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Performance evaluation of half effect Li/Br-H_2O vapour absorption systems using multi cascading of vapour compression cycles for ultra-low temperature applications

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Abstract

Most of the absorption cooling system use either LiBr-H_2O or NH_3-H_2O solutions. The LiBr-H_2O system can operate at a low generator temperature with better coefficient of performance than NH_3-H_2O system. However, COP of absorption system is relatively less as compared to the compression system. To improve its performances, several modifications have been made in the cycle. Therefore, this paper mainly deals with performance evaluations of half effect LiBr-H_2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications (at -150ºC) used for cryogenics applications . comparison were made with several integrated systems at -50ºC evaporator temperature in medium temperature cascaded cycle using several ecofriendly refrigerants with HFO-1234yf refrigerant and also with several integrated systems at -95ºC evaporator temperature using several ecofriendly refrigerants intermediate temperature cascaded cycle with R245fa refrigerant in the low temperature circuit using Ethylene and Hydrocarbons refrigerants with R236fa in the low temperature cascaded cycle at -150ºC temperature circuit and found that half effect LiBr-H_2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications using HFC152a in medium temperature cycle and R245fa in intermediate temperature cycle and R-236fa in LTC gives better thermodynamic performances than by using R404a refrigerants in low temperature cycles. Similarly thermodynamic performances at -150ºC, the hydrocarbons R290 & R600a gives better performance than R404a in ultra-low temperature cycle for cryogenic applications. However, thermodynamic performances using HFO-1234ze in medium temperature cycle and R245fa in intermediate temperature cycle and R236fa in ultra-low temperature cascaded cycle is better than with using HFO-1234yf in medium temperature cycle and R245fa in intermediate temperature cycle and R236fa in ultra-low temperature cascaded cycle.

Keywords: vapour absorption systems, vapour compression cycles, COP, Exergy.

1. Introduction

Vapor compression refrigeration system is normally used 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-Li/Br 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

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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 geo-thermal 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 NH3/H2O 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 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.

New ecofriendly refrigerants new refrigerants (such as fourth generation refrigerants (i.e. R-1234yf and R1234ze) of low GWP are required 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 thermodynamic performance is not completely tested in different applications.

The thermodynamic performances 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 -50ºC 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. The third-generation ecofriendly R134a refrigerant belonging to hydro fluorocarbons (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. Mishra [12] carried out thermodynamic Performances of Cascaded half effect Li/Br H_2O 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 -50ºC and found the effect of ecofriendly alternate refrigerants on Li/Br-H_2O cascaded vapour compression -absorption system and half effect, cascaded VARS-VCRS system. Mishra [13] found that the thermal performances of cascaded refrigeration using ecofriendly R141b 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 compared to R134a [13]. 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 dichloro1-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 H_2O-Li/Br vapour absorption system.

The half effect absorption systems have the advantage of using low temperature heat energy for cooling. The first law & second law performances (i.e. coefficient performance (COP) and the exergetic efficiency) of the half effect absorption systems are found as 0.45 and 0.24, respectively. Arivazhagan R, et.al [1] computed component's irreversibilities and also are found most of the exergy destruction occurred in the evaporator and in the absorbers and concluded that the half effect absorption systems is the best for cooling driven by low temperature heat energy and the performance of the evaporator and the absorbers is very important for the cycle. In recent years, the fourth generation Hydro-fluoro-olefins (HFOs)-R1234yf and R1234ze are being considered as alternative to R134a. A number of studies have been carried out using HFO 1234yf and HFO 1234ze. Although, R134a is a wide spread used refrigerant due to its commercial availability, similar properties to R12, less ODP value, excellent thermal stability, nontoxic and non-flammability etc. has high GWP value is more than 1430. The European Union (EU) regulation is phasing out the current generation HFCs like R134a due to its high GWP and environment consequences. The environmental characteristics of refrigerants in terms of GWP and ODP for replacing HFC 134a, shown in Table-1(a) to Table-1(c) respectively.

Table-1(a) Environmental characteristics (ODP and GWP) of ecofriendly refrigerants used in the medium temperature cycle of integrated system

MTC refrigerants	GWP	ODP
R1234yf	4	0
R1234ze	6	0
R152a	124	0
R717	0	0
R134a	1430	0

Table-1(b) Environmental characteristics (ODP and GWP) of ecofriendly refrigerants used in the intermediate temperature cycle of integrated system

ITC refrigerants	GWP	ODP
R245fa	1030	0
R134a	1430	*0*
R32	675	0
R410a	*1725/ 2088*	*0*
R407c	1774	0

The European Union (EU) regulation is phasing out the current generation HFCs like R134a due to its high GWP and environment consequences. A number of studies have been carried out using R1234yf and R1234ze [2]. In the notable studies [3-8],Yataganbaba et al. [3] performed exergy analysis on a two evaporator vapour compression refrigeration system using R1234yf, R1234ze and R134a as refrigerants. The two refrigerants R1234yf and R1234ze were good alternatives to R134a regarding their environment friendly properties.

Table-1(c) Environmental characteristics (ODP and GWP) of ecofriendly refrigerants used in the ultra-low temperature cycle of integrated system refrigerants

LTC refrigerants	GWP	ODP
R290	*3*	*0*
R600a	3	0
R404a	*3922*	*0*
R236fa	9810	0
R407c	1774	0

Sanchez et al. [8] compared five low GWP refrigerants R152a, R1234yf, R1234ze, R290 and R600a for the replacement of R134a using hermetic compressor in the experimental test rig and found that the R1234yf and R152a can be considered suitable drop-in alternative to R134a by considering the energy consumption and the cooling refrigerating capacity of facility. Arora and Kaushik [9-10] 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. Gomri[11] carried out thermodynamic analysis of single effect & double effect absorption refrigeration systems and found the COP of double effect system is approximately twice the COP of single effect system. S.B. Riffat N. Shankland [12] studied different types of absorption systems integrated with vapour-compression systems. Kilic and Kaynakli[13] 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. Chinnappa et al. [14] 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. The above investigators have not carried out the performance evaluation for low temperature applications in cryogenics and the effect of performance parameters using HFO-1234yf in intermediate temperature circuit and HFC/134a in low temperature circuit. Therefore, this paper mainly deals with performance evaluations at -150^{o}C used for cryogenics applications. The comparison with HFO-1234yf and other several ecofriendly refrigerants at-50^{o}C evaporator temperature in the medium temperature circuit. Also comparison with R-245farefrigerant with other ecofriendly refrigerants in the intermediate temperature circuit at-95^{o}C and also various hydro carbons and ethylene, R404a & R410a in ultra-low evaporator temperature in the low temperature circuit.

2. Results and Discussion

Following systems were chosen for numerical computation of integrated half effect LiBr-H_2O VARS multi cascaded VCRS for low temperature applications

System-1: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and R-236fa in cascaded vapour compression ultralow temperature cycle.

System-2: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and HFC-404a in cascaded vapour compression ultra-low temperature cycle.

System-3: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate temperature vapour compression cycle and HC-290 in cascaded vapour compression ultralow temperature cycle.

System-4: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and HC-600a in cascaded vapour compression ultralow temperature cycle

System-5: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and R410a in cascaded vapour compression ultralow temperature cycle.

System-6: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and R-407c in cascaded vapour compression ultralow temperature cycle.

System-7: Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded cascaded HFO-1234yf in /medium temperature vapour compression cycle and R-245fa in intermediate/ temperature vapour compression cycle and ethylene in cascaded vapour compression ultra-low temperature cycle

The following numerical values have been used for numerical computations

- Generator temperature is 80°C (although it varying from 60°C to 95°C
- Half effect vapour absorption refrigeration system evaporator temperature is 8°C (although it varying from 1°C to 10°C).
- Absorber temperature of half effect vapour absorption refrigeration system is 30°C (although it varying from 30°C to 40°C.
- Condenser temperature of half effect vapour absorption refrigeration system is 30°C (although it varying from 30°C to 40°C.
- Temperature overlapping between HFO condenser and LiBr-H_2O evaporator is 10°C (although it varying from 0°C to 15°C)
- Temperature overlapping between HFO condenser and LiBr-H_2O evaporator is 10°C (although it varying from 0°C to 15°C)
- Temperature overlapping between HC/HFC condenser and HFC/HFO evaporator is 10°C (although it varying from 0°C to 15°C)

Table-2(a) to Table-2(c) shows the variation of thermodynamic performance with VARS Generator Temperature (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as VARS Generator Temperature is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-2(a): Variation of thermodynamic performance parameters in terms of first law efficiency (various coefficient of performance : COP)and percentage improvement with generator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra low temperature applications

VARS Generator temperature (°C)	Overall system $COP_{\_LTC}$	Overall system $COP_{\_ITC}$	Overall system $COP_{\_MTC}$	% improvement in Overall system $COP_{\_LTC}$	% improvement in Overall system $COP_{\_ITC}$	% improvement in Overall system $COP_{\_MTC}$
65	0.7383	0.7276	0.6204	69.48	67.02	42.42
70	0.7334	0.7225	0.6158	69.81	67.30	42.59
75	0.7289	0.7180	0.6116	70.11	67.56	42.74
80	0.7249	0.7139	0.6079	70.37	67.79	42.87
85	0.7213	0.7102	0.6045	70.61	68.0	42.99
90	0.7181	0.7070	0.6016	70.82	68.18	43.09
95	0.7154	0.7042	0.5990	71.01	68.34	43.19

Table-2(b): Variation of thermodynamic performance parameters in terms of second law efficiency in terms of exergetic efficiency and percentage improvement with generator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle

VARS Generator temperature (°C)	Overall system Exergetic $Efficiency_{\_LTC}$	Overall system Exergetic $Efficiency_{\_ITC}$	Overall system Exergetic $Efficiency_{\_MTC}$	% improvement in overall system Exergetic $Efficiency_{\_MTC}$	% improvement in overall system Exergetic $efficiency_{\_LTC}$	% improvement in overall system Exergetic $efficiency_{\_MTC}$
65	0.6411	0.5387	0.4423	205.3	156.5	110.6
70	0.6199	0.5187	0.4208	230.1	176.2	124.1
75	0.6004	0.5006	0.4016	252.9	194.2	136.0
80	0.5824	0.4839	0.3844	273.8	210.6	146.7
85	0.5658	0.4687	0.3689	293.2	225.7	156.4
90	0.5505	0.4547	0.3550	311.1	239.5	165.0
95	0.5364	0.4419	0.3424	327.6	252.2	172.9

Table-2(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (EDR) and percentage decrement with generator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Generator Temperature (°C)	Overall system EDR_LTC	Overall systemEDR_ITC	Overall systemEDR_MTC	% decrement in EDR_LTC	% decrement in EDR_ITC	% decrement in EDR_MTC
65	0.5599	0.8564	1.261	85.12	77.24	66.49
70	0.6133	0.9277	1.377	85.82	78.55	68.17
75	0.6657	0.9978	1.490	86.35	79.54	69.45
80	0.7170	1.066	1.602	86.77	80.32	70.44
85	0.7673	1.34	1.711	87.10	80.95	71.24
90	0.8164	1.199	1.817	87.38	81.46	71.90
95	0.8642	1.263	1.921	87.60	81.88	72.44

Table-3(a) to Table-3(c) shows the variation of thermodynamic performance with VARS absorber temperature (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as VARS absorber temperature is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-3(a): Variation of thermodynamic performance parameters in terms of first law efficiency(coefficient of performance) and percentage improvement with absorber temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

VARS absorber temperature (°C)	Overall system COP_LTC	Overall system COP_ITC	Overall system COP_MTC	% improvement in Overall system COP_LTC	% improvement in Overall system COP_ITC	% improvement in overall system COP_MTC
30	0.7410	0.7303	0.6230	69.30	67.94	42.96
32	0.7340	0.7232	0.6164	69.77	67.94	42.96
34	0.7278	0.7168	0.6105	70.18	67.94	42.96
35	0.7249	0.7139	0.6079	70.37	67.94	42.96
36	0.7222	0.7111	0.6053	70.55	67.94	42.96
38	0.7172	0.7060	0.6006	70.89	67.94	42.96
40	0.7125	0.7013	0.5963	71.20	67.94	42.96
42	0.7083	0.6969	0.5924	71.48	67.94	42.96

Table-3(b): Variation of thermodynamic performance parameters in terms of second law efficiency (exergetic efficiency) and percentage improvement with absorber temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Absorber Temperature (°C)	Overall system Exergetic Efficiency_LTC	Overall system Exergetic Efficiency_ITC	Overall system Exergetic Efficiency_MTC	% improvement in Overall system Exergetic Efficiency_LTC	% improvement in Overall system Exergetic Efficiency_ITC	% improvement in Overall systemExergeticEfficiency_MTC
30	0.5882	0.4893	0.3899	267.1	205.3	143.3
32	0.5857	0.4870	0.3875	270.0	207.6	144.8
34	0.5834	0.4849	0.3853	272.6	209.7	146.1
35	0.5824	0.4839	0.3844	273.8	210.6	146.7
36	0.5814	0.4830	0.3834	275.0	211.6	147.3
38	0.5795	0.4818	0.3817	277.2	213.6	148.4
40	0.5778	0.4797	0.3801	279.2	214.8	149.4
42	0.5762	0.4783	0.3786	281.3	216.3	150.3

Table-3(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (EDR) and percentage decrement with absorber temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Absorber Temperature (°C)	Overall system EDR_LTC	Overall system EDR_ITC	Overall system EDR_MTC	% decrement in EDR_LTC	% decrement in EDR_ITC	% decrement in EDR_MTC
30	0.7601	1.044	1.565	86.64	80.08	70.14
32	0.7074	1.053	1.581	86.70	80.19	70.27
34	0.7140	1.062	1.595	86.75	80.28	70.39
35	0.7170	1.066	1.602	86.77	80.32	70.44
36	0.720	1.070	1.608	86.79	80.36	70.49
38	0.7255	1.078	1.620	86.83	80.44	70.59
40	0.7306	1.085	1.631	86.86	80.50	70.67
42	0.7354	1.091	1.642	86.9	80.56	70.75

Table-4(a) to Table-4(c) shows the variation of thermodynamic performance with VARS condenser Temperature (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as VARS condenser Temperature is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-4(a): Variation of thermodynamic performance parameters in terms of first law efficiency(coefficient of performance) and percentage improvement with condenser temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS condenser Temperature (°C)	Overall system COP_LTC	Overall system COP_ITC	Overall system COP_MTC	% improvement in Overall system COP_LTC	% improvement in Overall system COP_ITC	% improvement in Overall system COP_MTC
30	0.7270	0.7161	0.6099	70.23	67.67	42.80
32	0.7262	0.7152	0.6091	70.29	67.72	42.83
34	0.7253	0.7143	0.6083	70.35	67.76	42.86
35	0.7249	0.7138	0.6079	70.37	67.79	42.87
36	0.7245	0.7135	0.6075	70.40	67.81	42.88
38	0.7237	0.7126	0.6067	70.46	67.86	42.91
40	0.7228	0.7118	0.6059	70.51	67.81	42.94
42	0.7220	0.7109	0.6052	70.57	67.96	42.97

Table-4(b): Variation of thermodynamic performance parameters in terms of second law efficiency(exergetic efficiency) and percentage improvement with condenser temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Condenser Temperature (°C)	Overall second law efficiency (exergetic efficiency_LTC	Overall second law efficiency (exergetic efficiency_ITC	Overall second law efficiency (exergetic efficiency_MTC	% improvement in Overall second law efficiency (exergetic efficiency_LTC	% improvement in Overall second law efficiency (exergeticefficiency_ITC	% improvement in Overall second law efficiency (exergeticefficiency_MTC
30	0.5832	0.4846	0.3851	272.9	209.9	146.3
32	0.5829	0.4844	0.3848	273.3	210.2	146.5
34	0.5825	0.4841	0.3845	273.7	210.5	146.6
35	0.5824	0.4839	0.3844	273.8	210.6	146.7
36	0.5822	0.4838	0.3842	274.0	210.8	146.8
38	0.5819	0.4835	0.3839	274.4	211.1	147.0
40	0.5816	0.4832	0.3836	274.7	211.3	147.2
42	0.5813	0.4830	0.3834	275.1	271.6	147.4

Table-4(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (EDR) and percentage improvement with condenser temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Condenser Temperature (°C)	Overall system $EDR_{\_LTC}$	Overall system $EDR_{\_ITC}$	Overall system $EDR_{\_MTC}$	% decrement in $EDR_{\_LTC}$	% decrement in $EDR_{\_ITC}$	% decrement in $EDR_{\_MTC}$
30	0.7148	1.063	1.597	86.75	80.29	70.40
32	0.7167	1.065	1.599	86.76	80.30	70.42
34	0.7166	1.066	1.601	86.77	80.32	70.44
35	0.7170	1.066	1.602	86.77	80.32	70.44
36	0.7175	1.67	1.603	86.77	80.33	70.45
38	0.7184	1.068	1.605	86.78	80.34	70.47
40	0.7183	1.069	1.607	86.78	80.35	70.48
42	0.7202	1.071	1.609	86.79	80.36	70.50

Table-5(a) to Table-5(c) shows the variation of thermodynamic performance with VARS Evaporator Temperature (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as VARS Evaporator Temperature is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-5(a): Variation of thermodynamic performance parameters in terms of first law efficiency(coefficient of performance) and percentage improvement with evaporator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Evaporator Temperature (°C)	Overall system $COP_{\_LTC}$	Overall system $COP_{\_ITC}$	Overall system $COP_{\_MTC}$	% improvement in Overall system $COP_{\_LTC}$	% improvement in Overall system $COP_{\_ITC}$	% improvement in Overall system $COP_{\_MTC}$
4	0.7349	0.7239	0.6152	74.55	71.95	46.13
5	0.7324	0.7214	0.6134	73.52	70.91	45.32
6	0.7299	0.7189	0.6115	72.47	69.88	44.51
7	0.7274	0.7164	0.6097	71.43	68.84	43.69
8	0.7249	0.7139	0.6079	70.37	67.75	42.87
9	0.7224	0.7114	0.6061	69.31	66.74	42.05
10	0.7199	0.7089	0.6042	68.25	65.68	41.22
11	0.7174	0.7064	0.6024	67.18	64.61	40.39
12	0.7149	0.7039	0.6006	66.10	63.54	39.55

Table-5(b): Variation of thermodynamic performance parameters in terms of second law efficiency (exergetic efficiency) and percentage improvement with evaporator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS Evaporator Temperature (°C)	Overall system Exergetic $Efficiency_{\_LTC}$	Overall system Exergetic $Efficiency_{\_ITC}$	Overall system Exergetic $Efficiency_{\_MTC}$	% improvement in Overall system Exergetic $Efficiency_{\_LTC}$	% improvement in Overall system Exergetic $Efficiency_{\_ITC}$	% improvement in Overall system Exergetic $Efficiency_{\_MTC}$
4	0.5935	0.4918	0.4263	211.7	158.3	123.8
5	0.5908	0.4899	0.4156	224.9	189.4	128.6
6	0.5880	0.4880	0.4251	239.6	181.4	133.9
7	0.5852	0.4860	0.3946	255.8	195.4	139.9
8	0.5824	0.4839	0.3844	273.8	210.6	146.7
9	0.5795	0.4819	0.3742	294.1	227.7	154.5
10	0.5766	0.4797	0.3642	317.1	247.0	163.5
11	0.5736	0.4775	0.3554	343.3	269.1	173.9
12	0.5705	0.4753	0.3446	373.4	294.4	186.0

Table-5(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (EDR) and percentage decrement with evaporator temperature of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

VARS evaporator temperature (°C)	Overall system EDR_LTC	Overall system EDR_ITC	Overall system EDR_MTC	% improvement in Overall system EDR_LTC	% improvement in Overall system EDR_ITC	% improvement in Overall system EDR_MTC
4	0.6849	1.033	1.345	83.89	75.69	68.35
5	0.6926	1.041	1.406	84.61	76.86	68.76
6	0.7006	1.049	1.469	85.33	78.02	69.24
7	0.7087	1.058	1.534	86.05	79.17	69.80
8	0.7170	1.066	1.602	86.77	80.32	70.44
9	0.7256	1.075	1.672	87.49	81.46	71.18
10	0.7344	1.085	1.746	88.22	83.60	72.0
11	0.7435	1.094	1.822	88.95	83.24	72.92
12	0.7528	1.104	1.902	89.69	8488	73.94

2.1 Effect of temperature over lapping

Table-6(a) to Table-6(c) shows the variation of thermodynamic performance with LTC Approach (°C) of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as LTC temperature overlapping is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing. Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-6(a): Variation of thermodynamic performance parameters in terms of first law efficiency(coefficient of performance, i.e. COP) and percentage improvement with LTC Approach (°C) temperature overlapping in VARS evaporator and medium temperature condenser of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

LTC Approach (°C)	Overall system COP_LTC	Overall system COP_ITC	Overall system COP_MTC	% improvement in Overall system COP_LTC	% improvement in Overall system COP_ITC	% improvement in Overall system COP_MTC
0	0.7313	0.7139	0.6079	71.88	67.79	42.87
2	0.7300	0.7139	0.6079	71.57	67.79	42.87
4	0.7287	0.7139	0.6079	71.26	67.79	42.87
5	0.7280	0.7139	0.6079	71.11	67.79	42.87
6	0.7274	0.7139	0.6079	70.96	67.79	42.87
8	0.7261	0.7139	0.6079	70.66	67.79	42.87
10	0.7249	0.7139	0.6079	70.37	67.79	42.87
12	0.7237	0.7139	0.6079	70.09	67.79	42.87
14	0.7225	0.7139	0.6079	68.82	67.79	42.87
15	0.7220	0.7139	0.6079	69.58	67.79	42.87

Table-6(b): Variation of thermodynamic performance parameters in terms of second law efficiency(exergetic efficiency) and percentage improvement with LTC Approach (°C) temperature overlapping in VARS evaporator and medium temperature condenser of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFC-152a in Intermediate temperature circuit for ultra-low temperature applications

LTC Approach temp (°C)	Overall system exergetic eff_LTC	Overall system exergetic eff_ITC	Overall system exergetic eff_MTC	% improvement in Overall system exergetic eff_LTC	% improvement in Overall system exergetic eff_ITC	% improvement in Overall system exergetic eff_MTC
0	0.6044	0.4839	0.3844	288.0	210.6	146.7
2	0.5997	0.4839	0.3844	285.0	210.6	146.7
4	0.5952	0.4839	0.3844	282.1	210.6	146.7
5	0.5930	0.4839	0.3844	280.7	210.6	146.7
6	0.5908	0.4839	0.3844	279.3	210.6	146.7
8	0.5866	0.4839	0.3844	276.5	210.6	146.7
10	0.5824	0.4839	0.3844	273.8	210.6	146.7
12	0.5783	0.4839	0.3844	271.2	210.6	146.7
14	0.5744	0.4839	0.3844	268.7	210.6	146.7
15	0.5724	0.4839	0.3844	267.4	210.6	146.7

Table-6(c): Variation of thermodynamic performance parameters in terms of overall system exergy destruction ratio (EDR) and percentage decrement with LTC Approach (°C) temperature overlapping in VARS evaporator and medium temperature condenser of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

LTC Approach temp (°C)	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
0	0.6546	1.066	1.602	87.92	80.32	70.44
2	0.6674	1.066	1.602	87.68	80.32	70.44
4	0.6800	1.066	1.602	87.45	80.32	70.44
5	0.6863	1.066	1.602	87.34	80.32	70.44
6	0.6925	1.066	1.602	87.22	80.32	70.44
8	0.7048	1.066	1.602	86.99	80.32	70.44
10	0.7170	1.066	1.602	86.77	80.32	70.44
12	0.7291	1.066	1.602	86.55	80.32	70.44
14	0.7411	1.066	1.602	86.32	80.32	70.44
15	0.7470	1.066	1.602	86.22	80.32	70.44

Table-7(a-c) shows the variation of thermodynamic performance with ITC Approach (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as ITC temperature overlapping is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-7(a): Variation of thermodynamic performance parameters in terms of first law efficiency and percentage improvement with ITC Approach (°C) temperature overlapping in MTC evaporator and intermediate temperature condenser of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa

ITC Approach	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
0	0.7422	0.7334	0.6079	74.45	72.37	42.87
2	0.7387	0.7292	0.6079	73.60	71.42	42.87
4	0.7351	0.7254	0.6079	72.77	70.49	42.87
5	0.7334	0.7235	0.6079	72.37	70.03	42.87
6	0.7317	0.7215	0.6079	71.96	69.58	42.87
8	0.7282	0.7177	0.6079	71.16	68.68	42.87
10	0.7249	0.7139	0.6079	70.37	67.79	42.87
12	0.7216	0.7102	0.6079	69.60	66.92	42.87
14	0.7184	0.7065	0.6079	68.84	66.06	42.87
15	0.7168	0.7047	0.6079	68.47	65.63	42.87

Table-7(b): Variation of thermodynamic performance parameters in terms of second law efficiency(exergetic efficiency) and percentage improvement with ITC Approach (°C) temperature overlapping in MTC evaporator and intermediate temperature condenser (ITC condenser) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

ITC Approach	Overall system Exergetic Efficiency $\_{LTC}$	Overall system Exergetic Efficiency $\_{ITC}$	Overall system Exergetic Efficiency $\_{MTC}$	% improvement in Overall system COP_{LTC}	% improvement in Overall system Exergetic Efficiency $\_{ITC}$	% improvement in Exergetic Efficiency $\_{MTC}$
0	0.6096	0.5262	0.3844	291.3	237.8	146.7
2	0.6038	0.5173	0.3844	287.6	232.1	146.7
4	0.5982	0.5086	0.3844	284.0	226.5	146.7
5	0.5955	0.5044	0.3844	282.2	223.8	146.7
6	0.5928	0.5002	0.3844	280.5	221.1	146.7
8	0.5875	0.4920	0.3844	277.1	215.8	146.7
10	0.5824	0.4839	0.3844	273.8	210.6	146.7
12	0.5774	0.4761	0.3844	270.7	205.6	146.7
14	0.5726	0.4685	0.3844	267.6	200.7	146.7
15	0.5702	0.4647	0.3844	266.0	198.3	146.7

Table-7(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (Overall system EDRs) and percentage decrement with ITC Approach (°C) temperature overlapping in MTC evaporator and intermediate temperature condenser (ITC condenser) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

ITC Approach	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
0	0.6403	0.9004	1.602	88.18	83.29	70.44
2	0.6561	0.9331	1.602	87.89	82.78	70.44
4	0.6716	0.9660	1.602	87.61	82.17	70.44
5	0.6793	0.9826	1.602	87.46	81.87	70.44
6	0.6870	0.9992	1.602	87.32	81.56	70.44
8	0.7021	1.033	1.602	87.04	80.94	70.44
10	0.7170	1.066	1.602	86.77	80.32	70.44
12	0.7318	1.10	1.602	86.50	79.69	70.44
14	0.7464	1.135	1.602	86.23	79.06	70.44
15	0.7537	1.152	1.602	86.09	78.74	70.44

Table-8(a) to Table-8(c) shows the variation of thermodynamic performance with MTC Approach (°C)of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as MTC temperature overlapping is increasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances in terms of exergetic efficiencies and its improvement are also decreasing and while system exergy destruction ratio is also increasing.

Table-8(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with MTC Approach (°C) temperature overlapping in ITC evaporator and ultra-low temperature condenser (LTC condenser) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

MTC Approach (°C)	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
0	0.7647	0.7542	0.6404	79.73	77.26	50.52
2	0.7569	0.7462	0.6340	77.88	75.38	49.0
4	0.7489	0.7382	0.6275	76.02	73.50	47.47
5	0.7450	0.7342	0.6242	75.09	72.55	46.71
6	0.7410	0.7301	0.6209	74.15	71.61	45.94
8	0.7330	0.7221	0.6144	72.27	69.70	44.41
10	0.7249	0.7139	0.6079	70.37	67.79	42.87
12	0.7168	0.7057	0.6013	68.46	65.86	41.32
14	0.7085	0.6974	0.5947	66.53	63.92	39.77
16	0.7044	0.6933	0.5914	65.56	62.94	38.99

Table-8(b) : Variation of thermodynamic performance parameters in terms of second law efficiency and percentage improvement with MTC Approach (°C) temperature overlapping in ITC evaporator and ultra-low temperature condenser of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa

MTC Approach (°C)	Overall system Exergetic Efficiency $_{LTC}$	Overall system Exergetic Efficiency $_{ITC}$	Overall system Exergetic Efficiency $_{MTC}$	% improvement in Overall system COP_{LTC}	% improvement in Overall system Exergetic Efficiency $_{ITC}$	% improvement in Exergetic Efficiency $_{MTC}$
0	0.6534	0.5512	0.4423	319.4	253.8	183.9
2	0.6391	0.5376	0.4302	310.3	245.1	176.2
4	0.6249	0.5240	0.4184	301.2	236.4	168.6
5	0.6178	0.5173	0.4125	296.6	232.1	164.8
6	0.6108	0.5106	0.4068	292.1	227.8	161.1
8	0.5966	0.4972	0.955	283.0	219.2	153.9
10	0.5824	0.4839	0.3844	273.8	210.6	146.7
12	0.5682	0.4707	0.3734	264.7	202.1	139.7
14	0.5540	0.4575	0.3626	255.6	193.7	132.8
15	0.5468	0.4509	0.3574	251.0	189.4	129.4

Table-8(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (Overall system EDRs) and percentage decrement with MTC Approach (ºC) temperature overlapping in ITC evaporator and ultra-low temperature condenser (LTC condenser) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

MTC Approach (ºC)	Overall system $EDR_{\_LTC}$	Overall system $EDR_{\_ITC}$	Overall system $EDR_{\_MTC}$	% decrement in $EDR_{\_LTC}$	% decrement in $EDR_{\_ITC}$	% decrement in $EDR_{\_MTC}$
0	0.5305	0.8142	1.261	90.21	84.97	76.74
2	0.5646	0.8602	1.324	89.53	84.13	75.56
4	0.6002	0.9082	1.390	88.93	83.24	74.35
5	0.6185	0.9331	1.424	88.59	82.78	73.73
6	0.6373	0.9585	1.458	88.24	82.31	73.09
8	0.6762	1.011	1.529	87.52	81.34	71.79
10	0.717	1.066	1.602	86.77	80.32	70.44
12	0.7599	1.125	1.678	85.98	79.25	69.04
14	0.8051	1.186	1.757	85.14	78.12	67.58
15	0.8287	1.218	1.798	84.71	77.53	66.82

2.2 Effect of various evaporator temperatures

Table-9(a) to Table-9(c) shows the comparison of thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for LTC evaporator temperature of -50ºC using HFO1234yf and R245fa in intermediate temperature cycle of -100ºC and R235fa in ultra-temperature cycle(LTC) of -150ºC) and found that as LTC evaporator temperature is decreasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances are also increasing and while system exergy destruction ratio is also decreasing.

Table-9(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with LTC evaporator temperature (ºC)of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

LTC Evaporator Temperature (ºC)	Overall system $COP_{\_LTC}$	Overall system $COP_{\_ITC}$	Overall system $COP_{\_MTC}$	% improvement in Overall system $COP_{\_LTC}$	% improvement in Overall system $COP_{\_ITC}$	% improvement in Overall system $COP_{\_MTC}$
-120	0.7542	0.7139	0.6079	77.25	67.79	42.87
-125	0.7494	0.7139	0.6079	76.13	67.79	42.87
-130	0.446	0.7139	0.6079	75.0	67.79	42.87
-135	0.7397	0.7139	0.6079	73.86	67.79	42.87
-140	0.7348	0.7139	0.6079	72.70	67.79	42.87
-145	0.7299	0.7139	0.6079	71.54	67.79	42.87
-150	0.7249	0.7139	0.6079	70.37	67.79	42.87
-155	0.720	0.7139	0.6079	69.21	67.79	42.87
-160	0.715	0.7139	0.6079	68.06	67.79	42.87

Table-9(b): Variation of thermodynamic performance parameters in terms of second law efficiencies (exergetic efficiency) and percentage improvement with LTC evaporator temperature (ºC) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

LTC Evaporator Temperature (ºC)	Overall system $COP_{\_LTC}$	Overall system $COP_{\_ITC}$	Overall system $COP_{\_MTC}$	% improvement in Overall system $COP_{\_LTC}$	% improvement in Overall system $COP_{\_ITC}$	% improvement in Overall system $COP_{\_MTC}$
-120	0.6094	0.7139	0.6079	291.2	210.6	146.7
-125	0.6066	0.7139	0.6079	289.4	210.6	146.7
-130	0.6031	0.7139	0.6079	287.2	210.6	146.7
-135	0.5990	0.7139	0.6079	284.5	210.6	146.7
-140	0.5942	0.7139	0.6079	281.5	210.6	146.7
-145	0.5887	0.7139	0.6079	277.9	210.6	146.7
-150	0.5824	0.7139	0.6079	273.8	210.6	146.7
-155	0.5753	0.7139	0.6079	269.3	210.6	146.7
-160	0.5674	0.7139	0.6079	264.2	210.6	146.7

Table-9(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (System EDRs) and percentage improvement with LTC evaporator temperature (°C) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

LTC Evaporator Temperature (°C)	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% improvement in Overall system EDR_{LTC}	% improvement in Overall system EDR_{ITC}	% improvement in Overall system EDR_{MTC}
-120	0.6411	1.066	1.602	88.17	80.32	70.44
-125	0.6487	1.066	1.602	88.03	80.32	70.44
-130	0.6580	1.066	1.602	87.86	80.32	70.44
-135	0.6693	1.066	1.602	87.65	80.32	70.44
-140	0.6828	1.066	1.602	87.4	80.32	70.44
-145	0.6986	1.066	1.602	87.11	80.32	70.44
-150	0.7170	1.066	1.602	86.77	80.32	70.44
-155	0.7382	1.066	1.602	86.38	80.32	70.44
-160	0.7623	1.066	1.602	85.93	80.32	70.44

Table-10(a) to Table-10(c) shows the comparison of thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for ITC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as ITC evaporator temperature is decreasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances are also increasing and while system exergy destruction ratio is also decreasing.

Table-10(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with LTC evaporator temperature (°C)of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using usingHFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra-low temperature applications

ITC Evaporator Temperature (°C)	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
-65	0.7826	0.7862	0.6079	83.93	84.79	42.87
-70	0.7714	0.7742	0.6079	81.31	81.95	42.87
-75	0.7608	0.7620	0.6079	78.81	79.10	42.87
-80	0.7508	0.7499	0.6079	76.46	76.25	42.87
-85	0.7414	0.7379	0.6079	73.26	73.42	42.87
-90	0.7328	0.7258	0.6079	72.23	70.59	42.87
-95	0.7249	0.7139	0.6079	70.39	67.75	42.87
-100	0.7178	0.7021	0.6079	68.71	65.01	42.87

Table-10(b): Variation of thermodynamic performance parameters in terms of second law efficiencies (exergetic efficiency) and percentage improvement with ITC evaporator temperature (°C) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle

ITC Evaporator Temperature (°C)	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
-65	0.5116	0.4875	0.3844	228.4	213.0	146.7
-70	0.5219	0.4891	0.3844	235.0	214.0	146.7
-75	0.5327	0.4898	0.3844	241.9	214.4	146.7
-80	0.5440	0.4896	0.3844	249.2	214.3	146.7
-85	0.5560	0.4886	0.3844	256.9	213.9	146.7
-90	0.5687	0.4867	0.3844	265.1	212.4	146.7
-95	0.5824	0.4839	0.3844	273.8	210.6	146.7
-100	0.5971	0.4804	0.3844	283.3	208.4	146.7

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Table-10(c):Variation of thermodynamic performance parameters in terms of exergy destruction ratio (System EDRs) and percentage improvement with ITC evaporator temperature (°C) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using usingHFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

ITC Evaporator Temperature (°C)	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
-65	0.9547	1.051	1.602	82.32	80.60	70.74
-70	0.9161	1.044	146.7	83.10	80.73	70.74
-75	0.8774	1.042	146.7	83.81	80.78	70.74
-80	0.8382	1.042	146.7	84.53	80.76	70.74
-85	0.7986	1.047	146.7	85.26	80.68	70.74
-90	0.7582	1.055	146.7	86.01	80.54	70.74
-95	0.7170	1.066	146.7	86.77	80.32	70.74
-100	0.6748	1.081	146.7	87.55	80.04	70.74

Table 11(a) to Table-11(c) shows the comparison of thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that as MTC evaporator temperature is decreasing , the first law efficiencies are decreasing and also % improvement is also decreasing . Similarly second law performances are also increasing and while system exergy destruction ratio is also decreasing.

Table-11(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with MTC evaporator temperature (°C)of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using usingHFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra-low temperature applications

MTC Evaporator Temperature (°C)	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
-20	0.7890	0.7732	0.7163	85.43	81.72	68.12
-25	0.7806	0.7656	0.6972	83.46	79.93	63.86
-30	0.7713	0.7570	0.6791	81.27	77.91	59.61
-35	0.7610	0.7475	0.6611	78.85	75.68	56.37
-40	0.7498	0.7371	0.6432	76.23	73.24	51.17
-45	0.7378	0.7259	0.6254	73.40	70.61	47.0
-50	0.7249	0.7139	0.6079	70.37	67.79	42.87

Table-11(b): Variation of thermodynamic performance parameters in terms of second law efficiencies (exergetic efficiency) and percentage improvement with MTC evaporator temperature (°C) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra-low temperature cycle for ultra-low temperature applications

MTC Evaporator Temperature (°C)	Overall system Exergetic $Efficiency_{LTC}$	Overall system Exergetic $Efficiency_{ITC}$	Overall system Exergetic $Efficiency_{MTC}$	% improvement in Overall system COP_{LTC}	% improvement in Overall system Exergetic $Efficiency_{ITC}$	% improvement in Exergetic $Efficiency_{MTC}$
-20	0.5859	0.4087	0.3719	276.1	162.3	138.7
-25	0.5898	0.4269	0.3785	278.6	174.0	142.9
-30	0.5921	0.4430	0.3830	280.0	184.4	145.9
-35	0.5925	0.4569	0.3857	280.4	193.3	147.6
-40	0.5912	0.4684	0.3867	279.5	200.6	148.3
-45	0.5878	0.4774	0.3863	277.3	206.5	147.8
-50	0.5824	0.4839	0.3844	273.8	210.6	146.7

Table-11(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (System EDRs) and percentage improvement with MTC evaporator temperature (°C) of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO -1234yf in medium temperature circuit and R-245fa in intermediate temperature circuit and R236fa in ultra low temperature cycle for ultra low temperature applications

MTC Evaporator Temperature (°C)	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
-20	0.7069	1.447	1.689	86.96	73.30	68.84
-25	0.6955	1.342	1.642	87.17	75.23	69.70
-30	0.6890	1.257	1.811	87.29	76.80	70.27
-35	0.6876	1.189	1.593	87.31	78.06	70.61
-40	0.6916	1.135	1.586	87.24	79.05	70.74
-45	0.7013	1.095	1.589	87.06	79.80	70.68
-50	0.7170	1.066	1.602	86.77	80.32	70.44

2.3 Effect of ecofriendly refrigerants

Table-12 (a) to Table-12(c) shows the effect of LTC refrigerants on performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50°C using HFO1234yf and R245fa in intermediate temperature cycle of -100°C and R235fa in ultra-temperature cycle(LTC) of -150°C) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the low temperature application

Table-12(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with following LTC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS S using R245fa in intermediate temperature circuit and HFO-1234yf refrigerant inmedium temperature circuit for ultra-low temperature applications

LTC refrigerants	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
R236fa	0.7249	0.7139	0.6079	70.36	67.7	42.87
R290	0.7233	0.7139	0.6079	70.01	67.7	42.87
R600a	0.7248	0.7139	0.6079	70.36	67.7	42.87
Ethylene	0.7217	0.7139	0.6079	69.63	67.7	42.87
R404a	0.7228	0.7139	0.6079	69.87	67.7	42.87
R407c	0.7077	0.7139	0.6079	66.32	67.7	42.87
R410a	0.7207	0.7139	0.6079	69.38	67.7	42.87

*Table-12(b): Variation of thermodynamic performance parameters in terms of second law efficiencies (Overall system Exergetic Efficiency) and percentage improvement with following LTC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using R2*45fa in intermediate temperature circuit and HFO-1234yf refrigerant inmedium temperature circuit for *ultra*-low temperature applications

LTC refrigerants	Overall system Exergetic Efficiency $\_{LTC}$	Overall system Exergetic Efficiency $\_{ITC}$	Overall system Exergetic Efficiency $\_{MTC}$	% improvement in Overall system COP_{LTC}	% improvement in Overall system Exergetic Efficiency $\_{ITC}$	% improvement in Exergetic Efficiency $\_{MTC}$
R236fa	0.5824	0.4839	0.3840	273.8	210.6	146.7
R290	0.5771	0.4839	0.3840	270.4	210.6	146.7
R600a	0.5822	0.4839	0.3840	273.7	210.6	146.7
Ethylene	0.5716	0.4839	0.3840	266.9	210.6	146.7
R404a	0.5751	0.4839	0.3840	269.2	210.6	146.7
R407c	0.5250	0.4839	0.3840	237.0	210.6	146.7
R410a	0.5680	0.4839	0.3840	264.6	210.6	146.7

Table-12(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (Overall system EDRs) and percentage decrement with following LTC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using R245fa in intermediate temperature circuit and HFO-1234yf refrigerant in medium temperature circuit for ultra-low temperature applications

LTC Refrigerants	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
R236fa	0.7170	1.066	1.602	86.77	80.32	70.44
R290	0.7233	1.066	1.602	86.48	80.32	70.44
R600a	0.7176	1.066	1.602	86.76	80.32	70.44
Ethylene	0.7439	1.066	1.602	86.16	80.32	70.44
R404a	0.7389	1.066	1.602	86.37	80.32	70.44
R407c	0.9049	1.066	1.602	83.3	80.32	70.44
R410a	0.7207	1.066	1.602	85.97	80.32	70.44

Tables-13(a) to Table-13(c) shows the effect of ITC refrigerants on thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50ºC using HFO1234yf and R245fa in intermediate temperature cycle of -100ºC and R235fa in ultra-temperature cycle(LTC) of -150ºC) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the ultra-low temperature applications. Similarly shows the effect of LTC refrigerants on % improvement in thermodynamic performance performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50ºC using HFO1234yf and R245fa in intermediate temperature cycle of -100ºC and R235fa in ultra-temperature cycle(LTC) of -150ºC) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HC refrigerants(R290 & R600a) than R236fa and R404a & R410a and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the ultra-low temperature applications.

Table-13(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with following ITC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using using HFO-1234yf in medium temperature circuit and R236fa in ultra-low temperature circuit

ITC Refrigerants	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
R-245fa	0.7249	0.7139	0.6079	70.37	67.79	42.87
R134a	0.7241	0.7131	0.6079	70.20	67.59	42.87
R152a	0.7243	0.7133	0.6079	70.24	67.64	42.87
R290	0.7247	0.7137	0.6079	70.33	67.74	42.87
R600a	0.7253	0.7143	0.6079	70.46	67.89	42.87
Ethylene	0.7163	0.7042	0.6079	68.36	65.51	42.87
R143a	0.7236	0.6079	0.6079	70.06	67.43	42.87
R507a	0.7233	0.7121	0.6079	70.01	67.37	42.87
R407c	0.7046	0.6909	0.6079	65.61	62.38	42.87
R410a	0.7234	0.7122	0.6079	70.02	67.39	42.87
R404a	0.7213	0.7098	0.6079	69.53	66.03	42.87
R32	0.7183	0.7064	0.6079	68.81	66.02	42.87
R125	0.7227	0.7114	0.6079	69.86	67.20	42.87
R123	0.7248	0.7138	0.6079	70.36	67.77	42.87
R227ea	0.7220	0.7106	0.6079	69.69	67.02	42.87
R141b	0.7268	0.7160	0.6079	70.81	68.28	42.87

Table-13 (b): Variation of thermodynamic performance parameters in terms of second law efficiencies (Overall system Exergetic Efficiency) and percentage improvement with following ITC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using using HFO-1234yf in medium temperature circuit and R236fa in ultra-low temperature circuit .

ITC Refrigerants	Overall system $COP_{\_LTC}$	Overall system $COP_{\_ITC}$	Overall system $COP_{\_MTC}$	% improvement in Overall system $COP_{\_LTC}$	% improvement in Overall system $COP_{\_ITC}$	% improvement in Overall system $COP_{\_MTC}$
R-245fa	0.5824	0.4839	0.3844	273.8	210.6	146.7
R134a	0.5812	0.4821	0.3844	273.1	209.5	146.7
R152a	0.5815	0.4826	0.3844	273.3	209.8	146.7
R290	0.5821	0.4835	0.3844	273.7	210.4	146.7
R600	0.5830	0.4848	0.3844	274.2	211.2	146.7
Ethylene	0.5696	0.4638	0.3844	265.6	197.6	146.7
R143a	0.5804	0.4807	0.3844	272.5	208.6	146.7
R507a	0.580	0.4802	0.3844	272.3	208.2	146.7
R407c	0.5527	0.4366	0.3844	254.8	180.3	146.7
R410a	0.5801	0.4803	0.3844	272.4	208.3	146.7
R404a	0.5770	0.4754	0.3844	270.4	205.1	146.7
R32	0.5724	0.4682	0.3844	267.4	200.5	146.7
R125	0.5791	0.4787	0.3844	271.7	207.3	146.7
R123	0.5823	0.4838	0.3844	273.8	210.6	146.7
R227ea	0.5780	0.4770	0.3844	271.0	206.2	146.7
R141b	0.5852	0.4884	0.3844	275.7	213.5	146.7

Table-13(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (Overall system EDRs) and percentage decrement with following ITC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO-1234yf in medium temperature circuit and R236fa in ultra-low temperature circuit .

ITC Refrigerants	Overall system $EDR_{\_LTC}$	Overall system $EDR_{\_ITC}$	Overall system $EDR_{\_MTC}$	% improvement in Overall system $EDR_{\_LTC}$	% improvement in Overall system $EDR_{\_ITC}$	% improvement in Overall system $EDR_{\_MTC}$
R-245fa	0.7170	1.066	1.602	86.77	80.32	70.44
R134a	0.7204	1.074	1.602	86.71	80.18	70.44
R152a	0.7196	1.072	1.602	86.72	80.21	70.44
R290	0.7178	1.068	1.602	86.75	80.29	70.44
R600	0.7154	1.063	1.602	86.80	80.39	70.44
Ethylene	0.7557	1.157	1.602	86.06	78.66	70.44
R143a	0.7231	1.080	1.602	86.66	80.07	70.44
R507a	0.7241	1.082	1.602	86.64	80.03	70.44
R407c	0.8093	1.290	1.602	86.07	76.19	70.44
R410a	0.7238	1.082	1.602	86.64	80.04	70.44
R404a	0.7332	1.104	1.602	86.47	79.63	70.44
R32	0.7470	1.136	1.602	86.22	79.40	70.44
R125	0.7269	1.089	1.602	86.59	79.9	70.44
R123	0.7173	1.067	1.602	86.76	80.31	70.44
R227ea	0.7301	1.096	1.602	86.53	79.77	70.44
R141b	0.7087	1.048	1.602	86.92	80.67	70.44

Tables-14(a) to Table-14(c) shows the effect of ITC refrigerants on thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50ºC using HFO1234yf and R245fa in intermediate temperature cycle of -100ºC and R235fa in ultra-temperature cycle(LTC) of -150ºC) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the ultra-low temperature applications. Similarly shows the effect of LTC refrigerants on % improvement in thermodynamic performance performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for MTC evaporator temperature of -50ºC using HFO1234yf and R245fa in intermediate temperature cycle of -100ºC and R235fa in ultra-temperature cycle(LTC) of -150ºC) and found that HFC refrigerants R134a & R152a and R717 of low GWP gives better thermodynamic performances than ecofriendly refrigerants (R227ea, R32 , R125, R404a & R410a) and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the ultra-low temperature applications.

Table-14(a): Variation of thermodynamic performance parameters in terms of first law efficiencies (Overall system COPs) and percentage improvement with following MTC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using R245fa in intermediate temperature circuit and R236fa for ultra-low temperature applications

MTC refrigerants	Overall system COP_{LTC}	Overall system COP_{ITC}	Overall system COP_{MTC}	% improvement in Overall system COP_{LTC}	% improvement in Overall system COP_{ITC}	% improvement in Overall system COP_{MTC}
R1234yf	0.7249	0.7139	0.6079	72.37	67.79	42.87
R134a	0.7344	0.7234	0.6155	72.59	70.03	44.67
R717	0.7345	0.7236	0.6157	72.63	70.07	44.70
R152a	0.7418	0.7310	0.6216	74.34	71.80	44.09
R227ea	0.7097	0.6986	0.5956	66.80	64.19	39.99
R32	0.7323	0.7212	0.6138	72.10	69.54	44.27
R290	0.7338	0.7229	0.6151	72.48	69.91	44.57
R600a	0.7330	0.7221	0.6144	72.27	69.71	44.41
R143a	0.7235	0.7125	0.6068	70.05	67.46	42.61
R410a	0.7326	0.7212	0.6142	72.19	69.62	44.34
R404a	0.7166	0.7055	0.6011	66.41	65.81	41.29
R407c	0.7096	0.6985	0.5956	66.75	64.14	39.98
R125	0.7091	0.6979	0.5951	66.85	64.04	39.87
R123	0.7445	0.7337	0.6238	74.97	72.43	46.61
R507a	0.7204	0.7093	0.6842	69.71	66.31	42.01
R141b	0.7515	0.7408	0.6296	76.63	74.12	47.97

Table-14(b): Variation of thermodynamic performance parameters in terms of second law efficiencies (Overall system Exergetic Efficiency) and percentage improvement with following MTC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using R245fa in intermediate temperature circuit and R236fa for ultra-low temperature applications

MTC refrigerants	Overall system Exergetic $Efficiency_{LTC}$	Overall system Exergetic $Efficiency_{ITC}$	Overall system Exergetic $Efficiency_{MTC}$	% improvement in Overall system COP_{LTC}	% improvement in Overall system Exergetic $Efficiency_{ITC}$	% improvement in Exergetic $Efficiency_{MTC}$
R1234yf	0.5824	0.4839	0.3844	273.8	210.6	146.7
R134a	0.5990	0.4995	0.3974	284.5	220.7	155.1
R717	0.5993	0.4998	0.3977	284.7	220.8	155.3
R152a	0.6122	0.5120	0.4080	293.1	228.6	161.9
R227ea	0.5560	0.4593	0.3642	256.9	194.9	133.8
R32	0.5953	0.4961	0.3945	282.2	218.4	153.2
R290	0.5981	0.4987	0.3967	283.9	229.1	154.7
R600a	0.5966	0.4973	0.3955	283.0	219.2	153.9
R143a	0.580	0.4817	0.3928	272.3	209.2	145.5
R410a	0.5960	0.4967	0.3950	282.6	218.8	153.6
R404a	0.5679	0.4703	0.3732	264.5	201.9	139.5
R407c	0.5558	0.4592	0.3641	256.8	194.8	133.7
R125	0.5548	0.4583	0.3634	256.2	194.2	133.2
R123	6169	0.5165	0.4118	296.0	231.5	164.4
R507a	0.5745	0.4765	0.3782	268.8	205.9	142.8
R141b	0.6269	0.5285	0.4223	304.1	239.2	171.1

Table-14(c): Variation of thermodynamic performance parameters in terms of exergy destruction ratio (Overall system EDRs) and percentage decrement with following ITC refrigerants of integrated half effect LiBr-H_2O VARS multi cascaded VCRS using R245fa in intermediate temperature circuit and R236fa for ultra low temperature applications

MTC Refrigerants	Overall system EDR_{LTC}	Overall system EDR_{ITC}	Overall system EDR_{MTC}	% decrement in EDR_{LTC}	% decrement in EDR_{ITC}	% decrement in EDR_{MTC}
R1234yf	0.7170	1.068	1.602	86.77	80.32	70.44
R134a	0.6694	1.002	1.515	87.65	81.51	72.02
R717	0.6686	1.001	1.515	87.66	81.53	72.02
R152a	0.6335	0.9533	1.451	88.31	82.41	73.22
R227ea	0.7986	1.177	1.746	85.26	78.28	67.79
R32	0.6797	1.016	1.535	87.46	81.20	71.68
R290	0.6719	1.005	1.521	87.60	81.45	71.94
R600a	0.6762	1.011	1.528	87.52	81.34	71.80
R143a	0.7242	1.076	1.514	86.64	80.14	70.21

R410a	0.6779	1.013	1.532	87.49	81.30	71.74
R404a	0.7611	1.126	1.68	85.96	79.22	69.0
R407c	0.7991	1.178	1.746	85.26	78.28	67.77
R125	0.8023	1.182	1.752	85.20	78.19	67.67
R123	0.6209	0.9363	1.428	88.54	82.72	73.65
R507a	0.7408	1.099	1.644	86.33	79.79	69.66
R141b	0.5883	0.8922	1.368	89.14	83.54	74.75

3. Conclusions

Following conclusions were drawn from present investigations.

- Thermodynamic performance of cascaded integrated vapour compression half effect Li/Br H_2O absorption systems HFC-152a and HFO refrigerants in the intermediate temperature cycle for ITC evaporator temperature of -50ºC and R134a in low temperature cycle (LTC) of -150ºC and found that HFO refrigerants of low GWP gives lower thermodynamic performances than HFC-152a refrigerant and also gives better improvement in the thermodynamic performances.
- Half effect LiBr-H_2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications using HFC152a in intermediate temperature cycle and HFC-134a in LTC gives better thermodynamic performances than by using HFO refrigerants in intermediate temperature cycle & HFC-134a in low temperature cycle.
- The thermodynamic performances using HFO-1234ze in medium temperature cycle (up to evaporator temperature -30ºC) is better than using HFO-1234yf in intermediate temperature cycle.
- The first law efficiency (COP_Cascade) of multi-cascade system increases with an increase with increasing generator temperature.
- The first law efficiency (COP Cascade) of multi-cascade system increases with an increase with increasing evaporator temperature of vapour absorption refrigeration cycle.
- The second law efficiency (exergetic efficiency) of multi-cascade system decreases with an increase with increasing generator temperature of vapour absorption refrigeration cycle.
- The second law efficiency (exergetic efficiency) of multi-cascade system decreases with an increase with increasing evaporator temperature of vapour absorption refrigeration cycle.

References

[1] Regulation (EU) No 517/2014 of the European Parliament and of the Council of Fluorinated Greenhouse Gases and Repealing Regulation (EC), No 842/2006 (2014)

[2] Arivazhagan S., Saravanan R &Renganarayanan S[2006]Experimental studies on HFC based two-stage half effect vapour absorption cooling system Applied Thermal Eng, Vol-26, Issue-14-15, Page 1455-1462,

[3] Yataganbaba, A., Kilicarslan,A.,KurtbasI.,[2015]: Energy analysis of R1234yf and R1234ze as R134a replacements in two evaporator vapour compression refrigeration system, Int. J. Refrigeration, 60, page-26-37.

[4] Mota-Babiloni, A., Navarro-Esbrı, J., Barragan-Cervera, A., Moles, F., Peris, B., Verdu, G.[2015]: Commercial refrigeration- An overview of current status, Int. J. Refrigeration, 57, 186-196

[5] Mota-Babiloni, A., Navarro-Esbrí, J., Barragan, A., Moles, F., Peris, B.[2014]: Drop-in energy performance evaluation of R1234yf and R1234ze(E) in a vapor compression system as R134a replacements, Appl. Therm. Eng., 71, 259-265

[6] Mota-Babiloni, A., Navarro-Esbrı, J., Barragan-Cervera, A., Moles, F., Peris, B.[2015]: Experimental study of an R1234ze(E)/R134a mixture (R450A) as R134a replacement, Int. J. Refrigeration, Vol-51, page-52-58

[7] Mota-Babiloni, A., Navarro-Esbrı, J., Barragan-Cervera, A., Moles, F., Peris, B.[2015]Analysis based on EU Regulation No 517/2014 of new HFC/HFO mixtures as alternatives of high GWP refrigerants in refrigeration and HVAC systems, Int. J. Refrigeration, Vol-52, page-21-31,

[8] Sanchez, D., Cabello, R., Llopis, R., Araguzo, I., Catalan-Gil, J., Torrella, E.,[2017] Energy performance evaluation of R1234yf, R1234ze(E), R600a, R290 and R152a as low-GWP R134a alternatives, Int. J. Refrigeration, Vol-74, page-269-282;

[9] Arora, A., Dixit, M., Kaushik, S. C.[2016]: Computation of optimum parameters of a half effect water-lithium bromide vapour absorption refrigeration system, J. Thermal Eng., 2(2), page-683-692

[10] Arora, A., Dixit, M., Kaushik, S. C.[2016]: Energy and exergy analysis of a double effect parallel flow LiBr/H_2O absorption refrigeration system, J. Thermal Eng., Vol-2(2), page-541-549

[11] Gomri R. Second law comparison of single effect and double effect vapour absorption refrigeration systems, Energy Conversion and Management 2009; 50: 1279-1287.

[12] Riffat SB, Shankland N. Integration of absorption and vapour compression systems. Applied Energy 1993; 46 (4): 303-316

[13] Kilic M, Kaynakli O. Theoretical study on the effect of operating conditions on performance of absorption refrigeration system, Energy Conversion and Management 2007; 48: 599-607.

[14] Chinnappa J, Crees M, Murthy SS, Srinivasan K. Solar-assisted vapor compression/absorption cascaded air-conditioning systems. Solar Energy 1993; 50(5): 453-458.

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