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Thermodynamic performance evaluation of triple 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 triple 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 7.8% and using multi (two stages) cascade VCRS is 13.45% and using multi (three stages) cascade VCRS is 10.15% for all 8^{0}C 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 80.8% and using multi (two stages) cascade VCRS is 116.5% and using multi (three stages) cascade VCRS is 156.2% for all 10^{0}C of temperature overlapping. Similarly the percentage decreament in system exergy destruction ratio is found using single stage cascade vapour compression refrigeration system (VCRS) is 60.51 % and using multi (two stages) cascade VCRS is 72.85% and using multi (three stages) cascade VCRS is 82.55% 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 °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 invariably employed in these processes which either contribute electricity consumption and environmental impact or low

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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 was 5.5 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 EDR, 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 EDR it was found that as low temperature evaporator temperature is decreasing , the first law and second law efficiencies are increasing and EDR 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 EDR 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 EDR 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 EDR 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 CO_2-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 EDR 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 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 $overlapping\_{MTC}$ ($approach\_{MTC}$)= 10
- Temperature overlapping in the vapour compression refrigeration evaporator temperature using R-1234yf and vapour compression refrigeration condenser temperature using R2345f is known as $over\text{-}lapping\_{ITC}$ ($approach\_{ITC}$) =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 EDR based on output(exergy of product) is $EDR_{\_Output}$= 2.825
- The EDR 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(b) 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 EDRs 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 triple *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 first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 123K (i.e.-150°C) using R245fa	Over all first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 223K (i.e.-50°C) using R1234yf
R236fa	1.529	1.677	1.594
R404a	1.621	1.677	1.594
R290	1.623	1.677	1.594
R600a	1.628	1.677	1.594
Ethylene	1.616	1.677	1.594

Table-1(b): Effect of ecofriendly refrigerants in ultra-low temperature cycle on, second law performance (exergetic efficiency) and system EDR of vapour compression refrigeration system coupled with triple 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 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	0.6696	0.5659	0.4727
R404a	0.6611	0.5659	0.4727
R290	0.6635	0.5659	0.4727
R600a	0.6696	0.5659	0.4727
Ethylene	0.6569	0.5659	0.4727

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-1(a) to Table-1(b) 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 EDRs 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-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 triple 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	10.14	13.44	7.824
R404a	9.644	13.44	7.824
R290	9.779	13.44	7.824
R600a	10.13	13.44	7.824
Ethylene	9.405	13.44	7.824

Table-2(b): Effect of ecofriendly refrigerants in ultra low temperature cycle on, second law performance (exergetic efficiency) and system EDR of vapour compression refrigeration system coupled with triple 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 second law efficiency of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R236fa	156.2	116.5	80.79
R404a	152.9	116.5	80.79
R290	153.8	116.5	80.79
R600a	156.1	116.5	80.79
Ethylene	151.3	116.5	80.79

Table-2(c): Effect of ecofriendly refrigerants in ultra-low temperature cycle on system EDR with absorber temperature of vapour compression refrigeration system coupled with triple 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 vapor compression refrigeration temperature cycle	Over all (%) reduction in EDR of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
R236fa	82.55	72.85	60.51
R404a	81.25	72.85	60.51
R290	82.04	72.85	60.51
R600a	82.53	72.85	60.51
Ethylene	81.51	72.85	60.51

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

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 evaporator temperature of 123K using R245fa	Over all first law efficiency ($COP_{Overall}$) of system using to low evaporator temperature of 223K using R1234yf
R134a	1.629	1.677	1.594
R32	1.625	1.674	1.594
R-507a	1.601	1.65	1.594
R227ea	1.622	1.671	1.594
R 410a	1.617	1.665	1.594
R407c	1.622	1.671	1.594
R404a	1.546	1.594	1.594
R 143a	1.614	1.662	1.594
R125	1.623	1.672	1.594
R123	1.619	1.668	1.594
R141b	1.628	1.667	1.594
R290	1.636	1.685	1.594
R600a	1.628	1.677	1.594
R-245fa	1.633	1.682	1.594

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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit

Ecofriendly refrigerants in intermediate ITC circuit	Over all second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa	Over all second law efficiency (exergetic efficiency) of system using to intermediate evaporator temperature of 173K using R245fa	Over all second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-245fa	0.6693	0.5659	0.4727
R134a	0.6683	0.5637	0.4727
R32	0.6565	0.5462	0.4727
R-507a	0.6667	0.5613	0.4727
R227ea	0.6640	0.5573	0.4727
R 410a	0.6668	0.5614	0.4727
R407c	0.6305	0.5071	0.4727
R404a	0.6626	0.5552	0.4727
R 143a	0.6671	0.5619	0.4727
R125	0.6654	0.5594	0.4727
R123	0.6697	0.5658	0.4727
R141b	0.6736	0.5715	0.4727
R290	0.6695	0.5654	0.4727
R600a	0.6719	0.5690	0.4727

Table-3(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on system EDRs of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit.

Ecofriendly refrigerants in Intermediate ITC circuit	Over all EDR of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
R-245fa	0.4929	0.767	1.116
R134a	0.4964	0.7741	1.116
R32	0.5231	0.8307	1.116
R-507a	0.500	0.7817	1.116
R227ea	0.5061	0.7944	1.116
R 410a	0.4998	0.7811	1.116
R407c	0.5859	0.9721	1.116
R404a	0.5093	0.8011	1.116

R 143a	0.4990	0.7796	1.116
R125	0.5029	0.7811	1.116
R123	0.4932	0.7675	1.116
R141b	0.4846	0.7498	1.116
R290	0.4937	0.7687	1.116
R600a	0.4884	0.7575	1.116

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 EDRs 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 triple triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Ecofriendly refrigerants in Intermediate ITC circuit	Over all (%) improvement in first law efficiency ($COP_{\_Overall}$) of system using to low evaporator temperature of 123K using R236fa	Over all (%) 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
R134a	10.14	13.44	7.821
R32	9.926	13.23	7.821
R-507a	8.28	1.59	7.821
R227ea	9.70	13.0	7.821
R 410a	9.325	12.63	7.821
R407c	9.716	13.02	7.821
R404a	4.558	7.832	7.821
R 143a	9.128	12.43	7.821
R125	9.76	13.06	7.821
R123	9.52	12.82	7.821
R141b	10.12	13.43	7.821
R290	10.67	13.96	7.821
R600a	10.09	13.39	7.821
R-245fa	10.43	13.73	7.821

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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit

Ecofriendly refrigerants in intermediate ITC circuit	Over all (%) improvement in second law efficiency of system using to low temperature evaporator temperature of 123K using R236fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
R-245fa	156.2	116.5	80.79
R134a	155.6	115.6	80.79
R32	151.1	108.9	80.79
R-507a	155.0	114.7	80.79
R227ea	154.0	113.0	80.79
R 410a	155.0	114.7	80.79
R407c	141.2	93.95	80.79
R404a	153.4	112.4	80.79
R 143a	155.2	114.9	80.79
R125	154.5	114.0	80.79

R123	156.2	116.4	80.79
R141b	157.6	118.6	80.79
R290	156.1	116.3	80.79
R600a	157.0	117.6	80.79

Table-4(c): Effect of ecofriendly refrigerants in intermediate temperature cycle on system EDRs of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and following ecofriendly refrigerants in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in Intermediate ITC circuit	Over all (%) reduction in EDR of system using to low evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-245fa	82.55	72.85	60.51
R134a	82.43	72.60	60.51
R32	81.48	70.59	60.51
R-507a	82.30	72.33	60.51
R227ea	82.09	71.88	60.51
R 410a	82.31	72.35	60.51
R407c	79.26	65.59	60.51
R404a	81.87	71.64	60.51
R 143a	82.33	72.40	60.51
R125	82.2	72.10	60.51
R123	82.54	72.83	60.51
R141b	82.85	73.46	60.51
R290	82.52	72.79	60.51
R600a	82.71	73.18	60.51

3.5 Effect of ecofriendly refrigerants in medium temperature cycle on percentage improvements in 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 EDRs 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 triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all (%) improvement in first law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in first law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in first law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
R-1234yf	10.14	13.44	7.821
R717	11.92	15.46	10.07
R134a	11.88	15.42	10.03
R32	11.5	14..98	9.539
R507a	9305	12.5	6.774
R227ea	7.359	10.30	4.362
R410a	11.57	15.06	9.626
R407c	7.343	10.28	4343
R404a	8.608	11.71	5.905
R290	11.79	15.32	9.912
R600a	12.96	16.65	11.42

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 triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Ecofriendly refrigerants in MTC circuit	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf(%)
R-1234yf	156.2	116.5	60.51
R717	163.9	123.9	87.84
R134a	163.8	123.8	87.71
R32	162.1	122.2	86.16
R507a	152.6	113.0	77.56
R227ea	144.2	105.0	70.22
R410a	162.4	122.5	86.44
R407c	144.1	104.9	70.17
R404a	149.6	110.1	74.90
R290	163.4	123.4	87.34
R600a	168.5	128.4	92.12

Table-5(c): Effect of ecofriendly refrigerants in medium temperature cycle on system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Ecofriendly refrigerants in MTC circuit	Over all (%) reduction in EDR of system using to low temperature evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa (%)	Over all (%) reduction in EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
R-1234yf	82.55	72.85	60.51
R717	84.09	74.94	63.32
R134a	84.07	74.90	63.27
R32	83.74	74.45	62.67
R507a	81.80	71.83	59.14
R227ea	79.96	69.34	55.86
R410a	83.8	74.54	62.77
R407c	79.94	69.32	55.83
R404a	81.15	70.95	57.98
R290	83.99	74.99	63.12
R600a	84.96	76.11	64.92

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

Table-6(a) to Table-6(i) shows the variation of approach on the thermodynamic performance 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 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 EDR based on exergy of product is also decreasing as temperature overlapping is increasing.

Table-6(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 temperature condenser (°C) using R236fa	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	1.651	1.677	1.594
2	1.646	1.677	1.594
3	1.644	1.677	1.594

4	1.639	1.677	1.594
5	1.637	1.677	1.594
6	1.639	1.677	1.594
8	1.633	1.677	1.594
9	1.631	1.677	1.594

Table-6(b): Second law performances in terms of total exergetic efficiencies with variations of temperature over lapping (approach_$_{LTC}$) of 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.

Temperature over lapping (approach_$_{LTC}$) in Low temperature condenser (°C) using R236fa	Over all exergetic efficiency of system using to low temperature evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa	Over all exergetic Efficiency of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
0	0.6962	0.5659	0.4727
2	0.6907	0.5659	0.4727
3	0.6879	0.5659	0.4727
4	0.6853	0.5659	0.4727
5	0.6826	0.5659	0.4727
6	0.680	0.5659	0.4727
8	0.6748	0.5659	0.4727
9	0.6728	0.5659	0.4727
10	0.6698	0.5659	0.4727
12	0.6649	0.5659	0.4727
14	0.6602	0.5659	0.4727
15	0.6578	0.5659	0.4727

Table-6(c): EDR of system with variations in temperature over lapping (approach_$_{LTC}$) of triple 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 EDR of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	0.4363	0.767	1.116
2	0.4479	0.767	1.116
3	0.4536	0.767	1.116
4	0.4593	0.767	1.116
5	0.4650	0.767	1.116
6	0.4707	0.767	1.116
8	0.4819	0.767	1.116
9	0.4827	0.767	1.116
10	0.4929	0.767	1.116
12	0.5039	0.767	1.116
14	0.5148	0.767	1.116
15	0.5201	0.767	1.116

Table-6(d): First and second law performance with variations in temperature over lapping (approach_$_{ITC}$) of triple effect LiBr vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_$_{ITC}$) in intermediate temperature condenser (°C) using R245fa	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0	1.702	1.750	1.594
2	1.687	1.736	1.594
3	1.679	1.727	1.594
4	1.6672	1.720	1.594
5	1.664	1.713	1.594
6	1.657	1.705	1.594

8	1.643	1.691	1.594
9	1.636	1.684	1.594
10	1.629	1.677	1.594
12	1.615	1.664	1.594
14	1.602	1.65	1.594
15	1.595	1.644	1.594

Table-6(e):Second law performances (exergetic Efficiencies) with variations in temperature over lapping (approach$_{ITC}$) of 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.

Temperature over lapping (approach$_{ITC}$) in intermediate temperature Condenser (°C) using R245fa	Over all exergetic efficiency of system using to low temperature 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	0.7064	0.6192	0.4727
2	0.6986	0.6079	0.4727
3	0.6948	0.6024	0.4727
4	0.691	0.597	0.4727
5	0.6873	0.5916	0.4727
6	0.6837	0.5863	0.4727
8	0.6766	0.5760	0.4727
9	0.6732	0.5709	0.4727
10	0.6698	0.5659	0.4727
12	0.6632	0.5561	0.4727
14	0.6558	0.5466	0.4727
15	0.6537	0.5419	0.4727

Table-6(f): EDR (EDR$_{system}$) of system and % improvement in system first law performance with variations in temperature over lapping (approach$_{ITC}$) of 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.

Temperature over lapping (approach$_{ITC}$) in intermediate temp Condenser using R245fa	Over all EDR of system using to low evaporator temperature of 123K using R236fa	Over all EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.4156	0.6150	1.116
2	0.4315	0.6449	1.116
3	0.4393	0.650	1.116
4	0.4472	0.691	1.116
5	0.4549	0.6903	1.116
6	0.4626	0.7055	1.116
8	0.4779	0.7361	1.116
9	0.4854	0.7515	1.116
10	0.4925	0.7670	1.116
12	0.5078	0.7981	1.116
14	0.5226	0.8295	1.116
15	0.5299	0.8453	1.116

Table-6(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 lapping in medium temp Condenser (°C) using R1234yf	Over all COP of system using to low evaporator temperature of 123K using R236fa	Over all COP of system using to intermediate evaporator temp off 173K using R245fa	Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	1.738	1.803	1.737
2	1.716	1.778	1.708
3	1.705	1.765	1.693
4	1.694	1.752	1.675
5	1.683	1.74	1.665
6	1.673	1.727	1.65
8	1.651	1.702	1.622

9	1.640	1.690	1.608
10	1.629	1677	1.594
12	1.606	1.652	1.567
14	1.584	1.627	1.539
15	1.573	1.615	1.526

Table-6(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	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	0.7546	0.6491	0.5542
2	0.7375	0.6321	0.5369
3	0.7290	0.6237	0.5285
4	0.7205	0.6154	0.5202
5	0.7121	0.6070	0.5120
6	0.7036	0.5988	0.5039
8	0.6867	0.5823	0.4881
9	0.6783	0.5741	0.4805
10	0.6693	0.5659	0.4727
12	0.6529	0.5497	0.4576
14	0.6361	0.5335	0.4430
15	0.6276	0.5256	0.4358

Table-6(i): EDR of system with variations in temperature over lapping (approach_LTC) of 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.

Temperature over lapping (approach_MTC) in medium temperature condenser (ºC) using R1234yf	Over all EDR of system using to low temperature evaporator temperature of 123K (i.e.-150ºC) using R236fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K (i.e.100ºC) using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K (i.e.-50ºC) using HFO-1234yf
0	0.3252	0.5407	0.8044
2	0.3559	0.5820	0.8626
3	0.3717	0.6033	0.8922
4	0.3878	0.6251	0.9225
5	0.4044	0.6473	0.9532
6	0.4213	0.6701	0.9845
8	0.4562	0.7174	1.049
9	0.4744	0.7419	1.082
10	0.4929	0.7670	1.116
12	0.5315	0.8192	1.185
14	0.5722	08743	1.257
15	0.5933	0.9030	1.295

3.7 Effect of temperature over lappings on percentage improvements of thermodynamic performances

Table-7(a) to Table-7(i) show the variation of all three types of approaches on the percentage improvement in thermodynamic performance 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 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 EDR based on exergy of product is also decreasing as temperature overlapping (approach) 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 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 temperature evaporator temperature of 173K using R245fa	% improvement in Over all COP of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
0	11.63	13.44	7.821
2	11.32	13.44	7.821
3	11.17	13.44	7.821
4	11.01	13.44	7.821
5	10.36	13.44	7.821
6	10.72	13.44	7.821
8	10.42	13.44	7.821
9	10.28	13.44	7.821
10	10.14	13.44	7.821
12	9.863	13.44	7.821
14	9.591	13.44	7.821
15	9.458	13.44	7.821

Table-7(b): Second law performances in terms of total exergetic efficiencies with variations of temperature over lapping (approach_$_{LTC}$) of 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.

Temperature over lapping (approach_$_{LTC}$) in Low temperature condenser (°C) using R236fa	Over all exergetic efficiency of system using to low temperature 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	166.3	116.51	80.79
2	164.2	116.51	80.79
3	163.1	116.51	80.79
4	162.1	116.51	80.79
5	161.1	116.51	80.79
6	160.1	116.51	80.79
8	158.1	116.51	80.79
9	157.2	116.51	80.79
10	156.2	116.51	80.79
12	154.3	116.51	80.79
14	152.5	116.51	80.79
15	150.1	116.51	80.79

Table-7(c): EDR of system with variations in temperature over lapping (approach_$_{LTC}$) of triple 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 EDX of system using to low evaporator temperature of 123K using R236fa	% decrement in Overall EDX of system using to intermediate evaporator temperature of 173K using R245fa	% decrement in Overall EDX of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	84.56	72.85	60.51
2	84.15	72.85	60.51
3	83.94	72.85	60.51
4	83.74	72.85	60.51
5	83.54	72.85	60.51
6	83.34	72.85	60.51
8	82.94	72.85	60.51
9	82.75	72.85	60.51
10	82.55	72.85	60.51
12	82.16	72.85	60.51
14	81.78	72.85	60.51
15	8159	72.85	60.51

Table-7(d): First and second law performance with variations in temperature over lapping (approach_ITC) of triple effect LiBr vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Temperature over lapping (approach_ITC) in intermediate temperature condenser (°C) using R245fa	(%) Overall improvement in First law efficiency (COP_Overall) of system using to low temperature 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 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-7(e):Second law performances (exergetic Efficiencies) with variations in temperature over lapping (approach_ITC) of 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.

Temperature over lapping (approach_ITC) in intermediate temperature Condenser (°C) using R245fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	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-7(f): EDR (EDR_system) of system and % improvement in system first law performance with variations in temperature over lapping (approach_ITC) of 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

Temperature over lapping (approach_ITC) in intermediate temperature Condenser (°C) using R245fa	Over all EDR of system using to low temperature evaporator temperature of 123K using R236fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf	% decrement in Overall EDR of system using to low temperature evaporator temperature of 123K using R236fa	% decrement in Overall EDR of system using to intermediate evaporator temperature of 173K using R245fa	% decrement in Overall EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf
0	0.4156	0.6150	1.116	85.29	78.23	60.51
2	0.4315	0.6449	1.116	84.73	77.17	60.51
3	0.4393	0.650	1.116	84.45	76.64	60.51
4	0.4472	0.691	1.116	84.17	76.1	60.51
5	0.4549	0.6903	1.116	83.9	75.57	60.51
6	0.4626	0.7055	1.116	83.62	75.03	60.51

8	0.4779	0.7361	1.116	83.08	73.94	60.51
9	0.4854	0.7515	1.116	82.82	73.40	60.51
10	0.4925	0.7670	1.116	82.55	72.85	60.51
12	0.5078	0.7981	1.116	82.58	71.75	60.51
14	0.5226	0.8295	1.116	81.5	70.64	60.51
15	0.5299	0.8453	1.116	81.24	70.08	60.51

Table-7(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 lapping ($approach\__{MTC}$) in medium temperature Condenser (°C) using R1234yf	% improvement in overall COP of system using to low temperature 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	16.55	21.92	17.46
2	16.07	20.22	15.45
3	15.33	19.37	14.51
4	14.59	18.52	13.54
5	13.85	17.67	12.57
6	13.11	16.82	11.61
8	1.63	15.13	9.706
9	10.88	14.29	8.761
10	10.14	13.44	7.821
12	8.646	11.75	5.953
14	7.145	10.06	4.10
15	6.393	9.21	3.179

Table-7(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 (°C) using R1234yf	Over all exergetic efficiency of system using to low temperature evaporator temperature of 123K using R236fa	Over all exergetic efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all exergetic Efficiency of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf	% improvement in over all exergetic efficiency of system using to low temperature evaporator temperature of 123K using R236fa	% improvement in over all exergetic efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa	% improvement in over all exergetic Efficiency of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
0	0.7546	0.6491	0.5542	188.6	148.3	112.0
2	0.7375	0.6321	0.5369	182.1	141.8	105.4
3	0.7290	0.6237	0.5285	178.9	138.6	102.1
4	0.7205	0.6154	0.5202	175.6	135.4	98.96
5	0.7121	0.6070	0.5120	172.4	132.2	95.83
6	0.7036	0.5988	0.5039	169.1	129.0	92.75
8	0.6867	0.5823	0.4881	162.7	122.7	86.69
9	0.6783	0.5741	0.4805	159.4	119.6	83.72
10	0.6693	0.5659	0.4727	156.2	116.5	80.75
12	0.6529	0.5497	0.4576	149.8	110.3	75.04
14	0.6361	0.5335	0.4430	143.3	104.1	69.44
15	0.6276	0.5256	0.4358	140.1	101.0	66.68

Table-7(i): EDR of system with variations in temperature over lapping (approach_LTC) of 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.

Temperature over lapping (approach_MTC) in medium temperature condenser (°C) using R1234yf	Over all EDR of system using to low temperature evaporator temperature of 123K using R236fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf	% improvement in over all EDR of system using to low temperature evaporator temperature of 123K using R236fa	% improvement in overall EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	% improvement in over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
0	0.3252	0.5407	0.8044	88.49	80.86	71.52
2	0.3559	0.5820	0.8626	87.40	79.4	69.47
3	0.3717	0.6033	0.8922	86.84	78.65	68.42
4	0.3878	0.6251	0.9225	86.27	77.87	67.35
5	0.4044	0.6473	0.9532	85.69	77.09	66.26
6	0.4213	0.6701	0.9845	85.09	76.28	65.15
8	0.4562	0.7174	1.049	83.85	74.61	62.87
9	0.4744	0.7419	1.082	83.21	73.79	61.7
10	0.4929	0.7670	1.116	82.55	72.85	60.51
12	0.5315	0.8192	1.185	81.19	71.0	58.05
14	0.5722	08743	1.257	79.75	69.05	55.49
15	0.5933	0.9030	1.295	-79.0	68.04	54.17

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

Table-8(a) to Table-8(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 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 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 EDR based on exergy of product is increasing.

Table-8(a): Effect of generator *temperature of* triple *effect H_2O- Li/Br VARS on thermodynamic performances (First law Performance ($COP_{\_Overall}$), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator Temperature of single effect H_2O-Li/Br VARS (°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
160	1.294	1.310	1.193
165	1.453	1.484	1.378
170	1.540	1.579	1.483
175	1.593	1.638	1.550
180	1.629	1.677	1.594
185	1.653	1.704	1.625
190	1.670	1.724	1.648
195	1.683	1.738	1.664
200	1.692	1.748	1.676
205	1.699	1.756	1.685

Table-8(b): Effect of generator *temperature of triple effect H_2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with* triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of triple effect H_2O-Li/Br vapour absorption refrigeration system (^oC)	Over all exergetic efficiency of system using to low temperature evaporator temperature of 123K (i.e.-150^{o}C) using R236fa	Over all exergetic efficiency of system using to intermediate temperature evaporator temperature of 173K (i.e.100^{o}C) using R245fa	Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
160	0.6101	0.5097	0.4111
165	0.6437	0.5411	0.4450
170	0.6587	0.5553	0.4607
175	0.6661	0.5624	0.4687
180	0.6698	0.5659	0.4727
185	0.6713	0.5674	0.4743
190	0.6715	0.5676	0.4745
195	0.6709	0.5670	0.4738
200	0.6697	0.5658	0.4725
205	0.6681	0.5643	0.4708

Table-8(c): Effect of generator *temperature of triple effect H_2O Li/Br VARS on thermodynamic system EDR with absorber temperature of vapour compression refrigeration system coupled with* triple triple *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*

Generator temperature of triple effect H_2O-Li/Br VARS (^oC)	Over all EDR of system using to low temperature evaporator of 123K using R23fa	Over all EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate evaporator temperature of 223K using HFO-12341.432yf
160	0.6380	0.9620	1.247
165	0.5536	0.8480	1.17
170	0.5182	0.8007	1.134
175	0.5012	0.7780	1.134
180	0.4929	0.7670	1.116
185	0.4896	0.7625	1.108
190	0.4891	0.7619	1.107
195	0.4905	0.7637	1.110
200	0.4932	0.7673	1.116
205	0.4968	0.7721	1.124

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

Table-9(a) to Table-9(c) shows the variation of generator temperature with percentage improvement in thermodynamic performances such as first law efficiency , second law efficiency and system EDR 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 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 triple effect vapour absorption integrated refrigeration system are increasing as generator temperature is increasing. Similarly EDR based on exergy of product is also increasing as condenser temperature is decreasing.

Table-9(a): Effect of generator temperature of triple effect H_2O- Li/Br VARS on thermodynamic performances (First law Performance ($COP_{\_Overall}$), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Generator Temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (^oC)	Over all (%) improvement in First law efficiency (COP_Overall) of system using to low temperature evaporator temperature of 123K using R236fa	Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate temperature 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(%)
160	32.46	34.15	22.10
165	21.81	24.36	15.50
170	16.03	18.97	11.76
175	12.48	15.65	9.403

180	10.14	13.44	7.821
185	8.522	11.91	6.716
190	7.367	10.82	5.922
195	6.525	10.02	5.34
200	5.906	9.432	4.91
205	5.446	8.995	4.59

Table-9(b): Effect of generator temperature of triple effect H_2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit*

Generator temperature of *triple* effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low temperature evaporator temperature of 123K (i.e.-150ºC) using R236 fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 173K(i.e.100ºC) using R245fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 223K (i.e.-50ºC) using HFO-1234yf(%)
160	221.9	168.9	116.9
165	185.0	139.6	97.04
170	168.5	126.3	87.79
175	160.3	119.7	83.12
180	156.2	116.5	80.79
185	154.5	115.1	79.83
190	154.3	114.9	79.69
195	155.0	115.5	80.10
200	156.3	116.6	80.87
205	158.1	118.0	81.88

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

Generator temperature of triple effect H_2O-Li/Br vapour absorption refrigeration system (ºC)	Over all EDR of system using to low temperature evaporator temperature of 123K using R23fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf	Over all (%) reduction in EDR of system using to low temperature evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf
160	0.6380	0.9620	1.247	85.05	77.50	66.50
165	0.5536	0.8480	1.17	83.85	75.26	63.62
170	0.5182	0.8007	1.134	83.15	73.97	61.95
175	0.5012	0.7780	1.134	82.76	73.24	61.0
180	0.4929	0.7670	1.116	82.55	72.85	60.51
185	0.4896	0.7625	1.108	82.46	72.68	60.25
190	0.4891	0.7619	1.107	82.45	72.66	60.26
195	0.4905	0.7637	1.110	82.49	72.73	60.35
200	0.4932	0.7673	1.116	82.56	72.86	60.52
205	0.4968	0.7721	1.124	82.65	73.03	60.74

3.10 Effect of heat exchanger effectiveness on total thermodynamic performances of three cascaded cycles in integrated system

Table 10 (a-c) show the variation of heat exchanger effectiveness of combined triple 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 EDR based on exergy of product is also increasing as condenser temperature is increased.

Table-10(a): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R23fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0.40	1.605	1.651	1.564
0.45	1.629	1.677	1.594
0.50	1.653	1.704	1.625
0.55	1.678	1.732	1.658
0.60	1.704	1.761	1.691
0.65	1.730	1.791	1.726
0.70	1.757	1.822	1.762
0.75	1.785	1.853	1.80

Table-10(b): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/ VARS (°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
0.40	0.6611	0.5577	0.4634
0.45	0.6662	0.5625	0.4688
0.50	0.6713	0.5674	0.4743
0.55	0.6765	0.5724	0.480
0.60	0.6818	0.5774	0.4857
0.65	0.6871	0.5825	0.4916
0.70	0.6925	0.5877	0.4977
0.75	0.6980	0.5930	0.5038

Table-10(c): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all EDR of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R23fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
0.40	0.5125	0.7932	1.158
0.45	0.5010	0.7778	1.133
0.50	0.4896	0.7625	1.108
0.55	0.4781	0.7472	1.084
0.60	0.4667	0.7319	1.059
0.65	0.4553	0.7167	1.034
0.70	0.4440	0.7015	1.009
0.75	0.4326	0.6864	0.849

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

Table-11(a) to table-11(c) show the variation of heat exchanger effectiveness of combined triple 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 EDR based on exergy of product is also increasing as condenser temperature is increased.

Table-11(a): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/Br VARS	Over all (%) improvement in First law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in First law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in First law efficiency of system using to intermediate evaporator temp of 223K using HFO-1234yf
0.40	11.72	14.93	8.890
0.45	10.14	13.44	7.822
0.50	8.522	11.91	6.716
0.55	6.856	10.33	5.569
0.60	5.144	8.708	4.379
0.65	3.383	7.031	3.143
0.70	1.571	6.302	1.858
0.75	0.0	3.517	0.5226

Table-11(b): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/Br VARS (^oC)	Over all (%) improvement in second law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
0.40	165.8	124.2	86.25
0.45	160.2	119.7	83.07
0.50	154.5	115.1	79.83
0.55	148.8	110.5	76.50
0.60	143.0	105.8	73.12
0.65	137.1	101.0	69.65
0.70	131.2	96.17	66.11
0.75	125.1	91.25	62.50

Table-11(c): Effect of Heat exchanger effectiveness of VARS on total Thermodynamic performances (First law Performance (COP_overall), with condenser temperature of vapour compression refrigeration system coupled with triple 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

Heat exchanger effectiveness of triple effect H_2O-Li/Br VARS	Over all (%) reduction in EDR of system using to low evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
0.40	83.03	73.73	61.65
0.45	82.76	73.23	61.0
0.50	82.46	72.68	60.29
0.55	82.14	72.09	59.53
0.60	81.80	71.45	58.70
0.65	81.42	70.76	57.81
0.70	81.01	69.99	56.82
0.75	80.56	69.16	55.74

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

Table 12 (a-c), show the variation of condenser temperature of combined triple 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 EDR based on exergy of product is also increasing as condenser temperature is increased.

Table-12(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 triple 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 of triple effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R23fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
30	1.785	1.853	1.80
31	1.767	1.832	1.775
32	1.745	1.808	1.746
33	1.720	1.780	1.713
34	1.69	1.746	1.674
35	1.653	1.704	1.625
36	1.604	1.650	1.564
37	1.539	1.578	1.482
38	1.444	1.473	1.367
39	1.293	1.309	1.191
40	1.011	1.009	0.8878

Table-12(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 triple 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.

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
0.6980	0.5930	0.5038
0.6944	0.5890	0.4992
0.6902	0.5854	0.4950
0.6852	0.5806	0.4894
0.6791	0.5748	0.4827
0.6713	0.5674	0.4743
0.6610	0.5576	0.4632
0.6467	0.5440	0.4482
0.6247	0.5233	0.4256
0.5870	0.4882	0.3887
0.5056	0.4141	0.3157

Table-12(c): Effect of condenser temperature of VARS on thermodynamic performances such as system EDRs with condenser temperature of three vapour compression refrigeration systems coupled with triple effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Condenser temperature of triple effect H_2O-Li/Br VARS (°C)	Over all EDR of system using to low temperature evaporator temperature of 123K using R23fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
30	0.4326	0.6864	0.9848
31	0.4401	0.6964	1.001
32	0.4489	0.7082	1.02
33	0.4595	0.7223	1.043
34	0.4726	0.7398	1.072
35	0.4896	0.7625	1.108
36	0.5128	0.7935	1.159
37	0.5462	0.8382	1.231
38	0.6007	0.9110	1.349
39	0.7036	1.048	1.573
40	0.9778	1.415	2.167

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

Table 13 (a-c) show the variation of condenser temperature of combined triple 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 EDR based on exergy of product is also increasing as condenser temperature is increased.

Table-13(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 triple 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 triple effect H_2O-Li/Br VARS (°C)	Over all (%) improvement in First law efficiency of system using to low evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in First law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in First law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf
30	0.0	3.514	0.520
31	0.943	4.701	1.409
32	2.372	6.067	2.427
33	4.034	7.652	3.601
34	6.036	9.555	5.0
35	8.522	11.91	6.718
36	11.75	14.96	8.912
37	16.09	19.03	11.80
38	22.44	24.94	15.90
39	32.52	34.2	22.13
40	51.32	51.12	32.92

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* triple *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 triple effect H_2O-Li/Br VARS (°C)	Over all (%) improvement in second law efficiency of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in second law efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in second law efficiency of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf(%)
30	125.10	91.25	62.50
31	120.10	94.51	64.80
32	133.8	98.30	67.67
33	139.30	102.8	70.93
34	146.0	108.2	74.88
35	154.5	115.10	79.83
36	165.9	124.30	86.33
37	181.6	136.9	95.17
38	205.9	156.2	108.4
39	247.4	189.0	130.1
40	337.1	258.1	173.0

Table-13(c): Effect of condenser *temperature of VARS on thermodynamic performances such as system EDRs with condenser temperature of three vapour compression refrigeration systems coupled with* triple *effect vapour absorption refrigeration H_2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.*

Condenser temperature of triple effect H_2O-Li/Br vapour absorption refrigeration system (°C)	Over all (%) reduction in EDR of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa (%)	Over all (%) reduction in EDR of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa (%)	Over all (%) reduction in EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
30	80.56	69.15	55.74
31	80.86	69.72	56.42

32	81.2	70.34	57.27
33	81.56	71.02	58.15
34	81.98	71.79	59.14
35	82.46	72.68	60.29
36	83.03	73.75	61.66
37	83.72	75.02	63.30
38	84.58	76.62	65.37
39	85.70	78.69	68.03
40	87.21	81.50	71.65

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

Table-14(a) to Table-14(c) shows the variation of VARS evaporator temperature with 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 EDR based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration.

Table-14(a): Effect of Thermodynamic performances (First law Performances (COP_Overall), with absorber temperature of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with* condenser *temperature of VARS*

Evaporator temperature of single effect H_2O-Li/Br VARS (ºC)	Over all COP of system using to low temperature evaporator temperature of 123K (i.e.-150ºC) using R23fa	Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100ºC) using R245fa	Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50ºC) using HFO-1234yf
3	1.011	1.01	0.8854
4	1.281	1.297	1.176
5	1.431	1.459	1.36
6	1.524	1.561	1.462
7	1.585	1.629	1.539
8	1.629	1.677	1.594
9	1.659	1.712	1.634
10	1.682	1.736	1.663

Table-14(b): Effect of Thermodynamic Second law performance (exergetic efficiency) with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser temperature of VARS

Evaporator Temperature of single effect H_2O-Li/ 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
3	0.5144	0.4192	0.3546
4	0.5931	0.4914	0.4259
5	0.6301	0.5264	0.4569
6	0.6504	0.5462	0.4701
7	0.6624	0.5582	0.4740
8	0.6698	0.5659	0.4727
9	0.6742	0.5708	0.4679
10	0.6767	0.5738	0.4610

Table-14(c): Effect of Thermodynamic system EDR with absorber temperature of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with* condenser *temperature of VARS*

Evaporator Temperature of single effect H_2O-Li/Br VARS (ºC)	Over all EDR of system using to low temperature evaporator temperature of 123K usingR23fa	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
3	0.9442	1.386	1.82
4	0.6861	1.035	1.348
5	0.5872	0.8996	1.189
6	0.5376	0.8308	1.127
7	0.5097	0.7914	1.110
8	0.4929	0.7670	1.116
9	0.4831	0.7519	1.137
10	0.4777	0.7428	1.169

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-c) shows the variation of VARS 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 EDR based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration

Table-15(a): Effect of Thermodynamic performances (First law Performances (COP_Overall), with absorber temperature of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with* condenser *temperature of VARS*

Evaporator temperature of single effect H_2O-Li/Br VARS (ºC)	Over all (%) improvement in First law efficiency of system using to low evaporator temp of 123K using R236fa (%)	Over all (%) improvement in First law efficiency 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 evap temp of 223K using HFO-1234yf (%)
3	57.73	57.52	38.13
4	38.79	40.49	26.19
5	27.57	30.12	20.36
6	20.02	22.99	15.2
7	14.50	17.68	11.17
8	10.14	13.44	7.821
9	6.593	9.945	4.956
10	3.584	6.948	2.424

Table-15(b): Effect of Thermodynamic Second law performance (exergetic efficiency) with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser temperature of VARS

Evaporator Temperature of single effect H_2O-Li/Br VARS (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	244.5	180.7	137.5
4	190.1	140.3	108.3
5	167.2	123.3	93.79
6	157.4	116.2	86.08
7	154.6	114.6	82.22
8	156.2	116.5	80.79
9	161.2	121.1	81.27
10	169.1	128.1	83.31

Table-15(c): Effect of Thermodynamic system EDR with absorber temperature of vapour compression refrigeration system coupled with triple *effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with* condenser *temperature of VARS*

Evaporator Temperature of single effect H_2O-Li/Br VARS (°C)	% 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 evaporator temperature of 223K using HFO-1234yf
3	83.43	75.68	68.06
4	82.37	73.40	65.36
5	81.88	72.25	63.33
6	81.83	71.91	61.90
7	82.08	72.18	60.99
8	82.55	72.85	60.51
9	83.2	73.84	60.43
10	83.95	75.04	60.72

3.16 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-16(a) to Table-16(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 (-50°C to -20°C), the first law efficiency ($COP_{\_Cascade}$) of cascaded vapour compression single effect vapour absorption system is increasing while and second law efficiency (exergetic efficiency) of cascaded vapour compression half effect vapour absorption refrigeration system is decreasing as generator temperature is increasing. Similarly EDR based on exergy of product is also increasing as medium temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit is increased.

Table16 (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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (°C)	Over all first law efficiency of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all first law efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all first law efficiency of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
-20	1.717	1.818	2.104
-25	1.71	1.803	2.01
-30	1.70	1.784	1.919
-35	1.687	1.762	1.832
-40	1.671	1.736	1.749
-45	1.651	1.708	1.670
-50	1.621	1.677	1.594

Table-16(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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants	Over all second law efficiency of system using to low evaporator temperature of 123K using R236fa (%)	Over all second law efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all second law efficiency (exergetic efficiency) of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf
-20	0.6660	0.4781	0.4921
-25	0.6725	0.4997	0.4933
-30	0.6765	0.5187	0.4924
-35	0.6783	0.5349	0.4897

-40	0.6779	0.5483	0.4854
-45	0.6751	0.5586	0.4796
-50	0.6698	0.5659	0.4727

Table-16(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances: system EDR of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants	Over all EDR of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf(%)
-20	0.5002	1.092	1.032
-25	0.4869	1.0	1.027
-30	0.4762	0.9281	1.031
-35	0.4742	0.8695	1.042
-40	0.4751	0.8239	1.06
-45	0.4812	0.7901	1.085
-50	0.4929	0.7670	1.116

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

Table-17(a) to Table-17(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 EDR based on exergy of product is also increasing as 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 is increased.

Table17(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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (ºC)	Over all (%) improvement in first law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in first law efficiency of system using to intermediate temperature 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	16.11	22.97	42.31
-25	15.85	21.91	35.91
-30	14.98	20.63	29.78
-35	14.09	19.13	23.91
-40	12.98	17.43	18.30
-45	11.67	15.53	12.94
-50	10.14	13.44	7.821

Table-17(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 triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator of medium temperature circuit using HFO-1234yf refrigerants (ºC)	Over all (%) improvement in second law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temp of 173K using R245fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temp of 223K using HFO-1234yf
-20	155.0	82.87	88.21
-25	157.2	91.12	88.67
-30	158.8	98.38	88.33
-35	159.5	104.6	87.29
-40	159.3	109.7	85.65
-45	158.2	113.7	83.46
-50	156.2	116.5	80.79

Table-17(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances: system EDR of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

Evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants	Over all (%) reduction in EDR of system using to low evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K Using HFO-1234yf (%)
-20	82.29	61.36	63.46
-25	82.76	64.55	63.64
-30	83.07	67.15	63.51
-35	83.21	69.22	63.11
-40	83.18	70.83	62.47
-45	82.97	72.03	61.6
-50	82.55	72.85	60.51

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

Table-18(a) to Table-18 (c) shows the variation of Low temperature circuit evaporator Temperature of combined triple effect Li/BrVapour 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 Temperatureis increasing from (-70ºC to -30ºC), 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 EDR based on exergy of product is also increasing as Low temperature circuit evaporator Temperature of combined triple effect Li/BrVapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R134a eco-friendly refrigerants decreased.

Table-18(a): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (ºC) on thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with evaporator *temp of VARS*

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (ºC)	Over all first law efficiency of system using to low temperature evaporator temperature of 123Kusing R236fa (%)	Over all first law efficiency of system using to intermediate evaporator temperature of 73K using R245fa	Over all first law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
-70	1.841	1.91	1.594
-75	1.791	1.861	1.594
-80	1.745	1.813	1.594
-85	1.703	1.767	1.594
-90	1.664	1.722	1.594
-95	1.629	1.677	1.594
-100	1.597	1.634	1.594

Table-18(b): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with evaporator temperature of VARS

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all second law efficiency of system using to low evaporator temperature of 123K) using R236fa (%)	Over all second law efficiency of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all second law efficiency system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-70	0.6141	0.5838	0.4727
-75	0.6234	0.5820	0.4727
-80	0.6335	0.5794	0.4727
-85	0.6446	0.5757	0.4727
-90	0.6586	0.5713	0.4727
-95	0.6698	0.5659	0.4727
-100	0.6844	0.5598	0.4727

Table-18(c): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on Thermodynamic performances (First law Performance ($COP\_{Overall}$), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature cycle.

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all EDR of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all EDR) of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all EDR of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%)
-70	0.6284	0.7129	1.116
-75	0.6041	0.7101	1.116
-80	0.5785	0.7261	1.116
-85	0.5515	0.7369	1.116
-90	0.5230	0.7505	1.116
-95	0.4929	0.7670	1.116
-100	0.4612	0.7863	1.116

Table-19(a): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with evaporator *temperature of VARS*

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all first law efficiency ($COP\_{Overall}$) of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa (%)	Over all first law efficiency ($COP\_{Overall}$) of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa	Over all first law efficiency ($COP\_{Overall}$) of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf(%)
-70	24.48	29.14	7.821
-75	21.13	25.86	7.821
-80	18.02	22.64	7.821
-85	15.16	19.5	7.821
-90	12.53	16.43	7.821
-95	10.14	13.44	7.821
-100	7.994	10.53	7.821

Table-19(b): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°C) on Thermodynamic performances (First law Performance (COP_Overall), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple 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 temp circuit with evaporator *temper of VARS*

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 173K(i.e.100°C) using R245fa (%)	Over all (%) improvement in second law efficiency (exergetic Efficiency) system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf
-70	134.9	123.3	80.79
-75	138.4	122.6	80.79
-80	142.3	121.6	80.79
-85	146.5	120.2	80.79
-90	151.2	118.5	80.79
-95	156.2	116.5	80.79
-100	161.8	114.1	80.79

Table-19(c): Effect of evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants(°c) on thermodynamic performances (First law Performance ($COP\_{Overall}$), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration libr system using 1234yf ecofriendly refrigerant in medium temperature circuit and r245fa in intermediate temperature circuit and R236fa in the low temperature cycle.

evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C)	Over all % decrement EDR of system using to low evaporator temperature of 123K using R236fa	Over all % decrement EDR of system using to intermediate evaporator temperature of 173K using R245fa	Over all % decrement EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-70	78.33	74.58	60.51
-75	78.33	74.58	60.51
-80	79.52	74.30	60.51
-85	80.48	73.92	60.51
-90	81.49	73.43	60.51
-95	82.55	72.85	60.51
-100	83.67	72.17	60.51

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

Table-20(a) to Table-20(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 of vapour compression system is increasing while and second law efficiency cascaded vapour compression single effect vapour absorption refrigeration system is increasing as intermediate temperature circuit evaporator Temperature is increasing. Similarly EDR 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-20(a): Effect of LTC evaporator *temperature on thermodynamic performances (first law performance ($COP\_{Overall}$), of vapour compression refrigeration system coupled with* triple *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 of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all law first law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all law first law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
-120	1.731	1.677	1.594
-125	1.714	1.677	1.594
-130	1.697	1.677	1.594
-135	1.68	1.677	1.594
-140	1.663	1.677	1.594
-145	1.646	1.677	1.594

-150	1.629	1.677	1.594
-155	1.612	1.677	1.594

Table-20(b): Effect of LTC evaporator temperature on thermodynamic performances (second law performances (exergetic efficiencies), of vapour compression refrigeration system coupled with triple 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 second law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all second law 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
-120	0.7063	0.5659	0.4727
-125	0.7021	0.5659	0.4727
-130	0.6972	0.5659	0.4727
-135	0.6916	0.5659	0.4727
-140	0.6852	0.5659	0.4727
-145	0.6779	0.5659	0.4727
-150	0.6698	0.5659	0.4727
-155	0.6608	0.5659	0.4727

Table-20(c): Effect of LTC evaporator temperature Thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of ultra-low temperature circuit using R-236fa refrigerants (°C)	Over all EDR of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 73Kusing R245fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf(%)
-120	0.4159	0.7670	1.116
-125	0.4243	0.7670	1.116
-130	0.4343	0.7670	1.116
-135	0.4459	0.7670	1.116
-140	0.4595	0.7670	1.116
-145	0.4751	0.7670	1.116
-150	0.4929	0.7670	1.116
-155	0.5132	0.7670	1.116

3.20 Effect of ultra-low evaporator temperature on percentage improvements in total thermodynamic performances of 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 EDR 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 triple 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 of system using to low temperature evaporator temperature of 123K using R236fa (%)	Over all (%) improvement in first law efficiency of system using to intermediate temperature evaporator temperature of 173K using R245fa (%)	Over all (%) improvement in first law efficiency of system using to intermediate temperature evaporator temperature of 223K Using HFO-1234yf (%)
-120	17.06	13.44	7.021
-125	15.92	13.44	13.44
-130	14.76	13.44	7.021

-135	13.61	13.44	7.021
-140	12.45	13.44	7.021
-145	11.29	13.44	7.021
-150	10.14	13.44	7.021
-155	8.998	13.44	7.021

Table-21(b): Effect of LTC evaporator temperature on thermodynamic performances (second law performances (exergetic efficiencies), of vapour compression refrigeration system coupled with triple 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 of ultra-low temperature circuit using R-236fa refrigerants	Over all (%) reduction in EDR of system using to low evaporator temperature of 123K using R236fa	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 173K using R245fa (%)	Over all (%) reduction in EDR of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-120	170.10	116.50	80.79
-125	168.5	116.50	80.79
-130	166.7	116.50	80.79
-135	164.5	116.50	80.79
-140	162.1	116.50	80.79
-145	159.3	116.50	80.79
-150	156.2	116.50	80.79
-155	152.8	116.50	80.79

Table-21(c): Effect of LTC evaporator temperature thermodynamic performances (First law Performance (COP_VARS), Second law performance (Exergetic efficiency) and system EDR with absorber temperature of vapour compression refrigeration system coupled with triple effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

evaporator Temperature of ultra-low temperature circuit using R-236fa refrigerants	Over all (%) improvement in second law efficiency of system using to low evaporator temperature of 123K using R236fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 173K using R245fa	Over all (%) improvement in second law efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%)
-120	85.28	72.05	60.51
-125	84.98	72.05	60.51
-130	84.63	72.05	60.51
-135	84.22	72.05	60.51
-140	83.74	72.05	60.51
-145	83.18	72.05	60.51
-150	82.55	72.05	60.51
-155	81.83	72.05	60.51

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 triple effect vapour absorption refrigeration system using using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate tempe138.1rature circuit and R236fa in the low temperature circuit than R1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.
- Thermodynamic performance in terms of second law efficiency(Exergetic Efficiency) of combined cascaded vapour compression 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 triple effect vapour absorption refrigeration system is decreasing and EDR 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.

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- 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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