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

IJREI
International Journal of Research in Engineering and Innovation
Vol-5, Issue-1
ISSN: 2456-6934

ORIGNAL ARTICLE

Performance evaluation of double effect Li/Br-H_2O vapour absorption refrigeration system with three cascaded vapour compression refrigeration systems using HFO refrigerants for ultra-low temperature applications

R. S. Mishra

Department of Mechanical Engineering, Delhi Technological University Delhi, India

Article Information

Received: 16 July 2020
Revised: 02 September 2020
Accepted: 19 October 2020
Available online: 12 November 2020

Keywords:

HFO refrigerants;
Thermodynamic performance evaluation;
Energy-Exergy Evaluation;
Compression-Absorption; Cascade system;

Abstract

The vapour compression–absorption refrigeration system (VCARS) is a potential alternative refrigeration technology as it economizes the use of energy resources. At low generator temperatures, the ejector-assisted absorption section provides better performance than the conventional absorption system adapted in VCARS. Simulation results show that the overall COP of VCARS is improved by 22.6%, whereas the COP improvement of 25.2% is observed in the absorption section. The total irreversibility of the system is reduced by 38.8% using ejector at optimum generator temperature which is found to be 92.1°C while varying it from 117.9°C. Therefore, ejector-assisted VCAHRS also permits the utilization of low temperature heat source. This paper mainly deals with the utility of HFO refrigerants in cascaded vapour absorption- compression cycles for low temperature and ultra-low temperature applications using double effect Li/Br-H2O absorption unit. The percentage improvement in overall first law (energy) performance of cascaded system is 10.38% using R1233zd(E), 3.36% to 8.35% by using R1225ye(Z) and 8.45% using HFO-1336mzz(Z) by increasing the generator temperature from 130°C to 145°C, and percentage improvement in exergetic efficiency. from 2.16% to 7.35% by using R1233zd (E) for low evaporator temperature of -75°C respectively. However, the performances decrease by increasing condenser and absorber temperatures.

1. Introduction

In the present scenario, the energy, exergy, economy, environment and safety strategies are the most important issues which are being considered to calculating thermodynamic performances of the refrigeration cycles both having higher as well as lower evaporator temperatures. The low temperatures for cryogenics approaching -273^{o}C, and for air conditioning around 0°C. Similarly, for industrial refrigeration such as freeze drying, pharmaceuticals, chemical and petroleum industry are −35 to −50 °C and its applications by using cascaded refrigeration cycles [1-2,30]

The demand of refrigeration at the low evaporation temperature is increasing which ranges from high heat flux electronics to fast freezing, frozen food and cold storage. Although 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 between−15 to−50 °C. Generally, technologies of mechanical refrigeration are consistently

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
https://doi.org/10.36037/IJREI.2021.5103

employed in these processes which either contribute more electricity consumption and environmental impact [3].

These mechanical processes include vapor compression refrigeration, half, single, double and triple effect vapour absorption refrigeration systems. Although the performance of vapour compression refrigeration cycle supersedes the others yet its electricity consumption is higher.

Generally, the vapour compression refrigeration cycle and its configurations viz. double stage, triple stage or multistage cascade are employed for the production of low evaporation temperature at very high cooling power [2].

D. Coloradoet.al. [4] carried out exergy based thermodynamic analysis of compression-absorption refrigeration cycle using NH3, CO2 and R134a in VCR section and H_2O-Li/Br in the vapour absorption refrigeration section so as to find out best working substance and suitable operating parameters. It was shown that highest irreversibility occurs in cascade condenser, accounting for around 19.96%, 19.31% and 13.3% of the total irreversibilities using NH_3, CO_2 and R134a respectively. Szargut et al [5] studied energy-exergy methods to beused for increasing thermodynamic efficiencies and environmental impacts because exergy is usually to be considered as the measure of work potential in terms of maximum work that can be obtained from a system with respect to its environment or the quality of a heat source. Exergy,is a available energy, which is a non-conserved quantity, and exergy balances account for inputs, losses and wastes of a process. Exergy input and destruction rates give an accounting of the efficiency of resources used.

Dincer and Rosen [6-12,] have shown links between energy, exergy and sustainable development and have shown that exergy might allow for measuring impacts on the environment. K. Chopra[13] carried out energy exergy analysis of multiple evaporators at different temperature with compound compression and flash intercooler with individual throttle valves and multiple evaporators at different temperature with compound compression and flash intercooler with multiple throttle valves have been made in terms of energetic efficiency, exergetic efficiency and irreversibility destruction and from the current study and found that the Energetic and exergetic performance of multiple evaporators at different temperatures with compound compression, flash intercooler and multiple throttle valves (system-2) is higher than Multiple evaporators at different temperatures with compound compression, flash intercooler and individual throttle valves (system-1) for selected temperature range of condenser and evaporators for chosen ecofriendly refrigerants. Similarly, System exergy defect in sytem-2 is less as compare with system-1, so system-2 is better system than system-1 for selected refrigerants. Also found that the R407C shows minimum thermodynamic performances in terms of first law efficiency, second law efficiency and system defect for both systems. The thermodynamic performances of R600, R152a and R717 better with comparison of other selected refrigerants for system-1 and system-2. But R600 is highly inflammable and R717 is toxic and limited to industrial application, so R152a is recommended for both systems which has better thermodynamic performances than R134a. Lithium bromide (Li/Br) absorption chillers have been evaluated based on their exergy; Gebreslassie et al. [14] presented at detailed analysis of exergy for half to triple effect absorption chillers. The application of optimization has been applied to absorption chillers. Also assessed the relationship between heat exchange area and exergy. They used a structural method to obtain a simplified equation to estimate the optimum heat exchanger area for absorption chillers. Their analysis also concluded that in the optimum case the highest exergy destruction sources were in the solution heat exchanger and the condenser with all components decreasing their destruction rates as the heat exchange area increased [15]

Optimization of a double effect absorption chiller by Ghani et al. [16] showed that there was a relationship between temperatures, COP and exergy. They were able to conclude that an increase in temperature in the generator yielded an increase in exergy efficiency. Bereche et al [17]. analyzed single and double-effect LiBr systems using a thermo-economic analysis and exergy. They were able to conclude that single-effect absorption refrigeration systems are suitable utilizing waste heat or operating in cogeneration systems because of their operation at lower temperatures compared to double-effect chillers. Li/Br chillers have also been internally analyzed. Morosuk and Tsatsaronis [18] presented an exergy analysis of the internal components of absorption refrigeration machines. They were able to conclude that the absorber and generator destroy 40% of their exergy and are primary candidates for improvement.

Fernández-Seara et al. [19] carried out a study on compression-absorption cascade system. Ammonia-water was the working substance in absorption refrigeration cycle whereas carbon dioxide was used as a refrigerant in compression cycle. The COP of 0.253 was reported by them.

Garimella et al. [20] developed a computational model of a waste heat driven single effect LiBr/H2O absorption-subcritical CO2 compression cycle for megawatt scale low temperature (-40) cooling for high heat flux electronic application. They reported that this novel cascade cooling system consumed 31% less electricity than the equivalent VCR system. Kairouani and Nehdi [21] carried out studied three refrigerants (R717, R22, R134a) in the vapour compression cycle and an ammonia–water pair in the absorption cycle of the cascade refrigeration system in which geothermal heat was supplied in the generator at the temperature of 62°C for a fixed evaporation temperature of 10°C and found the maximum performance was obtained by R717 and achieved a refrigeration effect of 10 MW by the compressor work of 1.65 MW and reported that the same refrigeration effect could be produced by a conventional vapour compression refrigeration system by consuming around 3.6 MW of electricity which is 54% more than the combined installation consumption. They also showed good agreement with Ghani et al [16] in by increasing the heat source temperatures in the generator resulted in an increase in COP and exergy efficiency of the system. Goktun and Dehaper [22] determined the optimal operating temperature of the focusing collector and the COP of a vapour compression refrigerator cascaded with a solar driven absorption refrigerator both in cooling and heating modes.

Cimsit and Ozturk [23] compared six combinations of cascade cycles using Li/Br–H_2O and NH_3–H_2O pairs in the absorption section and R134a, R410a and NH3 in the vapour compression cycle and analyzed the first law efficiency in terms of COP and heat required in the generator for evaporator, condenser temperature and generator temperatures for a fixed 50 kW cooling capacity. A second law-based thermodynamic analysis of water and lithium bromide absorption refrigeration by Kilic and Kaynakli [24] showed exergy loss rates for the major components of the chiller. They were able to conclude that the generator, absorber and evaporator were the largest sources of exergy destruction. Osta-Omar and Micallef [25] created a mathematical model of a Li/Br and water absorption refrigeration system. Their model incorporated an adiabatic absorber with the goal of identifying key parameters that influence Li/Br mass concentrations for both strong and weak solutions. By plotting generator temperatures vs. COP, they showed that increasing temperatures in the generator resulted in a diminishing increase in COP. Many ideas were used solar and waste thermal energy to operate a double stage absorption refrigeration system. It is observed from these works that double-stage plants have higher COP than single-stage plants but their specific costs and the required driving temperatures are also higher. Other investigator shave also worked on the combined refrigeration cycles in which both the compression and absorber cycle have same compression ratio which is equal to the total compression rate of the combined cycle.

Jain et al. [26] performed the first law and second law based thermodynamic analysis of cascaded vapour compression-absorption system (CVCAS) which consists of single effect VAR system coupled with VCR system. The electric power consumption in CVCAS was 61% lower than that in VCR system for same operating conditions. Wang et al. [27] studied the solar assisted R134a compression LiBr/H_2O absorption cascade refrigeration system. Electric power consumption was reported to be lower by 50% in comparison with VCR system.

The above discussion reveals that the compression–absorption cascade system has become the focus of attention of several researchers currently. However, the effect of HFC & HC has not yet been studied with ammonia–water as a working fluid in vapour absorption section of cascade system.

Mishra [28,29,30] analyzed a two and three stage refrigeration system using HFC-404a, R410a, R404a, R236fa, R227ea, R507a and R143a in low temperature cycle and R152a, R134a, ammonia (NH_3) in high temperature section. He reported that R152a in high temperature cycle and R134a in lower temperature cycle - cascade refrigeration system gives best performances as compared to R404A, R125 for low evaporation temperatures (−70 to −90 °C). Mishra [31,] carried out exergy-energy analysis of compression-absorption (combined) or cascade cycles. Though, exhaustive research has been carried out on cascade cycles, but very less consideration has been given to explore the thermodynamic performance using HFO refrigerants in the range from -30ºC to -150ºC and none of the research work is available on performance analysis of compression-absorption cascade refrigeration system using HFO refrigerants.

Radhey Shyam Mishra [32-33] carried out thermodynamic performance of the HFO refrigerants in the medium temperature compression stage between 5oC to -50oC and NH3H2O, Li/Br-H2O refrigerants in the absorption stage and its overall effect on the cascade system. The effect of these HFO refrigerants on the intermediate temperature in the range of (-50ºC to 95ºC) using R245fa of medium temperature cycle cascade system using R32 refrigerant/ hydrocarbons in ultra-low evaporator temperature first and second law performances using the pair of NH_3–H_2O in the high temperature absorption stage and HFO refrigerants at the evaporator temperature of 223K (-50ºC) and R245fa in in the medium temperature compression cycle for evaporator temperature of -95ºC evaluated the effect of various performance parameters of multi cascade refrigeration system in which a compression system at the low temperature stage using R32 in low temperature cycle at evaporator temperature of -130ºC . It is found that R1233zd (E), R1225ye(Z) and HFO-1336mzz(z) gives better thermodynamic performances than using R1243yf. Therefore, the present work aims to study the performance of a cascade system, in which the compression and absorption units are cascaded. The applications of present cascade systems are potential alternative to reciprocating vapour compression chillers which are commonly used in a wide range of commercial and industrial refrigeration applications.

The large number of research studies on cascade refrigeration systems have been done. These research studies provide valuable insights about energy and exergy analysis of VCRS, VARS in the single, double and triple stage and compression-absorption in the form of cascade cycles. Most of the research studies considered till date emphasize on VCR and VAR cycles (single and double effect, triple and half effect in Li/Br-H_2O and NH_3H_2O) using HFC refrigerants.

The studies carried out so far on the double and triple effect cycles in the use of HFO refrigerants up to evaporator temperature of -50°C in cascaded vapour compression refrigeration systems. to some extent, the effect of HFO refrigerants in the intermediate temperature cycle at -75°C and -95°C is missing. Also the effect of HFO –refrigerants in ultra-low temperature cycle of compression –absorption refrigeration systems have not been investigated so far. The present study has therefore been carried out the effect of HFO refrigerants in intermediate temperature cycle (ITC) up to -95°C and LTC evaporator of -135°C and -150°C.

2. System description

The absorption-compression cascade refrigeration system comprises of vapour compression refrigeration (VCR) cycle and double effect H_2O-Li/Br vapor absorption refrigeration cycle. The vapor compression refrigeration system (VCRS) is in the lower temperature section in which lower temperature is achieved using HFO refrigerants as a refrigerant and double effect H_2O-Li/Br vapor absorption refrigeration system is in the high temperature section having Lithium Bromide (Li/Br) as an absorbent and water (H_2O) as a refrigerant. The evaporator of vapor absorption refrigeration system (VARS) is coupled with the condenser of VCRS i.e. the two cycles are coupled by a heat exchanger which is designated as cascade heat exchanger in which evaporator of VARS absorbs the heat of the condenser of VCRS. The lower temperature is obtained in the evaporator of the VCRS. The evaporator temperature of VCRS is lower than the VARS. This system can be used for various applications such as deep-freezers, chillers, biomedical applications, poultry industry etc. In this paper, the the effect of different HFO refrigerants have been theoretically analyzed using thermodynamic principles of energy and exergy.

3. Results and Discussion

Following systems have been taken for performance evaluations.

Double effect -Li/Br-H_2O vapour absorption refrigeration system at 5^{o}C of evaporator temperature cascaded with three stages vapour compression refrigeration system using following HFO refrigerants in cascaded temperature cycle at evaporator temperature =-75^{o}C,

Following numerical values have been used for validation of code developed for Integrated single effect *Li/Br-H_2O* VARS using ecofriendly refrigerants

- Generator temperature= 130^{o}C
- Absorber temperature=35^{o}C
- Condenser temperature =35^{o}C
- VARS evaporator temperature=5^{o}C
- load on VARS Evaporator= 35.167 kW
- Ambient (dead state) temperature=25^{o}C
- Temperature overlapping in MTC = 10^{o}C
- VCR evaporator temperature of MTC=-75^{o}C
- VCR compressor efficiency of MTC= 80%

Table-1 Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-75^{o}C

HFO refrigerants in the cascaded low temperature cycled stage	COP_$_{VARS}$	EDR_$_{MTC}$	Exergetic Efficiency _$_{ITC}$	%Improvement in COP _$_{MTC}$	%Improvement in EDR_$_{MTC}$	%Improvement in ETA_$_{MTC}$
R1233zd(E)	1.228	0.9544	0.5117	10.38	-61.68	78.6
HFO1336mzz(Z)	1.207	1.024	0.4942	8.544	-58.9	72.49
R1225ye(z)	1.205	0.9991	0.4923	8.348	-58.59	71.84
Double effect Li/Br-H_2O VARS	1.112	2.49	0.2865	----	------	------

Thermodynamic first law energy performances of integrated single effect Li/Br-H_2O VARS system cascaded with three stages vapour compression cascaded systems shown in table1(a)-table-1(b) respectively. It was observed that system using R1225ye(Z) in low temperature cycle has lowest thermodynamic performances than a cascade system- using HFO1336mzz(Z) in low temperature cycle. However cascaded system using R1233zd(E) in low temperature cycle has highest (Best/optimum) thermodynamic energy-exergy performances.

Table-1(a) Thermodynamic first law (energetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at VAR evaporator= 5^{o}C and using medium temperature cascade system evaporator temperature=-65^{o}C, Low temperature cascade system=-125^{o}C evaporator temperature=-65^{o}C,

Cycle stage	COP _$_{VARS}$	EDR_$_{MTC}$	Exergetic Efficiency	%Improvement in COP	% Improvement in EDR	%Improvement in Exergetic Eff
VAR system using Li/Br-H_2O	1.112	2.49	0.2865	0.0	0.0	0.0
Cascaded MTC using R1233zd(E) system	1.228	0.9544	0.5117	10.38	-61.68	78.60
Cascaded ITC using HFO-1336mzz(Z) in ITC	1.219	0.3853	0.7219	9.558	-84.53	152.0
Cascaded system using HFO-1336mzz(Z) in MTC and R1225ye(Z) in ITC	1.228	0.3606	0.7350	10.33	-85.52	156.5

Table-1(b) Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H2O VARS at evaporator temp =-125^{o}C

Cycle stage	COP_ $_{VARS}$	EDR _$_{MTC}$	Exergetic Efficiency $_{ITC}$	%Improvement in COP $_{cascade}$	%Improve-ment in EDR_	%Improvement in ETA_$_{cascade}$
VARS	1.112	2.49	0.2865	0.0	0.0	0.0
HFO1336mzz(Z) in MTC and R1225ye(z) in ITC	1.207	1.024	0.4942	8.544	-58.9	72.49
R1225ye(z) in ITC	1.211	0.395	0.3965	8.898	-84.11	150.1
R1225ye(z)in MTC and HFO1336mzz(Z)	1.205	0.999	0.4923	8.348	-58.59	71.84
HFO1336mzz(Z) in ITC	1.20	0.424	0.702	7.896	-82.95	145.0

Following numerical values have been used for validation of code developed for Integrated single effect Li/Br-H_2O VARS using ecofriendly refrigerants.

- Generator temperature= 130^{o}C
- Absorber temperature=35^{o}C
- Condenser temperature =35^{o}C

- VARS evaporator temperature=5^{o}C
- load on VARS Evaporator= 35.167 kW
- Ambient (dead state) temperature=25^{o}C
- Temperature overlapping in MTC = 10^{o}C
- VCR evaporator temperature of MTC=-75^{o}C

Thermodynamic first law energy performances of integrated double effect Li/Br-H_2O VARS system cascaded with vapour compression cascaded systems for evaporator temperature of -75^{o}C is shown in table2(a)-table-2(c) respectively. It was observed that by increasing evaporator temperature of low temperature evaporator increases first law efficiency (COP). similarly, the improvement in cascaded efficiency increases as low temperature evaporator is increases. Similarly, exergetic efficiency of cascaded system is decreases when low temperature evaporator temperature is increases for HFO refrigerants. Similarly, for low temperature evaporator temperature of -50^{o}C and -30^{o}C for all HFO refrigerants are shown in Table-2(d) to table-2(g) respectively.

Table-2(a) Thermodynamic first law (energetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-75^{o}C using R1233zd(E) in low cascaded temperature cycle

MTC Evaporator temperature	COP_Cascade	Cascade EDR	Cascade Exergetic Efficiency	% Improvement in COP _MTC	% decrement in EDR _ITC	% Improvement in Exergetic Efficiency _ LTC	Double Effect COP_VARS	Double Effect EDR	Double Effect Exergetic Efficiency
-75	1.136	1.031	0.4924	2.162	-58.61	71.87	1.112	2.49	0.2865
-70	1.181	0.9902	0.5025	6.191	-60.24	75.38	1.112	2.49	0.2865
-65	1.228	0.9544	0.5117	10.38	-61.68	78.6	1.112	2.49	0.2865
-60	1.276	0.9232	0.52	14.72	-62.93	81.49	1.112	2.49	0.2865
-55	1.326	0.8965	0.5273	19.22	-64.0	84.04	1.112	2.49	0.2865
-50	1.378	0.8743	0.5335	23.88	-64.89	86.23	1.112	2.49	0.2865
-45	1.431	0.8566	0.5386	28.71	-65.61	88.01	1.112	2.49	0.2865
-40	1.487	0.8434	0.5425	33.70	66.14	89.35	1.112	2.49	0.2865
-35	1.554	0.8351	0.5449	38.85	-66.47	90.21	1.112	2.49	0.2865
-30	1.604	0.8320	0.5459	44.17	-66.59	90.53	1.112	2.49	0.2865

Table-2(b) Thermodynamic exergy destruction ratio of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-75^{o}C using HFO1336mzz(Z) in low cascaded temperature cycle

MTC Evaporator temperature	COP_Cascade	Cascade EDR	Cascade Exergetic Efficiency	%Improvement in COP _MTC	% decrement in EDR _ITC	% Improvement in Exergetic Efficiency _ LTC	COP_VARS
-75	1.114	1.117	0.4724	0.175	-55.15	64.68	1.112
-70	1.160	1.068	0.4837	4.274	-57.13	68.82	1.112
-65	1.207	1.024	0.4942	8.544	-58.9	72.45	1.112
-60	1.257	0.9847	0.5038	12.98	-60.46	75.86	1.112
-55	1.308	0.9509	0.5126	17.60	-61.82	78.9	1.112
-50	1.361	0.922	0.5203	22.39	-62.98	81.6	1.112
-45	1.416	0.8980	0.5269	27.35	-63.94	83.9	1.112
-40	1.474	0.8589	0.5322	32.49	64.71	85.77	1.112
-35	1.533	0.8650	0.5362	37.80	-65.27	87.16	1.112
-30	1.594	0.8567	0.5386	43.28	-65.6	88.0	1.112
-25	1.656	0.8545	0.5392	48.93	-65.69	88.21	1.112
-20	1.721	0.8594	0.5378	54.75	-65.45	87.72	1.112
-15	1.788	0.8725	0.5340	60.74	-64.97	86.41	1.112

Table-2(c) Thermodynamic exergy destruction ratio of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-125^{o}C using R1225ye(Z) in low cascaded temperature cycle

MTC Evaporator temperature	COP_Cascade	Cascade EDR	Cascade Exergetic Eff	% Improvement in COP _MTC	% decrement in EDR _ITC	% Improvement in Exergetic Efficiency _ LTC	COP_VARS
-75	1.114	1.117	0.4724	0.1807	-55.16	64.90	1.112
-70	1.159	1.072	0.4827	4.174	-56.97	68.48	1.112
-65	1.205	1.031	0.4923	8.348	-58.59	71.84	1.112
-60	1.254	0.9950	0.5012	12.70	-60.05	74.96	1.112
-55	1.304	0.9633	0.5094	17.24	-61.32	77.79	1.112
-50	1.357	0.9358	0.5166	21.97	-62.42	80.31	1.112
-45	1.411	0.9124	0.5228	26.88	-63.35	82.48	1.112
-40	1.468	0.8943	0.5279	31.97	64.09	84.26	1.112

-35	1.527	0.8807	0.5317	37.25	-64.64	85.59	1.112
-30	1.587	0.8724	0.5341	42.72	-64.97	86.42	1.112
-25	1.650	0.8699	0.5348	48.37	-65.07	86.66	1.112
-20	1.715	0.8742	0.5336	54.21	-64.90	86.24	1.112
-15	1.782	0.8862	0.5302	60.23	-64.42	85.05	1.112

Table-2(d) Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-50^oC using R1234yf in low cascaded temperature cycle

MTC Evaporator temperature	COP_$_{Cascade}$	Cascade EDR	Cascade Exergetic Efficiency	% Improvement in COP _$_{MTC}$	% decrement in EDR _$_{ITC}$	% Improvement in Exergetic Efficiency _ $_{LTC}$	Double Effect COP_$_{VARS}$	Double Effect EDR	Double Effect Exergetic Efficiency
-50	1.338	0.9925	0.5024	20.33	-60.23	75.35	1.112	2.49	0.2865
-45	1.395	0.9599	0.5102	25.4	-61.46	78.09	1.112	2.49	0.2865
-40	1.453	0.9347	0.5169	30.65	-62.47	80.42	1.112	2.49	0.2865
-35	1.52	0.9134	0.5226	36.64	-63.33	82.43	1.112	2.49	0.2865
-30	1.576	0.9012	0.5260	41.71	-63.81	83.59	1.112	2.49	0.2865
-25	1.641	0.8938	0.5280	47.51	-64.11	84.31	1.112	2.49	0.2865
-20	1.707	0.8936	0.5281	53.50	-64.12	84.33	1.112	2.49	0.2865
-15	1.776	0.9017	0.5258	59.65	-63.79	83.54	1.112	2.49	0.2865

Table-2(e) Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-50^oC using R1243zf in low cascaded temperature cycle

MTC Evaporator temperature	COP_$_{Cascade}$	Cascade EDR	Cascade Exergetic Efficiency	% Improvement in COP _$_{MTC}$	% decrement in EDR _$_{ITC}$	% Improvement in Exergetic Efficiency _ $_{LTC}$	Double Effect COP_$_{VARS}$	Double Effect EDR	Double Effect Exergetic Efficiency
-30	1.590	0.8648	0.5363	42.99	-65.28	87.18	1.112	2.49	0.2865
-25	1.653	0.8638	0.5365	48.60	-65.32	87.28	1.112	2.49	0.2865
-20	1.717	0.8694	0.5349	54.38	-65.90	86.71	1.112	2.49	0.2865
-15	1.784	0.8827	0.5311	60.36	-64.56	85.39	1.112	2.49	0.2865

Table-2(f) Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-50^oC using R1234ze(E) in low cascaded temperature cycle

MTC Evaporator temperature	COP_$_{Cascade}$	Cascade EDR	Cascade Exergetic Efficiency	%Improvement in COP _$_{MTC}$	% decrement in EDR _$_{ITC}$	% Improvement in Exergetic Efficiency _ $_{LTC}$	Double Effect COP_$_{VARS}$	Double Effect EDR	Double Effect Exergetic Efficiency
-30	1.589	0.8674	0.5355	42.90	-65.17	86.92	1.112	2.49	0.2865
-25	1.653	0.8640	0.5365	48.59	-65.31	87.25	1.112	2.49	0.2865
-20	1.718	0.8678	0.5354	54.44	-65.15	86.87	1.112	2.49	0.2865
-15	1.785	0.8798	0.5320	60.46	-64.47	85.68	1.112	2.49	0.2865

Table-2(g) Thermodynamic second law (exergetic) Performances of Integrated double effect Li/Br-H_2O VARS using ecofriendly refrigerants at evaporator temperature=-50^oC using R1234ze(Z) in low cascaded temperature cycle

MTC Evaporator temperature	COP_$_{Cascade}$	Cascade EDR	Cascade Exergetic Efficiency	% Improvement in COP _$_{MTC}$	% decrement in EDR _$_{ITC}$	% Improvement in Exergetic Efficiency _ $_{LTC}$	Double Effect COP_$_{VARS}$	Double Effect EDR	Double Effect Exergetic Efficiency
-30	1.608	0.8199	0.5495	44.61	-67.08	91.79	1.112	2.49	0.2865
-25	1.669	0.8252	0.5479	50.02	-66.87	91.21	1.112	2.49	0.2865
-20	1.731	0.8367	0.5445	55.60	-66.40	90.04	1.112	2.49	0.2865
-15	1.52	0.9134	0.5226	36.64	-63.33	82.43	1.112	2.49	0.2865

The thermodynamic first law energy performances of integrated double effect Li/Br-H_2O VARS system cascaded with vapour compression refrigeration systems with varying evaporator temperature is shown in table 3 respectively. It was observed that by increasing VAR evaporator temperature, the thermodynamic first law (energy) performance is increases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases. Similarly, Thermodynamic second law exergy performances of cascaded double effect Li/Br-H_2O VARS system cascaded with VCRS with variation of absorber temperature is shown in table-4 respectively. It was observed thermodynamic performances is decreases, by increasing absorber temperature.

Table-3 Thermodynamic (exergy) performances of Integrated double effect Li/Br-H2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Evaporator temperature of VARS (ºC)	COP_ VARS	EDR	Exergetic Efficiency	COP_ cascade	EDR_ cascade	Exergetic Efficiency_ cascade	% Improvement in COP _ cascade	% Decrement in EDR _ cascade	%Improv-ment in Exergetic Efficiency _ cascade
3	1.032	2.421	0.2923	1.093	0.9933	0.5017	5.983	-58.98	71.64
4	1.075	2.44	0.2907	1.117	1.009	0.4978	3.958	-58.65	71.22
5	1.112	2.49	0.2865	1.136	1.031	0.4924	2.162	-58.61	71.87
6	1.145	2.569	0.2802	1.151	1.058	0.4859	0.5310	-58.82	73.42
7	1.174	2.673	0.2727	1.163	1.089	0.4787	0.0	-59.26	75.82

Table-4 Effect of Absorber temperature on thermodynamic performances of Integrated single effect Li/Br-H2O VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Absorber temperature of VARS (ºC)	COP_ VARS	EDR	Exergetic Efficiency	COP _ cascade	EDR_ cascade	Exergetic Efficiency_ cascade	% Improvement in COP _ cascade	% Decrement in EDR _ cascade	% Improvement in Exergetic Eff _ cascade
30	1.232	2.152	0.3173	1.214	0.9642	0.5091	0.0	-55.19	60.46
35	1.112	2.49	0.2865	1.136	1.031	0.4924	2.162	-58.61	71.87
40	0.8935	3.345	0.2302	0.977	1.99	0.4547	9.424	-65.15	97.57

Thermodynamic first law energy performances of integrated single effect $Li/Br-H_2O$ VARS system cascaded with three stages vapour compression cascaded systems with varying Condenser temperature is shown in table -5 respectively. It was observed that by increasing VARS Condenser temperature, the thermodynamic first law (energy) performance is decreases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases. Similarly, Thermodynamic performances of cascaded single effect $Li/Br-H_2O$ VARS system cascaded with three stages vapour compression cascaded systems with variation of generator temperature is shown in table-6 respectively. It was observed thermodynamic performances is decreases, by increasing generator temperature.

Table-5 Effect of condenser temperature on thermodynamic performances of Integrated single effect $Li/Br-H_2O$ VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Condenser temperature of VARS (ºC)	COP_ VARS	EDR	Exergetic Efficiency	COP _ cascade	EDR_ cascade	Exergetic Efficiency_ cascade	% Improvement in COP _ cascade	% Decrement in EDR _ cascade	% Improvement in Exergetic Effi _ cascade
34	1.145	2.39	0.2950	1.158	1.011	0.4973	1.145	-57.69	68.55
35	1.112	2.49	0.2865	1.136	1.031	0.4924	2.162	-58.61	71.87
36	1.074	2.616	0.2766	1.110	1.056	0.4865	3.37	-59.64	75.9
38	0.9741	2.985	0.2509	1.039	1.128	0.4698	6.631	-62.2	87.25
40	0.8261	3.699	0.2128	0.9242	1.269	0.4407	11.87	-65.7	107.1
42	0.5839	5.649	0.1504	0.7104	1.653	0.3770	21.67	-70.74	150.6

Table-6 Effect of generator temperature on thermodynamic performances of Integrated single effect $Li/Br-H_2O$ VARS using R1233zd(E) ecofriendly refrigerants at MTC evaporator temperature=-65ºC, T_Eva_VARS= 5ºC, Approach=, 5ºC

Generator temperature of VARS ºC)	COP_ VARS	EDR_ VARS	Exergetic Efficiency_VARS	COP _MTC	EDR _MTC	Exergetic Efficiency _ M TC	%Improvement in COP _MTC	% Decrement in EDR _ITC	%Improvement in exergetic Efficiency _ LTC
120	1.244	1.888	3.462	1.224	0.9124	---	---	-51.64	51.04
125	1.117	2.182	3.143	1.177	0.9701	0.5076	0.2043	-65.54	61.50
130	1.112	2.450	0.2865	1.136	1.011	0.4924	2.162	-58.61	68.61
135	1.054	2.813	0.2623	1.096	1.094	0.4775	4.010	-61.09	82.04
140	1.001	3.146	0.2412	1.058	1.160	0.4630	5.742	-63.13	91.95
145	0.9529	3.489	0.2228	1.023	1.227	0.4489	7.35	-64.82	101.50

Thermodynamic first law energy performances of integrated double effect $Li/Br-H_2O$ VARS system cascaded vapour compression systems with varying generator temperature for constant evaporator temperature of -75ºC in lower vapour compression cycle is shown in tables 6 for R1233zd(E), respectively. It was observed that by increasing VARS generator temperature, the thermodynamic first law (energy) performance is decreases while second law (exergy)efficiency is decreases and exergy destruction ratio is increases.

4. Conclusions

The cascaded absorption- compression refrigeration systems have been studied on the basis of energy-exergy analysis and following conclusions were drawn from present investigations

- By reducing the exergy destruction rate by using HFO refrigerants therefore, sustainability improved.
- The best thermodynamic performances were observed by using R1234ze(Z) and R1233zd(E), HFO-1336mzz(Z), and R1225ye(Z) and R1234ze(E) and R1243zf performance
- The lowest thermodynamic performances were fund by using R1234yf in cascaded system in lower circuit up to a VCR evaporator temperature.
- The use of HFO refrigerants in low temperature VCR circuit of can be an eco-safety step because of the ultra-low GWP and ODP for replacing R134a and R236fa and R227ea respectively.
- The larger value of temperature overlapping in the cascade heat exchanger reduces the first law performance (COP) and second law (exergetic efficiency) performances of the system
- The energetic efficiency (COP) and exergetic performance (exergetic efficiency) of the cascaded system decreases with increase in absorber temperature. The exergy destruction and exergy destruction ratio (EDR) increased at cascaded low temperature cycle evaporator of -75ºC
- In single cascading with VARS, at low temperature applications up to -30ºC evaporator temperature, HFO ecofriendly refrigerants (R-1234ze(Z), R-1234ze(E), R1233zd(E), R-1243zf, R1225ye(Z), HFO-1336mzz(Z) and R1234yf will be certainly useful for replacing HFC, HCFC and CFC refrigerants, while R1224yd(Z) will be suitable for -10ºC above evaporator temperature for replacing R134a.
- In single cascading with VARS, at low temperature applications up to -50ºC evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), R1233zd(E), HFO-1336mzz(Z) and R1234yf will be certainly useful for replacing HFC, HCFC and CFC refrigerants.
- In the double cascading with VARS, at low temperature applications up to -75ºC evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), R1233zd(E), HFO-1336mzz(Z) will be certainly useful for replacing HFC, HCFC and CFC refrigerants and can be better than replacing R134a
- In the triple cascading with VARS, at ultra-low temperature applications up to -150ºC evaporator temperature, HFO ecofriendly refrigerants (R1225ye(Z), HFO-1336mzz(Z) will be certainly useful for replacing R32, and, HCFC and CFC refrigerants.
- The first law (energy) efficiency (COP) and second (exergetic efficiency) law performance shows better performances than using R1234zf, R-1234yf and R1225ye(Z) for replacing R245fa, R236fa, R227ea and R134a respectively.

References

[1] R.S. Mishra[ ] Performance Optimization of Four Stage Cascade Refrigeration Systems using Energy-Exergy Analysis in the R1234ze & R1234yf in High Temperature Circuitand Ecofriendly Refrigerants in Intermediate Ciircuits and Ethane in the Low Temperature Circuit for Food, Pharmaceutical, Chemical Industries, International Journal of Advance Research and Innovation. ISSN 2347 - 3258 , Volume 2, Issue 4 (2014) 725-731.

[2] R.S. Mishra[ ] Use of Hydrocarbons in Low Temperature Circuit in Terms of First Law and Second Law Efficiency of Four Stage Cascade Refrigeration of Semen Preservation, International Journal of Advance Research and Innovation. ISSN 2347 - 3258 , Volume 2, Issue 4 (2014) 725-731.

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

[4] D. Colorado, W. Rivera[ ] Performance comparison between a conventional vapor compression and compression-absorption single-stage and double-stage systems used for refrigeration App. Therm. Engg., 87 (2015), pp. 273-28.

[5] Szargut, J.; Morris, D.R.; Steward, F.R. [1987]Exergy Analysis of Thermal, Chemical, and Metallurgical Processes; Hemisphere Publishing: New York, NY, USA.

[6] Dincer, I.; Rosen, M.A. Thermodynamic aspects of renewables and sustainable development. Renew. Sustain. Energy Rev. 2005, 9, 169–189.

[7] Dincer, I.; Rosen, M.A. A worldwide perspective on energy, environment, and sustainable development. Int. J. Energy Res. 1998, 22, 1305–1321.

[8] Dincer, I. The role of exergy in energy policy making. Energy Policy 2002, 30, 137–149.

[9] Rosen, M.A.; Dincer, I. Exergy as the confluence of energy, environment and sustainable development. Exergy Int. J. 2001, 1, 3–13.

[10] Rosen, M.A.; Dincer, I.[2005] Efficiency analysis of a cogeneration and district energy system. Appl. Therm. Eng. , 25, 147–159

[11] Dincer, I.; Rosen, M.A. Thermodynamic aspects of renewables and sustainable development. Renew. Sustain. Energy Rev. 2005, 9, 169–189.

[12] Rosen, M.A.; Dincer, I. Exergy as the confluence of energy, environment and sustainable development. Exergy Int. J. 2001, 1, 3–13.

[13] Kapil Chopra, V. Sahni , R. S Mishra [ ] Energetic and Exergetic Based Comparison Multiple Evaporators with Compound Compression and Flash Intercooler with Individual or Multiple Throttle Valves, International Journal of Advance Research and Innovation. ISSN 2347 - 3258 , Volume 1, Issue 1 (2013) 73-81.

[14] Gebreslassie, B.H.; Medrano, M.; Boer,D.[2010], Exergy analysis of multi-effect water-LiBr absorption systems: From half to triple effect. Renew. Energy , 35, 1773–1782

[15] Gebreslassie, B.H.; Medrano, M.; Mendes, F.; Boer, D. Optimum heat exchanger area estimation using coefficients of structural bonds: Application to an absorption chiller. Int. J. Refrig. 2010, 33, 529–537.

[16] Ghani, M.U.; Zaman, M.; Khan, I. Thermodynamic modeling and optimization of double effect series flow LiBr-H_2O vapor absorption chiller. In Proceedings of the ICET 2016 International Conference on Emerging Technologies, Singapore, 7–8 January 2016.

[17] Bereche, R.P.; Palomino, R.G.; Nebra, S.A. Thermoeconomic analysis of a single and double-effect LiBr/H_2O absorption refrigeration system. Int. J. Thermodyn. 2009, 12, 89–96.

[18] Morosuk, T.; Tsatsaronis, G.[2008] A new approach to the exergy analysis of absorption refrigeration machines. Energy ,33, 890–907

[19] J. Fernandez-Seara, J. Sieres and M. Vazquez, Compression-absorption cascade refrigeration system, Appl. Therm. Eng. 26 (2006) 502–512.

[20] Garimella, S., Brown, A.M., Nagavarapu, A.K., [2011]. Waste heat driven absorption/vapor-compression cascade refrigeration system for megawatt scale, high-flux, lowtemperature cooling. Int. J. Refrig. 34, 1776–1785.

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

[22] S. Goktun and I. Dehaper, The optimum performance of a solar assisted combined absorption– compression system for air conditioning and space heating, Sol. Energy 71 (2001) 213–216

[23] C. Cimsit and I. T. Ozturk, Analysis of compressionabsorption cascade refrigeration cycles, Appl. Therm. Eng. 40 (2012) 311–317.

[24] M Kilic,.; Kaynakli, O.[2007] Second law-based thermodynamic analysis of water-lithium bromide absorption refrigeration system. Energy , 32, 1505–1512.

[25] Osta-Omar, S.; Micallef, C. Mathematical Model of a Lithium-Bromide/Water Absorption Refrigeration System Equipped with an Adiabatic Absorber. Computation 2016, 4, 44.

[26] V Jain,., Kachhwaha, S.S., Sachdeva, G., 2013. Thermodynamic performance analysis of a vapor compression– absorption cascaded refrigeration system. Energy Convers. Manag. 75, 685–700.

[27] L. Wang, A. Ma, Y. Tan, X. Cui and H. Cui, Study on solar assisted cascade refrigeration system, Energy Procedia 16 (2012) 1503–1509.

[28] R. S. Mishra, Kapil Chopra , V. Sahni Methods for Improving Thermal Performance of Three Stage Vapour Compression Refrigeration Systems with Flash-Intercooler Using Energy– Exergy Analysis of Eight Ecofriendly Refrigerants, International Journal of Advance Research and Innovation, ISSN 2347 - 3258.Volume 3, Issue 1 (2015) 94-102

[29] R. S. Mishra Thermal Analysis & Optimization of Two Stages Vapour Compression Refrigeration Systems Using Sixteen Ecofriendly Refrigerants, International Journal of Advance Research and Innovation,ISSN 2347 – 3258, Volume 3, Issue 1 (2015) 31-36

[30] R. S. Mishra[2015] Performance Evaluation of Ecofriendly Refrigerants in the Low Temperature Circuit in Terms of First Law and Second Law Efficiency of Three Stages Cascade Vapour Compression Refrigeration of Biomedical Applications, International Journal of Advance Research and Innovation,ISSN 2347 – 3258, Volume 3, Issue 2 (2015) 31-36, () 332-339

[31] [31]Radhey Shyam Mishra [2019] Thermal performances (first law efficiency, exergy destruction ratio & exergetic efficiency) of cascade single effect ammonia-water (NH3-H20) vapour absorption refrigeration system coupled with vapour compression refrigeration using eco-friendly refrigerants in the low-temperature cycle of VCRS systemInternational Journal of Research in Engineering and Innovation Vol-3, Issue-1 (2019), 1-9.

[32] Radhey Shyam Mishra [2019] Thermal performance of cascaded vapour compression absorption systems, International Journal of Research in Engineering and Innovation Vol-3, Issue-1 (2019), 61-67.

[33] Radhey Shyam Mishra[2019], Performance evaluationof half effect Li/Br-H2O vapour absorption systems using multi cascading of vapour compression cycles for ultra-low temperature applications International Journal of Research in Engineering and Innovation Vol-3, Issue-6 (2019), 509-526.

Cite this article as: R.S. Mishra, Performance evaluation of double effect Li/Br-H_2O vapour absorption refrigeration system with three cascaded vapour compression refrigeration systems using HFO refrigerants for ultra-low temperature applications, International journal of research in engineering and innovation (IJREI), vol 5, issue 1 (2020), 20-28. *https://doi.org/10.36037/IJREI.2021.5103*.