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Thermodynamic performances using energy-exergy analysis of half effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration systems using ecofriendly refrigerants

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Abstract

A new refrigerants (such as fourth generation refrigerants i.e. R-1234yf and R1234ze) are needed because the high GWP of the R134A that are used in existing refrigeration and air conditioning systems. The hydro fluoro olefins (HFOs) i.e., fourth generation refrigerants are available in limited quantities and also their performance is not completely tested in different applications. The thermodynamic performance of fourth generation refrigerants in terms of their first low efficiency termed as coefficient of performance (COP, second law efficiency termed as exergetic efficiency and exergy destruction ratio for a specified cooling load and compared with the third generation HFC-134a refrigerant. It is found that fourth generation HFO-1234yf refrigerant have slightly low(around 1.36% first law efficiency (COP) and exergetic efficiency around 3.487% and reduction in exergy destruction ratio of 6.3433% at -53ºC of low temperature evaporator. However, HFO1234ze can replace R134a as its thermodynamic performance is almost similar to R134a for -30ºC of low temperature evaporator temperature due to low GWP (around. The effect of performance parameters such as temperature over lapping (approach), generator temperature, high pressure absorber temperature, low pressure absorber temperature, condenser temperature of vapour absorption on thermodynamic performances (such as first and second law efficiencies , exergy destruction ratio have been presented.

Keywords: Thermodynamic performances, cascaded vapour compression-absorption refrigeration systems, ecofriendly refrigerants

1. Introduction

The third-generation ecofriendly R134a refrigerant belonging to hydrofluorocarbons (HFCs) do not much contribute to ozone depletion due to their higher global warming potential. (1400 GWP) However, other HFCs are used now a day are much producer of as greenhouse gases are banned by Kyoto Protocol because of their relatively GWP. At present the research is now mainly focused on refrigerants with zero ozone depletion potential (ODP) and less GWP (Below 150 GWP), are termed as Fourth generation refrigerants. This paper analyzes the thermodynamic performances of HFO-1234yf refrigerant which can replace HFC-134a for -53ºC of low temperature evaporator used in the half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system used for cryogenic applications.

2. Thermodynamic Performances of Cascaded half effect Li/Br H2O vapour absorption refrigeration system cascaded with vapour compression refrigerant

Performance improvement of vapour absorption refrigeration system by cascading vapour compression refrigeration system using various ecofriendly refrigerants for low temperature evaporator temperature of -53ºC have been presented. The effect of ecofriendly alternate refrigerants on Li/Br-H_2O cascaded vapour compression -absorption system and half effect, cascaded VARS-VCRS system, and Mishra [1] found that the thermal performances of cascaded refrigeration using ecofriendly R141 refrigerant gives best thermodynamic performances in terms of first law efficiency and second law efficiency (exergetic efficiency) and percentage increment in terms of exergetic efficiency as compaired to R134a [1].
Vapor compression refrigeration system is normally used

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refrigeration system (around 80%) and requires a large amount of electrical energy for its operation. The advancement in refrigeration area has a major impact on energy demand which approximates to 15% of the total energy consumption in the world. Many developing countries like India currently suffer from a major shortage of electricity. Around 56% of the total electrical capacity is generated using coal in India. The depletion of fossil fuel, also results in the production of harmful gases due to the burning of fossil fuel, which causes greenhouse effect and declines the environment. But, energy conservation and ecological safety are the vital requirement for the sustainable development of any country. Cimsit and Ozturk [2] theoretically evaluated thermal performance of vapour compression absorption cascaded refrigeration system (VCACRS) with H_2O-LiBr as fluid pair in absorption section and R134a, R410A and NH3 refrigerants in the compression section of cascaded refrigeration system and found 48-51% less electrical energy consumption than conventional vapour compression refrigeration system. Chinnappa et al. [3] described a vapour compression absorption cascaded refrigeration system consisting of a conventional R22 VCRS cascaded with a solar operated, NH_3-H_2O, VARS for air conditioning application. It was found to yield 49.5% saving in electrical energy consumption by the compression system.

Nehdi [4] carried out theoretically the comparative performance of three refrigerants (R717, R22, R134a) in the compression section with NH_3-H_2O fluid pair in the absorption section of the vapour compression–absorption cascaded refrigeration system using eothermal heat supplied in the generator at the temperature of 335 K for a fixed evaporation temperature of 263 K. The highest performance was obtained by R717and found refrigeration effect of about 10 MW with the compressor power of 1.65 MW and concluded that the same refrigeration effect could be produced by a conventional VCRS by consuming 3.6 MW of electricity which was 54% more than the combined installation consumption. The investigators have not computed the percentage improvement in the first and second law efficiency and also % reduction in the exergy destruction ratio based on exergy of product. By using cascade evapour-absorption-compression refrigeration system using alternative refrigerants. Lee et al. [5] 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 [6] 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. . Kilic and Kaynakli [7] 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. S.B. Riffat N Shankland [8] 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 [9] studied a NH_3/H_2O cascaded absorption–compression system coupled with subcritical CO2 vapor–compression cycle to breed low-temperature refrigerant. Rogdakis and Antonopoulos [10] 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 [11] proposed a cascaded vapor NH_3/H_2O absorption refrigeration system with a CO2 compression vapour refrigeration system at an evaporation temperature of -45°C and found its COP using energy and exergy analysis.

Mishra [12-14] modelled the cascade single effect ammonia-water (NH_3-H_2O) vapour absorption refrigeration system coupled with vapour compression refrigeration using ecofriendly refrigerants in the low temperature cycle of VCRS system have been carried out and it is found that the dichloro-1-fluoroethane and Penta-fluoro-propane gives improved thermodynamic performances. The method for enhancement in the thermal performances of vapour absorption refrigeration system by using heat pipes developed by Mishra and Dewedi [13] by utilizing the waste heat in the condenser and found increase in COP of vapour absorption refrigeration 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 single effect LiBr/ H_2O vapour absorption system.

3. Results and Discussions

Following two cascade system have been chosen for numerical computation and input data is also given below of each system.

System1: Li/Br Half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system using HFC-134a ecofriendly refrigerant.

(i) Temperature of Absorber=35°C.
(ii) Temperature of Condenser=35°C
(iii) Temperature of Generator=80°C
(iv) Evaporator temperature of vapour compression refrigeration system= 5 °C
(v) Evaporator temperature of vapour compression refrigeration system= -53 °C
(vi) Compressor efficiency=0.8
(vii) Heat exchanger effectiveness =0.5
(viii) Refrigeration effect =29.09“kW”
(ix) Temperature overlapping(Approach) =10 °C

System 2: Li/Br Half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system using HFO-1234yf ecofriendly refrigerant.

(i) Temperature of Absorber=35°C.

(ii) Temperature of Condenser=35ºC
(iii) Temperature of Generator=80ºC
(iv) Evaporator temperature of vapour compression refrigeration system= 5 ºC
(v) Evaporator temperature of vapour compression refrigeration system= -53 ºC
(vi) Compressor efficiency=0.8
(vii) Heat exchanger effectiveness =0.5
(viii) Refrigeration effect =29.09“kW”
(ix) Temperature overlapping(Approach) =10 ºC

Input variables used in the for numerical computation of half effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration systems using HFC-134a (system-1) and HFO-1234yf (system-2) refrigerants following ranges

(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 18 using HFC-134a and HFO-1234yf refrigerants
(ii) Generator temperature variation single effect Li//Br vapour absorption refrigeration from 65 ºC to 90 ºC,
(iii) Evaporator temperature vapour compression refrigeration system from $T_{\_EVA\_VCRS}$ = -40 to - 53ºC.
(iv) Evaporator temperature vapour absorption refrigeration system $T_{\_EVA\_VARS}$= 30 ºC to 45ºC,
(v) Absorber temperature vapour absorption refrigeration system $T_{\_EVA\_VARS}$= 30 ºC to 45ºC.

3.1 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 half effect Li/Br-H_2O vapour 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_ is increasing. Similarly exergy destruction ratio based on the exergy of product ($EDR_{\_Cascade}$) is also decreasing.
Table-1 (b) shows the variation of approach with variation of thermal performances such as first law efficiency in terms of coefficient of performance (COP) of cascaded single effect vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of half 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 half 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 80ºC have been compared and also shown in Tables-1(a) & Tables-1(b) respectively and it is found that thermodynamic performances using HFO-1234yf in half effect cascaded vapour absorption system (system-2) in terms of COP is 1.354% lower and exergetic efficiency is 3.5543% lower than using HFC-134a For increaement in EDR is 6.1144% as temperature overlapping approach at 10ºC.

Table-1(a) : Variation of approach (temperature overlapping) with thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFC -134a refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80)

Approach	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
0	0.6350	1.209	0.4506	2.220	0.2702	0.7873	0.4255	5.419	0.1558
2	0.6290	1.276	0.4393	2.123	0.3284	0.7528	0.4255	5.419	0.1558
4	0.6232	1.335	0.4283	2.032	0.3883	0.7203	0.4255	5.419	0.1558
5	0.6203	1.365	0.4228	1.988	0.4180	0.7047	0.4255	5.419	0.1558
6	0.6173	1.395	0.4175	1.945	0.4502	0.6896	0.4255	5.419	0.1558
8	0.6115	1.457	0.4070	1.863	0.5142	0.6604	0.4255	5.419	0.1558
10	0.6056	1.521	0.3967	1.785	0.5803	0.6328	0.4255	5.419	0.1558
12	0.5998	1.586	0.3867	1.710	0.6489	0.6085	0.4255	5.419	0.1558
14	0.5940	1.654	0.3768	1.640	0.720	0.5814	0.4255	5.419	0.1558
15	0.5911	1.688	0.3720	1.606	0.7566	0.5693	0.4255	5.419	0.1558
16	0.5883	1.723	0.3672	1.572	0.7939	0.5575	0.4255	5.419	0.1558
18	0.4825	1.795	0.3577	1.508	0.8707	0.5346	0.4255	5.419	0.1558

Table-1(b): Variation of approach (temperature overlapping) with thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80)

Approach	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
0	0.6298	1.269	0.4407	2.135	0.3208	0.7571	0.4255	5.419	0.1558
2	0.6233	1.333	0.4266	2.035	0.3863	0.7213	0.4255	5.419	0.1558
4	0.6169	1.399	0.4168	1.939	0.4545	0.6875	0.4255	5.419	0.1558
5	0.6137	1.433	0.4109	1.893	0.4897	0.6713	0.4255	5.419	0.1558
6	0.6104	1.468	0.4052	1.849	0.5256	0.6555	0.4255	5.419	0.1558
8	0.6040	1.54	0.3938	1.763	0.5999	0.6250	0.4255	5.419	0.1558
10	0.5974	1.614	0.3826	1.681	0.6777	0.5960	0.4255	5.419	0.1558
12	0.5909	1.691	0.3716	1.603	0.7594	0.5684	0.4255	5.419	0.1558
14	0.5844	1.771	0.3608	1.529	0.8452	0.5420	0.4255	5.419	0.1558
15	0.5811	1.813	0.3555	1.493	0.8898	0.5292	0.4255	5.419	0.1558
16	0.5778	1.856	0.3502	1.457	0.9356	0.5166	0.4255	5.419	0.1558
18	0.5711	1.944	0.3397	1.389	1.031	0.4924	0.4255	5.419	0.1558

Table-2(a) : Variation of evaporator temperature of VCRS on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80)

Evaporator Temperature (ºC)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
-53	0.6019	1.429	0.4116	1.791	0.5751	0.6349	0.4221	4.50	0.1818
-52	0.6053	1.425	0.4124	1.837	0.5622	0.6401	0.4221	4.50	0.1818
-51	0.6088	1.421	0.4131	1.885	0.5493	0.6454	0.4221	4.50	0.1818
-50	0.6123	1.417	0.4137	1.935	0.5365	0.6508	0.4221	4.50	0.1818
-45	0.6298	1.403	0.4162	2.210	0.4739	0.6785	0.4221	4.50	0.1818
-40	0.6476	1.396	0.4173	2.537	0.4129	0.7078	0.4221	4.50	0.1818

Table-2(b): Variation of evaporator temperature of VCRS on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80)

Evaporator Temperature (ºC)	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
-53	0.6101	1.245	0.4265	1.903	0.4822	0.6747	0.4221	4.50	0.1818
-52	0.6133	1.343	0.4269	1.95	0.4716	0.6796	0.4221	4.50	0.1818
-51	0.6167	1.341	0.4272	1.999	0.4610	0.6845	0.4221	4.50	0.1818
-50	0.620	1.339	0.4275	2.05	0.4504	0.6895	0.4221	4.50	0.1818
-45	0.6367	1.335	0.4283	2.329	0.3983	0.7151	0.4221	4.50	0.1818
-40	0.6535	1.338	0.4277	2.611	0.3469	0.7425	0.4221	4.50	0.1818

3.2 Effect of of low temperature evaporator temperature of vapour compression refrigeration cycle on thermal performances of half effect vapour absorption refrigeration cascaded with vapour compression refrigeration system

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 half 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.The optimum values of single effect vapour absorption refrigeration cycle cascaded with vapour compression cycle for generator temperature of 80ºC and condenser temperature and absorber temperature of 35ºC by using HFO-1234yf refrigerant(system-2) has 1.344% lower COP and 3.49355% lower exergetic efficiency and 6.245% higher EDR than System-1 using HFC-134a

Table-3(b) : Effect of HFO refrigerant for replacing HFC-134a on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=5ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-30ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80, Approach=10)

Refrigerant	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
R-134a	0.6056	1.521	0.3967	1.785	0.5803	0.6328	0.4255	5.419	0.1558
R-1234ze	0.6023	1.559	0.3908	1.741	0.6199	0.6173	0.4255	5.419	0.1558
R-1234yf	0.5965	1.614	0.3826	1.68	0.677	0.5960	0.4255	5.419	0.1558

Table-3(b) : Effect of HFO refrigerant for replacing HFC-134a on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-30ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80, Approach=10)

Refrigerant	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
R-134a	0.6834	1.566	0.3897	3.2745	0.3495	0.7410	0.4221	4.50	0.1818
R-1234ze	0.6825	1.575	0.3883	3.245	0.3598	0.7354	0.4221	4.50	0.1818
R-1234yf	0.6791	1.399	0.3830	3.157	0.3995	0.7145	0.4221	4.50	0.1818

Table-3(a) & table-3(b) shows, the effect of ecofriendly 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 single effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration at 5ºc and at 8ºC of cascaded vapour absorption refrigeration system evaporator temperature and vapour compression evaporator temperature of -30ºC and it is found that the performance of HFC-134a..

Similarly Table-3(b)& Table-3(c) & shows, the effect of ecofriendly 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 single effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration at 8ºc of cascaded vapour absorption refrigeration system evaporator temperature and vapour compression evaporator temperature of -30ºC and it is found that the performance of HFC-134a . It was also observed that by changing evaporator temperature from 5oC to 10oC the thermodynamic performances enhanced significantly

Table-3(c) : Effect of HFO refrigerant for replacing HFC-134a on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For $T_{\_Eva\_VARS}$=8ºC, $T_{\_Generator}$= 80ºC, $T_{\_Eva\_VCRS}$=-30ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{_VCRS}$=0.80, Approach=10)

Refrigerant	$COP_{\_Cascade}$	$EDR_{\_Cascade}$	Cascaded system Exergetic Efficiency	$COP_{\_VCRS}$	$EDR_{\_VCRS}$	VCRS Exergetic Efficiency	$COP_{\_VARS}$	EDR_ VARS	VARS Exergetic Efficiency
R-134a	0.6878	1.368	0.4223	3.555	0.2423	0.8046	0.4221	4.50	0.1818
R-1234ze	0.6372	1.374	0.4212	3.535	0.2499	0.8001	0.4221	4.50	0.1818
R-1234yf	0.6842	1.402	0.4163	3.444	0.2829	0.7795	0.4221	4.50	0.1818

3.3 Variation of generator temperature ofhalf effect vapour absorption system with thermal performances of cascaded half effect vapour absorption compression refrigeration system

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 half 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. Table-4 (b) 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 half 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 half 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 half 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 110ºC have been compared and also shown in Table-4(a) to Tables-4(b) respectively and it is found that thermodynamic performances using HFO-1234yf (system-2) in cascaded vapour absorption system in terms of COP is 1.17% lower and exergetic efficiency is 2.9577 % lower than System-1

Table-4(a) : Variation of generator temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{VCRS}$=0.80)

Generator Temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
90	0.6039	1.542	0.3934	1.903	0.4815	0.6748	0.4172	5.393	0.1564
85	0.6068	1.444	0.4091	1.903	0.4815	0.6748	0.4195	4.953	0.1680
80	0.6101	1.344	0.4265	1.903	0.4815	0.6748	0.4221	4.50	0.1818
75	0.6138	1.242	0.4460	1.903	0.4815	0.6748	0.4250	4.037	0.1985
70	0.6180	1.138	0.4677	1.903	0.4815	0.6748	0.4284	3.563	0.2191
65	0.6226	1.032	0.4922	1.903	0.4815	0.6748	0.4320	3.081	0.2450

Table 4(b) : Variation of generator temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_absorber=T_Condenser=35ºC, Compressor Efficiency$_{VCRS}$=0.80)

Generator Temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
90	0.6298	1.269	0.4407	1.805	0.5624	0.6401	0.4172	5.393	0.1564
85	0.6233	1.333	0.4266	1.805	0.5624	0.6401	0.4195	4.953	0.1680
80	0.6169	1.399	0.4168	1.805	0.5624	0.6401	0.4221	4.50	0.1818
75	0.6137	1.433	0.4109	1.805	0.5624	0.6401	0.4250	4.037	0.1985
70	0.6104	1.468	0.4052	1.805	0.5624	0.6401	0.4284	3.563	0.2191
65	0.6040	1.54	0.3938	1.805	0.5624	0.6401	0.4320	3.081	0.2450

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

Table-5 (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 half 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-5 (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 half 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 half 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-5 (b) also 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 half effect vapour absorption system & second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of fuel of half effect Li/Br-H_2O vapour 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 half 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 90ºC have been compared and also shown in Table-5(a) to Table-5(b) respectively and it is found that thermodynamic performances using HFO-1234yf (system-2) in cascaded vapour absorption system in terms of COP, is 1.344 % lower than using HFC-134a (system-1)at 35ºC 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 3.49355% lower than R134a at 35ºC and exergy destruction ratio is 6.245% higher than system-1 at 35ºC respectively.

Table-5(a) : Variation of condenser temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFC -134a refrigerant (For T_{Eva_VARS}=8ºC, $T\_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_absorber=35ºC, Compressor Efficiency$_{VCRS}$=0.80)

Condenser temperature (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6121	1.269	0.4407	1.805	0.5624	0.6401	0.4237	4.48	0.1825
35	0.6101	1.333	0.4266	1.805	0.5624	0.6401	0.4221	4.50	0.1818
40	0.6081	1.399	0.4168	1.805	0.5624	0.6401	0.4205	4.521	0.1811
45	0.6061	1.433	0.4109	1.805	0.5624	0.6401	0.4189	4.541	0.1805

Table-5(b): Variation of condenser temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T\_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_Condenser=35ºC, Compressor Efficiency$_{VCRS}$=0.80)

Condenser temperature (ºC)	$COP\_{Cascade}$	$EDR\_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6038	1.425	0.4124	1.791	0.5751	0.6349	0.4237	4.48	0.1825
35	0.6019	1.429	0.4116	1.791	0.5751	0.6349	0.4221	4.50	0.1818
40	0.5999	1.434	0.4108	1.791	0.5751	0.6349	0.4205	4.521	0.1811
45	0.5980	1.439	0.4101	1.791	0.5751	0.6349	0.4189	4.541	0.1805

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

Table-6 (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 single 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-6(b) respectively.Table-6(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 single 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 single 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-6(d) respectively.

The performance of single effect Li/Br-H_2O vapour absorption system cascaded with vapour compression system using HFC-134a and HFO-1234yf for absorber temperature at 35ºC have been compared and also shown in Tables-6(a) & Tables-6(b) respectively and it is found that thermodynamic performances using HFO-1234yf in cascaded vapour absorption system (system-2) in terms of COP is 1.163 % lower than using HFC-134a (system-1) at 35ºC of vapour compression absorber temperature. .

Table-6(a) : Variation of absorber temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_absorber=T_Condenser=35ºC, Compressor $Efficiency_{VCRS}$=0.80)

Absorber temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6248	1.312	0.4326	1.903	0.4819	0.6748	0.4338	4.352	0.1868
35	0.6101	1.344	0.4265	1.903	0.4819	0.6748	0.4221	4.50	0.1818
40	0.5999	1.370	0.4219	1.903	0.4819	0.6748	0.4132	4.618	0.1780
45	0.5980	1.393	0.4180	1.903	0.4819	0.6748	0.4060	4.718	0.1749

Table-6(b) : Variation of absorber temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFC -134a refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_condenser =35ºC, Compressor $Efficiency_{VCRS}$=0.80)

Absorber temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6174	1.385	0.4193	1.805	0.5624	0.6401	0.4338	4.352	0.1868
35	0.6030	1.418	0.4136	1.805	0.5624	0.6401	0.4221	4.50	0.1818
40	0.5920	1.444	0.4091	1.805	0.5624	0.6401	0.4132	4.618	0.1780
45	0.5829	1.467	0.4054	1.805	0.5624	0.6401	0.4060	4.718	0.1749

3.6 Effect of high pressure absorber temperature and low pressure absorber temperature of vapour absorption system, when absorber temperature is not same as condenser temperature

Table-6 (c) shows the variation of high pressure absorber temperatures 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 half effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant when low pressure absorber temperature absorber temperature is constant 35ºC and & Table-6(d)) shows the variation of low pressure absorber temperatures 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 half effect Li/Br-H_2O vapour absorption refrigeration system cascaded with vapour compression refrigeration using HFC-134a refrigerant when high pressure absorber temperature absorber temperature is constant 35ºC 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 as absorber temperature 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-6(d) respectively.Table-6(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 single 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 single 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-6(d) respectively.

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Table-6(c) : Variation of absorber temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_absorber=T_Condenser=35ºC, Compressor $Efficiency_{VCRS}$=0.80)

Absorber temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6123	1.395	0.4175	1.903	0.4819	0.6748	0.430	4.399	0.1852
35	0.6030	1.418	0.4136	1.903	0.4819	0.6748	0.4221	4.50	0.1818
40	0.5957	1.435	0.4106	1.903	0.4819	0.6748	0.4162	4.578	0.1793
45	0.5897	1.450	0.4082	1.903	0.4819	0.6748	0.4114	4.643	0.1772

Table-6(d): Variation of Absorber temperature on thermal performances of half effect vapour absorption cascaded with compression refrigeration systems using HFO -1234yf refrigerant (For T_{Eva_VARS}=8ºC, $T_{Generator}$= 80ºC, T_{Eva_VCRS}=-53ºC, T_condenser =35ºC, Compressor Efficiency$_{VCRS}$=0.80)

Absorber temperature (ºC)	$COP_{Cascade}$	$EDR_{Cascade}$	Cascaded system Exergetic Efficiency	COP_{VCRS}	EDR_{VCRS}	VCRS Exergetic Efficiency	COP_{VARS}	EDR_ VARS	VARS Exergetic Efficiency
30	0.6174	1.385	0.4193	1.805	0.5024	0.6401	0.4338	4.453	0.1834
35	0.6030	1.418	0.4136	1.805	0.5024	0.6401	0.4221	4.50	0.1818
40	0.5920	1.444	0.4091	1.805	0.5024	0.6401	0.4190	4.54	0.1805
45	0.5829	1.467	0.4054	1.805	0.5024	0.6401	0.4164	4.576	0.1794

4. Conclusions

The following conclusions were drawn from present investigations.

- The thermal performance of single Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system using HFO -1234yf refrigerant is always than the single effect Li/Br H_2O vapour absorption refrigeration system cascaded with vapour compression system (system-1)using HFC -134a refrigerants. The thermodynamic performances using HFO-1234yf (system-2) in cascaded vapour absorption system in terms of COP is 1.353 % lower and exergetic efficiency is 3.036% lower than using HFC-134a in the vapour compression refrigeration system.
- In the half 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 half 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_ is decreasing .
- In the half 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 half 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 half 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 half 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
- In the half 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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