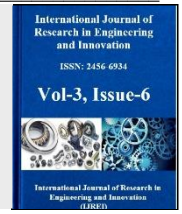
International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934



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

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Abstract

Performance evaluation of double effect LiBr-H_2O 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 15.27% and using multi (two stages) cascade VCRS is 24.45% and using multi (three stages) cascade VCRS is 21.03% for all 8oC of vapour absorption evaporator temperature. However the percentage improvement in second law efficiency (exergetic efficiency) is found using single stage cascade vapour compression refrigeration system (VCRS) is 79.43% and using multi (two stages) cascade VCRS is 113.2% and using multi (three stages) cascade VCRS is 152.2% 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 59.21 % and using multi (two stages) cascade VCRS is 72.03% and using multi (three stages) cascade VCRS is 81.96% for all 10^{0}C of temperature overlapping with 8^{0}C of evaporator temperature of VARS

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

1. Introduction

The use of vapour absorption refrigeration system is a brilliant way towards utilizing waste heat from industrial processes. H_2O-Li/Br absorption refrigeration system and ammonia–water absorption refrigeration systems are commonly used for low temperature applications. Even though ammonia–water absorption refrigeration system is commonly used for freezing applications with temperatures lower than 0 [1-2]. A number of research work is devoted to thermodynamic, analyses of vapour absorption refrigeration systems. The performance of NH_3H_2O system has low first law efficiency. When the refrigeration temperature is lower than -25^{0}C, the thermal performance dramatically decreases. Kaushik and Arora[3-4] carried out the energy and energy analysis of single effect and series flow double effect water–lithium bromide absorption system and developed thermal computational model for parametric investigation. Their analysis involves the effect of generator, absorber and evaporator temperatures on the energetic and energetic performance. They concluded that the irreversibility is highest in the absorber in both systems as compared to other systems. 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. Tassou et al. [5], 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

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http://doi.org/10.36037/IJREI.2019.3611

invariably employed in these processes which either contribute electricity consumption and environmental impact or low performance. Tassouet al. [6], 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.

1.1. Cascade vapour refrigeration systems

Cabello et al. [7], 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. Messineo [8], analyzed a two stage cascade refrigeration system using carbon dioxide (CO_2) 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 to 50°C. R.S.Mishra [9] 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^{0}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.

1.2 Vapour absorption refrigeration systems

Kairouani and Nehdi [10], analyzed NH_3-H_2O 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 was5.5 and the COP value was 37–54% higher than that of vapor com-pression refrigeration cycle. Gomri [11,14] carried out comparative thermodynamic analysis between single effect and double effect absorption refrigeration systems and developed the computer program using thermodynamic properties based on energy balance equations and found that for each condenser and evaporator temperature, there is an optimum generator temperature where change in energy of single effect and double effect absorption refrigeration system is minimum. They also found that the COP of double effect system is approximately twice the COP of single effect system but there is marginal difference between the energetic efficiency of the system Rogdakis and Antonopoulos [12] studied a NH_3/H_2O absorption refrigeration system driven by waste heat and predicted the theoretical COP below 0.40 when the lowest temperature is in the range of -64^{0}C to -30^{0}C.

Kilic and Kaynakli [13] carried out first and second law thermodynamic analysis to analyze the performance of a single stage water lithium bromide absorption refrigeration system by varying some working parameters and developed a mathematical model based on energy method and found that the performance of the ARS increases with increasing generator and evaporator temperatures but decreases with increasing condenser and absorber temperatures. Also concluded that the highest energy loss occurs in generator regardless of operating conditions and therefore it is most important component of the system. Garimella and Brown [15] developed a novel cascaded absorption–compression system that coupled a single-effect $LiBr/H_2O$ absorption cycle and a subcritical CO_2 vapor–compression cycle to generate low-temperature refrigerant (-40 °C).

1.3 Vapour absorption compression refrigeration systems

The utility of vapour compression-absorption systems mostly used for low temperature applications such as cryogenic applications. The term cryogenic is derived from the Greek work "Kryos" which means cold or frost. Cryogenic technology frequently applied to very low temperature refrigeration applications such as in biomedical, semen preservation, and pharmacological application as well as liquefaction of gases. Vapour compression systems with single compressor for different refrigerants are limited to an evaporator temperature of -40^{o}C. Therefore, multistage stage compression refrigeration system for low temperature applications. The main drawback of two stage compression refrigeration system is employed when low evaporator temperatures up to –60^{o}C and while as, three stages compression system is used up to evaporator temperature of -68^{o}C. Therefore, there is an urgent need for cascade refrigeration system. The cascade system was first used by Pictet in 1877 for liquefaction of oxygen. For low temperature cascade system uses R12 refrigerant was used in the high temperature cycle and R22 was used in intermediate temperature cycle and a refrigerant such as R13 with low boiling temperature used in low temperature cycle. S.B. Riffat N. Shankland [16] described the integration of different types of absorption systems with vapour-compression systems. The performances of the single-effect and double-effect series and the double-effect parallel continuous absorption systems and their integration with vapour-compression systems have been carried out. Yi Chena,et.al. [17], proposed a new absorption–compression refrigeration system to produce cooling energy at -30^{0}C to -40^{0}C and showed that the coefficient of performance of 0.277, which was approximately 50% higher than that of a conventional two-stage absorption refrigeration system. Fernández–Seara et al. [18] studied a cascade refrigeration system with a CO_2 compression vapour refrigeration system and an NH_3/H_2O absorption system at an evaporation temperature of -45 °C and found its first law efficiency in terms of COP. Kaushik and Arora [3] 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. Mishra[19] 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. Azhar and Siddiqui [20-21] 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. R.S.Mishra [22] 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 -1ºC to -2 ºC and for system-3using HFO-1234yf in HTC and HFC-134a in LTC was found between 1^{0}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 60ºC to -20ºC 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 -20ºC to -50ºC and found that by increasing evaporator temperature overall first law efficiency in terms of COP of the system is increases. V. Jain et al.[23]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. Pratihar et al. [24] 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. R.S.Mishra [25], 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. We proposed 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 °C R.S. Mishra [26] analyzed half, single, double and triple effect vapour absorption refrigeration systems and also 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. 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. Mishra [28] 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^oC 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 -50^0C 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. The comparison of four cascaded systems were also carried out at -55^0C 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 systems. M. Dixit et al [29] 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%. The solar assisted half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system using ecofriendly refrigerants have not been studied in detail. Cimsit and Ozturk [30] 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%. The CO_2/NH_3cascade cycle was safer than the CO_2/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%. Chinnappaet 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. Garimella et. al. [34] 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. Sun and Guo [35] 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. Similarly, Alvarez et al. [36] 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. Wang et al. [37] 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. Colorado and Rivera [38] 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 0K, 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. W. Han et al. [39] 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.

1.4 Use of Integration system for low temperature applications

Although the ultralow temperatures for cryogenics is approaching 0 K, and its applications such as freeze drying, pharmaceuticals, chemical and petroleum industry use cascade refrigeration cycles [40-41]. R.S. Mishra [42] 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 irreversibilities 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.

Although the performance of vapor compression refrigeration cycle succeeds the others yet its electricity consumption is higher. 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.

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 triple effect H_2O-Li/Br refrigeration system is in the high temperature section having Lithium Bromide (Li/Br) as an absorbent and water (H_2O) 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. 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.

3. Results and Discussion

Following input variables have been chosen for validation of model.

- Evaporator Temperature of triple effect Li/Br vapour absorption refrigeration system= 8°C.
- Generator temperature=180°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 = -95°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 overlaping$_{MTC}$ (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 triple effect vapour absorption refrigeration system using H_2O-Li/Br was computed by developed model is given below.

- First law efficiency of vapour absorption refrigeration system is (COP_VARS) =1.479,
- The second law efficiency of vapour absorption refrigeration system is the exergetic_efficiency= 0.2614.
- The exergy destruction ratio based on output(exergy of product) is EDR$_{Output}$= 2.825
- The exergy destruction ratio based on input (exergy of exergy of fuel) is EDR$_{Input}$= 0.7386.

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

Table-1(a) to Table-1(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 triple 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 triple 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-1(a): Effect of ecofriendly refrigerants in ultra-low temperature cycle on thermodynamic performances (First law performance (COP$_{Overall}$), of vapour compression refrigeration system coupled with double *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*

Ecofriendly refrigerants in ultra lowvapour compression refrigeration temperature cycle	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
R236fa	1.459	1.490	1.385
R404a	1.453	1.490	1.385
R290	1.454	1.490	1.385
R600a	1.459	1.490	1.385
Ethylene	1.450	1.490	1.385

Table-1(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 double 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

Ecofriendly refrigerants in ultra-low vapour compression refrigeration temperature cycle	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
R236fa	0.6642	0.5606	0.4666
R404a	0.6556	0.5606	0.4666
R290	0.6579	0.5606	0.4666
R600a	0.6640	0.5606	0.4666
Ethylene	0.6514	0.5606	0.4666

Table-1(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 double 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 lowvapour compression refrigeration temperature cycle	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
R236fa	0.5056	0.7839	1.143
R404a	0.5254	0.7839	1.143
R290	0.520	0.7839	1.143
R600a	0.5061	0.7839	1.143
Ethylene	0.5351	0.7839	1.143

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

Table-2(a) to Table-2(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 double 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 double 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-2(a): Effect of ecofriendly refrigerants in ultra-low temperature cycle on thermodynamic performances (First law performance ($COP_{\_Overall}$), of vapour compression refrigeration system coupled with double 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 vapour compression refrigeration temperature cycle	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 (%)
R236fa	21.45	24.03	15.27
R404a	20.94	24.03	15.27
R290	21.08	24.03	15.27
R600a	21.44	24.03	15.27
Ethylene	20.70	24.03	15.27

Table-2(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 double 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 vapour compression refrigeration 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 evap temp of 223K HFO-1234yf
R236fa	152.6	113.2	77.43
R404a	149.3	113.2	77.43
R290	150.3	113.2	77.43
R600a	152.5	113.2	77.43
Ethylene	147.7	113.2	77.43

Table-2(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 double 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 vapour compression refrigeration 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	81.96	72.03	59.21
R404a	81.25	72.03	59.21
R290	81.45	72.03	59.21
R600a	81.94	72.03	59.21
Ethylene	80.91	72.03	59.21

3.3 *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-3(a) to Table-3(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 double 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-3(a): Effect of ecofriendly refrigerants in intermediate temperature cycle on Thermodynamic performances (First law Performance (COP_overall), vapour compression refrigeration system coupled with double 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

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	1.459	1.490	1.385
R134a	1.456	1.487	1.385
R 410a	1.454	1.485	1.385
R32	1.436	1.467	1.385
R 143a	1.454	1.485	1.385
R-507a	1.453	1.484	1.385
R227ea	1.449	1.480	1.385
R290	1.458	1.489	1.385
R600a	1.460	1.491	1.385
Ethylene	1.430	1.461	1.385
R123	1.459	1.490	1.385
R125	1.451	1.482	1.385
R407c	1.391	1.421	1.385
R404a	1.447	1.477	1.385

Table-3(b): Effect of ecofriendly refrigerants in intermediate temperature cycle on over all second law efficiencies (exergetic efficiencies) of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O Li/Br 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 law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-245fa	0.6642	0.5606	0.4666
R134a	0.6627	0.5583	0.4666
R 410a	0.6812	0.5581	0.4666
R32	0.6511	0.5411	0.4666
R 143a	0.6615	0.5566	0.4666
R-507a	0.6611	0.5560	0.4666
R227ea	0.6585	0.5521	0.4666
R290	0.6638	0.560	0.4666
R600a	0.6649	0.5617	0.4666
Ethylene	0.6475	0.5356	0.4666
R123	0.6641	0.5604	0.4666
R125	0.6598	0.5541	0.4666
R407c	0.6256	0.5025	0.4666
R404a	0.6571	0.550	0.4666

Table-3(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on system exergy destruction ratios of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O Li/Br 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	0.5056	0.7839	1.143
R134a	0.5090	0.7910	1.143
R 410a	05124	0.7981	1.143
R32	0.5358	0.8479	1.143
R 143a	0.5117	0.7966	1.143
R-507a	0.5127	0.7981	1.143
R227ea	0.5187	0.8114	1.143
R290	0.5064	0.7856	1.143
R600a	0.5039	0.7804	1.143
Ethylene	0.5445	0.867	1.143
R123	0.5058	0.7844	1.143
R125	0.5155	0.8047	1.143
R407c	0.5985	0.9901	1.143
R404a	0.5219	0.8182	1.143

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

Table-4(a) to Table-4(c) show the comparison between with ecofriendly refrigerants in terms of percentage improvement in the 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 triple 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 R507.

Table-4(a): Effect of ecofriendly refrigerants in intermediate temperature cycle on Thermodynamic performances (First law Performance (COP_overall), vapour compression refrigeration system coupled with double 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

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 (%) 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-245fa	21.45	24.03	15.27
R134a	21.24	23.81	15.27
R 410a	21.03	23.6	15.27
R32	18.79	22.14	15.27
R 143a	21.07	23.64	15.27
R-507a	21.01	23.58	15.27
R227ea	20.63	23.20	15.27
R290	21.4	23.98	15.27
R600a	2156	24.13	15.27
Ethylene	19.04	21.6	15.27
R123	21.44	24.01	15.27
R125	20.83	23.1	15.27
R407c	15.81	18.3	15.27
R404a	20.43	23.0	15.27

Table-4(b): Effect of ecofriendly refrigerants in intermediate temperature cycle on over all second law efficiencies (exergetic efficiencies) of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O Li/Br 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 (%) 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	152.6	113.2	77.43
R134a	152.0	112.3	77.43
R 410a	151.4	111.5	77.43
R32	147.6	105.8	77.43
R 143a	151.5	111.6	77.43
R-507a	151.4	111.4	77.43
R227ea	150.4	109.9	77.43
R290	152.4	113.0	77.43
R600a	152.8	113.6	77.43
Ethylene	146.2	103.7	77.43
R123	152.5	113.1	77.43
R125	150.9	110.7	77.43
R407c	137.9	91.07	77.43
R404a	149.8	109.1	77.43

Table-4(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on system exergy destruction ratios of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O Li/Br 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 (%) 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	81.96	72.03	59.21
R134a	81.84	71.77	59.21
R 410a	81.72	71.52	59.21
R32	80.88	72.65	59.21
R 143a	81.74	71.57	59.21
R-507a	81.71	71.50	59.21

R227ea	81.49	71.05	59.21
R290	81.93	71.95	59.21
R600a	82.02	72.15	59.21
Ethylene	80.57	69.05	59.21
R123	81.95	72.01	59.21
R125	81.6	71.28	59.21
R407c	78.64	64.67	59.21
R404a	81.38	70.80	59.21

3.5 *Effect of ecofriendly refrigerants in medium temperature cycle on total thermodynamic performances of three cascaded cycles in integrated system*

Table-5(a) to Table-5(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 triple 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-5(a): Effect of ecofriendly refrigerants in medium temperature cycle on the thermodynamic performances (First law Performance ($COP_{\_Overall}$), vapour compression refrigeration system coupled with double 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 circut

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 in first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	1.459	1.49	1.385
R134a	1.481	1.515	1.411
R717	1.482	1.515	1.411
R152a	1.499	1.534	1.431
R143a	1.456	1.486	1.381
R141b	1.522	1.56	1.459
R410a	1.477	1.510	1.406
R32	1.476	1.509	1.405
R507a	1.448	1.478	1.372
R290	1.480	1.513	1.409
R600a	1.478	1.511	1.407
R123	1.505	1.541	1.439
R125	1.422	1.449	1.342
R407c	1.423	1.45	1.343
R404a	1.439	1.468	1.362
R227ea	1.423	1.45	1.344

Table-5(b): Effect of ecofriendly refrigerants in medium temperature cycle on the Second law performance (Exergetic efficiency) of vapour compression refrigeration system coupled with double 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 MTC circuit	Over all in 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 law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K Using HFO-1234yf(%)
R-1234yf	0.6642	0.5606	0.4666
R134a	0.6838	0.5795	0.4843
R717	0.6840	0.5798	0.4847
R152a	0.6993	0.5946	0.4988
R143a	0.6614	0.5579	0.4641
R410a	0.6802	0.5760	0.4811
R32	0.6794	0.5753	0.4804

R141b	0.7199	0.6148	0.5185
R507a	0.6549	0.5516	0.4583
R290	0.6827	0.5785	0.4834
R600a	6809	0.5767	0.4817
R123	0.7049	0.6001	0.5041
R125	0.6318	0.5296	0.4384
R407c	0.6330	0.5307	0.4394
R404a	0.6471	0.5441	0.4915
R227ea	0.6332	0.5308	0.4395

Table-5(c): Effect of ecofriendly refrigerants in medium temperature cycle on system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with double 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 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 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-1234yf	0.5056	0.7839	1.143
R134a	0.4625	0.7256	1.065
R717	0.4617	0.7246	1.143
R152a	0.430	0.7246	1.063
R143a	0.5120	0.7926	1.155
R410a	0.4701	0.736	1.079
R32	0.4718	0.7382	1.082
R141b	0.3891	0.6266	0.9288
R507a	0.5270	0.8129	1.182
R290	0.4648	0.7287	1.069
R600a	0.4686	0.7339	1.076
R123	0.4186	0.6664	0.9838
R125	0.5827	0.8884	1.281
R407c	0.5798	0.8844	1.276
R404a	0.5454	0.8378	1.215
R227ea	0.5794	0.8838	1.275

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

Table-6(a) to Table-6(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 double 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-6(a): Effect of ecofriendly refrigerants in medium temperature cycle on the thermodynamic performances (First law Performance ($COP_{Overall}$), vapour compression refrigeration system coupled with double 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

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	21.45	24.03	15.27
R134a	23.31	26.09	17.44
R717	23.35	26.13	17.48
R152a	24.78	27.73	19.17
R143a	21.18	23.73	14.96
R410a	22.98	25.72	17.05
R32	22.9	25.63	16.98
R141b	26.72	29.89	21.48
R507a	20.56	23.04	14.22
R290	23.21	25.98	17.32
R600a	23.04	25.79	17.12
R123	25.31	28.32	19.6
R125	18.36	20.6	11.72
R407c	18.47	20.72	11.85
R404a	19.82	22.21	13.39
R227ea	18.46	20.74	11.86

Table-6(b): Effect of ecofriendly refrigerants in medium temperature cycle on the Second law performance (Exergetic efficiency) of vapour compression refrigeration system coupled with double *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 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 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 (%)
R-1234yf	152.6	113.2	77.43
R134a	152.6	120.3	84.16
R717	160.10	120.5	84.29
R152a	165.9	126.1	89.66
R143a	151.5	112.10	76.47
R410a	158.6	119.0	82.92
R141b	173.7	133.8	97.14
R32	158.3	118.8	82.65
R507a	149.0	109.7	74.28
R290	159.6	120.0	83.8
R600a	158.9	119.3	83.13
R123	168..0	128.2	91.68
R125	140.2	101.4	66.69
R407c	140.7	101.8	67.07
R404a	146.0	106.9	71.68
R227ea	140.8	101.8	67.13

Table-6(c): Effect of ecofriendly refrigerants in medium temperature cycle on system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with double 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 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	81.96	72.03	59.21
R134a	83.5	74.11	62.01
R717	83.52	74.14	62.06
R152a	84.66	75.67	64.14
R143a	81.73	71.71	58.79

R410a	83.22	73.74	61.51
R32	83.16	73.66	61.40
R141b	86.12	77.64	66.86
R507a	81.19	70.99	57.83
R290	83.42	74.0	61.86
R600a	83.28	73.81	61.61
R123	85.06	76.22	57.3
R125	79.2	68.3	54.29
R407c	79.31	64.44	54.47
R404a	80.54	70.1	56.65
R227ea	79.33	68.46	54.45

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

Table-7(a) to Table-7(i) shows the variation of approach on the thermodynamic performance of combined double 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-7(a): First law performance in terms of $COP_{\_Overall}$ with variations temperature over lapping ($approach_{\_LTC}$) of triple 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 temp condenser(ºC) using R236fa	Over all COP of system using to low evaporator temp 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	1.477	1.49	1.385
2	1.473	1.49	1.385
3	1.472	1.49	1.385
4	1.470	1.49	1.385
5	1.468	1.49	1.385
6	1.466	1.49	1.385
8	1.462	1.49	1.385
9	1.461	1.49	1.385
10	1.459	1.49	1.385
12	1.455	1.49	1.385
14	1.452	1.49	1.385
15	1.45	1.49	1.385

Table-7(b): Second law performances in terms of total exergetic efficiencies with variations of temperature over lapping ($approach_{\_LTC}$) of double 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 (ºC) using R236fa	Over all exergetic efficiency of system using to low evap temp of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evap temp of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evap temp of 223K using HFO-1234yf
0	0.6642	0.5606	0.4666
2	0.6848	0.5606	0.4666
3	0.6821	0.5606	0.4666
4	0.6794	0.5606	0.4666
5	0.6768	0.5606	0.4666
6	0.6742	0.5606	0.4666
8	0.6691	0.5606	0.4666
9	0.6667	0.5606	0.4666
10	0.6642	0.5606	0.4666
12	0.6594	0.5606	0.4666
14	0.6547	0.5606	0.4666
15	0.6523	0.5606	0.4666

Table-7(c): Exergy destruction ratio of system with variations in temperature over lapping (approach_LTC) of double 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 (°C) using R236fa	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	0.5056	0.7839	1.143
2	0.4603	0.7839	1.143
3	0.4661	0.7839	1.143
4	0.4718	0.7839	1.143
5	0.4775	0.7839	1.143
6	0.4832	0.7839	1.143
8	0.4944	0.7839	1.143
9	0.500	0.7839	1.143
10	0.5056	0.7839	1.143
12	0.5166	0.7839	1.143
14	0.5275	0.7839	1.143
15	0.5329	0.7839	1.143

Table-7(d): First and second law performance with variations in temperature over lapping (approach_ITC) of double 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_ITC) in intermediate temperature condenser (°C) using R245fa	Over all COP of system using to low temperature evaporator temperature of 123K using R236fa	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
0	1.519	1.55	1.385
2	1.506	1.537	1.385
3	1.50	1.531	1.385
4	1.498	1.525	1.385
5	1.488	1.519	1.385
6	1.482	1.513	1.385
8	1.470	1.501	1.385
9	1.485	1.495	1.385
10	1.459	1.49	1.385
12	1.448	1.478	1.385
14	1.437	1.467	1.385
15	1.431	1.462	1.385

Table-7(e):Second law performances (exergetic efficiencies) with variations in temperature over lapping (approach_ITC) of double 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 (°C) using R245fa	Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa0.5415	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	0.70	0.6131	0.4666
2	0.6924	0.6020	0.4666
3	0.6887	0.5965	0.4666
4	0.6850	0.5912	0.4666
5	0.6814	0.5859	0.4666
6	0.6778	0.5807	0.4666
8	0.6709	0.5705	0.4666
9	0.6675	0.5655	0.4666
10	0.6642	0.5606	0.4666
12	0.6577	0.5509	0.4666
14	0.6514	0.5415	0.4666
15	0.6483	0.5369	0.4666

Table-7(f): Exergy destruction ratio ($EDR_{\_system}$) of system with variations in temperature over lapping ($approach_{\_ITC}$) of double 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 ($approach_{\_ITC}$) in intermediate temperature Condenser (ºC) using R245fa	Over all exergy destruction ratio (EDR) of system using to low temperature evaporator temperature of 123K using R236fa	Over all exergy destruction ratio(EDR) of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all exergy destruction ratio(EDR) of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
0	0.4283	0.6311	1.143
2	0.4442	0.6612	1.143
3	0.4520	0.6763	1.143
4	0.4598	0.6915	1.143
5	0.4676	0.7068	1.143
6	0.4753	0.7221	1.143
8	0.4905	0.7529	1.143
9	0.4981	0.7683	1.143
10	0.5056	0.7839	1.143
12	0.5205	0.8152	1.143
14	0.5352	0.8467	1.143
15	0.5425	0.8626	1.143

Table-7(g): First law Performances ($COP_{\_Overall}$) with variations in temperature over lapping ($approach_{\_MTC}$) of doublele 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 (ºC) using R1234yf	Over all COP of system using to low temperature evaporator temperature of 123K using R236fa	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
0	1.554	1.596	1.463
2	1.535	1.574	1.475
3	1.525	1.564	1.44
4	1.516	1.553	1.429
5	1.506	1.543	1.407
6	1.497	1.532	1.396
8	1.478	1.511	1.385
9	1.468	1.50	1.385
10	1.459	1.49	1.362
12	1.44	1.469	1.341
14	1.42	1.447	1.341
15	1.411	1.437	1.33

Table-7(h): second law Performances (exergetic efficiencies) variations with temperature over lapping ($approach_{\_LTC}$) of double 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	0.7481	0.6426	0.5464
2	0.7312	0.6259	0.5295
3	0.7228	0.6176	0.5213
4	0.7144	0.6094	0.5131
5	0.7060	0.6012	0.5051
6	0.6976	0.593	0.4972
8	0.6809	0.5767	0.4817
9	0.67245	0.5686	0.4710
10	0.6642	0.5606	0.4666
12	0.6475	0.5445	0.4519
14	0.6308	0.5286	0.4375
15	0.6224	0.5206	0.4304

Table-7(i): Exergy destruction ratio (EDR) of system with variations in temperature over lapping (approach$_{LTC}$) of double 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 laping (approach$_{MTC}$) in medium temperature condenser (°C) 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	0.3368	0.5561	0.8302
2	0.3676	0.5977	0.8885
3	0.3836	0.6191	0.9184
4	0.3998	0.6410	0.9488
5	0.4164	0.6635	0.9798
6	0.4335	0.6864	1.011
8	0.4687	0.7339	1.076
9	0.4869	0.7586	1.109
10	0.5056	0.7839	1.143
12	0.5444	0.8364	1.213
14	0.5853	0.8919	1.286
15	0.6066	0.9207	1.323

3.8 Effect of temperature overlapping on percentage improvements of thermodynamic performances

Table-8(a) to Table-8(i) show the variation of all three types of approaches on the percentage improvement in thermodynamic performance of combined double 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-8(a): First law performance in terms of COP$_{_Overall}$ with variations of temperature over lapping (approach$_{LTC}$) of double 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	% improvement in Overall COP of system using to low evaporator temperature of 123K using R236fa	% improvement in Overall COP of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in Overall COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	22.99	24.03	15.27
2	22.67	24.03	15.27
3	22.51	24.03	15.27
4	22.36	24.03	15.27
5	22.2	24.03	15.27
6	21.85	24.03	15.27
8	21.75	24.03	15.27
9	21.6	24.03	15.27
10	21.45	24.03	15.27
12	21.17	24.03	15.27
14	20.89	24.03	15.27
15	20.75	24.03	15.27

Table-8(b): Second law performances in terms of total exergetic efficiencies with variations of temperature over lapping (approach_LTC) of double 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 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	152.6	113.2	77.43
2	155.6	113.2	77.43
3	159.4	113.2	77.43
4	158.4	113.2	77.43
5	157.4	113.2	77.43
6	156.4	113.2	77.43
8	154.4	113.2	77.43
9	153.5	113.2	77.43
10	152.6	113.2	77.43
12	150.7	113.2	77.43
14	148.9	113.2	77.43
15	148.0	113.2	77.43

Table-8(c): Exergy destruction ratio of system with variations in temperature over lapping (approach_LTC) of double 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 (°C) using R236fa	% decrement in Overall Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R236fa	% decrement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa	% decrement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	81.96	72.03	59.21
2	83.58	72.03	59.21
3	83.37	72.03	59.21
4	83.13	72.03	59.21
5	82.96	72.03	59.21
6	82.76	72.03	59.21
8	82.36	72.03	59.21
9	82.16	72.03	59.21
10	81.96	72.03	59.21
12	81.57	72.03	59.21
14	81.18	72.03	59.21
15	80.98	72.03	59.21

Table-8(d): First and second law performance with variations in temperature over lapping (approach_ITC) of double 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_ITC) in intermediate condenser temp (°C) using R245fa	(%) Overall improvement in First law efficiency (COP_Overall) of system using to low evap temp of 123K using R236fa (%)	(%) Overall improvement in First law efficiency (COP_Overall) of system using to intermediate evap temp of 173K using R245fa (%)	(%) Over all improvement in First law efficiency (COP_Overall) of system using to intermediate evap temp of 223K using HFO1234yf
0	15.14	18.35	7.821
2	14.08	17.33	7.821
3	13.57	16.82	7.821
4	13.06	16.32	7.821
5	12.56	15.83	7.821
6	12.06	15.34	7.821
8	11.09	14.38	7.821
9	10.61	13.91	7.821
10	10.14	13.44	7.821
12	9.216	12.52	7.821
14	8.314	11.62	7.821
15	7.871	11.18	7.821

Table-8(e):Second law performances(exergetic Efficiencies) with variations in temperature over lapping (approach_$_{ITC}$) of double 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_$_{ITC}$) in intermediate temperature condenser (°C) using R245fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 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 law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
0	170.2	136.8	80.79
2	167.2	132.5	80.79
3	165.7	130.4	80.79
4	164.3	128.3	80.79
5	162.9	126.3	80.79
6	161.5	124.3	80.79
8	158.8	120.3	80.79
9	157.5	118.4	80.79
10	156.2	116.5	80.79
12	153.7	112.7	80.79
14	151.2	109.1	80.79
15	150.0	107.3	80.79

Table-8(f): Exergy destruction ratio (EDR_$_{system}$) of system and % improvement in system first law performance with variations in temperature over lapping (approach_$_{ITC}$) of double 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_$_{ITC}$) in intermediate temperature Condenser (°C) using R245fa	Over all Exergy Destruction Ratio (EDR) of system using to low evaporator temp 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	% decrement in Overall Exergy Destruction Ratio (EDR) of system using to low evaporator temperature of 123K using R236fa	% decrement in Overall Exergy Destruction Ratio(EDR) of system using to intermediate evaporator temp of 173K using R245fa	% decrement in Overall Exergy Destruction Ratio(EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.4283	0.6311	1.143	84.72	77.48	59.21
2	0.4442	0.6612	1.143	84.15	76.41	59.21
3	0.4520	0.6763	1.143	83.87	75.87	59.21
4	0.4598	0.6915	1.143	83.59	75.32	59.21
5	0.4676	0.7068	1.143	83.32	74.78	59.21
6	0.4753	0.7221	1.143	83.04	74.23	59.21
8	0.4905	0.7529	1.143	82.5	73.14	59.21
9	0.4981	0.7683	1.143	82.23	72.58	59.21
10	0.5056	0.7839	1.143	81.96	72.03	59.21
12	0.5205	0.8152	1.143	81.43	70.91	59.21
14	0.5352	0.8467	1.143	80.9	69.79	59.21
15	0.5425	0.8626	1.143	80.64	69.22	59.21

Table-8(g): First law Performances (COP_$_{Overall}$) with variations in temperature over lapping (approach_$_{MTC}$) of triple 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	% improvement in overall COP of system using to low evaporator temperature of 123K using R236fa	% improvement in overall COP of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in overall COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	29.34	32.8	24.67
2	27.77	31.08	22.76
3	26.99	30.2	21.81
4	26.2	29.32	20.86
5	25.41	28.43	19.92
6	24.62	27.55	18.99

8	23.04	25.79	17.12
9	22.95	24.91	16.2
10	21.45	24.03	15.27
12	19.86	22.26	13.43
14	18.26	20.49	11.61
15	17.46	19.6	10.69

Table-8(h): second law Performances (exergetic efficiencies) variations with temperature over lapping (approach_$_{LTC}$) of triple 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	% improvement in overall exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	% improvement in overall exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in overall exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	184.40	144.4	107.8
2	178.0	138.0	101.3
3	174.8	134.8	98.20
4	171.6	131.7	95.11
5	168.4	128.6	92.06
6	165.3	125.5	89.06
8	158.9	119.3	83.17
9	155.7	116.2	80.26
10	152.6	113.2	77.43
12	146.2	107.1	71.83
14	139.9	101.0	66.36
15	136.7	97.97	63.67

Table-8(i): Exergy destruction ratio (EDR) of system with variations intemperature over lapping (approach_$_{LTC}$) of double 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	% improvement in overall Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R236fa	% 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
0	87.98	80.16	70.38
2	86.88	78.67	68.29
3	86.31	77.91	67.23
4	85.73	77.13	66.14
5	85.14	76.33	65.04
6	84.53	75.51	63.91
8	8328	73.81	61.61
9	82.63	72.93	60.42
10	81.96	72.03	59.21
12	80.57	70.75	56.72
14	79.11	68.18	54.12
15	78.35	67.14	52.18

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

Table-9(a) to Table-9(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 double 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-9(a): Effect of generator *temperature of* double *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 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*

Generator Temperature of double effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	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
115	1.567	1.609	1.517
120	1.530	1.568	1.471
125	1.494	1.529	1.427
130	1.459	1.490	1.385
135	1.426	1.452	1.344
140	1.392	1.416	1.305
145	1.360	1.382	1.269
150	1.331	1.350	1.235
155	1.355	1.378	1.262

Table-9(b): Effect of generator *temperature of* double *effect H_2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with* double *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*

Generator temperature of double effect H_2O-Li/Br VARS (ºC)	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
115	0.6867	0.5821	0.4911
120	0.6793	0.5750	0.480
125	0.6718	0.5678	0.4748
130	0.6642	0.5606	0.4666
135	0.6567	0.5534	0.4586
140	0.6493	0.5464	0.4509
145	0.6421	0.5397	0.4434
150	0.6352	0.5331	0.4363
155	0.6408	0.5384	0.4420

Table-9(c): Effect of generator *temperature of* double *effect H_2O Li/Br VARS on thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with* double *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*

Generator temperature of *double* effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	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
115	0.4562	0.7179	1.036
120	0.4721	0.7392	1.071
125	0.4886	0.7612	1.106
130	0.5056	0.8606	1.148
135	0.5228	0.8069	1.118
140	0.5401	0.830	1.218
145	0.5573	0.8530	1.255
150	0.5743	0.8757	1.292
155	0.5607	0.5324	1.263

3.10 Effect of generator temperature 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 generator temperature with percentage improvement in thermodynamic performances such as first law efficiency, second law efficiency and system exergy destruction ratio of combined double 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 double 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-10(a): Effect of generator *temperature of* double *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 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*

Generator Temperature ofdouble 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 (%)
115	14.25	17.31	10.58
120	16.68	19.58	12.10
125	19.10	21.83	13.76
130	21.45	24.03	15.27
135	23.74	26.14	16.72
140	25.93	28.16	18.10
145	28.01	30.8	19.39
150	29.98	31.88	20.59
155	28.4	30.44	19.63

Table-10(b): Effect of generator *temperature of double effect H_2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with* double *effect vapour absorption refrigeration H2O-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 *double* 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 R236 fa (%)	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(%)
115	103.6	72.58	45.61
120	119.5	85.75	56.03
125	135.8	99.32	66.66
130	152.6	113.2	77.43
135	169.6	127.2	88.27
140	186.8	141.4	99.14
145	204.10	155.5	110.0
150	221.9	169.7	120.7
155	223.4	171.7	123.1

Table-10(c): Effect of generator temperature of triple effect H_2O Li/Br VARS on thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O-LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature

Generator temp of double effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evap temp of 123K using R236fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evap temp 173K using R245fa (%)	Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evap temp 223K using HFO-1234yf (%)
115	76.78	63.46	47.27
120	78.84	66.86	52.01
125	80.54	69.68	55.93
130	8196	72.03	59.29
135	83.16	74.01	61.98
140	84.19	75.71	64.36
145	85.08	77.16	66.39
150	85.85	78.42	68.16
155	86.16	78.81	68.8

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

Fig-11(a) to Table-11(c) show the variation of absorber temperature of combined double 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-11(a): Effect of absorber temperature *of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with* double *effect vapour absorption 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*

Absorber temperature of double 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
30	1.522	1.559	1.461
32	1.449	1.533	1.438
34	1.473	1.505	1.402
36	1.113	1.473	1.366
38	1.408	1.434	1.324
40	1.361	1.383	1.27
42	1.296	1.313	1.195

Table-11(b): Absorber temperature of double effect H_2O-Li/Br vapour absorption refrigeration system on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with double effectvapour absorption refrigeration H_2O-LiBr 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 double 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	0.6775	0.5733	0.4810
32	0.6727	0.5687	0.4758
34	0.6672	0.5635	0.4699
36	0.6608	0.5674	0.4630
38	0.6529	0.5498	0.4546
40	0.6423	0.5398	0.4436
42	0.6268	0.5252	0.4277

Table-11(c): Absorber temperature of double effect H_2O-Li/Br vapour absorption refrigeration system on total thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with double effect vapour absorption refrigeration H_2O-LiBr 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 double 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	0.4760	0.7444	1.079
32	0.4866	0.7687	1.102
34	0.4987	0.7747	1.126
36	0.5132	0.7941	1.16
38	0.5317	0.8187	1.20
40	0.5569	0.8525	1.255
42	0.5995	0.9040	1.338

3.12Effect of heat exchanger effectiveness on percentage improvement in total thermodynamic performances of three cascaded cycles in integrated system

Table-12(a) to Table-12(c) show the variation of Absorber temperature of VARS on combined double effect *H_2O 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-12(a): Absorber temperature of double effect H_2O-Li/Br vapour absorption refrigeration system on total thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with double absorption refrigeration H2O-LiBr 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 double 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	17.26	20.13	12.56
32	18.8	21.56	13.57
34	20.51	23.15	14.67
36	22.48	24.98	15.93
38	24.87	27.19	17.44
40	27.97	30.04	19.36
42	32.31	34.01	22.01

Table-12(b): Absorber temperature of double effect H_2O-Li/Br vapour absorption refrigeration system on total thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with double effect 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 double 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 HFO1234yf (%)
30	138.4	101.8	69.29
32	143.6	105.9	72.26
34	149.3	110.5	75.57
36	156.1	116.0	79.45
38	164.5	122.8	84.21
40	175.8	131.8	90.46
42	192.2	144.9	99.42

Table-12(c): Absorber temperature of double effect H_2O-Li/Br vapour absorption refrigeration system on total Thermodynamic performances reduction in exergy destruction ratio (EDR) with condenser temperature of vapour compression refrigeration system coupled with double effectvapour absorption refrigeration H_2O-LiBr 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 double 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	81.11	70.46	57.17
32	81.43	71.56	57.95
34	81.78	71.69	58.77
36	82.15	72.36	59.67
38	82.58	73.17	60.69
40	83.09	74.12	61.91
42	83.74	75.32	63.47

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

Table-13(a) to Table-13(c) show the variation of condenser temperature of combined double effect Li/Brvapour 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-13(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* double *effect vapour absorption refrigeration H_2O-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 double effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	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
30	1.518	1.555	1.456
32	1.498	1.533	1.432
34	1.474	1.506	1.402
36	1.442	1.471	1.364
38	1.399	1.424	1.314
40	1.338	1.358	1.248
42	1.245	1.258	1.138

Table-13(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* double *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 double effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	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	0.6767	0.5726	0.4801
32	0.6726	0.5686	0.4757
34	0.6674	0.5636	0.470
36	0.6605	0.5571	0.4627
38	0.651	0.5430	0.4526
40	0.6369	0.5347	0.4380
42	0.6140	0.5133	0.4150

Table-13(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 double 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*

Condenser temperature of double effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	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	0.4777	0.7467	1.083
32	0.4868	0.7587	1.102
34	0.4984	0.7743	1.128
36	0.5140	0.7952	1.161
38	0.5362	0.8248	1.209
40	0.5701	0.8701	1.283
42	0.6286	0.9482	1.41

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

Fig-14(a) to Table-14(c) show the variation of condenser temperature of combined triple effect H_2O-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-14(a): Effect of condenser *temperature of VARS on* (%) improvement in the *total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with* double *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 double effect H_2O-Li/Br vapour absorption refrigeration system (^oC)	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 temperature evaporator temperature of 223K using HFO-1234yf(%)
30	17.52	20.36	12.73
32	18.83	21.58	13.58
34	20.47	23.17	14.64
36	22.59	25.68	15.99
38	25.44	27.72	17.79
40	29.5	3144.	20.35

Table-14(b): Effect of condenser *temperature of VARS on total thermodynamic terms of Second law performances (exergetic efficiencies) with condenser temperature of vapour compression refrigeration system coupled with* double *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*

Condenser temperature ofdouble effect H_2O-Li/Br vapour absorption refrigeration system (^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 173 using R245fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
30	139.3	102.4	69.78
32	143.6	106.0	72.3
34	149.2	110.4	75.49
36	156.5	116.3	79.66
38	166.5	124.4	85.35
40	181.5	136.4	93.6
42	205.8	155.6	106.6

Table-14(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 double 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 ofdouble effect H_2O-Li/Br vapour absorption refrigeration system (^oC)	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	81.16	70.56	57.31
32	81.44	71.07	57.96
34	81.77	71.68	58.75
36	82.17	72.42	59.72
38	82.68	73.35	60.92
40	83.33	74.56	62.48
42	84.2	76.17	64.57

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

Table-15(a) to Table-15(c) shows the variation of VARS evaporator temperature with thermodynamic performances combined double 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 MTC temperature circuit evaporator temperature of combined double effectH_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration.

Table-15(a): Effect of Thermodynamic performances (First law Performances (COP_Overall), with abso VARS evaporator temperature of vapour compression refrigeration system coupled with double 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 condenser temperature of VARS

VARS evaporator temperature ofdouble effect H_2O-Li/Br (ºC)	Over all COP of system using to low evap temp of 123K using R23fa	Over all COP of system using to intermediate evap temp of 173K using R245fa	Over all COP of system using to intermediate evap temp of 223K using HFO-1234yf
3	1.379	1.403	1.288
4	1.404	1.431	1.318
5	1.424	1.452	1.342
6	1.438	1.468	1.359
7	1.450	1.480	1.374
8	1.459	1.49	1.385
9	1.466	1.447	1.393
10	1.471	1.503	1.40

Table-15(b): Effect of Thermodynamic Second law performance (exergetic efficiency) with VARS evaporator temperature of vapour compression refrigeration system coupled with double 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 condenser temperature of VARS

VARS evaporator temp of double effect H_2O-Li/Br (ºC)	Over all exergetic efficiency of system using to low evap temp of 123K using R236fa	Over all exergetic efficiency of system using to intermediate evap temp of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate evap temp of 223K using HFO-1234yf
3	0.6555	0.5491	0.5040
4	0.6598	0.5538	0.4994
5	0.6624	0.5569	0.4929
6	0.6638	0.5589	0.485
7	0.6643	0.5601	0.4761
8	0.6642	0.5604	0.4666
9	0.6635	0.5606	0.4566
10	0.6624	0.5602	0.4463

Table-15(c): Effect of Thermodynamic system exergy destruction ratio with VARS evaporator temperature of vapour compression refrigeration system coupled with double 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 condenser *temperature of VARS*

VARS evaporator temperature of double effect H_2O-Li/Br (ºC)	Over all Exergy Destruction Ratio of system using to low evap temp of 123K usingR23fa	Over all Exergy Destruction Ratio of system using to intermediate evap temp of 173K using R245fa	Over all Exergy Destruction Ratio of system using to intermediate evap temp of 223K using HFO-1234yf
3	0.5255	0.8210	0.9841
4	0.5157	0.8057	1.002
5	0.5098	0.7956	1.029
6	0.5065	0.7892	1.062
7	0.5053	0.7855	110
8	0.5056	0.7849	1.143
9	0.5071	0.7839	1.19
10	0.5096	0.7852	1.241

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

Table-16(a) to Table-16(c) shows the variation of VARS evaporator temperature with percentage improvement in thermodynamic performances combined double 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 double effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration

Table-16(a): Effect of Thermodynamic performances (First law Performances ($COP_{\_Overall}$), with VARS evaporator temperature of vapour compression refrigeration system coupled with double 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 condenser temperature of VARS

VARS evaporator temperature of double effect H_2O-Li/Br (ºC)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evap temp of 123K using R236fa	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evap temp of 173K using R245fa	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evap temp of 223K using HFO-1234yf
3	33.72	36.05	24.91
4	30.68	33.12	22.68
5	28.03	30.54	20.64
6	28.20	25.65	18.75
7	23.47	26.04	16.97
8	21.45	24.03	15.27
9	19.55	22.12	13.64
10	17.75	20.29	12.06

Table-16(b): Effect of thermodynamic second law performance (exergetic efficiency) with VARS evaporator r temperature of vapour compression refrigeration system coupled with double effect VARS 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 condenser temperature of VARS

VARS evaporator temperature of double effect H_2O-Li/Br (ºC)	% improvement in Overall exergetic efficiency of system using to low evaporator temperature of 123K using R236fa	% improvement in Overall exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in Overall exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
3	124.3	87.91	72.42
4	127.0	90.52	71.81
5	131.2	94.42	72.06
6	135.9	99.5	73.17
7	144.0	105.7	74.9
8	152.6	113.2	77.43
9	162.6	121.9	80.74
10	174.4	132.1	84.9

Table-16(c): Effect of Thermodynamic system exergy destruction ratio with VARS evaporator *temperature of vapour compression refrigeration system coupled with* double *effect vapour absorption refrigeration H_2O-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*

VARS evap temp of double effect H_2O-Li/Br (ºC)	% improvement in Overall EDR of system using to low evaporator temperature of 123K using R23fa	% improvement in Overall EDR of system using to intermediate evaporator temperature of 173K using R245fa	% improvement in Overall EDR of system using to intermediate evap temp of 223K using HFO-1234yf
3	78.30	66.10	59.37
4	78.87	66.98	58.93
5	79.54	68.06	58.69
6	80.29	69.29	58.67
7	81.10	70.62	58.84
8	81.96	72.03	59.21
9	82.86	73.50	59.77
10	83.79	75.02	60.53

3.17 Effect of various thermodynamic parameters such as 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-17(a) to Table-17(c) show the variation of medium temperature circuit evaporator temperature of combined double 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 (-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 double effect vapour absorption refrigeration system is decreasing as MTC temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as medium temperature circuit evaporator temperature of combined double 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 is decreased.

Table17 (a): Effect of MTC evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performance (COP_overall), of VCRS coupled with vapour absorption refrigeration double effect 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

MTC evaporator temperature of medium temperature circuit using HFO-1234yf 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
-20	1.547	1.615	1.781
-25	1.539	1.60	1.709
-30	1.528	1.583	1.64
-35	1.515	1.564	1.572
-40	1.499	1.541	1.507
-45	1.480	1.517	1.445
-50	1.459	1.49	1.385

Table-17(b): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performance (exergetic efficiency) of VCRS coupled with double 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

MTC evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants (°C)	Over all second law efficiency (exergetic efficiency) of system using to low evap 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 of system using to intermediate evaporator temperature of 223K using HFO-1234yf
-20	0.6614	0.4736	0.4833
-25	0.6672	0.4949	0.4850
-30	0.6711	0.5137	0.4846
-35	0.6728	0.5298	0.4823
-40	0.6724	0.5430	0.4785
-45	0.6695	0.5533	0.4732
-50	0.6642	0.5606	0.4666

Table-17(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances system EDR of VCRS coupled with vapour absorption refrigeration double effect 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

MTC medium evaporator temperature circuit using HFO-1234yf 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
-20	0.5002	1.112	1.069
-25	0.4869	1.021	1.062
-30	0.4762	0.9466	1.064
-35	0.4742	0.8875	1.073
-40	0.4751	0.8415	1.090
-45	0.4812	0.8072	1.113
-50	0.5056	0.7839	1.143

3.18Effect of various thermodynamic parameters such as temperature of MTC evaporator on percentage improvement in overall system performances of cascade evaporators using ecofriendly refrigerants

Table-18(a) to Table-18(c) show the variation of medium temperature circuit evaporator temperature of combined triple 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 double 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 is increased.

Table18(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 double 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

MTC evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants (ºC)	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 (%)
-20	28.80	34.42	48.31
-25	28.13	33.23	42.31
-30	27.24	31.81	36.5
-35	26.12	30.17	30.89
-40	24.78	28.32	25.49
-45	23.23	26.27	20.28
-50	21.45	24.03	15.27

Table-18(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 double 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

MTC evaporator temperature of medium temperature circuit using HFO-1234yf 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 evaporator temperature of 223K using HFO-1234yf (%)
-20	151.5	80.07	83.76
-25	153.7	88.18	84.40
-30	155.2	95.23	84.25
-35	155.8	101.4	83.40
-40	155.7	106.5	81.93
-45	154.6	110.4	79.92
-50	152.6	113.2	77.43

Table-18(c): Effect of MTC evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances in terms of system exergy destruction ratio of vapour compression refrigeration system coupled with double 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

MTC 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 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 usingHFO-1234yf (%)
-20	81.74	60.33	61.80
-25	82.2	63.58	62.10
-30	82.51	66.22	62.04
-35	82.65	68.33	61.70
-40	82.61	69.97	61.11
-45	82.39	71.19	60.27
-50	81.96	72.03	59.21

3.19 Effect of various thermodynamic parameters such as temperature of ITC evaporator on overall system performances of cascade evaporators using ecofriendly refrigerants

Table-19(a-c) shows the variation of Low temperature circuit evaporator Temperature of combined triple 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 (-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 double effect H_2O-Li/Brvapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R134a eco-friendly refrigerants decreased.

Table-19(a): Effect of ITC evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on Thermodynamic performances in terms of first law performance (COP_Overall), with ITC evaporator temperature of vapour compression refrigeration system coupled with double 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 evaporator temperature of VARS

ITC evaporator temperature of intermediate temp 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	1.63	1.68	1.385
-75	1.590	1.640	1.385
-80	1.553	1.601	1.385
-85	1.520	1.563	1.385
-90	1.487	1.526	1.385
-95	1.459	1.45	1.385
-100	1.433	1.454	1.385

Table-19(b): Effect of ITC evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on second law performance (Exergetic efficiency) with ITC evaporator temperature of vapour compression refrigeration system coupled with double 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,

ITC evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	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) system using to intermediate evaporator temperature of 223K using HFO-1234yf
-70	0.6080	0.5775	0.4665
-75	0.6175	0.5759	0.4665
-80	0.6277	0.5734	0.4665

-85	0.6388	0.570	0.4665
-90	0.6509	0.5657	0.4665
-95	0.6642	0.5606	0.4665
-100	0.6788	0.5546	0.4665

Table-19(c): Effect of ITC evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with double 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 cycle.

ITC evaporator temperature of intermediate temp 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 temp of 173K using R245fa	Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
-70	0.6646	0.7316	1.143
-75	0.6195	0.7364	1.143
-80	0.5931	0.7439	1.143
-85	0.5654	0.7544	1.143
-90	0.5363	0.7677	1.143
-95	0.5056	0.7839	1.143
-100	0.4733	0.8030	1.143

3.20 *Effect of various thermodynamic parameters such as temperature of ITC evaporator on overall percentage improvement of system performances of cascade evaporators using ecofriendly refrigerants*

Table-20(a) to Table-20 (c) shows the variation of Low temperature circuit evaporator Temperature on overall percentage improvement of thermodynamic performance of combined double 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 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 double effectH_2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R134a eco-friendly refrigerants decreased.

Table-20(a): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on Thermodynamic performances (First law Performance (COP_Overall) with ITC evaporator temperature of vapour compression refrigeration system coupled with double 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 evaporator temperature of VARS

ITC evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all percentage improvement of thermodynamic performance i.e. first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 123K using R236fa	Over all percentage improvement of thermodynamic performance i.e. first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 173K using R245fa	Over all percentage improvement of thermodynamic performance i.e. first law efficiency ($COP_{\_Overall}$) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
-70	35.69	39.83	15.27
-75	32.38	36.55	15.27
-80	29.31	33.33	15.27
-85	26.46	30.16	15.27
-90	23.84	27.06	15.27
-95	21.45	24.03	15.27
-100	19.31	21.06	15.27

Table-20(b): Effect of ITC evaporator temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on percentage improvement of Second law performance (exergetic efficiency) with ITC evaporator temperature of vapour compression refrigeration system coupled with double 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 evaporator temperature of VARS

ITC evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	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) system using to intermediate evaporator temperature of 223K using HFO-1234yf
-70	131.2	119.6	77.43
-75	134.8	119.0	77.43
-80	138.7	118.0	77.43
-85	142.9	116.7	77.43
-90	147.5	115.1	77.43
-95	1526	113.2	77.43
-100	158.1	110.9	77.43

Table-20(c): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on Thermodynamic performances i.e. System exergy destruction ratio with ITC evaporator temperature of vapour compression refrigeration system coupled with double 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 cycle.

ITC evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all percentage decrement of thermodynamic performance i.e. exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa	Over all percentage decrement exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa	Over all percentage decrement exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-70	77.0	73.89	59.21
-75	77.89	73.72	59.21
-80	78.84	73.45	59.21
-85	79.82	73.08	59.21
-90	80.86	72.61	59.21
-95	81.96	72.03	59.21
-100	83.11	71.35	59.21

3.21 Effect of ultralow evaporator temperature on total thermodynamic performances of combined three cascaded cycles in integrated system

Table-21(a) to Table-21(c) shows the variation of intermediate temperature circuit evaporator temperature with percentage improvement in thermodynamic performances combined triple 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 triple effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R236fa eco-friendly refrigerant is decreased.

Table-21(a): Effect of LTC evaporator temperature on thermodynamic performances (first law performance ($COP_{\_Overall}$), of vapour compression refrigeration system coupled with double 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 of ultra-low temperature circuit using R-236fa 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 (%)
-120	1.544	1.490	1.385
-125	1.530	1.490	1.385
-130	1.516	1.490	1.385
-135	1.502	1.490	1.385
-140	1.487	1.490	1.385
-145	1.473	1.490	1.385

-150	1.459	1.490	1.385
-155	1.445	1.490	1.385
160	1.431	1.490	1.385

Table-21(b): Effect of LTC evaporator *temperature on thermodynamic performances (second law performances (exergetic efficiencies), of vapour compression refrigeration system coupled with* double *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 of ultra-low temperature circuit using R-236fa 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 temperature of 223K using HFO-1234yf (%)
-120	0.700	0.5606	0.4666
-125	0.6959	0.5606	0.4666
-130	0.6911	0.5606	0.4666
-135	0.6856	0.5606	0.4666
-140	0.6793	0.5606	0.4666
-145	0.6642	0.5606	0.4666
-150	0.6698	0.5606	0.4666
-155	0.6553	0.5606	0.4666
155	0.6456	0.5606	0.4666

Table-21(c): Effect of LTC evaporator *temperature Thermodynamic performances (First law Performance (COP_VARS), Second law performance (exergetic efficiency) and system exergy destruction ratio with ultra-evaporator temperature of vapour compression refrigeration system coupled with* double *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 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 (%)
-120	0.4286	0.7839	1.143
-125	0.4370	0.7839	1.143
-130	0.4469	0.7839	1.143
-135	0.4585	0.7839	1.143
-140	0.4721	0.7839	1.143
-145	0.4877	0.7839	1.143
-150	0.5056	0.7839	1.143
-155	0.5259	0.7839	1.143
160	0.5489	0.7839	1.143

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

Table-22(a) to Table-22(c) shows the variation of intermediate temperature circuit evaporator temperature with percentage improvement in thermodynamic performances combined triple 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 triple effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R236fa eco-friendly refrigerant is decreased.

Table-22(a): Effect of LTC evaporator *temperature on thermodynamic performances (first law performance ($COP_{\_Overall}$), of vapour compression refrigeration system coupled with*double *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 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 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 (%)
-120	28.56	24.03	15.27
-125	27.39	24.03	15.27
-130	26.21	24.03	15.27
-135	25.02	24.03	15.27
-140	23.83	24.03	15.27
-145	22.64	24.03	15.27
-150	21.93	24.03	15.27
-155	20.28	24.03	15.27
160	19.11	24.03	15.27

Table-22(b): Effect of LTC evaporator temperature on thermodynamic performances (second law performances (exergetic efficiencies), of vapour compression refrigeration system coupled with double 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 (°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
-120	166.2	113.20	77.43
-125	164.5	113.20	77.43
-130	162.8	113.20	77.43
-135	160.7	113.20	77.43
-140	158.3	113.20	77.43
-145	155.6	113.20	77.43
-150	152.6	113.20	77.43
-155	149.2	113.20	77.43
-160	142.2	113.20	77.43

Table-22(c): Effect of LTC evaporator temperature Thermodynamic performances system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with double *effect vapour absorption refrigeration H_2O-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 ultra-low temperature circuit using R-236fa refrigerants (°C)	Over all (%) decrement in system exergy destruction ratio of system using to low evap temp of 123K using R236fa (%)	Over all (%) decrement in system exergy destruction ratio of system using to intermediate evap temp of 173K using R245fa	Over all (%) decrement in system exergy destruction ratio of system using to intermediate evap temp of 223K usingHFO-1234yf
-120	84.71	72.03	59.29
-125	84.41	72.03	59.29
-130	84.05	72.03	59.29
-135	83.64	72.03	59.29
-140	83.16	72.03	59.29
-145	82.6	72.03	59.29
-150	81.96	72.03	59.29
-155	59.21	59.29	72.03

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 double effect vapour absorption refrigeration system 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 triple 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 is higher 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 double 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 in the low temperature circuit.
- 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.

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***Cite this article as**:* R.S. Mishra, Thermodynamic performance evaluation of double effect H_2O-Li/Br vapour absorption systems using multi cascading of vapour compression cycles for ultra-low temperature applications, International Journal of Research in Engineering and Innovation Vol-3, Issue-6 (2019), 428-464. *http://doi.org/10.36037/IJREI.2019.3611*.