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

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

Radhey Shyam Mishra

Department of Mechanical Engineering, Delhi Technological University Delhi, India

Abstract

Performance evaluation of LiBr-H2O vapour absorption systems using multi cascading of vapour compression systems using HFO-1234yf in medium temperature cycle for -50^{0}C and R-245fa in intermediate temperature cycle for -100^{0}C and R-236fa in low temperature cycle for -150^{0}C ultra-low temperature applications have been carried out It is found that overall first law efficiency (COP_Overall) for 123K evaporator temperature using R236fa is less than the overall first law efficiency (COP_Overall) for 273K evaporator temperature using 245fa. However when continuous improvement in second law (exergetic) performances which caused continuous reduction in system exergy destruction ratio. The percentage improvement in first law efficiency (COP_Overall) is found using single stage cascade vapour compression refrigeration system (VCRS) is 7.96% and using multi (two stages) cascade VCRS is 21.53% and using multi (three stages) cascade VCRS is 15.52% for all 10^{0}C of temperature overlapping however the percentage improvement in second law efficiency (exergetic efficiency) is found using single stage cascade vapour compression refrigeration system (VCRS) is 37.27% and using multi (two stages) cascade VCRS is 128% and using multi (three stages) cascade VCRS is 146.9% for all 10^{0}C of temperature overlapping. Similarly the percentage decrement in system exergy destruction ratio is found using single stage cascade vapour compression refrigeration system (VCRS) is 34.32% and using multi (two stages) cascade VCRS is 70.63% and using multi (three stages) cascade VCRS is 74.77% for all 10^{0}C of temperature overlapping.

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

1. Introduction

In the present-day, the situation, the energy, exergy, economy, environment and safety strategies are the key issues which are practicality restrained to evaluate refrigeration cycles both having higher as well as ultra-low evaporator temperatures. Although the ultra-low temperatures for cryogenics is approaching 0 K, and its applications such as freeze drying, pharmaceuticals, chemical and petroleum industry use cascade refrigeration cycles[1-2].
As reported by Chen et.al. [3], that the demand of refrigeration at the low evaporation temperature is increasing which ranges from high heat flux microchip technology to rapid freezing, freezing food and cold storage. The demand of refrigeration at the low evaporation temperature is increasing which ranges from high heat flux electronics to rapid freezing, frozen food and cold storage. Tassouet al. [4], suggested that the refrigeration is a necessary part of the food chain and to slow down the physical, chemical and microbiological activities that cause deterioration in food, the food is frozen between18 to35°C. Generally, technologies of mechanical refrigeration are invariably employed in these processes which either contribute electricity consumption and environmental impact or low performance.
These processes include vapor compression refrigeration, half, single, double and triple effect vapor absorption refrigeration systems. Although the performance of vapor compression refrigeration cycle succeeds the others yet its electricity consumption is higher. Rabah Gomri [5-6] carried out exergy analysis and thermo-economic optimization of the triple-effect Li/Br-water absorption refrigerating system and found maximum exergetic efficiency of triple effect refrigeration system is about 35.1 % for condenser 30°C , absorber cooling water temperature

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
http://doi.org/10.36037/IJREI.2020.4103

(25°C) and chilled water temperature (12°C/7°C) respectively. Colorado and Rivera [7] compared the thermal performance of a conventional vapor compression and compression-absorption single-stage and double-stage refrigeration systems. They recognized that in the current situation, the energy, exergy, economy, and environment and safety strategies are the main issues which are being considered to evaluate refrigeration cycles both having higher as well as lower evaporator temperatures. The low temperatures approaching 0 K, air conditioning and its applications such as freeze drying, pharmaceuticals, chemical and petroleum industry used cascade refrigeration cycles and also acknowledged that the electrical energy consumption in compression-absorption single-stage and double stage refrigeration system was 45% lower than that of vapour compression refrigeration cycle and the COP of double stage refrigeration system was 50% higher than that of single stage compression-absorption refrigeration system.

R.S. Mishra [8] compared three cascaded vapour compression systems cascaded with evaporator of LiBr-H_2O vapour absorption refrigeration system cascaded by condenser of single vapour compression refrigeration system using ecofriendly refrigerants (i.e. R1234yf, R134a, R-32, R507a, R227ea, R236fa, R245fa , R717) and energy and exergy analysis of all three systems were carried out because exergy (second law) analysis used to facilitates the identification of the system components with high exergy loss compared the performance parameters with three cascaded vapour absorption-single stage vapour compression refrigeration system and it was observed that 122% first law efficiency enhancement using triple effect VARS cascaded with VCRS and 79.45% enhancement in second law efficiency using triple effect VARS cascaded with VCRS. Similarly exergy reduction is 56.60% using triple effect VARS cascaded with single stage VCRS and 25.9% reduction using double effect VARS cascaded with single stage VCRS An Similarly performance parameters have been compared with three cascade vapour absorption-compression refrigeration system and it was observed that 22.87% first law efficiency enhancement using triple effect VARS cascaded with VCRS and 46.3% enhancement in second law efficiency using triple effect VARS cascaded with VCRS as compared with double effect vapour absorption refrigeration cascaded with single stage vapour compression refrigeration system. Similarly exergy reduction is 41.4% using triple effect VARS cascaded with single stage VCRS as compared to double effect VARS cascaded with single stage VCRS.

Tassouet al. [9] suggested that the refrigeration is a essential part of the food chain and to slow down the physical, chemical and microbiological activities that cause deterioration in food, the food is frozen between16°C. to35°C.

Generally, technologies of mechanical refrigeration are always employed in these processes which either contribute electricity consumption and environmental impact or lower performance. These processes include vapor compression refrigeration, half, single, double and triple effect vapor absorption refrigeration systems. Ayala et al. [10], analyzed Ammonia/Lithium Nitrate vapour absorption and Ammonia mechanical vapor compression combined refrigeration plant. They deduced that the over-all efficiency of the combined refrigeration plant was higher than that of individual compression or absorption refrigeration cycle and increased by 10%. A large number of studies are available in the literature on compression-absorption (combined) or cascade refrigeration cycles. The considered studies fall under two categories viz. single stage and double stage cycles. The first configuration is the combination of single effect VAR cycle coupled to a VCR cycle and the second configuration comprises of a double effect VAR cycle coupled to a VCR cycle. R.S. Mishra[11], develop an integrated solar refrigeration system where waste heat from different energy resources assists a combined vapour absorption compression system, and to analyze feasibility & practicality of that system of thermodynamically for improving its COP and exergetic efficiency by reduction of irreversibility in terms of exergy destruction /losses occurred in the system components. The combined thermodynamic first law efficiency in terms of coefficient of performance ($COP_{\_Overall}$), second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of product of a combined vapour absorption-compression system working with each of the following refrigerants in the cascaded vapour compression cycle R1234yf, R227ea, R236fa, R245fa, R143a,R134a, R32, R507 operating at -223 K evaporator temperature with temperature overlapping (Approach means the difference between cascaded condenser temperature of vapour compression cycle and evaporator temperature of vapour absorption refrigeration cycle working at 13.5 bar of highest generator pressure and 1.75 bar as lowest evaporator pressure have been presented and it is found thatR141b and R245fa gives better performances. Kairouani and Nehdi [12], analyzed aNH3-H2O vapor absorption cycle powered by geothermal energy-R717, R22 and R134a vapor compression cascade cycle and combined cycle. They concluded that the COP of cascade cycle was 5.5 and the COP value was 37–54% higher than that of vapor com-pression refrigeration cycle. Mishra [13] found that the thermodynamic performances in the case of cascaded half effect vapour absorption refrigeration system coupled with vapour compression cycle is improved by 44.65% increment of first law efficiency (i.e. over all COP), 172.87% increment of second law efficiency (i.e. exergetic efficiency) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a, 42.87% enhancement in first law efficiency (COP) of 142.73% increment of second law efficiency using HFO -1234yf for -50^{o}C of evaporator temperature of VCRS . Similarly 72.02% reduction in exergy destruction ratio based on exergy of output of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a and 70.44% reduction in exergy destruction ratio using HFO-1234yf ecofriendly refrigerant for -50^{0}C of evaporator temperature of VCRS. The performances of single effect cascaded vapour absorption refrigeration system coupled with vapour compression cycle significantly higher than cascaded half effect vapour absorption refrigeration coupled with vapour compression cycle. Mishra[14] proposed four cascaded half effect, single effect, double effect and triple effect Lithium/Bromide vapour absorption–compression refrigeration systems using fifteen ecofriendly refrigerants such as hydrocarbons, HFC and HFO refrigerants and natural refrigerants to produce cooling capacity at -30^{0}C. The comparison of four cascaded systems were also carried out at -55^{0}C using HFC refrigerants with R717 refrigerant. It is found that cascaded vapour compression absorption systems significantly improve first and second law performances as compared to simple vapour absorption refrigeration system.

R.S.Mishra [15], presented optimum thermodynamic performances of three cascade vapour compression refrigeration systems. The numerical thermal model have been developed for two stages cascade refrigeration systems and thermodynamic performances in terms of and first law efficiency, second law efficiency system exergy destruction ratio , first law efficiency of lower temperature and high temperature circuit have been computed. The effect of low temperature evaporator on the system first and second law performances and system exergy destruction ratio it was found that as low temperature evaporator temperature is decreasing , the first law and second law efficiencies are increasing and exergy destruction ratio is decreasing . from the developed thermal model, the optimum performance parameters in terms of the optimum temperature of high temperature evaporator for system-1(using HFO1234ze in HTC and HFO1234yf in LTC) was found between -6^{0}C to -7^{0}C, for sytem-2 (using HFO1234ze in HTC and HFC134a in LTC) : was found between -1^{o}C to -2^{0}C and for system-3using HFO-1234yf in HTC and HFC-134a in LTC was found between 1^{o}C to 2^{0}C of temperature and found that the volumetric refrigerating capacity of HFO R1234ze is below that of R134a and Its boiling point is also higher than that of R134a in the high temperature circuit of cascade refrigeration system in the range of HTC Circuit from 60^{o}C to -20^{o}C is suitable for replacing R134a and also concluded that the HFO R1234yf is suitable for replacing R134a in the low temperature circuit of cascade refrigeration system in the range of low temperature circuit (LTC) from -20^{o}C to -50^{o}C and found that by increasing evaporator temperature overall first law efficiency in terms of COP of the system is increases. Azhar and Siddiqui [16-17] analyzed gas operated H_2O-LiBr single to triple effect vapor absorption refrigeration cycles and a triple effect vapour absorption refrigeration cycle separately and used liquefied petroleum gas (LPG)and compressed natural gas (CNG) as sources of energy. They concluded that the COP of the triple effect cycle was 132% higher than the single effect. Thus the triple effect series flow VAR cycle is per-forming best among all. However, it requires input heat energy at the higher temperature range 175 to 200°C. They added that the maximum COP of triple effect vapor absorption refrigeration cycle was 2.16. V. Jain et al.[18]carried out thermodynamic analysis of vapor compression (R22, R410A, R407C andR134A)-single effect absorption (LiBr-H_2O) cascade refrigeration system and found that the COP of vapour compression section of CVCAS enhanced by 155% and electricity consumption reduced by 61% in comparison to a conventional VCRS. Moreover, evaporator and condenser changed irreversibility of the system significantly. R.S.Mishra [19] observed that two stage cascade refrigeration system using R1234ze in high temperature circuit and R1234yf in the low temperature evaporator (up to -50^{0}C) cascade system, can replace R134a. The numerical computations have been carried out for three stage proposed system (system-1: using R1234ze in high temperature circuit and R1234yf in intermediate temperature circuit and fifteen ecofriendly refrigerants in low temperature circuit). To validate the results obtained by developed model, proposed three stage cascade refrigeration system (system-1) and three stage conventional cascade refrigeration system (system-2) have been compared in terms of their thermal first and second law performances and power consumption by system and its compressors. The proposed three stage cascade refrigeration system (System-1) using HFO refrigerants up to -100^{o}C gives similar thermodynamic performances and 2% less power consumption than conventional three stage cascade refrigeration system (system-2). In case of three stage cascade refrigeration using HFO-1234ze in the high temperature circuit and HFO-1234yf in intermediate temperature circuit two stage refrigeration cascade system circuit andR245fa in low temperature circuit gives better thermal performances. The first and second law thermal performance parameters using HFO-245fa in low temperature circuit are around 0.75% higher than that of HFC-134a.Pratihar et al. [20] carried out simulation of a 400 kW NH_3-H_2O absorption-compression refrigeration system for summer air conditioning and concluded that the COP increased by 16% with increase in relative solution heat exchanger area from10 to 30% when compared to conventional R22 vapor compression chiller. Sun and Guo [21] carried out experiments on prototype of combined vapour compression-absorption refrigeration system driven by a gas engine and found that the primary energy utilization efficiency of combined system improved by the utilization of waste heat of gas engine in absorption refrigeration cycle. M. Dixit et al. [22] did thermodynamic and thermo-economic analyses of two stage hybrid absorption compression refrigeration system having LiBr-H_2O as working fluid and stated that hybrid system could be operated on low generator temperature and performed better than the two stage absorption refrigeration system .The COP and exergetic efficiency of optimized hybrid system were 0.43 and 11.68% respectively and the reduction in annual cost of operation was 5.2%. Similarly, Alvarez et al. [23] analyzed an alkali-nitrate triple-effect (single effect lithium, potassium, sodium nitrate cycle coupled to a double effect H_2O/LiBr cycle) absorption cycle for high temperature heat source. The alkali-titrate triple effect cycle was feasible efficient with slight higher COP than H_2O/LiBr triple effect cycle at generator temperature over 180°C.

The solar assisted half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system using ecofriendly refrigerants have not been studied in detail.

R.S.Mishra [24] investigated the performance of above system along with variation of performance parameters and its effect on system performances in terms of exergetic efficiency, coefficient of performance along with exergy destruction ratio based on exergy of product. Han et al [25] proposed a hybrid absorption-compression refrigerator powered by waste heat. They declared that the system COP was 41.9% higher than that of a simple NH_3absorption refrigerator and had confirmed performance improvement by exergy analysis and found that the COP of compression-absorption combined cycle was higher than VCR or vapor absorption refrigeration (VAR) cycle. Kaushik and Arora[26] had analyzed half; single and double effect series and parallel flow vapor absorption cycles and defined that the generator temperature and COP for half, single and double effect series flow refrigeration cycles and found the COP of double effect system was about twice that of single effect. Cimsit and Ozturk [27] performed analysis of compression-absorption cascade refrigeration systems by using H_2O-LiBr and NH_3-H_2O pairs in vapour absorption refrigeration system and R134a, R410a and NH_3in vapor compression refrigeration system and predicted that the electrical energy consumption in cascade refrigeration cycle was 48–50% less than that of conventional vapour compression refrigeration cycle and the COP of the cascade refrigeration system enhanced by 33%. Garimellaet al.[28] proposed absorption/vapour compression cascade refrigeration system driven by waste heat used in naval ship and determined that the electricity consumption reduced by 30% than that of conventional vapour compression refrigeration system.

Wang et al.[29] studied solar assisted cascaded refrigeration system and found that the power consumption was reduced by 50% and the COP of the system reached up to 6.1.

Einiet al.[30] stated that the CO_2/NH_3cascade cycle was safer than the CO2/C3H8with no significance difference in economic and exergetic efficiency. Since the water is a natural refrigerant, it can be used safely with H_2OLi/Br in the high temperature circuit of cascade cycle. However, the safety group of R1234yf is A2L.Bhattacharyya et al.[31] evaluated a CO2-Propane cascade system for simultaneous refrigeration and heat pump system and concluded that the approach and overlap temperatures must be minimum possible for the optimization of system performance and found that the optimum value of intermediate temperature of cascade system decreases with decrease in approach temperature and with increase in overlap temperature. Mafi et al.[32] had carried out exergy analysis of multistage cascade low temperature cascade refrigeration system and found that the exergetic efficiency of the system was 30.88%. Chinnappa et al. [33] studied R22 vapour compression-NH_3-H_2O absorption cascade refrigeration by using solar energy and determined that the cascaded system saved electrical energy than that of vapour compression system. Additionally the use of HFO refrigerant having zero potential (ODP) and low global warming potential (GWP) i.e. R1234yf is strongly recommended by Regulation (EU) No 517/2014 [11] to reduce mitigating climate change risk, environmental impact and deterioration. Therefore, refrigerant R1234yf could be a choice for vapour compression refrigeration system. Cabello et al. [34] substituted R134a, which is a high GWP refrigerant to the low GWP refrigerant R152a in cascade refrigeration plants. The drop in replacement was technically and enthusiastically feasible. The GWP and ODP rating of R1234yf are 4 and 0.

Generally, the vapour compression refrigeration cycle and its configurations viz. double stage, triple stage or multistage cascade are employed for the production of low evaporation temperature at very high cooling power. Messineo [35] analyzed a two stage cascade refrigeration system using carbon dioxide (CO2) in low temperature circuit and ammonia (NH_3) in high temperature section. He reported that CO_2-NH_3cascade refrigeration system was a motivating alternative to R404A for low evaporation temperatures (30°C to50°C

Most of the research studies considered till date emphasize on VCR and VAR cycles (single and double effect) and compression-absorption (combined) or cascade cycles. Though, exhaustive research has been carried out on cascade cycles, very less consideration has been given to explore the thermodynamic performance of single effect VAR cycle coupled with multi cascaded VCRS. Additionally, none of the research work is available on thermodynamic performance analysis of compression-absorption single effect multi cascaded three stages refrigeration system. Accordingly, in the present communication, the thermodynamic and exergetic performance analysis of absorption compression (single effect H_2O-Li/Br) cascade refrigeration system has been carried out. The analysis is performed considering H_2O/LiBr in absorption system and R1234yf in medium temperature VCR system. R-245fa in intermediate temperature VCR system along with R-236fa in intermediate temperature VCR system. The effect of medium temperature evaporator temperature, intermediate temperature of evaporator using R1234yf, intermediate temperature evaporator temperature, intermediate temperature of evaporator using R245fa and low temperature evaporator temperature, intermediate temperature of evaporator using R236fa/ hydrocarbons (i.e. R290, R600a) and ethylene temperature overlapping in each cascade condenser, condenser , absorber temperatures generator and evaporator temperatures of single effect H_2O-Li/Br vapour absorption system , have been investigated on various performance parameters viz. COP, exergetic efficiency, total exergy destruction and exergy destruction ratio (EDR).Additionally, exergy destruction and EDR of system components have also been computed.

2. System Description

Integrated absorption-compression multi cascaded refrigeration system used for ultra-low temperature is considered in this investigation is comprises of single effect H_2O-Li/Br refrigeration system is in the high temperature section having Lithium Bromide (Li/Br) as an absorbent and water (H2O) as a refrigerant. The evaporator of vapour system (VARS) is coupled with the condenser of medium VCRS using HFO-1234yf as a refrigerant up to a Temperature of 223K*(i.e* -50ºC) and vapour compression refrigeration system (VCRS) is in the intermediate temperature section in which intermediate temperature is achieved using 245fa as a refrigerant up to a Temperature of 173K *(i.e.* -100ºC) and vapour compression refrigeration system (VCRS) is in the intermediate temperature section in which intermediate temperature is achieved using 236fa as a refrigerant up to a temperature of 123K *(i.e* -150ºC).

3. Results and Discussion

Following input variables have been chosen for validation of model

- Evaporator Temperature of single effect Li/Br vapour absorption refrigeration system= 8°C, Generator temperature=110°C.
- Evaporator Temperature of vapour compression

refrigeration system in the medium temperature circuit = -50°C

- Evaporator Temperature of vapour compression refrigeration system in the intermediate temperature circuit = -50°C
- Evaporator Temperature of vapour compression refrigeration system in the low temperature circuit = -150°C
- Temperature overlapping in the vapour absorption refrigeration evaporator temperature and vapour compression refrigeration condenser temperature using R1234yf is known as overlapping$_{_MTC}$ (approach$_{_MTC}$)= 10
- Temperature overlapping in the vapour compression refrigeration evaporator temperature using R-1234yf and vapour compression refrigeration condenser temperature using R2345f is known as over-lapping$_{_ITC}$ (approach$_{_ITC}$)=10
- Temperature overlapping in the vapour compression refrigeration evaporator temperature using R-123fa and vapour compression refrigeration condenser temperature using 245fa is known as overlapping$_{_MTC}$ (Approach$_{_LTC}$)=10
- Refrigerating Capacity=35.167 "kW"
- Condenser temperature =35°C,
- Absorber Temperature=35°C,
- MTC Compressor Efficiency=0.80,
- ITC Compressor Efficiency=0.80,
- LTC Compressor Efficiency=0.80,

Thermal performance of single effect vapour absorption refrigeration systemusing H_2O-Li/Br was computed by developed model is given below.

(i) First law efficiency of vapour absorption refrigeration system is (COP_VARS) =0.7496,
(ii) (ii) The second law efficiency of vapour absorption refrigeration system is the exergetic_efficiency= 0.2043.
(iii) (iii) The exergy destruction ratio based on out put(exergy of product) is EDR$_{_Output}$= 3.894
(iv) The exergy destruction ratio based on input (exergy of exergy of fuel) is EDR$_{_Input}$= 0.7957.

3.1 Effect of temperature overlapping in cascade condensers on total thermodynamic performances of three cascaded cycles in integrated system

Table-1(a) to Table-1(c) shows the variation of approach of combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit. and it was observed that as temperature overlapping in increasing, the first law efficiency (COP) and second law efficiency (exergetic efficiency) of various combined cascade cycles of integrated multi cascaded system are decreasing as temperature overlapping in each stage is increasing. Similarly exergy destruction ratio based on exergy of product is also decreasing as temperature overlapping is increasing.

Table-1(a): First law performance in terms of COP$_{_Overall}$ with variations temperature over lapping (approach$_{_LTC}$) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach$_{_LTC}$) in Low temperature condenser (°C) using R236fa	Over all COP of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all COP of system using to intermediate evaporator temperature of 173K (i.e.-100°C) using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	0.8764	0.9109	0.8093
5	0.8711	0.9109	0.8093
10	0.8659	0.9109	0.8093
15	0.8609	0.9109	0.8093

Table-1(b): Second law performances in terms of total exergetic efficiencies with variations of temperature over lapping (approach$_{_LTC}$) of single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach$_{_LTC}$) in Low temperature condenser (°C) using R236fa	Over all exergetic efficiency of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K (i.e.-100°C) using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	0.5248	0.4665	0.2806
5	0.5145	0.4665	0.2806
10	0.5045	0.4665	0.2806
15	0.4948	0.4665	0.2806

Table-1(c): Exergy destruction ratio of system with variations in temperature over lapping (approach_LTC) of single effect H_20-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Temperature over lapping (approach_LTC) in Low temperature condenser (ºC) using R236fa	Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K (i.e.-150ºC) using R236fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K (i.e.100ºC) using R245fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K (i.e.-50ºC) using HFO-1234yf
0	0.9054	1.143	2.565
5	0.9438	1.143	2.565
10	0.9823	1.143	2.565
15	1.027	1.143	2.565

Table-1(d): First and second law performance with variations in temperature over lapping (approach_ITC) of single effect LiBr vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_ITC) in intermediate condenser temperature (ºC) using R245fa	Over all COP of system using to low evaporator temperature of 123K using R236fa	Over all COP of system using to intermediate evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.8839	0.9351	0.8093
5	0.8748	0.9227	0.8093
10	0.8659	0.9109	0.8093
15	0.8574	0.8996	0.8093

Table-1(e):Second law performances (exergetic Efficiencies) with variations in temperature over lapping (approach_ITC) of single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_ITC) in intermediate temperature Condenser (ºC) using R245fa	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.5317	0.4969	0.2806
5	0.5178	0.4813	0.2806
10	0.5045	0.4665	0.2806
15	0.4915	0.4526	0.2806

Table-1(f): Exergy destruction ratio (EDR_system) of system and % improvement in system first law performance with variations in temperature over lapping (approach_ITC) of single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_ITC) in intermediate temperature Condenser (ºC) using R245fa	Over all Exergy Destruction Ratio (EDR) of system using to low evaporator temperature of 123K using R236fa	Over all Exergy Destruction Ratio(EDR) of system using to intermediate evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio(EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.8808	1.013	2.565
5	0.9311	1.078	2.565
10	0.9823	1.143	2.565
15	1.034	1.21	2.565

Table-1(g): First law Performances (COP_Overall) with variations in temperature over lapping (approach_LTC) of single effect H_2O- Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_MTC) in medium temperature Condenser (ºC) using R1234yf	Over all COP of system using to low evaporator temperature of 123K using R236fa	Over all COP of system using to intermediate evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.9278	0.9881	0.8764
5	0.8977	0.9502	0.8432
10	0.8659	0.9109	0.8093
15	0.8322	0.8698	0.7743

Table-1(h): second law Performances (exergetic efficiencies) variations with temperature over lapping (approach_LTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_MTC) in medium temperature Condenser (ºC) using R1234yf	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.5721	0.5459	0.3355
5	0.5391	0.5065	0.3076
10	0.5045	0.4665	0.2805
15	0.4679	0.4258	0.2639

Table-1(i): Exergy destruction ratio (EDR) of system with variations in temperature over lapping (approach_LTC) of single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_MTC) in medium temperature condenser (ºC) using R1234yf	Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R236fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.7479	0.8317	1.981
5	0.8550	0.9744	2.261
10	0.9823	1.143	2.566
15	1.137	1.348	2.939

3.2 Effect of temperature overlapping on percentage improvements of thermodynamic performances

Table-2(a) to Table-2(i) show the variation of all three types of approaches of combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with percentage variation of thermodynamic first and second law performances and it was observed that as temperature overlapping in increasing, the first law efficiency (COP) and second law efficiency (exergetic efficiency) VCRS of cascaded system are decreasing as temperature overlapping is increasing. Similarly exergy destruction ratio based on exergy of product is also decreasing as temperature overlapping (approach) is increasing.

Table-2(a): % improvement in system first law Performance with variations in temperature over lapping (approach_LTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Temperature over lapping (Approach_LTC) in Low temperature Condenser (ºC) using R236fa	(%) Overall improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	(%) Overall improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%)	(%) Overall improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K Using HFO1234yf (%)
0	16.92	21.53	7.96
5	16.21	21.53	7.96
10	15.52	21.53	7.96
15	14.85	21.53	7.96

Table-2(b): % improvement in system first law Performance variations and % reduction in exergy destruction ratio (EDR_System) of system and with temperature over lapping (approach_LTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over laping (Approach_LTC) in Low temperature Condenser (ºC) using R236fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate temp evaporator temp of 223K Using HFO-1234yf (%)
0	156.8	128.3	37.27
5	151.8	128.3	37.27
10	146.9	128.3	37.27
15	142.1	128.3	37.27

Table-2(c): % reduction in exergy destruction ratio of system and with varying temperature over lapping (approach_LTC) of single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_LTC) in low temp condenser (°C) using R236fa	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
0	76.75	70.63	34.32
5	75.76	70.63	34.32
10	74.77	70.63	34.32
15	73.77	70.63	34.32

Table-2(d): % improvement in system first law performance variations with varying temperature over lapping (approach_ITC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Temperature over lapping (approach_ITC) in intermediate temp Condenser (°C) using R245fa	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
0	17.91	24.74	7.96
5	16.7	23.09	7.96
10	15.52	21.52	7.96
15	14.38	20.0	7.96

Table-2(e): % improvement in system second law Performance variations of system and with varying temperature over lapping (approach_ITC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_ITC) in intermediate temperature Condenser (°C) using R245fa	Over all (%) improvement in second law efficiency (exergetic efficiency) of system using to low evaporator temperature of 123Kusing R236fa (%)	Over all (%) improvement in second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
0	160.2	143.2	37.27
5	153.4	135.5	37.27
10	146.9	128.3	37.27
15	140.5	121.5	37.27

Table-2(f): % reduction Exergy destruction ratio (EDR) of system and with varying temperature over lapping (approach_LTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (Approach_MTC) in medium temperature condenser (°C) using R1234yf	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO1234yf (%)
0	77.38	73.99	34.12
5	76.09	72.32	34.12
10	74.77	70.63	34.12
15	73.43	68.93	34.12

Table-2(g) % improvement in system first law performance (COP_Overall) variations with varying temperature over lapping (approach_MTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over laping (approach_MTC) in medium temperature condenser (°C) using R1234yf	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	0.9278	0.9881	0.8764
5	0.8977	0.9502	0.8432
10	0.8659	0.9109	0.8093
15	0.8322	0.8698	0.7743

Table-2(h): % improvement in system second law performance (exergetic efficiencies) variations and % reduction Exergy destruction ratio of system and with varying temperature over lapping (approach_MTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over laping (approach_MTC) in medium temperature condenser (°C) using R1234yf	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
0	180.0	167.2	64.16
5	163.8	147.9	50.56
10	146.9	128.3	37.27
15	129.0	108.4	24.23

Table-2(i): % reduction Exergy destruction ratio(EDR) of multi cascade system and with varying temperature over lapping (approach_LTC) of single effect H_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over laping (approach_MTC) in medium temp Condenser (°C) using R1234yf	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
0	80.79	78.64	49.13
5	78.04	74.97	47.25
10	74.77	70.63	34.12
15	70.75	65.37	24.5

3.3 Effect of generator temperature on total thermodynamic performances of three cascaded cycles in integrated system

Table-3(a) to Table-3(c) shows the variation of generator temperature of VARS on thermodynamic performances such as first law efficiency , second law efficiency and system exergy destruction of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as generator temperature increasing, the first law efficiency (COP_overall) of three cycles and second law efficiency (exergetic efficiency) of three cycles of combined vapour absorption cascaded refrigeration system is decreasing as generator temperature is increasing. Similarly exergy destruction ratio based on exergy of product is increasing

Table-3(a): Effect of generator *temperature of single effect H_2O- Li/Br VARS on thermodynamic performances (First law Performance (COP_Overall), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low evaporator temperature of 123K using R23fa	Over all COP of system using to intermediate evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
90	0.880	0.9274	0.8252
95	0.8754	0.9221	0.820
100	0.9312	1.075	0.8156
105	0.8683	0.9137	0.8120
110	0.8659	0.9109	0.8093
115	0.8639	0.9085	0.8069

Table-3(b): Effect of generator *temperature of single effect H_2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temp of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all exergetic efficiency of system using to low evaporator temp of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temp of 173K using R245fa	Over all exergetic eff of system using to intermediate evaporator temp of 223K using HFO-1234yf
90	0.5329	0.4995	0.3045
95	0.5252	0.4904	0.2975
100	0.5178	0.4819	0.2916
105	0.5109	0.4739	0.2858
110	0.5045	0.4665	0.2805
115	0.4983	0.4596	0.2765

Table-3(c): Effect of generator *temperature of single effect H_2O Li/Br VARS on thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all Exergy Destruction Ratio of system using to low temperature evaporator temperature of 123K using R23fa	Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
90	0.8765	1.002	2.284
95	0.9042	1.039	2.357
100	0.9312	1.075	2.429
105	0.9573	1.11	2.499
110	0.9823	1.143	2.565
115	1.007	1.176	2.630

3.4 Effect of generator temperature on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-4(a) to Table-4(c) shows the variation of generator temperature with percentage improvement in thermodynamic performances such as first law efficiency , second law efficiency and system exergy destruction ratio of Combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as generator temperature increasing, the percentages improvement in first law efficiency ($COP\_{Overall}$) of three cycles and second law efficiency (exergetic efficiency) of three cycles of multi cascaded single effect vapour absorption integrated refrigeration system are increasing as generator temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as condenser temperature is decreasing.

Table-4(a): Effect of generator *temperature of single effect H_2O- Li/Br VARS on percentage improvement of thermodynamic performances (First law performance ($COP\_{Overall}$)of three cycles are , with generator temperature of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
90	14.26	20.42	7.151
95	14.67	20.77	7.414
100	15.02	21.08	7.641
105	15.31	21.33	7.824
110	15.52	21.52	7.961
115	15.71	21.68	8.08

Table-4(b): Effect of generator *temperature of single effect H_2O- Li/Br VARS on percentage improvement of thermodynamic performances (second law performance (over all exergetic efficiencies)of three combined cycles are , with generator temperature of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
90	104.8	91.96	17.04
95	116.3	102.0	22.67
100	137.3	102.1	32.78
105	137.3	120.2	32.78
110	146.9	128.3	37.27
115	155.9	136.0	41.48

Table-4(c): Table-4(b): Effect of generator *temperature of single effect H_2O- Li/Br VARS on percentage improvement of thermodynamic performances of three combined cycles are , with generator temperature in terms of exergy destruction ratios of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173Kusing R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
90	69.17	64.76	19.68
95	71.01	66.68	24.41
100	72.5	68.25	28.27
105	73.74	69.55	31.46
110	74.77	70.63	34.12
115	75.66	71.56	36.41

3.5 Effect of absorber temperature on total thermodynamic performances of three cascaded cycles in integrated system

Table-5(a)to Table-5(c) show the variation of absorber temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature cycle and it was observed that as absorber temperature increasing, the first law efficiency (COP) and second law efficiency (exergetic efficiency) of cascaded system are decreasing as absorber temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as absorber temperature is increased. Similarly solar collector area is also increasing as absorber temperature is increasing.

Table-5(a): Effect of absorber temperature of VARS Thermodynamic performances (first law Performance ($COP_{\_overall}$), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low temperature evaporator temperature of 123K using R23fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
30	0.8723	0.9183	0.8003
31	0.8709	0.9167	0.8149
32	0.8696	0.9151	0.8134
33	0.8683	0.9137	0.8119
34	0.8671	0.9123	0.8106
35	0.8659	0.9109	0.8093
36	0.8649	0.9097	0.8081
37	0.8638	0.9084	0.8069
38	0.8629	0.9073	0.8058
39	0.8619	0.9062	0.8048
40	0.8610	0.9052	0.8038
41	0.8602	0.9042	0.8028
42	0.8594	0.9033	0.8019
43	0.8587	0.9024	0.8011
44	0.8580	0.9016	0.8003
45	0.8573	0.9008	0.7996

Table-5(b): Effect of absorber temperature of VARS on Thermodynamic second law performances (exergetic efficiencies) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
30	0.5060	0.4683	0.2818
31	0.5057	0.4679	0.2815
32	0.5053	0.4675	0.2812
33	0.5050	0.4672	0.2810
34	0.5047	0.4669	0.2807

35	0.5045	0.4665	0.2805
36	0.5042	0.4662	0.2803
37	0.5040	0.4660	0.2801
38	0.5037	0.4657	0.2799
39	0.5035	0.4654	0.2797
40	0.5033	0.4652	0.2795
41	0.5031	0.4650	0.2794
42	0.5029	0.4647	0.2792
43	0.5027	0.4645	0.2790
44	0.5025	0.4643	0.2789
45	0.5024	0.4641	0.2788

Table-5(c): Effect of absorber temperature of VARS on Thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all Exergy Destruction Ratio of system using to low temperature evaporator temperature of 123K using R23fa	Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
30	0.9763	1.135	2.549
31	0.9776	1.137	2.553
32	0.9789	1.139	2.566
33	0.9801	1.140	2.559
34	0.9812	1.142	2.562
35	0.9823	1.143	2.565
36	0.9833	1.145	2.568
37	0.9843	1.146	2.570
38	0.9853	1.147	2.573
39	0.9861	1.149	2.575
40	0.9870	1.150	2.578
41	0.9878	1.151	2.580
42	0.9886	1.152	2.582
43	0.9893	1.153	2.584
44	0.990	1.154	2.585
45	0.9906	1.154	2.587

3.6 Effect of absorber temperature on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-5(a)to Table-5(c) show the variation of absorber temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature cycle and it was observed that as absorber temperature increasing, the first law efficiency (COP) and second law efficiency (exergetic efficiency) of cascaded system are decreasing as absorber temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as absorber temperature is increased. Similarly solar collector area is also increasing as absorber temperature is increasing.

Table-6(a): Effect of Thermodynamic performances (First law Performances (COP_overall), with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with absorber temperature

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
30	14.95	21.02	7.596
31	15.08	21.13	7.676
32	15.2	21.24	7.753
33	15.31	21.33	7.826
34	15.42	21.43	7.895
35	15.52	21.52	7.961

36	15.62	21.60	8.03
37	15.71	21.68	8.082
38	15.79	21.76	8.138
39	15.88	21.83	8.191
40	15.96	21.9	8.242
41	16.03	21.97	8.290
42	16.10	22.03	8.335
43	16.17	22.09	8.378
44	16.23	22.14	8.418
45	16.29	22.19	8.456

Table-6(b): Effect of thermodynamic performances Second law performances (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with single effect H_2O-Li/Br vapour absorption refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with absorber temperature

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
30	144.6	126.4	36.21
31	145.1	126.8	36.44
32	145.6	127.2	36.66
33	146.0	127.6	38.87
34	146.5	128.0	37.07
35	146.9	128.3	37.27
36	147.3	128.6	37.45
37	147.6	129.0	37.62
38	148.0	129.3	37.78
39	148.3	129.5	37.94
40	148.6	129.8	38.09
41	148.9	130.1	38.23
42	149.2	130.3	38.36
43	149.5	130.5	38.49
44	149.7	130.8	38.6
45	150.0	131.0	38.72

Table-6(c): Effect of Thermodynamic performances system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with absorber temperature

Absorber temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
30	74.54	70.39	33.52
31	74.59	70.44	33.65
32	74.64	70.49	33.78
33	74.69	70.54	33.90
34	74.73	70.59	34.01
35	74.77	70.63	31.12
36	74.81	70.68	34.22
37	74.85	70.72	34.32
38	74.89	70.75	34.41
39	74.92	70.79	34.50
40	74.95	70.82	34.58
41	74.98	70.85	34.65
42	75.01	70.88	34.73
43	75.04	70.91	34.80
44	75.06	70.94	34.87
45	75.09	70.96	34.93

3.7 Effect of condenser temperature on total thermodynamic performances of three cascaded cycles in integrated system

Fig-7(a) to Table-7(c) show the variation of condenser temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with Vapour compression refrigeration system 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as condenser temperature increasing, the first law efficiencies ($COP_{\_Overall}$) and second law efficiencies (exergetic efficiencies) of combined system is decreasing as absorber temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as condenser temperature is increased.

Table-7(a): Effect of condenser *temperature of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with*

Condenser temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low evaporator temperature of 123K using R23fa	Over all COP of system using to intermediate evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate evaporator temp of 223K using HFO-1234yf
30	0.8696	0.9152	0.8135
31	0.8690	0.9195	0.8127
32	0.8683	0.9137	0.8119
33	0.8675	0.9128	0.8110
34	0.8660	0.9118	0.8102
35	0.8659	0.9109	0.8093
36	0.8652	0.910	0.8084
37	0.8645	0.9092	0.8076
38	0.8638	0.9084	0.8068
39	0.8631	0.9076	0.8061
40	0.8626	0.9069	0.8054
41	0.8620	0.9063	0.8048
42	0.8615	0.9057	0.8042
43	0.860	0.9051	0.8037
44	0.8606	0.9047	0.8032

Table-7(b): Effect of condenser *temperature of VARS on total thermodynamic performance sin terms of Second law performances (exergetic efficiencies) with condenser temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with*

Condenser temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
30	0.5054	0.4676	0.2812
31	0.5052	0.4674	0.2811
32	0.5050	0.4672	0.2810
33	0.5048	0.4670	0.2808
34	0.5047	0.4668	0.2807
35	0.5045	0.4665	0.2805
36	0.5043	0.4663	0.2803
37	0.5041	0.4661	0.2802
38	0.5039	0.4659	0.2801
39	0.5038	0.4658	0.2799
40	0.5036	0.4656	0.2798
41	0.5035	0.4654	0.2797
42	0.5034	0.4653	0.2796
43	0.5033	0.4652	0.2795
44	0.5032	0.4651	0.2794
45	0.5031	0.4649	0.2793

Table-7(c): Effect of condenser *temperature of VARS on thermodynamic performances such as system exergy destruction ratios with condenser temperature of three vapour compression refrigeration systems coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.*

Condenser temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R23fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf
30	0.9888	1.139	2.586
31	0.9794	1.140	2.597
32	0.9801	1.140	2.599
33	0.9800	1.141	2.561
34	0.9816	1.142	2.563
35	0.9823	1.143	2.565
36	0.9830	1.144	2.567
37	0.9837	1.145	2.569
38	0.9844	1.146	2.571
39	0.9850	1.147	2.572
40	0.9856	1.148	2.574
41	0.9861	1.148	2.575
42	0.9866	1.149	2.577
43	0.9870	1.150	2.578
44	0.9875	1.150	2.579
45	0.9878	1.151	2.580

3.8 Effect of condenser temperature on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-8(a): Effect of condenser *temperature of VARS on thermodynamic performances (First law Performance (COP_overall) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Condenser Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
30	15.19	21.23	7.748
31	15.25	21.28	7.785
32	15.31	21.34	7.826
33	15.38	21.40	7.87
34	15.45	21.46	7.915
35	15.52	21.52	7.961
36	15.59	21.58	8.005
37	15.65	21.63	8.047
38	15.71	21.69	8.086
39	15.77	21.74	8.123
40	15.83	21.79	8.158
41	15.87	21.83	8.189
42	15.92	21.87	8.218
43	15.96	21.91	8.245
44	16.0	21.94	8.27
45	16.04	21.97	8.293

Table-8(b): Effect of condenser *temperature of VARS on thermodynamic Second law performances (Exergetic efficiencies) with condenser temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Condenser Temp of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
30	145.6	127.2	36.65
31	145.8	127.4	36.76
32	146.0	127.6	36.88
33	146.3	127.8	37.0
34	146.6	128.1	37.13
35	146.9	128.3	37.27
36	147.1	128.5	37.39
37	147.4	129.8	37.52
38	147.7	129.0	37.63
39	147.9	129.2	37.74
40	148.1	129.4	37.84
41	148.3	129.5	37.93
42	148.5	129.7	38.02
43	148.6	129.8	38.10
44	148.8	130.0	38.17
45	148.9	130.1	38.24

Table-8(c): Effect of condenser *temperature of VARS on thermodynamic system exergy destruction ratio with condenser temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.*

Condenser Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
30	74.64	70.49	33.77
31	74.65	70.52	33.85
32	74.69	70.54	33.90
33	74.71	70.57	33.97
34	74.74	70.60	34.05
35	74.77	70.63	34.12
36	74.80	70.66	34.19
37	74.83	70.69	34.26
38	74.85	70.72	34.33
39	74.88	70.74	34.39
40	74.90	70.77	34.44
41	74.92	70.79	34.51
42	74.94	70.81	34.54
43	74.95	70.82	34.59
44	74.97	70.86	34.63
45	74.98	70.85	34.67

3.9 Effect of evaporator temperature of vapour absorption refrigeration system on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-9(a) to Table-9(c) shows the variation of VARS evaporator temperature with thermodynamic performances combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using R1234yf eco-friendly refrigerant and it was observed that as intermediate temperature circuit evaporator temperature is increasing from (-50°C to -20°C), the first law efficiency (COP_VCRS) of vapour compression system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression single effect vapour absorption refrigeration system is increasing as intermediate temperature circuit evaporator Temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with VCR.

Table-9(a): Effect of Thermodynamic performances (First law Performances (COP_Overall), with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser *temperature of VARS*

Evaporator temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low evaporator temperature of 123K using R23fa	Over all COP of system using to intermediate evaporator temperature of 173K using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
1	0.8532	0.8961	0.7950
2	0.8548	0.8979	0.7967
3	0.8564	0.8998	0.7986
4	0.8582	0.9018	0.8005
5	0.860	0.9040	0.8026
6	0.8619	0.9062	0.8047
7	0.8639	0.9085	0.8070
8	0.8659	0.9109	0.8093
9	0.8681	0.9134	0.8117
10	0.8704	0.9161	0.8143

Table-9(b): Effect of Thermodynamic Second law performance (Exergetic efficiency) with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser temperature of VARS

Evaporator Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
1	0.5240	0.4909	0.3113
2	0.5211	0.4873	0.3068
3	0.5182	0.4837	0.3023
4	0.5154	0.4802	0.2979
5	0.5126	0.4767	0.2935
6	0.5099	0.4733	0.2891
7	0.5071	0.4699	0.2848
8	0.5045	0.4665	0.2805
9	0.5018	0.4632	0.2762
10	0.4992	0.460	0.2720

Table-9(c): Effect of Thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser *temperature of VARS*

Evaporator Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K usingR23fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf
1	0.9084	1.037	2.212
2	0.9191	1.052	2.260
3	0.9297	1.067	2.308
4	0.9403	1.082	2.357
5	0.9508	1.098	2.408
6	0.9613	1.113	2.459
7	0.9718	1.126	2.511
8	0.9823	1.143	2.565
9	0.9927	1.159	2.62
10	1.003	1.174	2.676

3.10Effect of evaporator temperature of vapour absorption refrigeration system on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-10(a) to Table-10(c) shows the variation of VARS evaporator temperature with percentage improvement in thermodynamic performances combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using R1234yf eco-friendly refrigerant and it was observed that as intermediate temperature circuit evaporator temperature is increasing from (-50°C to -20°C), the first law efficiency (COP_VCRS) of vapour compression system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression single effect vapour absorption refrigeration system is increasing as intermediate temperature circuit evaporator Temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration.

Table-10(a): Effect of Thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser temperature of VARS

Evaporator Temp of single effect H_2O-Li/Br vapour absorption refrigeration system(°C)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
1	16.65	22.51	8.689
2	16.52	22.39	8.60
3	16.37	22.26	8.505
4	16.21	22.12	8.406
5	16.05	21.98	8.302
6	15.88	21.83	8.193
7	15.71	21.68	8.08
8	15.52	21.52	7.961
9	15.3	21.35	7.836
10	15.2	21.17	7.707

Table-10(b): Effect of Thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser *temperature of VARS*

Evaporator Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	% improvement in Over allexergetic efficiency of system using to low evaporator temperature of 123K using R236fa	% improvement in Over allexergetic efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa	% improvement in Over allexergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
1	81.5	70.05	7.842
2	88.47	76.39	8.60
3	96.04	82.99	14.36
4	104.3	90.36	18.08
5	113.4	98.45	22.17
6	123.4	1.7.4	26.67
7	134.5	117.3	31.68
8	146.9	128.3	37.27
9	160.8	140.7	43.55
10	176.5	154.7	50.66

Table-10(c): Effect of Thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser *temperature of VARS*

evaporatorTemperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C)	% improvement in Overall Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R23fa	% improvement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf
1	63.13	57.91	10.22
2	64.88	59.79	13.66
3	66.59	61.65	17.07
4	68.28	63.48	20.48
5	69.94	65.3	23.88
6	71.57	67.09	27.28
7	73.18	68.87	30.7
8	74.77	70.63	34.12
9	76.34	72.39	37.57
10	77.9	74.13	41.04

3.11 Effect of temperature of MTC evaporator on overall system performances of cascade evaporators using ecofriendly refrigerants

In this section, the effect of various cascaded evaporator have been discussed in detail as given below.

Table-11(a) to Table-11(c) show the variation of medium temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as Low temperature circuit evaporator Temperature is increasing from (-50ºC to -20ºC), the first law efficiency ($COP_{\_Cascade}$) of cascaded vapour compression single effect vapour absorption system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression half effect vapour absorption refrigeration system is decreasing as generator temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as medium temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit is increased.

Table11(a): Effect of evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performance such as First law Performance (COP_overall), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperaturet, R245fa in intermediate temperature circuit and R236fa in low temperature

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (ºC)	Over all first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 123K using R236fa (%)	Over all first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-20	0.9389	1.036	1.012
-25	0.9296	1.015	0.9759
-30	0.9192	0.9997	0.9408
-35	0.9076	0.9794	0.9065
-40	0.8948	0.9577	0.8731
-45	0.8809	0.9348	0.8404
-50	0.8659	0.9109	0.8098

Table-11(b): Effect of evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performance such as Second law performance (Exergetic efficiency) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (ºC)	Over all second law efficiency (exergetic efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-20	0.4406	0.4572	0.2921
-25	0.4566	0.4656	0.2939
-30	0.4707	0.4712	0.2941
-35	0.4827	0.4741	0.2927
-40	0.4997	0.4743	0.2895
-45	0.4924	0.4717	0.2857
-50	0.5045	0.4665	0.2805

Table-11(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances: system exergy destruction ratio of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in low temperature

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (ºC)	Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-20	1.27	1.187	2.424
-25	1.19	1148	2.402
-30	1.124	1.122	2.40
-35	1.072	1.109	2.417
-40	1.031	1.108	2.45
-45	1.0	1.12	2.50
-50	0.9823	1.143	2.565

3.12 Effect of temperature of MTC evaporator on percentage improvement in overall system performances of cascade evaporators using ecofriendly refrigerants

Table-12(a) to Table-12(c) show the variation of medium temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with VCRS using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as Low temperature circuit evaporator Temperature is increasing from (-50°C to -20°C), the first law efficiency ($COP_{\_Cascade}$) of cascaded vapour compression single effect vapour absorption system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression half effect vapour absorption refrigeration system is decreasing as generator temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as medium temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit is increased.

Table-12(a): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in thermodynamic performances such as first law performance ($COP_{\_Overall}$) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (°C)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-20	25.26	38.18	34.98
-25	24.01	35.88	30.09
-30	22.62	33.36	25.5
-35	21.08	30.65	20.93
-40	19.17	27.76	16.47
-45	17.52	24.71	12.15
-50	15.52	21.52	7.961

Table-12(b): Effect of evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in thermodynamic performances such as first law performance ($COP_{\_Overall}$) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temp of medium temp circuit using HFO-1234yf refrigerants (°C)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-20	115.6	123.8	42.92
-25	123.5	127.8	43.35
-30	130.4	130.6	43.92
-35	136.2	132.0	43.22
-40	141.0	132.1	41.84
-45	144.5	130.9	39.84
-50	146.9	128.3	37.29

Table-12(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in the thermodynamic performances such as first law performance ($COP_{\_Overall}$) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-20	67.39	69.51	37.76
-25	69.44	70.52	38.31
-30	71.12	71.18	38.35
-35	72.48	71.51	37.93
-40	73.53	71.53	37.08
-45	74.29	71.21	35.8
-50	74.77	70.63	34.12

3.13 Effect of temperature of ITC evaporator on overall system performances of cascade evaporators using ecofriendly refrigerants

Table-13(a) to Table-13 (c) shows the variation of Low temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with VCRS using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as Low temperature circuit evaporator Temperature is increasing from (-70°C to -30°C), the first law efficiency(COP_VCRS) of cascaded vapour compression system is increasing while and second law efficiency (exergetic efficiency) of Cascaded vapour compression single effect vapour absorption refrigeration system is increasing as Low temperature circuit evaporator Temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as Low temperature circuit evaporator Temperature of combined single effect Li/BrVapour absorption refrigeration system cascaded with VCRS using R134a refrigerant is decreased.

Table-13(a): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature, R245fa in intermediate temperature and R236fa in the low temperature with evaporator temperature of VARS

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all first law efficiency ($COP_{Overall}$) of system using to low evaporator temperature of 123K using R236fa (%)	Over all first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-70	0.9205	0.9857	0.8098
-75	0.90971	0.9706	0.8098
-80	0.8989	0.9556	0.8098
-85	0.888	0.9406	0.8098
-90	0.877	0.9257	0.8098
-95	0.8659	0.9109	0.8098
-100	0.8963	0.8549	0.8098

Table-13(b): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with evaporator temperature of VARS

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all second law efficiency (exergetic Efficiency) of system using to low evaporator temp of 123K using R236fa (%)	Over all second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all second law efficiency (exergetic Efficiency) system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-70	0.5157	0.4688	0.2805
-75	0.5145	0.4696	0.2805
-80	0.5127	0.4698	0.2805
-85	0.5105	0.4693	0.2805
-90	0.5077	0.4683	0.2805
-95	0.5045	0.4665	0.2805
-100	0.5007	0.4642	0.2805

Table-13(c): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature cycle.

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all exergy destruction ratio (EDR)) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-70	0.9390	1.133	2.565
-75	0.9437	1.131	2.565
-80	0.9503	1.129	2.565
-85	0.9588	1.131	2.565
-90	0.9695	1.136	2.565
-95	0.9823	1.143	2.565
-100	0.9974	1.154	2.565

3.14 Effect of ultra-low evaporator temperature on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-14(a) to Table-14(c) shows the variation of intermediate temperature circuit evaporator temperature with percentage improvement in thermodynamic performances combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using R1234yf eco-friendly refrigerant and it was observed that as intermediate temperature circuit evaporator temperature is increasing from (-50ºC to -20ºC), the first law efficiency (COP_VCRS) of vapour compression system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression single effect vapour absorption refrigeration system is increasing as intermediate temperature circuit evaporator Temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R236fa eco-friendly refrigerant is decreased.

Table-14(a): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (ºC) on the percentage improvement of Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (ºC)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-70	22.80	31.50	7.961
-75	21.36	29.48	7.961
-80	19.91	27.48	7.961
-85	18.45	25.48	7.961
-90	16.99	23.49	7.961
-95	15.52	21.52	7.961
-100	14.05	19.57	7.961

Table-14(b): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (ºC) on the percentage improvement of in terms of second law performances (exergetic efficiencies) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2OLi/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (ºC)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
-70	152.4	129.4	37.27
-75	151.8	129.8	37.27
-80	150.9	129.9	37.27
-85	149.8	129.7	37.27
-90	148.5	129.2	37.27
-95	146.9	128.3	37.27
-100	145.0	123.7	37.27

Table-14(c): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(ºC) on the percentage improvement of system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with evaporator temperature of VARS

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (ºC)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-70	75.88	70.90	34.12
-75	75.76	70.99	34.12
-80	75.56	70.97	34.12
-85	75.37	70.96	34.12
-90	75.10	70.84	34.12
-95	74.77	70.63	34.12
-100	74.38	70.36	34.12

3.15 Effect of ultra-low evaporator temperature on total thermodynamic performances of three cascaded cycles in integrated system

Table-15(b): Effect of LTC evaporator *temperature on thermodynamic performances (first law performance ($COP_{Overall}$), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

evaporator Temperature ofultra low temperature circuit using R-236fa refrigerants (ºC)	Over all l first law efficiency ($COP_{Overall}$) of system using to low evaporator temperature of 123K using R236fa (%)	Over all law first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all law first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-120	0.9213	0.9109	0.8093
-125	0.9116	0.9109	0.8093
-130	0.9021	0.9109	0.8093
-135	0.8928	0.9109	0.8093
-140	0.8836	0.9109	0.8093
-145	0.8747	0.9109	0.8093
-150	0.8659	0.9109	0.8093
-155	0.8578	0.9109	0.8093

Table-15(b): Effect of LTC evaporator *temperature on thermodynamic performances (second law performances (exergetic efficiencies), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

evaporator Temperature ofultra low temperature circuit using R-236fa refrigerants (ºC)	Over all second law law efficiency (exergetic Efficiency) of system using to low evaporator temp of 123K using R236fa (%)	Over all second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
-120	0.5425	0.4665	0.2805
-125	0.5374	0.4665	0.2805
-130	0.5319	0.4665	0.2805
-135	0.528	0.4665	0.2805
-140	0.5191	0.4665	0.2805
-145	0.5120	0.4665	0.2805
-150	0.5045	0.4665	0.2805
-155	0.4964	0.4665	0.2805

Table-15(c): Effect of LTC evaporator *temperature Thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

evaporator Temperature of ultra-low temperature circuit using R-236fa refrigerants (ºC)	Over all exergy destruction ratio (EDR) of system using to low temperature evaporator temperature of 123K (i.e.-150ºC) using R236fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-120	0.8433	1.143	2.565
-125	0.8607	1.143	2.565
-130	0.8802	1.143	2.565
-135	0.9020	1.143	2.565
-140	0.9263	1.143	2.565
-145	0.9530	1.143	2.565
-150	0.9823	1.143	2.565
-155	1.014	1.143	2.565

3.16 Effect of ultra-low evaporator temperature on percentage total thermodynamic performances of three cascaded cycles in integrated system

Table-16(a): Effect of ultra-low evaporator temperature on percentage improvement of thermodynamic performances (First law Performance (COP_ Overall), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

evaporator temperature of ultra-low temperature circuit using R-236fa refrigerants (°C)	Over all (%) improvement in first law efficiency ($COP_{overall}$) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in first law efficiency ($COP_{overall}$) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in first law efficiency ($COP_{overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-120	22.9	21.52	7.961
-125	21.61	21.52	7.961
-130	20.15	21.52	7.961
-135	19.1	21.52	7.961
-140	17.87	21.52	7.961
-145	16.68	21.52	7.961
-150	15.52	21.52	7.961
-155	14.4	21.52	7.961

Table-16(b): Effect of ultra low evaporator *temperatureon improvement of thermodynamic performances second law performances (Exergetic efficiencies) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

evaporator temperature of ultra-low temperature circuit using R-236fa refrigerants (°C)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
-120	165.5	128.3	37.27
-125	163.0	128.3	37.27
-130	160.3	128.3	37.27
-135	157.3	128.3	37.27
-140	154.1	128.3	37.27
-145	150.6	128.3	37.27
-150	146.9	128.3	37.27
-155	142.9	128.3	37.27

Table-16(c): Effect of ulta low evaporator *temperature on reduction in system exergy destruction ratio of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

evaporator Temperature ofultra low temperature circuit using R-236fa refrigerants (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
-120	78.34	70.63	34.12
-125	77.9	70.63	34.12
-130	77.35	70.63	34.12
-135	76.83	70.63	34.12
-140	76.21	70.63	34.12
-145	75.33	70.63	34.12
-150	74.77	70.63	34.12
-155	73.5	70.63	34.12

3.17 Effect of ecofriendly refrigerants in Intermediate temperature cycle on total thermodynamic performances of three cascaded cycles in integrated system

Table-10(a) to Table-10(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances ($COP_{Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression - vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R1234yf is slightly lower than R152a, R134a,R410a , R407c R245fa and higher than R227ea and R404a.

Table-17(a): Effect of ecofriendly refrigerants in medium temperature cycle on the *thermodynamic performances (First law Performance (COP_Overall), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all first law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	Over all first law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all first law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	0.8659	0.8659	0.8093
R407c	0.8690	0.9147	0.8125
R404a	0.8464	0.8859	0.7015
R-152a	0.9264	0.9863	0.8748
R410a	0.8936	0.9454	0.8390
R134a	0.9011	0.9545	0.8469
R227ea	0.8172	0.8519	0.7592

Table-17(b): Effect of ecofriendly refrigerants in medium temperature cycle on the *Second law performance (Exergetic efficiency) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all second law efficiency (exergetic efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	0.5045	0.4665	0.2805
R407c	0.5708	0.4703	0.8230
R404a	0.4822	0.4416	0.264
R-152a	0.5706	0.5441	0.3342
R410a	0.5349	0.5015	0.3042
R134a	0.5423	0.5109	0.3107
R227ea	0.4517	0.4084	0.2427

Table-17(c): Effect of ecofriendly refrigerants in medium temperature cycle on *system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all exergy destruction ratio (EDR) of system of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all exergy destruction ratio (EDR) of system of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R-1234yf	0.9823	1.143	2.565
R407c	0.9692	1.126	2.533
R404a	1.074	1.265	2.787
R-152a	0.8696	0.9939	2.287
R410a	0.7525	0.838	1.992
R134a	0.8422	0.9574	2.219
R227ea	1.2141	1.449	3.12

3.18 Effect of ecofriendly refrigerants in Intermediate temperature cycle on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-18(a) to Table-18(c) show the comparison between with ecofriendly refrigerants in terms of percentage improvements in thermodynamic performances (First law performances ($COP_{Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression -vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R32 is slightly lower than R245fa and higher than HFC-134a, R404a , R410a, R407c and R507a.

Table-18(a): Effect of ecofriendly refrigerants in medium temperature cycle(MTC) on the percentage improvement *thermodynamic performances (First law Performance (COP_VARS), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all (%) improvement in first law efficiency ($COP_{Overall}$) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in first law efficiency ($COP_{Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	15.52	21.52	7.967
R407c	15.93	22.02	8.393
R404a	12.78	18.17	5.106
R-152a	19.24	26.12	11.3
R410a	23.59	31.58	16.7
R134a	20.21	27.33	12.98
R227ea	9.021	13.64	1.277

Table-18(b): Effect of ecofriendly refrigerants in medium temperature cycle on the *Second law performance (exergetic efficiencies) and of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R-1234yf	146.9	128.3	37.27
R407c	148.5	130.2	38.51
R404a	136.0	116.1	29.22
R-152a	179.2	166.3	63.53
R410a	161.8	145.4	48.08
R134a	165.7	150.0	52.05
R227ea	121.1	99.85	18.75

Table-18(c): Effect of ecofriendly refrigerants in medium temperature cycle on *system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	74.77	70.63	34.12
R407c	75.11	71.08	34.94
R404a	72.42	67.52	28.42
R-152a	80.67	78.48	48.83
R410a	77.67	74.47	41.25
R134a	78.37	75.41	43.02
R227ea	68.53	62.79	19.88

3.19 Effect of ecofriendly refrigerants in intermediate temperature cycle of cascaded vapour compression cycle on total thermodynamic performances of three cascaded cycles in integrated system

Table-19(a) to Table-19(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances ($COP_{Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression - vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R32 is slightly lower than R245fa and higher than HFC-134a, R404a , R410a, R407c and R507a.

Table-19(a): Effect of ecofriendly refrigerants in intermediate temperature cycle on *Thermodynamic performances (First law Performance (COP_overall), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all first law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa	Over all first law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R245fa	Over all first law efficiency (COP_Overall) of system using to low evaporator temperature of 223K using R1234yf
R-245fa	0.8659	0.9109	0.8093
R134a	0.8652	09099	0.8093
R32	0.8590	0.9016	0.8093
R-507a	0.8643	0.9067	0.8093
R404a	0.8622	0.9059	0.8093
R 410a	0.8644	0.9088	0.8093
R407c	0.4444	0.8825	0.8093

Table-19(b): Effect of ecofriendly refrigerants in intermediate temperature cycle on over all second law efficiencies (exergetic efficiencies) *of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 173K using R245fa	Over all second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-245fa	0.5045	0.4665	0.2805
R134a	0.5033	0.4652	0.2805
R32	0.4939	0.4551	0.2805
R-507a	0.5020	0.4638	0.2805
R404a	0.4987	0.4603	0.2805
R 410a	0.5021	0.4639	0.2805
R407c	0.472	0.4319	0.2805

Table-19(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on *system exergy destruction ratios of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-245fa	0.9823	1.143	2.565
R134a	0.987	1.149	2.565
R32	1.025	1.197	2.565
R-507a	0.9921	1.156	2.565
R404a	1.005	1.122	2.565
R 410a	0.9917	1.155	2.565
R407c	0.9917	1.315	2.565

3.20 Effect of ecofriendly refrigerants in Intermediate temperature cycle on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-20(a) to Table-20(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances ($COP_{\_Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression - vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R32 is slightly lower than R245fa and higher than HFC-134a, R404a , R410a, R407c and R507a

Table-20(a): Effect of ecofriendly refrigerants in intermediate temperature cycle on *Thermodynamic performances (First law Performance (COP_Overall), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in intermediate ITC circuit	Over all (%) improvement in first law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in first law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-245fa	15.52	21.52	7.961
R134a	15.41	21.38	7.961
R32	15.49	20.26	7.961
R-507a	15.30	21.23	7.961
R404a	15.01	20.85	7.961
R 410a	15.31	21.24	7.961
R407c	12.65	17.73	7.961

Table-20(b): Effect of ecofriendly refrigerants in intermediate temperature cycle on *Second law performance (Exergetic efficiency) and of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K Using HFO-1234yf (%)
R-245fa	146.9	128.3	37.27
R134a	146.3	127.7	37.27
R32	141.7	122.7	37.27
R-507a	145.7	127.0	37.27
R404a	144.1	125.3	37.27
R 410a	145.7	127.0	37.27
R407c	131.0	111.3	37.27

Table-20(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on *percentage reduction in system exergy destruction ratio of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-245fa	74.77	70.63	34.72
R134a	74.65	70.48	34.72
R32	73.68	69.25	34.72
R-507a	74.52	70.20	34.72
R404a	74.19	69.89	34.72
R 410a	74.53	70.33	34.72
R407c	71.27	66.21	34.72

3.21 Effect of ecofriendly refrigerants in ultra-low cascaded vapour compression cycle on total thermodynamic performances of three cascaded cycles in integrated system

Table-21(a) to Table-21(c) show the comparison between hydro carbons and ethylene with ecofriendly refrigerant R236fa in terms of thermodynamic performances (First law performances ($COP_{\_Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2OLi/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle and following refrigerants in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression -vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and following ecofriendly refrigerants in the low temperature circuit using R600a is maximum and lowest when using ethylene.

Table-21(a): Effect of ecofriendly refrigerants in ultra-low temperature cycle on *thermodynamic performances (First law Performance (COP_VARS), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R236fa	0.8659	0.9109	0.8093
R290	0.8664	0.9109	0.8093
R600a	0.8685	0.9109	0.8093
Ethylene	0.8566	0.9109	0.8093

Table-21(b): Effect of ecofriendly refrigerants in ultra-low temperature cycle on, *Second law performance (Exergetic efficiency) and system exergy destruction ratio of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%)
R236fa	0.5045	0.4665	0.2805
R290	0.5053	0.4665	0.2805
R600a	0.5094	0.4665	0.2805
Ethylene	0.4865	0.4665	0.2805

Table-21(c): Effect of ecofriendly refrigerants in ultra-low temperature cycle on *system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H_2O- Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	Over all exergy destruction ratio (EDR) of system of system using to low evaporator temperature of 123K using R236fa (%)	Over all exergy destruction ratio (EDR) of system of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all exergy destruction ratio (EDR) of system of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R236fa	0.9823	1.143	2.565
R290	0.979	1.143	2.565
R600a	0.9630	1.143	2.565
Ethylene	1.056	1.143	2.565

3.22 Effect of ecofriendly refrigerants on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table-22(a) to Table-22(c) shows the comparison between hydro carbons and ethylene with ecofriendly refrigerant R236fa in terms of thermodynamic performances (First law performances ($COP_{Overall}$), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H_2OLi/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle and following refrigerants in the ultra-low temperature cycle and it is found that the percentage improvement in first and second law performances of cascaded vapour compression vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and following ecofriendly refrigerants in the low temperature circuit using R600a is maximum and lowest when using ethylene.

Table-22(a): Effect of ecofriendly refrigerants in ultra-low temperature cycle on percentage improvement of *thermodynamic performances such as first law performance ($COP_{\_overall}$), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	% improvement in Overall First law efficiency ($COP_{\_Overall}$) to low temperature evaporator of 123K using R236fa (%)	% improvement in Overall First law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa (%)	% improvement in Overall First law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R236fa	15.52	21.52	7.964
R290	15.58	21.52	7.964
R600a	15.86	21.52	7.964
Ethylene	14.27	21.52	7.964

Table-22(b): Effect of ecofriendly refrigerants in ultra low temperature cycle on *percentage improvement in Second law performances (exergetic efficiencies) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R236fa	146.9	128.3	37.27
R290	147.3	128.3	37.27
R600a	149.3	128.3	37.27
Ethylene	138.1	128.3	37.27

Table-22(c): Effect of ecofriendly refrigerants in ultra low temperature cycle on *percentage reduction of exergy destruction ratios of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in ultra-low temperature cycle	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R236fa	74.77	70.63	34.12
R290	74.86	70.63	34.12
R600a	75.27	70.63	34.12
Ethylene	72.89	70.63	34.12

4. Conclusions and Recommendations

The following conclusions were drawn from present investigations.

- Thermodynamic performance in terms of first law efficiency($COP\_{Cascade\_System}$) of combined cascaded vapour compression -single effect vapour absorption refrigeration system using using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate tempe138.1rature circuit and R236fa in the low temperature circuit than R1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.
- Thermodynamic performance in terms of second law efficiency(Exergetic Efficiency) of combined cascaded vapour compression single effect vapour absorption refrigeration system using HFC-134a ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit ishigher than the combined cascaded vapour compression single effect vapour absorption refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit than R1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.
- As Low temperature circuit evaporator Temperature is decreasing , the first law performances (($COP\_{Cascade\_System}$) and second law efficiency (Exergetic efficiency) of cascaded vapour compression -single effect vapour absorption refrigeration system is decreasing and exergy destruction ratio of combined vapour compression-single effect vapour absorption system is increasing.
- The best thermodynamic performances in terms of first and second law efficiencies have been found by using R152a in medium temperature circuit.
- Use of hydrocarbon is also feasible by considering safety measures because hydrocarbons are flammable and R600a gives best thermodynamic performances.
- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of generator temperature and also decreasing as generator temperature is increasing.
- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of absorber temperature and also decreasing as absorber temperature is increasing.
- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of condenser temperature and also decreasing as condenser temperature is increasing.
- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of approach (temperature over lapping) and also decreasing as temperature over lapping is increasing because larger value of temperature overlapping (approach) in each cascade heat exchanger circuit reduces the COP and exergetic efficiency of the system.

References

[1] R.S. Mishra [2014] Performance Optimization of Four Stage Cascade Refrigeration Systems using Energy-Exergy Analysis in the R1234ze & R1234yf in High Temperature Circuit and Eco friendly Refrigerants in Intermediate Circuits and Ethane in the Low Temperature Circuit for Food, Pharmaceutical, Chemical Industries" International Journal of Advance

Research and Innovation, ISSN 2347 - 3258 , Volume 2, Issue 4 , page- 701-709

[2] R.S. Mishra[2014] Use of Hydrocarbons in Low Temperature Circuit in Terms of First Law and Second Law Efficiency of Four Stage Cascade Refrigeration of Semen Preservation" International Journal of Advance Research and Innovation (IJARI), ISSN 2347 - 3258 , Volume 2, Issue 4, page725-731.

[3] Y. Chen, W. Han, H. Jin,[2017] Proposal and analysis of a novel heat-driven absorption–compression refrigeration system at low temperatures, Applied Energy Vol-185 , page-2106–2117.

[4] S.A. Tassou, J.S. Lewis, Y.T. Ge, A. Hadawey, I. Chaer, A review of emerging technologies for food refrigeration applications, applied Thermal Engineering. 30 (2010)263–276.

[5] Rabah Gomri R and Hakimi R [2009] second law analysis of double effect vapour absorption cooler system , International journal of energy conversion and management, Elsevier , Vol-49, page-3343-48.

[6] Rabah Gomri R [2008] second law comparison of single and double effect vapour absorption refrigeration system, International journal of energy conversion and management, Elsevier , Vol-50, page-1279-1287.

[7] D. Colorado, W. Rivera, (2015) Performance comparison between a conventional vapour compression and compression-absorption single-stage and double-stage systems used for refrigeration, Applied. Thermal. Engineering. 87 273–285.

[8] R.S. Mishra [2018] Comparison of thermal performances of single effect, double effect and triple effect LiBr-H2O absorption system cascaded with vapour compression refrigeration systems using ecofriendly refrigerants, International Journal of Research in Engineering and Innovation (IJREI), ISSN (Online): 2456-6934, Vol-2, Issue-6 (2018), 610-621, journal home page:

[9] S.A.Tassou, J.S. Lewis, Y.T. Ge, A. Hadawey, I. Chaer, A review of emerging technologies for food refrigeration applications, Appl. Thermal Engg. 30 (2010)263–276.

[10] R.Ayala, C.L. Heard, F. Holland, Ammonia/lithium nitrate absorption /compression refrigeration cycle, Part I, Appl. Therm. Eng. 17 (3)(1997) 223–233.

[11] R.S. Mishra[2019], Thermal performances (first law efficiency, exergy destruction ratio &exergetic efficiency) of cascade single effect ammonia-water (NH3-H20) vapour absorption refrigeration system coupled with vapour compression refrigeration using ecofriendly refrigerants in the low temperature cycle of VCRS system, International Journal of Research in Engineering and Innovation (IJREI) journal home page: http://www.ijrei.com ISSN (Online): 2456-6934, Vol-3, Issue-1,page-1-5

[12] L.Kairouani, E. Nehdi, Cooling performance and energy saving of a compression-absorption refrigeration system assisted by geothermal energy, Appl. Therm. Engg. 26 (2006) 288–294.

[13] R.S. Mishra [2019] Comparison of half effect absorption-compression cascaded refrigeration system using thermodynamic (energy-exergy) analysis. International Journal of Research in Engineering and Innovation (IJREI), ISSN (Online): 2456-6934, Vol-3, Issue-1 (2019), page-6-11.

[14] R.S. Mishra [2019] Thermal performance of cascaded vapour compression absorption systems, International Journal of Research in Engineering and Innovation (IJREI), ISSN (Online): 2456-6934, Vol-3, Issue-1 (2019), page-61-67.

[15] R.S. Mishra [2019] Use of fourth generation ecofriendly refrigerants in two and three cascade refrigeration systems for reducing global warming and ozone depletion, International Journal of Research in Engineering and Innovation (IJREI), ISSN (Online): 2456-6934, Vol-2, Issue-2 (2018), page-20-208.

[16] M.Azhar, M.A. Siddiqui, Optimization of operating temperatures in the gas operated single to triple effect vapour absorption refrigeration cycles, Int. J.Refrig. 82 (2017) 401–425.

[17] M.Azhar, M.A. Siddiqui, Thermodynamic analysis of a gas operated triple effect absorption cycle, Int. J. Innovative Res. Sci. Eng. Technol. 2 (5) (2013)1610–1616.

[18] V. Jain, S.S. Kachhwaha, G. Sachdeva, Thermodynamic performance analysis of a vapor compression–absorption cascaded refrigeration system, Energy Convers. Manage. 75 (2013) 685–700.16S.

[19] R.S. Mishra [2018] Performance parameters optimization of cascade refrigeration system using ecofriendly refrigerants, International Journal of Research in Engineering and Innovation (IJREI), ISSN (Online): 2456-6934 , Vol-2, Issue-6 , 602-609 Vol-2, Issue-6 (2018), 602-609.

[20] A.K.Pratihar, S.C. Kaushik, R.S. Agarwal, Simulation of an ammonia–water compression absorption refrigeration system for water chilling application, Int J Refrig 33 (2010) 1386–1394.

[21] Z.G. Sun, K.H. Guo, Cooling performance and energy saving of a compression–absorption refrigeration system driven by a gas engine, Int. J. Energy Res. 30(13) (2006) 1109–1116.

[22] M. Dixit, A. Arora, S.C. Kaushik, Thermodynamic and thermo economic analyses of two stage hybrid absorption compression refrigeration system, App. Thermal Engg. 113 (2017) 120–131.

[23] M.E. Alvarez, X. Esteve, M. Bourouis, Performance analysis of a triple-effect absorption cooling cycle using aqueous (lithium, potassium, sodium) nitrate solution as a working pair, Appl. Thermal. Engineering. 79 (2015) 27–36.

[24] R.S. Mishra[2019] Performance evaluation of solar assisted half effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using eco-friendly refrigerants, International Journal of Advance Research and Innovation , ISSN 2347 - 3258 , Volume 7 Issue 2 ,page-156-161.

[25] W. Han, L. Sun, D. Zheng, H. Jin, S. Ma, X. Jing, [2013] New hybrid absorption–compression refrigeration system based on cascade use of mid-temperature waste heat, Applied. Energy 106, page-383–390.

[26] S.C. Kaushik, Akhilesh Arora, Energy and exergy analysis of single effect and series flow double effect water–lithium bromide absorption refrigeration systems, Int. J. Refrig. (2009) 1–12.

[27] C.Cimsit, I.T. Ozturk, [2012], Analysis of compression-absorption cascade refrigeration cycles, App. Therm. Engg. 40, page- 311–317.

[28] S. Garimella, A.M. Brown, A.K. Nagavarapu, [2011] Waste heat driven absorption/vapor compression cascade refrigeration system for megawattscale, high-flux, low-temperature cooling, Int. J. Refrigeration 34, page- 1176–1185

[29] L. Wang, A. Ma, Y. Tan, X. Cui, H. Cui, [2012] Study on Solar-Assisted CascadeRefrigeration System, Engergyprocedia 16, page-1503–1509.

[30] S.Eini, H. Shahhosseini, N. Delgarm, M. Lee, [2016], A. Bahadori, Multi-objectiveoptimization of a cascade refrigeration system: exergetic, economic,environmental, and inherent safety analysis, Appl. Therm. Engg. 107, page-804–817.

[31] S. Bhattacharyya, S. Mukhopadhyay, A. Kumar, R.K. Khurana, J. Sarkar,Optimization of a CO_2–C3H8 cascade system for refrigeration and heating,Int J Refrig. 28 (2005) 1284–1292.

[32] M. Mafi, S.M. Mousavi Naeynian, M. Amidpour, Exergy analysis of multistage cascade low temperature refrigeration systems used in olefin plants, Int. J.Refrig. 32 (2009) 279–294.

[33] J.C.V.Chinnappa, M.R. Crees, S.S. Murthy, K. Srinivasan, Solar-assisted vapour compression/absorption cascaded air-conditioning systems, Sol. Energy 50 (5)(1993) 453–458

[34] R. Cabello, D. SánCHEz, R. Llopis, J. Catalán, L. Nebot-Andrés, E. Torrella, Energy evaluation of R152a as drop in replacement for R134a in cascade refrigeration plants, App. Therm. Engg. 110 (2017) 972–984

[35] A.Messineo, R744–R717 Cascade Refrigeration System: Performance evaluation compared with a HFC Two-Stage System, ICAEE 2011, Energy Procedia 14 (2012) 56–65.

Cite this article as: R. S. Mishra, Performance evaluation of single effect Li/Br-H_2O vapour absorption systems using multi cascading of vapour compression cycles for ultra-low temperature applications, International Journal of Research in Engineering and Innovation Vol-4, Issue-1 (2020), 8-38. *https://doi.org/10.36037/IJREI.2020.4103*.