0.5028	1.610	1.404	0.4159

- Effect of Approach; 0 to 16 using HFC-1234yf , Compressor efficiency= 0.80
- Generator temperature= 130 ºC, T_{EVA_VCRS} = - 52ºC. T_{EVA_VARS}= 08ºC, RE=35.167 “kW’
- Performance of Vapour Absorption System: COP_VARS=1.201, EDR=2.802,
- ExergeticEfficiency_VARS=0.2630, $EDR_{Rational}$ =0.7370, Solar collector Area= 38.2 m^2

Table-2 (a) Effect of Approach on rational exergy destruction Ratio (EDR) of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VCRS}	Rational EDR_{VCRS}	VCRS Second Law Efficiency
0	1.845	0.2541	0.7459	2.193	0.4333	0.5667
2	1.783	0.2930	0.7070	2.089	0.4602	0.5398
4	1.723	0.3292	0.6707	1.990	0.4857	0.5143
6	1.665	0.3631	0.6369	1.897	0.5093	0.4902
8	1.609	0.3948	0.6052	1.808	0.5327	0.4673
10	1.555	0.4247	0.5753	1.724	0.5545	0.4455
12	1.503	0.4523	0.5471	1.644	0.5752	0.4248
14	1.452	0.4796	0.5204	1.567	0.5951	0.4049
16	1.403	0.5048	0.4952	1.494	0.6140	0.3860

- Effect of Approach; 0 to 16 using HFO-1234yf , Compressor efficiency= 0.80
- Generator temperature= 130 °C, T_{EVA_VCRS} = - 52°C. T_{EVA_VARS}= 08°C, RE=35.167 "kW'
- Performance of Vapour Absorption System: COP_VARS=1.201, EDR=2.802,
- Exergetic Efficiency_VARS=0.2630, $EDR\_{Rational}$ =0.7370, Solar collector Area= 38.2 m^2

Table-2(b) Effect of Approach on exergy destruction Ratio (EDR) of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature overlapping / Approach(°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VCRS}	Rational EDR_{VCRS}	VCRS Second Law Efficiency
0	1.845	0.3407	0.7459	2.193	0.7645	0.5667
2	1.783	0.4141	0.7070	2.089	0.8526	0.5398
4	1.723	0.4907	0.6707	1.990	0.9444	0.5143
6	1.665	0.570	0.6369	1.897	1.040	0.4902
8	1.609	0.6524	0.6052	1.808	1.140	0.4673
10	1.555	0.7382	0.5753	1.724	1.245	0.4455
12	1.503	0.8278	0.5471	1.644	1.354	0.4248
14	1.452	0.9214	0.5204	1.567	1.47	0.4049
16	1.403	1.019	0.4952	1.494	1.591	0.3860

- Generator temperature varying from 105 to 140 °C
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = -52°C. T_{EVA_VARS}= 08°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-3(a) Effect of generator temperature on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T\_{generator}$ (°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency	Solar collector Area required
105	1.751	0.4575	0.5425	1.495	0.5969	0.4031	30.74
110	1.733	0.4522	0.5478	1.433	0.6316	0.3684	32.07
115	1.715	0.4464	0.5536	1.371	0.6627	0.3373	33.52.
120	1.696	0.4399	0.5601	1.312	0.6905	0.3095	35.05
125	1.676	0.4329	0.5671	1.255	0.7151	0.2849	36.64
130	1.656	0.4252	0.5748	1.201	0.7370	0.2630	38.27
135	1.637	0.4169	0.5831	1.151	0.7564	0.2436	39.93
140	1.618	0.4079	0.5921	1.105	0.7736	0.2264	41.6

- Generator temperature varing from 105 to 140 °C
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = - 52°C. T_{EVA_VARS}= 08°C, RE=35.167 "kW'
- Performance ofVapour 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-3(b) Effect of generator temperature on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T\_{generator}$ (°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency
105	1.751	0.8433	0.5425	1.495	1.481	0.4031
110	1.733	0.8255	0.5478	1.433	1.714	0.3684
115	1.715	0.8062	0.5536	1.371	1.965	0.3373
120	1.696	0.7854	0.5601	1.312	2.231	0.3095
125	1.676	0.7632	0.5671	1.255	2.510	0.2849
130	1.656	0.7397	0.5748	1.201	2.802	0.2630
135	1.637	0.7148	0.5831	1.151	3.105	0.2436
140	1.618	0.6888	0.5921	1.105	3.417	0.2264

- Generator temperature varing from 105 to 140 °C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = - 52°C. T_{EVA_VARS}= 08°C, RE=35.167 "kW'
- Performance ofVapour 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-4(a) Effect of generator temperature on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T\_{generator}$ (°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency	Solar collector Area required
105	1.616	0.4667	0.5333	1.495	0.5969	0.4031	30.74
110	1.641	0.4599	0.541	1.433	0.6316	0.3684	32.07
115	1.62	0.4524	0.5476	1.371	0.6627	0.3373	33.52.
120	1.598	0.440	0.5560	1.312	0.6905	0.3095	35.05
125	1.577	0.4348	0.5652	1.255	0.7151	0.2849	36.64
130	1.555	0.4247	0.5753	1.201	0.7370	0.2630	38.27
135	1.533	0.4137	0.5863	1.151	0.7564	0.2436	39.93
140	1.512	0.4016	0.5984	1.105	0.7736	0.2264	41.6

- Generator temperature varing from 105 to 140°C
- VCRS using HFC-1234yf , Compressor efficiency= 0.80
- Approach=10, T_{EVA_VCRS} = - 52°C. T_{EVA_VARS}= 08°C, RE=35.167 "kW'
- Performance ofVapour 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-4(b) Effect of generator temperature on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

$T\_{generator}$ (°C)	$COP\_{Cascade}$	Rational $EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	Rational EDR_{VARS}	VARS Second Law Efficiency
105	1.616	0.875	0.5425	1.481	1.481	0.4031
110	1.641	0.8516	0.5478	1.714	1.714	0.3684
115	1.62	0.8261	0.5536	1.965	1.965	0.3373
120	1.598	0.7987	0.5601	2.231	2.231	0.3095
125	1.577	0.7693	0.5671	2.510	2.510	0.2849
130	1.555	0.7382	0.5748	2.802	2.802	0.2630
135	1.533	0.7055	0.5831	3.105	3.105	0.2436
140	1.512	0.6711	0.5921	3.417	3.417	0.2264

- Evaporator temperature varying from 30 to 50 °C, T_Cond=35°C.
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, $T\_{generator}$= 130°C. T_{EVA_VARS}= 08°C, RE=35.167 "kW'
- Performance ofVapour absorption 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-5(a) Effect of Evaporator temperature of VCRS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature VCRS Evaporator $T_{\_Evaporator}$ (°C)	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VCRS}$	Rational EDR$_{_VCRS}$	VCRS Second Law Efficiency
-30	2.484	0.1745	0.8255	3.274	0.3957	0.6043
-35	2.260	0.2472	0.7528	2.836	0.4289	0.5711
- 40	2.060	0.3083	0.6917	2.476	0.4599	0.5401
- 45	1.880	0.3612	0.6388	2.175	0.4891	0.5109
-50	1.717	0.4079	0.5921	1.92	0.5168	0.4832

- Evaporator temperature varying from 30 to 50 °C, T_Cond=35°C.
- VCRS using HFC-134a , Compressor efficiency= 0.80
- Approach=10, $T_{\_generator}$= 130°C. $T_{\_EVA\_VARS}$= 08°C, RE=35.167 “kW’
- Performance ofVapour absorption 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-5(b) Effect of Evaporator temperature of VCRS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature VCRS Evaporator $T_{\_Evaporator}$(°C)	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VCRS}$	Rational EDR$_{_VCRS}$	VCRS Second Law Efficiency
-30	2.484	0.2113	0.8255	3.274	0.6549	0.6043
-35	2.260	0.3283	0.7528	2.836	0.7510	0.5711
- 40	2.060	0.4457	0.6917	2.476	0.8514	0.5401
- 45	1.880	0.5654	0.6388	2.175	0.9573	0.5109
-50	1.717	0.6889	0.5921	1.92	1.700	0.4832

- Evaporator temperature varying from 30 to 50 °C, T_Cond=35°C.
- VCRS using HFO-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_generator}$= 130°C. $T_{\_EVA\_VARS}$= 08°C, RE=35.167 “kW’
- Performance ofVapour absorption 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-6(a) Effect of Evaporator temperature of VCRS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature VCRS Evaporator $T_{\_Evaporator}$(°C)	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VCRS}$	Rational EDR$_{_VCRS}$	VCRS Second Law Efficiency
-30	2.308	0.1745	0.8705	3.157	0.4174	0.5826
-35	2.106	0.2472	0.7823	2.722	0.4519	0.5481
- 40	1.924	0.3083	0.7098	2.365	0.4842	0.5158
- 45	1.760	0.3612	0.6483	2.067	0.5146	0.4854
-50	1.611	0.4079	0.5949	1.814	0.5434	0.4566

- Evaporator temperature varying from 30 to 50 °C, T_Cond=35°C.
- VCRS using HFO-1234yf , Compressor efficiency= 0.80
- Approach=10, $T_{\_generator}$= 130°C. $T_{\_EVA\_VARS}$= 08°C, RE=35.167 “kW’
- Performance ofVapour absorption 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-6(b) Effect of Evaporator temperature of VCRS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

Temperature VCRS Evaporator $T_{Evaporator}$(°C)	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VCRS}$	EDR$_{_VCRS}$	VCRS Second Law Efficiency
-30	2.308	0.1487	0.8705	3.157	0.7163	0.5826
-35	2.106	0.2763	0.7823	2.722	0.8246	0.5481
- 40	1.924	0.4068	0.7098	2.365	0.9387	0.5158
- 45	1.760	0.5424	0.6483	2.067	1.06	0.4854
-50	1.611	0.6810	0.5949	1.814	1.19	0.4566

- Evaporator temperature of VCRS using HFC-134a = - 52^{o}C, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, T$_{generator}$= 130^{o}C. T$_{EVA_VARS}$= 08^{o}C, RE=35.167 "kW', T_Cond=35^{o}C
- 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 absorber temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VARS}$	Rational EDR$_{_VARS}$	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.691	0.4318	0.5642	1.298	0.7158	0.2842	35.42
32	1.678	0.4295	0.5705	1.262	0.7276	0.2762	36.44
34	1.664	0.4268	0.5732	1.222	0.5276	0.2677	37.6
35	1.656	0.4253	0.5747	1.828	0.7370	0.2634	38.27
36	1.648	0.4236	0.5764	1.179	0.7419	0.2581	39.0
38	1.627	0.4194	0.5806	1.127	0.7532	0.2468	40.78
40	1.60	0.4137	0.5863	1.064	0.7671	0.2329	43.21

- Evaporator temperature of VCRS using HFC-134a = - 52 ^{o}C, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, T$_{generator}$= 130^{o}C. T$_{EVA_VARS}$= 08^{o}C, RE=35.167 "kW', T_Cond=35^{o}C
- 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 absorber temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber	COP$_{_Cascade}$	EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VARS}$	EDR$_{_VARS}$	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.691	0.7599	0.5642	1.298	2.519	0.2842	35.42
32	1.678	0.7528	0.5705	1.262	2.62	0.2762	36.44
34	1.664	0.7446	0.5732	1.222	2.736	0.2677	37.6
35	1.656	0.740	0.5747	1.828	2.802	0.2634	38.27
36	1.648	0.7349	0.5764	1.179	2.875	0.2581	39.0
38	1.627	0.7225	0.5806	1.127	3.051	0.2468	40.78
40	1.60	0.7055	0.5863	1.064	3.293	0.2329	43.21

- Evaporator temperature of VCRS using HFO-1234yf = - 52 ^{o}C, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, T$_{generator}$= 130^{o}C. T$_{EVA_VARS}$= 08^{o}C, RE=35.167 "kW', T_Cond=35^{o}C
- 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-8(a) Effect of absorber temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber	COP$_{_Cascade}$	Rational EDR$_{_Cascade}$	Cascaded System Second Law Efficiency	COP$_{_VARS}$	Rational EDR$_{_VARS}$	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.583	0.4379	0.5621	1.298	0.7158	0.2842	35.42
32	1.569	0.4349	0.5651	1.262	0.7276	0.2762	36.44
34	1.553	0.4314	0.5686	1.222	0.5276	0.2677	37.6
35	1.545	0.4294	0.5747	1.828	0.7370	0.2634	38.27
36	1.535	0.4272	0.5728	1.179	0.7419	0.2581	39.0
38	1.513	0.4217	0.5783	1.127	0.7532	0.2468	40.78
40	1.483	0.4141	0.5859	1.064	0.7671	0.2329	43.21

- Evaporator temperature of VCRS using HFO-1234yf = - 52 ^{o}C, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, T$_{generator}$= 130^{o}C. T$_{EVA_VARS}$= 08^{o}C, RE=35.167 "kW', T_Cond=35^{o}C
- 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-8(b) Effect of absorber temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Absorber	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	EDR_{VARS}	VARS Second Law Efficiency	Solar collector Area required(m^2)
30	1.583	0.7790	0.5621	1.298	2.519	0.2842	35.42
32	1.569	0.7696	0.5651	1.262	2.62	0.2762	36.44
34	1.553	0.7587	0.5686	1.222	2.736	0.2677	37.6
35	1.545	0.740	0.5747	1.828	2.802	0.2634	38.27
36	1.535	0.7457	0.5728	1.179	2.875	0.2581	39.0
38	1.513	0.7293	0.5783	1.127	3.051	0.2468	40.78
40	1.483	0.7066	0.5859	1.064	3.293	0.2329	43.21

- Evaporator temperature of VARS using HFO-1234yf = - 52 ^oC, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 130^oC. T_{EVA_VARS}= 08^oC, RE=35.167 "kW', T_Absorber=35^oC
- 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-9(a) Effect of condenser temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Cond	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	EDR_{VARS}	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.698	0.4314	0.5686	1.293	0.7172	0.2828	35.6
31	1.684	0.4305	0.5695	1.277	0.7204	0.2796	35.6
32	1.678	0.4294	0.5706	1.261	0.7239	0.2761	35.6
33	1.672	0.4283	0.5717	1.243	0.7278	0.2722	35.6
34	1.665	0.4269	0.5731	1.223	0.7321	0.2679	35.6
35	1.656	0.4253	0.5747	1.201	0.7370	0.2630	35.6
36	1.647	0.4234	0.5766	1.176	0.7424	0.2576	35.6
37	1.635	0.4212	0.5788	1.148	0.7487	0.2513	35.6
38	1.622	0.4184	0.5816	1.115	0.7558	0.2442	35.6
39	1.602	0.4150	0.5850	1.078	0.7640	0.2360	35.6
40	1.586	0.4106	0.5894	1.013	0.7737	0.2263	35.6

- Evaporator temperature of VARS using HFO-1234yf = - 52 ^oC, Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, $T\_{generator}$= 130^oC. T_{EVA_VARS}= 08^oC, RE=35.167 "kW', T_Absorber=35^oC
- 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-9(b) Effect of condenser temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Cond	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded System Second Law Efficiency	COP_{VARS}	EDR_{VARS}	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.6985	0.7587	0.5686	1.293	2.536	0.2828	35.6
31	1.6840	0.7559	0.5695	1.277	2.576	0.2796	35.6
32	1.678	0.7527	0.5706	1.261	2.622	0.2761	35.6
33	1.672	0.7490	0.5717	1.243	2.674	0.2722	35.6
34	1.665	0.7448	0.5731	1.223	2.733	0.2679	35.6
35	1.656	0.740	0.5747	1.201	2.802	0.2630	35.6
36	1.647	0.7343	0.5766	1.176	2.883	0.2576	35.6
37	1.635	0.7276	0.5788	1.148	2.979	0.2513	35.6
38	1.622	0.7194	0.5816	1.115	3.095	0.2442	35.6
39	1.602	0.7094	0.5850	1.078	3.238	0.2360	35.6
40	1.586	0.6966	0.5894	1.013	3.419	0.2263	35.6

- Evaporator temperature of VARSusing HFO-1234yf = - 52 ^{o}C,Compressor efficiency= 0.80
- Double effect Li/Br-H_2O VARS
- Approach=10, T_$_{generator}$= 130^{o}C. T_$_{EVA_VARS}$= 08^{o}C, RE=35.167 "kW',T_Absorber=35^{o}C
- 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-10(a) Effect of condenser temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Cond	COP_$_{Cascade}$	EDR_$_{Cascade}$	Cascaded System Second Law Efficiency	COP_$_{VARS}$	EDR_ $_{VARS}$	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.581	0.4374	0.5626	1.292	0.7172	0.2828	42.66
31	1.575	0.4362	0.5638	1.277	0.7204	0.2796	42.66
32	1.569	0.4348	0.5652	1.261	0.7239	0.2761	42.66
33	1.562	0.4333	0.5667	1.243	0.7278	0.2722	42.66
34	1.554	0.4315	0.5685	1.223	0.7321	0.2679	42.66
35	1.545	0.4294	0.5706	1.201	0.7370	0.2630	42.66
36	1.534	0.4269	0.5737	1.176	0.7424	0.2576	42.66
37	1.522	0.4240	0.5760	1.148	0.7487	0.2513	42.66
38	1.507	0.4204	0.5796	1.115	0.7558	0.2442	42.66
39	1.489	0.4158	0.5842	1.078	0.7640	0.2360	42.66
40	1.468	0.410	0.590	1.033	0.7737	0.2263	42.66

Table-10(b) Effect of evaporator temperature of VARS on thermal performances of double effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

T_Cond	COP_$_{Cascade}$	EDR_$_{Cascade}$	Cascaded System Second Law Efficiency	COP_$_{VARS}$	EDR_ $_{VARS}$	VARS Second Law Efficiency	Solar collector Area required (m^2)
30	1.581	0.7775	0.5626	1.292	2.536	0.2828	42.66
31	1.575	0.7737	0.5638	1.277	2.576	0.2796	42.66
32	1.569	0.7694	0.5652	1.261	2.622	0.2761	42.66
33	1.562	0.7646	0.5667	1.243	2.674	0.2722	42.66
34	1.554	0.7590	0.5685	1.223	2.733	0.2679	42.66
35	1.545	0.7526	0.5706	1.201	2.802	0.2630	42.66
36	1.534	0.745	0.5737	1.176	2.883	0.2576	42.66
37	1.522	0.7361	0.5760	1.148	2.979	0.2513	42.66
38	1.507	0.7257	0.5796	1.115	3.095	0.2442	42.66
39	1.489	0.7118	0.5842	1.078	3.238	0.2360	42.66
40	1.468	0.6949	0.590	1.033	3.419	0.2263	42.66

3. Conclusions

(i) The thermal performance of double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is always than the double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.

(ii) 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 5.54% to 6.2% lower than the double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.

(iii) 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 double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.

(iv) The variation of temperature of evaporator in vapour compression 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 6.5 % to 7% lower than the double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.

(v) The variation of absorber temperature on thermal performance of double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is 6.5 % to 7% lowerthan the double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants.

(vi) The variation of condenser temperature on thermal performance of double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is 7.4 % to 8% lower than the double effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFC -134a refrigerants

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