Performance evaluation of single effect Li/Br-H₂O vapour absorption systems using multi cascading of vapour compression cycles for ultra-low temperature applications

Radhey Shyam Mishra

Department of Mechanical Engineering, Delhi Technological University Delhi, India

Abstract

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

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

1. Introduction

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

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
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A large number of studies are available in the literature on compression-absorption (combined) or cascade refrigeration cycles. The considered studies fall under two categories viz. single stage and double stage cycles. The first configuration is the combination of single effect VAR cycle coupled to a VCR cycle and the second configuration comprises of a double effect VAR cycle coupled to a VCR cycle. R.S. Mishra[11], develop an integrated solar refrigeration system where waste heat from different energy resources assists a combined vapour absorption compression system, and to analyze feasibility & practicality of that system of thermodynamically for improving its COP and exergetic efficiency by reduction of irreversibility in terms of exergy destruction /losses occurred in the system components. The combined thermodynamic first law efficiency in terms of coefficient of performance (COP_{Overall}), second law efficiency in terms of exergetic efficiency and exergy destruction ratio based on exergy of product of a combined vapour absorption-compression system working with each of the following refrigerants in the cascaded vapour compression cycle R1234yf, R227ea, R236fa, R245fa, R143a, R134a, R32, R507 operating at -223 K evaporator temperature with temperature overlapping (Approach means the difference between cascaded condenser temperature of vapour compression cycle and evaporator temperature of vapour absorption refrigeration cycle working at 13.5 bar of highest generator pressure and 1.75 bar as lowest evaporator pressure have been presented and it is found that R141b and R245fa gives better performances. Kairouani and Nehdi [12], analyzed aNH3-H2O vapor absorption cycle powered by geothermal energy-R717, R22 and R134a vapor compression cascade cycle and combined cycle. They concluded that the COP of cascade cycle was 5.5 and the COP value was 37–54% higher than that of vapor com-pression refrigeration cycle. Mishra [13] found that the thermodynamic performances in the case of cascaded half effect vapour absorption refrigeration system coupled with vapour compression cycle is improved by 44.65% increment of first law efficiency (i.e. over all COP), 172.87% increment of second law efficiency (i.e. exergetic efficiency ) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a, 42.87% enhancement in first law efficiency (COP) of 142.73% increment of second law efficiency using HFO -1234yf for -50°C of evaporator temperature of VCRS. Similarly 72.02% reduction in exergy destruction ratio based on exergy of output of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a and 70.44% reduction in exergy destruction ratio using HFO-1234yf ecofriendly refrigerant for -50°C of evaporator temperature of VCRS. The performances of single effect cascaded vapour absorption refrigeration system coupled with vapour compression cycle significantly higher than cascaded half effect vapour absorption refrigeration coupled with vapour compression cycle. Mishra[14] proposed four cascaded half effect, single effect, double effect and triple effect Lithium/Bromide vapour absorption–compression refrigeration systems using fifteen ecofriendly refrigerants such as hydrocarbons, HFC and HFO refrigerants and natural refrigerants to produce cooling capacity at -30°C. The
comparison of four cascaded systems were also carried out at -55°C using HFC refrigerants with R717 refrigerant. It is found that cascaded vapour compression absorption systems significantly improve first and second law performances as compared to simple vapour absorption refrigeration system.

R.S. Mishra [15], presented optimum thermodynamic performances of three cascade vapour compression refrigeration systems. The numerical thermal model have been developed for two stages cascade refrigeration systems and thermodynamic performances in terms of and first law efficiency, second law efficiency system exergy destruction ratio , first law efficiency of lower temperature and high temperature circuit have been computed. The effect of low temperature evaporator on the system first and second law performances and system exergy destruction ratio it was found that as low temperature evaporator temperature is decreasing , the first law and second law efficiencies are increasing and exergy destruction ratio is decreasing . from the developed thermal model, the optimum performance parameters in terms of the optimum temperature of high temperature evaporator for system-1( using HFO1234ze in HTC and HFO1234yf in LTC ) was found between -6°C to -7°C, for system-2 (using HFO1234ze in HTC and HFC134a in LTC ) : was found between -1°C to -2°C and for system-3using HFO-1234yf in HTC and HFC-134a in LTC was found between 1°C to 2°C of temperature and found that the volumetric refrigerating capacity of HFO R1234ze is below that of R134a and Its boiling point is also higher than that of R134a in the high temperature circuit of cascade refrigeration system in the range of HTC Circuit from 60°C to -20°C is suitable for replacing R134a and also concluded that the HFO R1234yf is suitable for replacing R134a in the low temperature circuit of cascade refrigeration system in the range of low temperature circuit (LTC ) from -20°C to -50°C and found that by increasing evaporator temperature overall first law efficiency in terms of COP of the system is increases. Azhar and Siddiqui [16-17] analyzed gas operated H2O-LiBr single to triple effect vapor absorption refrigeration cycles and a triple effect vapour absorption refrigeration cycle separately and used liquefied petroleum gas (LPG)and compressed natural gas (CNG) as sources of energy. They concluded that the COP of the triple effect cycle was 132% higher than the single effect. Thus the triple effect series flow VAR cycle is per-forming best among all. However, it requires input heat energy at the higher temperature range 175 to 200°C. They added that the maximum COP of triple effect vapor absorption refrigeration cycle was 2.16. V. Jain et al.[18]carried out thermodynamic analysis of vapor compression (R22, R410A, R407C andR134A)-single effect absorption (LiBr-H2O) cascade refrigeration system and found that the COP of vapour compression section of CVCAS enhanced by 155% and electricity consumption reduced by 61% in comparison to a conventional VCRS. Moreover, evaporator and condenser changed irreversibility of the system significantly. R.S.Mishra [19] observed that two stage cascade refrigeration system using R1234ze in high temperature circuit and R1234yf in the low temperature evaporator (up to -50°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°C gives similar thermodynamic performances and 2% less power consumption than conventional three stage cascade refrigeration system (system-2). In case of three stage cascade refrigeration using HFO-1234ze in the high temperature circuit and HFO-1234yf in intermediate temperature circuit two stage refrigeration cascade system circuit andR245fa in low temperature circuit gives better thermal performances. The first and second law thermal performance parameters using HFO-245fa in low temperature circuit are around 0.75% higher than that of HFC-134a.Pratihar et al. [20] carried out simulation of a 400 kW NH3-H2O absorption-compression refrigeration system for summer air conditioning and concluded that the COP increased by 16% with increase in relative solution heat exchanger area from10 to 30% when compared to conventional R22 vapor compression chiller. Sun and Guo [21] carried out experiments on prototype of combined vapour compression-absorption refrigeration system driven by a gas engine and found that the primary energy utilization efficiency of combined system improved by the utilization of waste heat of gas engine in absorption refrigeration cycle. M. Dixit et al. [22] did thermodynamic and thermo-economic analyses of two stage hybrid absorption compression refrigeration system having LiBr-H2O as working fluid and stated that hybrid system could be operated on low generator temperature and performed better than the two stage absorption refrigeration system . The COP and exergetic efficiency of optimized hybrid system were 0.43 and 11.68% respectively and the reduction in annual cost of operation was 5.2%. Similarly, Alvarez et al. [23] analyzed an alkali-nitrate triple-effect (single effect lithium, potassium, sodium nitrate cycle coupled to a double effect H2O/LiBr cycle) absorption cycle for high temperature heat source. The alkali-nitrate triple effect cycle was feasible efficient with slight higher COP than H2O/LiBr triple effect cycle at generator temperature over 180°C. The solar assisted half effect vapour absorption refrigeration system cascaded with vapour compression refrigeration system using ecofriendly refrigerants have not been studied in detail. R.S.Mishra [24] investigated the performance of above system along with variation of performance parameters and its effect on system performances in terms of exergetic efficiency, coefficient of performance along with exergy destruction ratio based on exergy of product. Han et al [25] proposed a hybrid absorption-compression refrigerator powered by waste heat. They declared that the system COP was 41.9% higher than that of a simple NH3absorption refrigerator and had confirmed performance improvement by exergy analysis and found that the COP of compression-absorption combined cycle was higher than VCR or vapor absorption refrigeration (VAR) cycle. Kaushik and Arora[26] had analyzed half; single and double effect series and
parallel flow vapor absorption cycles and defined that the generator temperature and COP for half, single and double effect series flow refrigeration cycles and found the COP of double effect system was about twice that of single effect. Cimsit and Ozturk [27] performed analysis of compression-absorption cascade refrigeration systems by using H₂O-LiBr and NH₃-H₂O pairs in vapour absorption refrigeration system and R134a, R410a and NH₃ in 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%. Garimella et al. [28] proposed absorption/vapour compression cascade refrigeration system driven by waste heat used in naval ship and determined that the electricity consumption reduced by 30% than that of conventional vapour compression refrigeration system. Wang et al. [29] studied solar assisted cascaded refrigeration system and found that the power consumption was reduced by 50% and the COP of the system reached up to 6.1.

Einiet al. [30] stated that the CO₂/NH₃ cascade cycle was safer than the CO₂/C3H8 with no significance difference in economic and exergetic efficiency. Since the water is a natural refrigerant, it can be used safely with H₂O/Li/Br in the high temperature circuit of cascade cycle. However, the safety group of R1234yf is A2L. Bhattacharyya et al. [31] evaluated a CO₂-Propane cascade system for simultaneous refrigeration and heat pump system and concluded that the approach and overlap temperatures must be minimum possible for the optimization of system performance and found that the optimum value of intermediate temperature of cascade system decreases with decrease in approach temperature and with increase in overlap temperature. Mafi et al. [32] had carried out exergy analysis of multistage cascade low temperature cascade refrigeration system and found that the exergetic efficiency of the system was 30.88%. Chinnappa et al. [33] studied R22 vapour compression-NH₃-H₂O absorption cascade refrigeration by using solar energy and determined that the cascaded system saved electrical energy than that of vapour compression system. Additionally the use of HFO refrigerant having zero potential (ODP) and low global warming potential (GWP) i.e. R1234yf is strongly recommended by Regulation (EU) No 517/2014 [11] to reduce mitigating climate change risk, environmental impact and deterioration. Therefore, refrigerant R1234yf could be a choice for vapour compression refrigeration system. Cabello et al. [34] substituted R134a, which is a high GWP refrigerant to the low GWP refrigerant R152a in cascade refrigeration plants. The drop in replacement was technically and enthusiastically feasible. The GWP and ODP rating of R1234yf are 4 and 0.

Generally, the vapour compression refrigeration cycle and its configurations viz. double stage, triple stage or multistage cascade are employed for the production of low evaporation temperature at very high cooling power. Messineo [35] analyzed a two stage cascade refrigeration system using carbon dioxide (CO₂) in low temperature circuit and ammonia (NH₃) in high temperature section. He reported that CO₂-NH₃ cascade refrigeration system was a motivating alternative to R404A for low evaporation temperatures (30°C to 50°C).

Most of the research studies considered till date emphasize on VCR and VAR cycles (single and double effect) and compression-absorption (combined) or cascade cycles. Though, exhaustive research has been carried out on cascade cycles, very less consideration has been given to explore the thermodynamic performance of single effect VAR cycle coupled with multi cascaded VCRS. Additionally, none of the research work is available on thermodynamic performance analysis of compression-absorption single effect multi cascaded three stages refrigeration system. Accordingly, in the present communication, the thermodynamic and exergetic performance analysis of absorption compression (single effect H₂O-Li/Br) cascade refrigeration system has been carried out. The analysis is performed considering H₂O/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 evaporator temperature 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 H₂O-Li/Br vapour absorption system, have been investigated on various performance parameters viz. COP, exergetic efficiency, total exergy destruction and exergy destruction ratio (EDR). Additionally, exergy destruction and EDR of system components have also been computed.

2. System Description

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

3. Results and Discussion

Following input variables have been chosen for validation of model

- Evaporator Temperature of single effect Li/Br vapour absorption refrigeration system= 8°C, Generator temperature=110°C.
- Evaporator Temperature of vapour compression
refrigeration system in the medium temperature circuit = 50°C

- Evaporator Temperature of vapour compression refrigeration system in the intermediate temperature circuit = -50°C
- Evaporator Temperature of vapour compression refrigeration system in the low temperature circuit = -150°C
- Temperature overlapping in the vapour absorption refrigeration evaporator temperature and vapour compression refrigeration condenser temperature using R1234yf is known as overlapping_MTC (approach_MTC) = 10
- Temperature overlapping in the vapour compression refrigeration evaporator temperature using R-1234yf and vapour compression refrigeration condenser temperature using R2345f is known as overlapping_RTC (approach_RTC) = 10
- 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_MTC) = 10
- Refrigerating Capacity = 35.167 “kW”
- Condenser temperature = 35°C
- Absorber Temperature = 35°C
- MTC Compressor Efficiency = 0.80
- ITC Compressor Efficiency = 0.80
- LTC Compressor Efficiency = 0.80

Thermal performance of single effect vapour absorption refrigeration system using H2O-Li/Br was computed by developed model is given below.

(i) First law efficiency of vapour absorption refrigeration system is (COP_VARS) = 0.7496,
(ii) (ii) The second law efficiency of vapour absorption refrigeration system is the exergetic efficiency = 0.2043.
(iii) (iii) The exergy destruction ratio based on output(exergy of product) is EDR_Output = 3.894
(iv) The exergy destruction ratio based on input (exergy of fuel) is EDR_Input = 0.7957.

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

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

Table 1(a): First law performance in terms of COP_Overall with variations temperature over lapping (approach_LTC) of single effect H2O-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 low temperature circuit.

| Temperature over lapping (approach_LTC) in Low temperature condenser (°C) using R236fa | Over all COP of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa | Over all COP of system using to intermediate evaporator temperature of 173K (i.e.-100°C) using R245fa | Over all COP of system using to intermediate evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf |
|----------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 0                                     | 0.8764                                           | 0.9109                                           | 0.8093                                           |
| 5                                     | 0.8711                                           | 0.9109                                           | 0.8093                                           |
| 10                                    | 0.8695                                           | 0.9109                                           | 0.8093                                           |
| 15                                    | 0.8604                                           | 0.9109                                           | 0.8093                                           |

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

| Temperature over lapping (approach_LTC) in Low temperature condenser (°C) using R236fa | Over all exergetic efficiency of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa | Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K (i.e.-100°C) using R245fa | Over all exergetic efficiency of system using to intermediate evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf |
|----------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 0                                     | 0.5248                                           | 0.4665                                           | 0.2806                                           |
| 5                                     | 0.5145                                           | 0.4665                                           | 0.2806                                           |
| 10                                    | 0.5045                                           | 0.4665                                           | 0.2806                                           |
| 15                                    | 0.4948                                           | 0.4665                                           | 0.2806                                           |
Table-1(c): Exergy destruction ratio of system with variations in temperature over lapping (approach_ITC) of single effect H2O-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 Low temperature condenser (°C) using R236fa | Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K (i.e.-150°C) using R236fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K (i.e.100°C) using R245fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf |
|---|---|---|---|
| 0 | 0.9054 | 1.143 | 2.565 |
| 5 | 0.9438 | 1.143 | 2.565 |
| 10 | 0.9823 | 1.143 | 2.565 |
| 15 | 1.027 | 1.143 | 2.565 |

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

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

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

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

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

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

Table-1(g): First law Performances (COP_overall) with variations in temperature over lapping (approach_ITC) of single effect H2O-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 medium temperature 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 temperature of 173K using R245fa | Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 0 | 0.9278 | 0.9881 | 0.8764 |
| 5 | 0.8977 | 0.9502 | 0.8432 |
| 10 | 0.8659 | 0.9109 | 0.8093 |
| 15 | 0.8322 | 0.8698 | 0.7743 |
Table-1(h): second law Performances (exergetic efficiencies) variations with temperature over lapping (approach \_t_o) of single effect H2O-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_ttc) in medium temperature condenser (°C) 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 | 0.5271 | 0.5459 | 0.3355 |
| 5 | 0.5391 | 0.5065 | 0.3075 |
| 10 | 0.5045 | 0.4665 | 0.2805 |
| 15 | 0.4679 | 0.4258 | 0.2639 |

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

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

3.2 Effect of temperature overlapping on percentage improvements of thermodynamic performances

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

Table-2(a): % improvement in system first law Performance with variations in temperature over lapping (approach_ttc) of single effect H2O-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_ttc) in Low temperature Condenser (°C) using R236fa (%) | Overall improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%) | Overall improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Overall improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 0 | 16.92 | 21.53 | 7.96 |
| 5 | 16.21 | 21.53 | 7.96 |
| 10 | 15.52 | 21.53 | 7.96 |
| 15 | 14.85 | 21.53 | 7.96 |

Table-2(b): % improvement in system first law Performance variations and % reduction in exergy destruction ratio (EDR_system) of system with and without temperature over lapping (approach_ttc) of single effect H2O-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_ttc) in Low temperature Condenser (°C) using R236fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low temperature evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temperature evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate temp evaporator temp of 223K Using HFO-1234yf (%) |
|---|---|---|---|
| 0 | 156.8 | 128.3 | 37.27 |
| 5 | 151.8 | 128.3 | 37.27 |
| 10 | 146.9 | 128.3 | 37.27 |
| 15 | 142.1 | 128.3 | 37.27 |
Table-2(c): % reduction in exergy destruction ratio of system and with varying temperature over lapping (approach_LTC) of single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

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

Table-2(d): % improvement in system first law performance variations with varying temperature over lapping (approach_LTC) of single effect H2O-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 intermediate temp Condenser (°C) using R245fa | Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temp of 123K using R236fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 173K using R245fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%) |
|----------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 0                                     | 17.91                                           | 23.09                                           | 7.96                                            |
| 5                                     | 16.7                                           | 21.52                                           | 7.96                                            |
| 10                                    | 15.52                                           | 20.0                                            | 7.96                                            |
| 15                                    | 14.38                                           |                                                  | 7.96                                            |

Table-2(e): % improvement in system second law Performance variations of system and with varying temperature over lapping (approach_LTC) of single effect H2O-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 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                                     | 160.2                                           | 143.2                                           | 37.27                                           |
| 5                                     | 153.4                                           | 135.5                                           | 37.27                                           |
| 10                                    | 146.9                                           | 128.3                                           | 37.27                                           |
| 15                                    | 140.5                                           | 121.5                                           | 37.27                                           |

Table-2(f): % reduction Exergy destruction ratio (EDR) of system and with varying temperature over lapping (approach_LTC) of single effect H2O-Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

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

Table-2(g): % improvement in system first law performance (COP_Overall) variations with varying temperature over lapping (approach_MTC) of single effect H2O-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 COP of system using to low temperature evaporator temperature of 123K (i.e.-150°C) using R236fa | Over all COP of system using to intermediate temperature evaporator temperature of 173K (i.e.100°C) using R245fa | Over all COP of system using to intermediate temperature evaporator temperature of 223K (i.e.-50°C) using HFO-1234yf |
|----------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 0                                     | 0.9278                                          | 0.9881                                          | 0.8764                                          |
| 5                                     | 0.8977                                          | 0.9502                                          | 0.8432                                          |
| 10                                    | 0.8659                                          | 0.9109                                          | 0.8093                                          |
| 15                                    | 0.8322                                          | 0.8698                                          | 0.7743                                          |
Table-2(h): % improvement in system second law performance (exergetic efficiencies) variations and % reduction Exergy destruction ratio of system and with varying temperature over lapping (approach_mtc) of single effect H2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Temperature over laping (approach_mtc) in medium temperature condenser (°C) using R1234yf | Over all (%)
|---|---|
| 0 | 180.0 |
| 5 | 163.8 |
| 10 | 146.9 |
| 15 | 129.0 |

Table-2(i): % reduction Exergy destruction ratio (EDR) of multi cascade system and with varying temperature over lapping (approach_mtc) of single effect H2O-Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Temperature over laping (approach_mtc) in medium temp Condenser (°C) using R1234yf | Over all (%)
|---|---|
| 0 | 80.79 |
| 5 | 78.04 |
| 10 | 74.77 |
| 15 | 70.75 |

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

Table-3(a) to Table-3(c) shows the variation of generator temperature of VARS on thermodynamic performances such as first law efficiency, second law efficiency and system exergy destruction of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Table-3(a): Effect of generator temperature of single effect H2O-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 H2O-Li/Br vapour absorption refrigeration system (°C) | Over all COP of system using to low evaporator temp of 123K using R23fa | Over all COP of system using to intermediate evaporator temperature of 173K using R245fa | Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 90 | 0.880 | 0.9274 | 0.8252 |
| 95 | 0.8754 | 0.9221 | 0.820 |
| 100 | 0.9312 | 1.075 | 0.8156 |
| 105 | 0.8683 | 0.9137 | 0.8120 |
| 110 | 0.8659 | 0.9109 | 0.8093 |
| 115 | 0.8639 | 0.9085 | 0.8069 |

Table-3(b): Effect of generator temperature of single effect H2O Li/Br VARS on thermodynamic second law performance (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration 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 temp of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all exergetic efficiency of system using to low evaporator temp of 123K using R236fa | Over all exergetic efficiency of system using to intermediate evaporator temp of 173K using R245fa | Over all exergetic eff of system using to intermediate evaporator temp of 223K using HFO-1234yf |
|---|---|---|---|
| 90 | 0.5329 | 0.4995 | 0.3045 |
| 95 | 0.5252 | 0.4904 | 0.2975 |
| 100 | 0.5178 | 0.4819 | 0.2916 |
| 105 | 0.5109 | 0.4739 | 0.2858 |
| 110 | 0.5045 | 0.4665 | 0.2805 |
| 115 | 0.4983 | 0.4596 | 0.2765 |
Table 3(c): Effect of generator temperature of single effect H₂O Li/Br VARs on thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Generator temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all Exergy Destruction Ratio of system using to low temperature evaporator temperature of 123K using R236fa (%) | Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 173K using R245fa (%) | Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 90                                           | 0.8765                                                        | 1.002                                                         | 2.284                                                         |
| 95                                           | 0.9042                                                        | 1.039                                                         | 2.357                                                         |
| 100                                          | 0.9312                                                        | 1.075                                                         | 2.429                                                         |
| 105                                          | 0.9573                                                        | 1.11                                                          | 2.499                                                         |
| 110                                          | 0.9823                                                        | 1.143                                                         | 2.565                                                         |
| 115                                          | 1.007                                                         | 1.176                                                         | 2.630                                                         |

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

Table 4(a) to Table 4(c) shows the variation of generator temperature with percentage improvement in thermodynamic performances such as first law efficiency, second law efficiency and system exergy destruction ratio of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

Table 4(a): Effect of generator temperature of single effect H₂O Li/Br VARs on percentage improvement of thermodynamic performances (First law performance (COP_Overall) of three cycles are , with generator temperature of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Generator temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 90                                           | 14.26                                                         | 20.42                                                         | 7.151                                                         |
| 95                                           | 14.67                                                         | 20.77                                                         | 7.414                                                         |
| 100                                          | 15.02                                                         | 21.08                                                         | 7.641                                                         |
| 105                                          | 15.31                                                         | 21.33                                                         | 7.824                                                         |
| 110                                          | 15.52                                                         | 21.52                                                         | 7.962                                                         |
| 115                                          | 15.71                                                         | 21.68                                                         | 8.08                                                          |

Table 4(b): Effect of generator temperature of single effect H₂O Li/Br VARs on percentage improvement of thermodynamic performances (second law performance (over all exergetic efficiencies) of three combined cycles are , with generator temperature of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Generator temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 90                                           | 104.8                                                         | 91.96                                                         | 17.04                                                         |
| 95                                           | 116.3                                                         | 102.0                                                         | 22.67                                                         |
| 100                                          | 137.3                                                         | 102.1                                                         | 32.78                                                         |
| 105                                          | 137.3                                                         | 120.2                                                         | 32.78                                                         |
| 110                                          | 146.9                                                         | 128.3                                                         | 37.27                                                         |
| 115                                          | 155.9                                                         | 136.0                                                         | 41.48                                                         |
Table 4(c): Effect of generator temperature of single effect H2O-Li/Br VARS on percentage improvement of thermodynamic performances of three combined cycles are, with generator temperature in terms of exergy destruction ratios of vapour absorption refrigeration system coupled with three cascaded vapour compression refrigeration cycles using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

| Generator temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 90 | 69.17 | 64.76 | 19.68 |
| 95 | 71.01 | 66.68 | 24.41 |
| 100 | 72.5 | 68.25 | 28.27 |
| 105 | 73.74 | 69.55 | 31.46 |
| 110 | 74.77 | 70.63 | 34.12 |
| 115 | 75.66 | 71.56 | 36.41 |

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

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

Table 5(a): Effect of absorber temperature of VARS Thermodynamic performances (first law Performance (COP_overall), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

| Absorber temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all COP of system using to low temperature evaporator temperature of 123K using R236fa | Over all COP of system using to intermediate temperature evaporator temperature of 173K using R245fa | Over all COP of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 30 | 0.8723 | 0.9183 | 0.8003 |
| 31 | 0.8709 | 0.9167 | 0.8149 |
| 32 | 0.8696 | 0.9151 | 0.8134 |
| 33 | 0.8683 | 0.9137 | 0.8119 |
| 34 | 0.8671 | 0.9123 | 0.8106 |
| 35 | 0.8659 | 0.9109 | 0.8093 |
| 36 | 0.8649 | 0.9097 | 0.8081 |
| 37 | 0.8638 | 0.9084 | 0.8069 |
| 38 | 0.8629 | 0.9073 | 0.8058 |
| 39 | 0.8619 | 0.9062 | 0.8048 |
| 40 | 0.8610 | 0.9052 | 0.8038 |
| 41 | 0.8602 | 0.9042 | 0.8028 |
| 42 | 0.8594 | 0.9033 | 0.8019 |
| 43 | 0.8587 | 0.9024 | 0.8011 |
| 44 | 0.8580 | 0.9016 | 0.8003 |
| 45 | 0.8573 | 0.9008 | 0.7996 |

Table 5(b): Effect of absorber temperature of VARS on Thermodynamic second law performances (exergetic efficiencies) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

| Absorber temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa | Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa | Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 30 | 0.5060 | 0.4683 | 0.2818 |
| 31 | 0.5057 | 0.4679 | 0.2815 |
| 32 | 0.5053 | 0.4675 | 0.2812 |
| 33 | 0.5050 | 0.4672 | 0.2810 |
| 34 | 0.5047 | 0.4669 | 0.2807 |
Table 5(c): Effect of absorber temperature of VARS on Thermodynamic system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H2O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with Absorber temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) Over all Exergy Destruction Ratio of system using to low temperature evaporator temperature of 123K using R23fa Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 173K using R245fa Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf

| Absorber temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all Exergy Destruction Ratio of system using to low temperature evaporator temperature of 123K using R23fa | Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 173K using R245fa | Over all Exergy Destruction Ratio of system using to intermediate temperature evaporator temperature of 223K using HFO-1234yf |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 30                                             | 0.9763                                          | 1.135                                           | 2.549                                           |
| 31                                             | 0.9776                                          | 1.137                                           | 2.553                                           |
| 32                                             | 0.9789                                          | 1.139                                           | 2.566                                           |
| 33                                             | 0.9801                                          | 1.140                                           | 2.559                                           |
| 34                                             | 0.9812                                          | 1.142                                           | 2.562                                           |
| 35                                             | 0.9823                                          | 1.143                                           | 2.565                                           |
| 36                                             | 0.9833                                          | 1.145                                           | 2.568                                           |
| 37                                             | 0.9843                                          | 1.146                                           | 2.570                                           |
| 38                                             | 0.9853                                          | 1.147                                           | 2.573                                           |
| 39                                             | 0.9861                                          | 1.149                                           | 2.575                                           |
| 40                                             | 0.9870                                          | 1.150                                           | 2.578                                           |
| 41                                             | 0.9878                                          | 1.151                                           | 2.580                                           |
| 42                                             | 0.9886                                          | 1.152                                           | 2.582                                           |
| 43                                             | 0.9893                                          | 1.153                                           | 2.584                                           |
| 44                                             | 0.990                                           | 1.154                                           | 2.585                                           |
| 45                                             | 0.9906                                          | 1.154                                           | 2.587                                           |

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

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

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

| Absorber temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all (% improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (% improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (% improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| 30                                                                                         | 14.95                                                                                                            | 21.02                                                                                                            | 7.596                                                                                                            |
| 31                                                                                         | 15.08                                                                                                            | 21.13                                                                                                            | 7.676                                                                                                            |
| 32                                                                                         | 15.2                                                                                                              | 21.24                                                                                                            | 7.753                                                                                                            |
| 33                                                                                         | 15.31                                                                                                            | 21.33                                                                                                            | 7.826                                                                                                            |
| 34                                                                                         | 15.42                                                                                                            | 21.43                                                                                                            | 7.895                                                                                                            |
| 35                                                                                         | 15.52                                                                                                            | 21.52                                                                                                            | 7.961                                                                                                            |
Table-6(b): Effect of thermodynamic performances Second law performances (exergetic efficiencies) with absorber temperature of vapour compression refrigeration system coupled with single effect H₂O-Li/Br vapour absorption refrigeration system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with absorber temperature

| Absorber temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 30                                           | 144.6                                           | 126.4                                           | 36.21                                           |
| 31                                           | 145.1                                           | 126.8                                           | 36.44                                           |
| 32                                           | 145.6                                           | 127.2                                           | 36.66                                           |
| 33                                           | 146.0                                           | 127.6                                           | 38.87                                           |
| 34                                           | 146.5                                           | 128.0                                           | 37.07                                           |
| 35                                           | 146.9                                           | 128.3                                           | 37.27                                           |
| 36                                           | 147.3                                           | 128.6                                           | 37.45                                           |
| 37                                           | 147.6                                           | 129.0                                           | 37.62                                           |
| 38                                           | 148.0                                           | 129.3                                           | 37.78                                           |
| 39                                           | 148.3                                           | 129.5                                           | 37.94                                           |
| 40                                           | 148.6                                           | 129.8                                           | 38.09                                           |
| 41                                           | 148.9                                           | 130.1                                           | 38.23                                           |
| 42                                           | 149.2                                           | 130.3                                           | 38.36                                           |
| 43                                           | 149.5                                           | 130.5                                           | 38.49                                           |
| 44                                           | 149.7                                           | 130.8                                           | 38.6                                            |
| 45                                           | 150.0                                           | 131.0                                           | 38.72                                           |

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

| Absorber temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 30                                           | 74.54                                           | 70.39                                           | 33.52                                           |
| 31                                           | 74.59                                           | 70.44                                           | 33.65                                           |
| 32                                           | 74.64                                           | 70.49                                           | 33.78                                           |
| 33                                           | 74.69                                           | 70.54                                           | 33.90                                           |
| 34                                           | 74.73                                           | 70.59                                           | 34.01                                           |
| 35                                           | 74.77                                           | 70.63                                           | 31.12                                           |
| 36                                           | 74.81                                           | 70.68                                           | 34.22                                           |
| 37                                           | 74.85                                           | 70.72                                           | 34.32                                           |
| 38                                           | 74.89                                           | 70.75                                           | 34.41                                           |
| 39                                           | 74.92                                           | 70.79                                           | 34.50                                           |
| 40                                           | 74.95                                           | 70.82                                           | 34.58                                           |
| 41                                           | 74.98                                           | 70.85                                           | 34.65                                           |
| 42                                           | 75.01                                           | 70.88                                           | 34.73                                           |
| 43                                           | 75.04                                           | 70.91                                           | 34.80                                           |
| 44                                           | 75.06                                           | 70.94                                           | 34.87                                           |
| 45                                           | 75.09                                           | 70.96                                           | 34.93                                           |
3.7 Effect of condenser temperature on total thermodynamic performances of three cascaded cycles in integrated system

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

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

| Condenser temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C) | Over all COP of system using to low evaporator temperature of 123K using R236fa | Over all COP of system using to intermediate evaporator temperature of 173K using R245fa | Over all COP of system using to intermediate evaporator temp of 223K using HFO-1234yf |
|---|---|---|---|
| 30 | 0.8696 | 0.9152 | 0.8135 |
| 31 | 0.8690 | 0.9195 | 0.8127 |
| 32 | 0.8683 | 0.9137 | 0.8119 |
| 33 | 0.8675 | 0.9128 | 0.8110 |
| 34 | 0.8660 | 0.9118 | 0.8102 |
| 35 | 0.8659 | 0.9109 | 0.8093 |
| 36 | 0.8652 | 0.9100 | 0.8084 |
| 37 | 0.8645 | 0.9092 | 0.8076 |
| 38 | 0.8638 | 0.9084 | 0.8068 |
| 39 | 0.8631 | 0.9076 | 0.8061 |
| 40 | 0.8626 | 0.9069 | 0.8054 |
| 41 | 0.8620 | 0.9063 | 0.8048 |
| 42 | 0.8615 | 0.9057 | 0.8042 |
| 43 | 0.8600 | 0.9051 | 0.8037 |
| 44 | 0.8606 | 0.9047 | 0.8032 |

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

| Condenser temperature of single effect H_2O-Li/Br vapour absorption refrigeration system (°C) | Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa | Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa | Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 30 | 0.5054 | 0.4676 | 0.2812 |
| 31 | 0.5052 | 0.4674 | 0.2811 |
| 32 | 0.5050 | 0.4672 | 0.2810 |
| 33 | 0.5048 | 0.4670 | 0.2808 |
| 34 | 0.5047 | 0.4668 | 0.2807 |
| 35 | 0.5045 | 0.4665 | 0.2805 |
| 36 | 0.5043 | 0.4663 | 0.2803 |
| 37 | 0.5041 | 0.4661 | 0.2802 |
| 38 | 0.5039 | 0.4659 | 0.2801 |
| 39 | 0.5038 | 0.4658 | 0.2799 |
| 40 | 0.5036 | 0.4656 | 0.2798 |
| 41 | 0.5035 | 0.4654 | 0.2797 |
| 42 | 0.5034 | 0.4653 | 0.2796 |
| 43 | 0.5033 | 0.4652 | 0.2795 |
| 44 | 0.5032 | 0.4651 | 0.2794 |
| 45 | 0.5031 | 0.4649 | 0.2793 |
Table-7(c): Effect of condenser temperature of VARS on thermodynamic performances such as system exergy destruction ratios with condenser temperature of three vapour compression refrigeration systems coupled with single effect vapour absorption refrigeration H₂O-Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit.

| Condenser temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R23fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 30 | 0.9888 | 1.139 | 2.586 |
| 31 | 0.9794 | 1.140 | 2.597 |
| 32 | 0.9801 | 1.140 | 2.599 |
| 33 | 0.9800 | 1.141 | 2.561 |
| 34 | 0.9816 | 1.142 | 2.563 |
| 35 | 0.9823 | 1.143 | 2.565 |
| 36 | 0.9830 | 1.144 | 2.567 |
| 37 | 0.9837 | 1.145 | 2.569 |
| 38 | 0.9844 | 1.146 | 2.571 |
| 39 | 0.9850 | 1.147 | 2.572 |
| 40 | 0.9856 | 1.148 | 2.574 |
| 41 | 0.9861 | 1.148 | 2.575 |
| 42 | 0.9866 | 1.149 | 2.577 |
| 43 | 0.9870 | 1.150 | 2.578 |
| 44 | 0.9875 | 1.150 | 2.579 |
| 45 | 0.9878 | 1.151 | 2.580 |

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

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

| Condenser Temperature of single effect H₂O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 30 | 15.19 | 21.23 | 7.748 |
| 31 | 15.25 | 21.28 | 7.785 |
| 32 | 15.31 | 21.34 | 7.826 |
| 33 | 15.38 | 21.40 | 7.87 |
| 34 | 15.45 | 21.46 | 7.915 |
| 35 | 15.52 | 21.52 | 7.961 |
| 36 | 15.59 | 21.58 | 8.005 |
| 37 | 15.65 | 21.63 | 8.047 |
| 38 | 15.71 | 21.69 | 8.086 |
| 39 | 15.77 | 21.74 | 8.123 |
| 40 | 15.83 | 21.79 | 8.158 |
| 41 | 15.87 | 21.83 | 8.189 |
| 42 | 15.92 | 21.87 | 8.218 |
| 43 | 15.96 | 21.91 | 8.245 |
| 44 | 16.0 | 21.94 | 8.27 |
| 45 | 16.04 | 21.97 | 8.293 |
3.9 Effect of evaporator temperature of vapour absorption refrigeration system on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

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

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

| Condenser Temp of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) improvement in second law efficiency (exergetic Efficiency) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 30 | 145.6 | 127.2 | 36.65 |
| 31 | 145.8 | 127.4 | 36.76 |
| 32 | 146.0 | 127.6 | 36.88 |
| 33 | 146.3 | 127.8 | 37.0 |
| 34 | 146.6 | 128.1 | 37.13 |
| 35 | 146.9 | 128.3 | 37.27 |
| 36 | 147.1 | 128.5 | 37.68 |
| 37 | 147.4 | 129.8 | 37.92 |
| 38 | 147.7 | 129.0 | 37.92 |
| 39 | 147.9 | 129.2 | 37.94 |
| 40 | 148.1 | 129.4 | 37.96 |
| 41 | 148.3 | 129.5 | 37.93 |
| 42 | 148.5 | 129.7 | 38.02 |
| 43 | 148.6 | 129.8 | 38.10 |
| 44 | 148.8 | 130.0 | 38.17 |
| 45 | 148.9 | 130.1 | 38.24 |

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

| Condenser Temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 30 | 74.64 | 70.49 | 33.77 |
| 31 | 74.65 | 70.52 | 33.85 |
| 32 | 74.69 | 70.54 | 33.90 |
| 33 | 74.71 | 70.57 | 33.97 |
| 34 | 74.74 | 70.60 | 34.05 |
| 35 | 74.77 | 70.63 | 34.12 |
| 36 | 74.80 | 70.66 | 34.19 |
| 37 | 74.83 | 70.69 | 34.26 |
| 38 | 74.85 | 70.72 | 34.33 |
| 39 | 74.88 | 70.74 | 34.39 |
| 40 | 74.90 | 70.77 | 34.44 |
| 41 | 74.92 | 70.79 | 34.51 |
| 42 | 74.94 | 70.81 | 34.54 |
| 43 | 74.95 | 70.82 | 34.59 |
| 44 | 74.97 | 70.86 | 34.63 |
| 45 | 74.98 | 70.85 | 34.67 |
Table-9(a): Effect of Thermodynamic performances (First law Performances (COP, Overall), with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit with condenser temperature of VARS

| Evaporator temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all COP of system using to low evaporator temperature of 123K using R23fa | Over all COP of system using to intermediate evaporator temperature of 173K using R245fa | Over all COP of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 1 | 0.8532 | 0.8961 | 0.7950 |
| 2 | 0.8548 | 0.8979 | 0.7967 |
| 3 | 0.8564 | 0.8998 | 0.7986 |
| 4 | 0.8582 | 0.9018 | 0.8005 |
| 5 | 0.860 | 0.9040 | 0.8026 |
| 6 | 0.8619 | 0.9062 | 0.8047 |
| 7 | 0.8639 | 0.9085 | 0.8070 |
| 8 | 0.8659 | 0.9109 | 0.8093 |
| 9 | 0.8681 | 0.9134 | 0.8117 |
| 10 | 0.8704 | 0.9161 | 0.8143 |

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

| Evaporator Temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all exergetic efficiency of system using to low evaporator temperature of 123K using R236fa | Over all exergetic efficiency of system using to intermediate evaporator temperature of 173K using R245fa | Over all exergetic Efficiency of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 1 | 0.5240 | 0.4909 | 0.3113 |
| 2 | 0.5211 | 0.4873 | 0.3068 |
| 3 | 0.5182 | 0.4837 | 0.3023 |
| 4 | 0.5154 | 0.4802 | 0.2979 |
| 5 | 0.5126 | 0.4767 | 0.2935 |
| 6 | 0.5099 | 0.4733 | 0.2891 |
| 7 | 0.5071 | 0.4699 | 0.2848 |
| 8 | 0.5045 | 0.4665 | 0.2805 |
| 9 | 0.5018 | 0.4632 | 0.2762 |
| 10 | 0.4992 | 0.460 | 0.2720 |

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

| Evaporator Temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | Over all Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R23fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa | Over all Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 1 | 0.9084 | 1.037 | 2.212 |
| 2 | 0.9191 | 1.052 | 2.260 |
| 3 | 0.9297 | 1.067 | 2.308 |
| 4 | 0.9403 | 1.082 | 2.357 |
| 5 | 0.9508 | 1.098 | 2.408 |
| 6 | 0.9613 | 1.113 | 2.459 |
| 7 | 0.9718 | 1.126 | 2.511 |
| 8 | 0.9823 | 1.143 | 2.565 |
| 9 | 0.9927 | 1.159 | 2.62 |
| 10 | 1.003 | 1.174 | 2.676 |

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

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

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

| Evaporator Temp of single effect H2O-Li/Br vapour absorption refrigeration system(°C) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to low evaporator temp of 123K using R236fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 173K using R245fa (%) | Over all (%) improvement in First law efficiency (COP_Overall) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%) |
|---|---|---|---|
| 1 | 16.65 | 22.51 | 8.689 |
| 2 | 16.52 | 22.39 | 8.60 |
| 3 | 16.37 | 22.26 | 8.505 |
| 4 | 16.21 | 22.12 | 8.406 |
| 5 | 16.05 | 21.98 | 8.302 |
| 6 | 15.88 | 21.83 | 8.193 |
| 7 | 15.71 | 21.68 | 8.08 |
| 8 | 15.52 | 21.52 | 7.961 |
| 9 | 15.3 | 21.35 | 7.836 |
| 10 | 15.2 | 21.17 | 7.707 |

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

| Evaporator Temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | % improvement in Over all exergetic efficiency of system using to low 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 evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 1 | 81.5 | 70.05 | 7.842 |
| 2 | 88.47 | 76.39 | 8.60 |
| 3 | 96.04 | 82.99 | 14.36 |
| 4 | 104.3 | 90.36 | 18.08 |
| 5 | 113.4 | 98.45 | 22.17 |
| 6 | 123.4 | 1.74 | 26.67 |
| 7 | 134.5 | 117.3 | 31.68 |
| 8 | 146.9 | 128.3 | 37.27 |
| 9 | 160.8 | 140.7 | 43.55 |
| 10 | 176.5 | 154.7 | 50.66 |

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

| evaporator Temperature of single effect H2O-Li/Br vapour absorption refrigeration system (°C) | % improvement in Overall Exergy Destruction Ratio of system using to low evaporator temperature of 123K using R236fa | % improvement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 173K using R245fa | % improvement in Overall Exergy Destruction Ratio of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|---|---|---|---|
| 1 | 63.13 | 57.91 | 10.22 |
| 2 | 64.88 | 59.79 | 13.66 |
| 3 | 66.59 | 61.65 | 17.07 |
| 4 | 68.28 | 63.48 | 20.48 |
| 5 | 69.94 | 65.3 | 23.88 |
| 6 | 71.57 | 67.09 | 27.28 |
| 7 | 73.18 | 68.87 | 30.7 |
| 8 | 74.77 | 70.63 | 34.12 |
| 9 | 76.34 | 72.39 | 37.57 |
| 10 | 77.9 | 74.13 | 41.04 |
3.11 Effect of temperature of MTC evaporator on overall system performances of cascade evaporators using ecofriendly refrigerants

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

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

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

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

Table11(b): Effect of evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performance of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in low temperature circuit

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

Table11(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on the thermodynamic performances: system exergy destruction ratio of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in low temperature circuit

| evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants (°C) | Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%) | Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| -20 | 1.27 | 1.187 | 2.424 |
| -25 | 1.19 | 1.148 | 2.402 |
| -30 | 1.124 | 1.122 | 2.40 |
| -35 | 1.072 | 1.109 | 2.417 |
| -40 | 1.031 | 1.108 | 2.45 |
| -45 | 1.0 | 1.12 | 2.50 |
| -50 | 0.9823 | 1.143 | 2.565 |
3.12 Effect of temperature of MTC evaporator on percentage improvement in overall system performances of cascade evaporators using ecofriendly refrigerants

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

![Table-12(a): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in thermodynamic performances such as first law performance (COP_{Overall}) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit](attachment:image1.png)

![Table-12(b): Effect of evaporator Temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in thermodynamic performances such as first law performance (COP_{Overall}) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit](attachment:image2.png)

![Table-12(c): Effect of evaporator temperature of medium temperature circuit using HFO-1234yf refrigerants on percentage improvement in the thermodynamic performances such as first law performance (COP_{Overall}) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit](attachment:image3.png)
3.13 Effect of temperature of ITC evaporator on overall system performances of cascade evaporators using ecofriendly refrigerants

Table-13(a) to Table-13 (c) shows the variation of Low temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with VCRS using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit and it was observed that as Low temperature circuit evaporator Temperature is increasing from (~7°C to -30°C), the first law efficiency(COP_VCRS) of cascaded vapour compression system is increasing while and second law efficiency (exergetic efficiency) of Cascaded vapour compression single effect vapour absorption refrigeration system is increasing as Low temperature circuit evaporator Temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as Low temperature circuit evaporator Temperature of combined single effect Li/Br Vapour absorption refrigeration system cascaded with VCRS using R134a refrigerant is decreased.

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

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

| evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C) | Over all exergy destruction ratio (EDR) of system using to low evaporator temperature of 123K using R236fa (%) | Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all exergy destruction ratio (EDR) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| -70 | 0.9390 | 1.133 | 2.565 |
| -75 | 0.9437 | 1.131 | 2.565 |
| -80 | 0.9503 | 1.129 | 2.565 |
| -85 | 0.9588 | 1.131 | 2.565 |
| -90 | 0.9695 | 1.136 | 2.565 |
| -95 | 0.9823 | 1.143 | 2.565 |
| -100 | 0.9974 | 1.134 | 2.565 |
3.14 Effect of ultra-low evaporator temperature on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

Table 14(a) to Table 14(c) shows the variation of intermediate temperature circuit evaporator temperature with percentage improvement in thermodynamic performances combined single effect Li/Br vapour absorption refrigeration system cascaded with vapour compression refrigeration system using R1234yf eco-friendly refrigerant and it was observed that as intermediate temperature circuit evaporator temperature is increasing from (-70°C - 20°C), the first law efficiency (COP_VCRS) of vapour compression system is increasing while and second law efficiency (Exergetic efficiency) of cascaded vapour compression single effect vapour absorption refrigeration system is increasing as intermediate temperature circuit evaporator temperature is increasing. Similarly exergy destruction ratio based on exergy of product is also increasing as intermediate temperature circuit evaporator temperature of combined single effect Li/Br vapour absorption refrigeration system cascaded with Vapour compression refrigeration system using R236fa eco-friendly refrigerant is decreased.

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

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

Table 14(b): Effect of evaporator temperature of intermediate temperature circuit using R-245fa refrigerants (°C) on the percentage improvement of in terms of second law performances (exergetics efficinices) of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H2OLi/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit:

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

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

| evaporator Temperature of intermediate temperature circuit using R-245fa refrigerants (°C) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to low evaporator temp of 123K using R236fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 173K using R245fa (%) | Over all (%) reduction in exergy destruction ratio (EDR) of system using to intermediate evaporator temp of 223K using HFO-1234yf (%) |
|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| -70                                           | 75.88                                          | 70.90                                          | 34.12                                           |
| -75                                           | 75.76                                          | 70.99                                          | 34.12                                           |
| -80                                           | 75.56                                          | 70.97                                          | 34.12                                           |
| -85                                           | 75.37                                          | 70.96                                          | 34.12                                           |
| -90                                           | 75.10                                          | 70.84                                          | 34.12                                           |
| -95                                           | 74.77                                          | 70.63                                          | 34.12                                           |
| -100                                          | 74.38                                          | 70.36                                          | 34.12                                           |
3.15 Effect of ultra-low evaporator temperature on total thermodynamic performances of three cascaded cycles in integrated system

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

| evaporator Temperature of ultra low temperature circuit using R-236fa refrigerants (°C) | Over all 1 first law efficiency (COP\text{\_Overall}) of system using to low evaporator temperature of 123K using R236fa (%) | Over all 2 first law efficiency (COP\text{\_Overall}) of system using to intermediate evaporator temperature of 173K using R245fa (%) | Over all 2 first law efficiency (COP\text{\_Overall}) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|---|---|---|---|
| -120 | 0.9213 | 0.9109 | 0.8093 |
| -125 | 0.9116 | 0.9109 | 0.8093 |
| -130 | 0.9021 | 0.9109 | 0.8093 |
| -135 | 0.8928 | 0.9109 | 0.8093 |
| -140 | 0.8836 | 0.9109 | 0.8093 |
| -145 | 0.8747 | 0.9109 | 0.8093 |
| -150 | 0.8659 | 0.9109 | 0.8093 |
| -155 | 0.8578 | 0.9109 | 0.8093 |

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

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

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

| evaporator Temperature of ultra low temperature circuit using R-236fa refrigerants (°C) | Over all exergy destruction ratio (EDR) 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 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 (%) |
|---|---|---|---|
| -120 | 0.8433 | 1.143 | 2.565 |
| -125 | 0.8607 | 1.143 | 2.565 |
| -130 | 0.8802 | 1.143 | 2.565 |
| -135 | 0.9020 | 1.143 | 2.565 |
| -140 | 0.9263 | 1.143 | 2.565 |
| -145 | 0.9530 | 1.143 | 2.565 |
| -150 | 0.9823 | 1.143 | 2.565 |
| -155 | 1.014 | 1.143 | 2.565 |

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

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

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

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

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

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

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

Table-10(a) to Table-10(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances (COP_Overall)), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H$_2$O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression - vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R1234yf is slightly lower than R152a, R134a,R410a, R407c R245fa and higher than R227ea and R404a.
Table-17(a): Effect of ecofriendly refrigerants in medium temperature cycle on the thermodynamic performances (First law Performance (COP_Overall), vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

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

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

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

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

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

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

Table-18(a) to Table-18(c) show the comparison between with ecofriendly refrigerants in terms of percentage improvements in thermodynamic performances (First law performances (COP_Overall), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression -vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R32 is slightly lower than R245fa and higher than HFC-134a, R404a, R410a, R407c and R507a.
Table 18(a): Effect of ecofriendly refrigerants in medium temperature cycle (MTC) on the percentage improvement thermodynamic performances (First law performance (COP_VARS), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit)

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

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

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

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

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

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

Table 19(a) to Table 19(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances (COP_overall), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H₂O-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.
3.20 Effect of ecofriendly refrigerants in Intermediate temperature cycle on percentage improvements in total thermodynamic performances of three cascaded cycles in integrated system

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

| Ecofriendly refrigerants in Intermediate ITC circuit | Over all first law efficiency (COP_Overall ) of system using to low evaporator temperature of 123K using R236fa | Over all first law efficiency (COP_Overall ) of system using to low evaporator temperature of 123K using R245fa | Over all first law efficiency (COP_Overall ) of system using to low evaporator temperature of 223K using R236fa |
|-----------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| R-245fa                                             | 0.8659                                                       | 0.9109                                                       | 0.8093                                                        |
| R134a                                               | 0.8652                                                       | 0.9099                                                       | 0.8093                                                        |
| R32                                                 | 0.8590                                                       | 0.9016                                                       | 0.8093                                                        |
| R-507a                                              | 0.8643                                                       | 0.9067                                                       | 0.8093                                                        |
| R404a                                               | 0.8622                                                       | 0.9059                                                       | 0.8093                                                        |
| R 410a                                              | 0.8644                                                       | 0.9088                                                       | 0.8093                                                        |
| R407c                                               | 0.4444                                                       | 0.8825                                                       | 0.8093                                                        |

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

| Ecofriendly refrigerants in Intermediate ITC circuit | Over all second law efficiency (exergetic Efficiency ) of system using to low evaporator temperature of 123K using R236fa | Over all second law efficiency (exergetic Efficiency ) of system using to intermediate evaporator temperature of 173K using R245fa | Over all second law efficiency (exergetic Efficiency ) of system using to intermediate evaporator temperature of 223K using HFO-1234yf |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| R-245fa                                             | 0.5045                                                        | 0.4655                                                        | 0.2805                                                        |
| R134a                                               | 0.5033                                                        | 0.4652                                                        | 0.2805                                                        |
| R32                                                 | 0.4939                                                        | 0.4551                                                        | 0.2805                                                        |
| R-507a                                              | 0.5020                                                        | 0.4638                                                        | 0.2805                                                        |
| R404a                                               | 0.4987                                                        | 0.4603                                                        | 0.2805                                                        |
| R 410a                                              | 0.5021                                                        | 0.4639                                                        | 0.2805                                                        |
| R407c                                               | 0.472                                                         | 0.4319                                                        | 0.2805                                                        |

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

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

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

Table-20(a) to Table-20(c) show the comparison between with ecofriendly refrigerants in terms of thermodynamic performances (First law performances (COP_Overall ), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H2O-Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and following ecofriendly refrigerants in intermediate temperature cycle and R236fa refrigerant in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression - vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R236fa in ultra-low temperature circuit and found that by using R32 is slightly lower than R245fa and higher than HFC-134a, R404a, R410a, R407c and R507a.
Table 20(a): Effect of ecofriendly refrigerants in intermediate temperature cycle on Thermodynamic performances (First law Performance (COP-Overall), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

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

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

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

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

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

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

Table 21(a) to Table 21(c) show the comparison between hydro carbons and ethylene with ecofriendly refrigerant R236fa in terms of thermodynamic performances (First law performances (COP_Overall), second law performance (Exergetic efficiencies)) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H2O/Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle and following refrigerants in the ultra-low temperature cycle and it is found that the first and second law performances of cascaded vapour compression -vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and following ecofriendly refrigerants in the low temperature circuit using R600a is maximum and lowest when using ethylene.
Table 21(a): Effect of ecofriendly refrigerants in ultra-low temperature cycle on thermodynamic performances (First law Performance (COP_VARS), of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration LiBr system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

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

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

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

Table 21(c): Effect of ecofriendly refrigerants in ultra-low temperature cycle on system exergy destruction ratio with absorber temperature of vapour compression refrigeration system coupled with single effect vapour absorption refrigeration H2O- Li/Br system using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit

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

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

Table-22(a) to Table-22(c) shows the comparison between hydro carbons and ethylene with ecofriendly refrigerant R236fa in terms of thermodynamic performances (First law performances (COP_overall)), second law performance (Exergetic efficiencies) and system exergy destruction Ratios of three cascaded vapour compression refrigeration system coupled with single effect vapour absorption Refrigeration H2O/Li/Br System using HFO-1234yf ecofriendly refrigerant in medium temperature cycle and R245fa in intermediate temperature cycle and following refrigerants in the ultra-low temperature cycle and it is found that the percentage improvement in first and second law performances of cascaded vapour compression vapour single effect absorption system is higher by using HFO-1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and following ecofriendly refrigerants in the low temperature circuit using R600a is maximum and lowest when using ethylene.

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

| Ecofriendly refrigerants in ultra-low temperature cycle | % improvement in Overall First law efficiency (COP_overall) to low temperature evaporator of 123K using R236fa (%) | % improvement in Overall First law efficiency (COP_overall) of system using to intermediate evaporator temperature of 173K using R245fa (%) | % improvement in Overall First law efficiency (COP_overall) of system using to intermediate evaporator temperature of 223K using HFO-1234yf (%) |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| R236fa                                                 | 15.52                                                                                                          | 21.52                                                                                                          | 7.964                                                                                                          |
| R290                                                   | 15.58                                                                                                          | 21.52                                                                                                          | 7.964                                                                                                          |
| R600a                                                  | 15.86                                                                                                          | 21.52                                                                                                          | 7.964                                                                                                          |
| Ethylene                                               | 14.27                                                                                                          | 21.52                                                                                                          | 7.964                                                                                                          |
4. Conclusions and Recommendations

The following conclusions were drawn from present investigations.

- Thermodynamic performance in terms of first law efficiency (COP, Cascade System) of combined cascaded vapour compression - single effect vapour absorption refrigeration system using using 1234yf ecofriendly refrigerant in medium temperature circuit and R245fa in intermediate temperature circuit and R236fa in the low temperature circuit is increasing. The best thermodynamic performances in terms of first and second law efficiencies have been found by using R152a in medium temperature circuit.

- Use of hydrocarbon is also feasible by considering safety measures because hydrocarbons are flammable and R600a gives best thermodynamic performances.

- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of generator temperature and also decreasing as generator temperature is increasing.

- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of absorber temperature and also decreasing as absorber temperature is increasing.

- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of condenser temperature and also decreasing as condenser temperature is increasing.

- Thermodynamic performances in terms of first and second law efficiencies also affected by variation of approach (temperature over lapping) and also decreasing as temperature over lapping is increasing because larger value of temperature overlapping (approach) in each cascade heat exchanger circuit reduces the COP and exergetic efficiency of the system.

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