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Comparison of half effect absorption-compression cascaded refrigeration system using thermodynamic (energy-exergy) analysis

R.S. Mishra

Department of Mechanical & Production Engineering, Delhi Technological University Delhi, India

Abstract

In the most of industrial processes, the waste heat energy increases production cost. Using this waste heat to produce power or cooling can decrease the costs and increases the thermo-economic efficiency of the industrial systems. A growing need for refrigeration in industry due to demands of higher living standards, the increasing requirements for comfort, and the increasing thermal load a half effect, single & double effect and triple effect LiBr-H_2O vapour absorption refrigeration systems provide very good efficiency for cooling up to 0^0C temperature . The energy-exergy analysis in the vapour absorption and compression systems helped to find out the major loss incurring component. In order to reduce those losses many attempts has been made so that first law efficiency (COP) of the vapour absorption refrigeration system cascaded with vapour compression cycle can be increased. It is 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), 172.867% increment of second law efficiency (i.e. exergetic efficiency) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a, 42.867% enhancement in first law efficiency (COP) of 142.7267% increment of second law efficiency using HFO -1234yf for -50ºC of evaporator temperature of VCRS . Similarly 72.024% 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 -50ºC 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.

Keywords: Energy-exergy analysis, Absorption-compression cascaded refrigeration system, Thermodynamic analysis

1. Introduction

For the rapid growth and development of the countries there has been continues demand of energies. These energies are generally meet with burning of fossil fuels which has led to global warming. So for meeting the huge demand of Refrigeration and air conditioning at large scale Vapor absorption system working on Lithium Bromide and water is used. Solar energy and Waste heat from industries are the most favorable options because these sources do not degrade the environment anyway.
The research work done on VAS working on LiBr/H2O for cooling purpose is based on First and Second Law of thermodynamics has been done in context of one of its major component Generator. The researchers have tried to find out the optimum COP of the system varying the different parameters affecting its performance. They found that Generator temperature has highest influence on the COP of the system.

1.1 Energy-exergy analysis of vapour absorption system

Energy analysis of vapour absorption refrigeration system and its effect on Generator The basic thermodynamic analysis is the Energy analysis for any system. Energy analysis helps to find out the major loss incurring component. In order to reduce

Corresponding author: R. S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in

those losses many attempts has been made so that COP of the cycle can be increased. Energy from external source is given in Generator so generator temperature is found to play an important role in COP of the cycle. The second laws, have been employed to be a tool for consideration of the quantity and quality of energy in the thermal system. Exergy analysis has determined the destruction and losses of exergy in various components and hence exergy destruction ratio which is calculated based on exergy of overall system input or exergy of overall system output. Refrigeration systems are generally driven by electrical power in the mechanical vapour compression system. Absorption chillers are an alternative approach; whose use the thermal power (industrial waste heat, renewable energy sources, or other thermal sources) as a driving force. Furthermore, absorption cooling systems do not cause ozone depletion, as long they use natural substances, as working fluids .A lot of researchers have studied various absorption refrigeration systems which use different thermal energy sources.

A parametric study of double effect series flow and double effect parallel flow vapour absorption machines is carried out by Meraj , Adnan Hafiz , M. Jamil Ahmad [1] to provide design engineers, appropriate information for developing sustainable machines to reduce irreversibility in each component of the whole system, thereby reducing net exergy loss and efforts have been made by performed Second law analysis and found that the exergetic efficiency first increases , reaches a maxima and then starts decreasing with increase in high pressure generator temperature and also concluded that the exergetic efficiency is more in parallel flow as compared to the series flow for the same generator temperatures in the vapour absorption refrigeration system. Similarly irreversibility first decreases in both cases, reaches a minimum and then increases. Irreversibility is less in parallel configuration as compared to the series one. Absorption cooling cycles are environmental and can use solar or waste heat for cooling with very small electric power.

SC Kaushik, Akhilesh Arora,[1] carried out the energy and exergy analysis of single effect and series flow double effect water–lithium bromide absorption systems by developing computational model using water–lithium bromide solution. This analysis involved the determination of effects of generator, absorber and evaporator temperatures on the energetic and exergetic performance of these absorption refrigeration systems. The effects of pressure drop between evaporator and absorber, and effectiveness of heat exchangers are also investigated for vapour absorption systems. The numerical computation was carried out for finding performance parameters (i.e. coefficient of performance, exergy destruction, efficiency defects and exergetic efficiency) and it is found that the coefficient of performance of the single effect system lies in range of 0.6–0.75 and 0.90 to 1.2 for double effect system respectively. Mohd. Meraj et.al [2] studied double effect series flow and double effect parallel flow vapour absorption machines and carried out second law analysis to reduce irreversibility in each component of the whole system, thereby reducing net exergy loss and found that the exergetic efficiency first increases , reaches a maxima and then starts decreasing with increase in high pressure generator temperature. . It has also been observed that the exergetic efficiency is more in parallel flow as compared to the series flow for the same generator temperatures Rabi Karaali [3] carried out work on thermal analysis of a double effect parallel flow and single effect absorption cooling systems by developing computer program for the thermodynamic properties of lithium bromide-water solutions using the exergy analysis and found that the double effect parallel flow absorption systems have better advantages than the single effect absorption system. The coefficient performance (COP) and the exergetic efficiency (exergetic coefficient of performance) of the double effect parallel flow absorption systems (i.e. the double effect cycle COP is 1.195 and exergetic efficiency as 0.28) , are higher than the single effect cycle (COP is 0.68) and exergetic efficiency (as 0.23) . Rabi Karaali [4] presented exergy analysis of a half effect absorption system using thermodynamic properties of lithium bromide-water solutions, by developing computer program in FORTRAN codes. Due to the reason that the half effect absorption systems is used for low temperature heat energy or waste heat energy and found that the coefficient performance (COP) and the exergetic efficiency of the half effect absorption system are 0.45 and 0.24, respectively. For each component the exergy loss is calculated and it was found that the 92 % of total irreversibilities in the absorber and in the evaporator and also concluded that better design and efficiencies of the evaporator and the absorber is very important for the half effect absorption cycles. By improving the design of these two components will directly improve and affect the working conditions and thermal performances of the cycle. Md Azhar and M. Altamush Siddiqui [5] analyzed Triple Effect Vapour Absorption cycle using liquefied petroleum gas (LPG) and compressed natural gas (CNG) as sources of energy selected because the triple effect system requires heat at relatively high temperature using LiBr-H2O solution as working pair and compared with the Single and Double Effect cycles. The thermodynamic analysis is done for different values of the evaporator and the condenser temperatures; the absorber temperature is assumed to be equal to the main condenser temperature by assuming the temperature and concentration of LiBr salt in the high pressure generator, to which heat is supplied, are varied simultaneously for fixed temperatures/pressures in the middle and high pressure condensers and investigated the effect of the high pressure generator temperature on the coefficient of performance (COP), volume flow rate and cost of the LPG and CNG. Arora et al. [6] have developed a double effect cycle 120-150^{0}C, half effect 60-75^{0}C and triple effect cycles which require generator temperature even higher than 150^{0}C.

Dixit Manoj et.al [7] developed mathematical model of vapour absorption-compression cascaded refrigeration system, comprising of a vapour compression refrigeration system in low temperature stage using CO2, NH3 and R134a as ecofriendly refrigerants and H_2O-LiBr vapour absorption refrigeration system at the high temperature stage and found that the cascade condenser, compressor and refrigerant throttle valve are the major source of exergy destruction**.** S Arivazhagan et.al. [8] carried out experimental investigation on the performance of a two-stage half effect vapour absorption cooling system The prototype is designed for 1 kW cooling capacity using HFC based working fluids (R134a as refrigerant and DMAC as absorbent). The performance of the system in terms of degassing range, coefficient of performance and second law efficiency has been obtained. The system is capable of producing evaporating temperature as low as −7^{0}C with generator temperatures ranging from 55^0 to 75^{0}C. The degassing range is 40% more in high absorber than in low absorber as the high absorber is operated at optimum intermediate pressure. The optimum generator temperature is found to be in the range of 65–70^{0}C at which the coefficient of performance is 0.36. Shun-Fu Lee and S. A. Sheriff [9] carried out parametric analysis using thermodynamic analysis of a lithium bromide/water absorption system for cooling and heating applications and it was found that a low cooling water temperature yields both a higher cooling COP and higher exergetic efficiency and also observed that by increasing the heat source generator temperature can improve the COP of the system and also found that the heat source temperature increases beyond a certain limit , the COP of the system decreases due to the negative effect of increasing the heat source temperature. Inzunza et al. [10], compared of the performance of single-effect, half-effect, double-effect in series and inverse absorption cooling systems operating with the mixture LiBr- H_2O and found that for the generation temperature between 100^{0}C and 110^{0}C, the COP of the single effect was up to 0.89, for the generation temperature of over 55 ^{0}C the COP of the half effect was up to 0.44. They also found that the most efficient system is double effect of the COP up to 1.48 for higher temperature while, for low temperatures the half effect systems work better than any other. Wang and Zheng [11] developed the performance of half effect & single effect LiBr / H_2O absorption cooling cycle and found that half effect cycle's absorption cooling cycle can be used for generator temperature from 50^{0}C to 80^{0}C. This paper mainly deals with half effect vapour absorption-compression cascade system is lowest by using R141b and highest while using R227ea as shown in table-2. The cascade system exergetic refrigeration system, comprising of a vapour compression cascade refrigeration system in low temperature stage and half effect absorption refrigeration system at the high temperature stage, is analyzed. CO_2, NH3 and R134a have been considered as refrigerants in the compression stage and the H2O-LiBr refrigerant absorbent pair in the absorption stage using energy-exergy analysis. The performance of the refrigeration system. The comparative study carried out in terms of their thermal performances using HFC-134a and HFo-1234yf for evaporator temperature of VCRS is -50^{0}C and -30^{0}C respectively using HFO-1234ze respectively.

2. Results and Discussion

Following numerical values have been taken for validation of thermal models for half effect LiBr-H_2O cascade vapour compression-absorption refrigeration systems.

2.1 Half Effect Cascade vapour compression-absorption refrigeration system using ecofriendly refrigerants

$T\_{Generator}$=80ºC.T_Cond=30ºC, T_{Eva}=5ºC,
T_absorber=30ºC, Compressor Efficiency=0.80,
T_Eva_LTC=-50ºC (for using R-1234yf and HFCs, hydrocarbons, natural refrigerants in VCRS), & -30ºC (for using R1234ze & R1234yf, HFCs, hydrocarbons, natural refrigerants in the VCRS), approach (Temperature Overlapping) =10ºC)

Table-1 shows the variation of thermal performance parameters of triple effect cascade vapour absorption refrigeration system using lithium bromide -water solution coupled with vapour compression refrigeration system using 29.09 kW of load. The evaporator of VARS is cascaded with condenser of vapour compression refrigeration systems using following nine ecofriendly refrigerants. It is found that overall first law efficiency in terms of coefficient of performance (COP) of cascade refrigeration system using R245fa refrigerant is highest and lowest by using R227ea as shown inTable-1(a) and Table-1(b) respectively while exergy destruction of

efficiency is highest by using R141b and lowest by using R227ea as shown in table-3.

Table-1(a):Thermal performance of single Effect LiBrH_2O Vapour absorption refrigeration system cascaded by vapour compression refrigeration system using ecofriendly refrigerants at the evaporator temperature of -30ºC in the VCRS cycle

S.No	Refrigerant	COP_{Over_alll}	$EDR\_{Overall}$	Exergetic efficiency
1	R134a	1.126	2.057	0.3271
2	R1234ze	1.124	2.070	0.3257
3	R1234yf	1.117	2.122	0.3203
4	R227ea	1.117	2.218	0.3107
5	R236fa	1.119	2.108	0.3217
6	R245fa	1.133	2.008	0.3324
7	R32	1.122	2.087	0.3239
8	R507a	1.110	2.174	0.3151
9	R717	1.129	2.04	0.3289

10	R123	1.138	1.976	0.3360
11	R125	1.099	2.260	0.3068
12	R152a	1.134	2.003	0.3330
13	R404a	1.105	2.216	0.3109
14	R410a	1.122	2.086	0.3240
15	R407c	1.004	2.382	0.2957
16	R290	1.125	2.069	0.3258
17	R600	1.133	2.011	0.3321
18	R600a	1.125	2.063	0.3265
19	R141b	1.145	1.929	0.3414
20	R143a	1.141	2.154	0.3171

Table-1(b)::Thermal performance of Half Effect LiBrVapour absorption refrigeration system cascaded by vapour compression refrigeration system using ecofriendly refrigerants (for T_EVA_VCRS= -50^{o}C)

S.No	Refrigerant	COP$_{_Over_alll}$	EDR$_{_Overall}$	Exergetic Efficiency
1	R134a	0.6155	1.516	0.3974
2	R1234yf	0.6079	1.602	0.3844
3	R227ea	0.5956	1.746	0.3642
4	R236fa	0.6084	1.596	0.3853
5	R245fa	0.6196	1.473	0.4044
6	R32	0.6138	1.535	0.3945
7	R507a	0.6042	1.644	0.3782
8	R717	0.6157	1.515	0.3977
9	R123	0.6238	1.428	0.4118
10	R125	0.5951	1.752	0.3634
11	R404a	0.6011	1.680	0.3732
12	R410a	0.6142	1.532	0.3950
13	R407c	0.5956	1.746	0.3641
14	R290	0.6151	1.521	0.3967
15	R600	0.6203	1.465	0.4057
16	R600a	0.6144	1.528	0.3955
17	R141b	0.6296	1.368	0.4223
18	R143a	0.6068	1.614	0.3825

Table-2:Thermal performance of double Effect LiBrH$_2$O Vapour absorption refrigeration system cascaded by vapour compression refrigeration system using ecofriendly refrigerants at the evaporator temperature of -30^{o}C in the VCRS cycle,

S.No	Refrigerant	COP$_{_Over_alll}$	EDR$_{_Overall}$	Exergetic Efficiency
1	R134a	1.822	1.037	0.4910
2	R1234ze	1.817	1.047	0.4884
3	R1234yf	1.80	1.085	0.4796
4	R227ea	1.77	1.156	0.4638
5	R236fa	1.805	1.075	0.4820
6	R245fa	1.838	1.001	0.4998
7	R32	1.813	1.057	0.4863
8	R507a	1.784	1.123	0.4711
9	R717	1.829	1.021	0.4949
10	R123	1.849	0.9767	0.5059
11	R125	1.757	1.187	0.4573
12	R152a	1.84	0.9964	0.5009
13	R404a	1.772	1.152	0.4647
14	R410a	1.812	1.059	0.4858
15	R407c	1.731	1.251	0.4442
16	R290	1.818	1.045	0.4889
17	R600	1.837	1.003	0.4994
18	R600a	1.819	1.041	0.4899
19	R141b	1.865	0.9424	0.5148
20	R143a	1.79	1.108	0.4744

Table-3:Thermal performance of Tripple Effect LiBrH$_2$O Vapour absorption refrigeration system cascaded by vapour compression refrigeration system using ecofriendly refrigerants at the evaporator temperature of -30^{o}C in the VCRS cycle,

S.No,1	Refrigerant	COP_$_{Over_alll}$	EDR_$_{Overall}$	Exergetic Efficiency
1	R134a	2.151	1.421	0.4131
2	R1234ze	2.148	1.429	0.4116
3	R1234yf	2.131	1.469	0.4050
4	R227ea	2.10	1.543	0.3933
5	R236fa	2.135	1.459	0.4067
6	R245fa	2.168	1.382	0.4198
7	R32	2.139	1.448	0.4084
8	R507a	2.113	1.510	0.3984
9	R717	2.154	1.414	0.4142
10	R123	2.179	1.357	0.4242
11	R125	2.087	1.574	0.3885
12	R152a	2.169	1.380	0.4202
13	R404a	2.098	1.547	0.3926
14	R410a	2.142	1.442	0.4095
15	R407c	2.034	1.712	0.3687
16	R744	1.993	1.827	0.3537
17	R290	2.147	1.430	0.4115
18	R600	2.167	1.385	0.4194
19	R600a	2.148	1.425	0.4124
20	R141b	2.196	1.321	0.4309
21	R143a	2.12	1.495	0.4008

Table 4(a): Performance comparison of single effect vapour absorption refrigerated cascaded with vapour compression refrigeration system using HFC-134a at evaporator temperature of -50^{o}C .

Performance Parameters	Half effect Vapour Absorption System	Half effect Cascade VARS_VCRS	% improvement
COP	0.4255	0.6155	44.65
Exergetic Efficiency	0.1558	0.3974	155
EDR	5.419	1.516	72.022 (Reduction)

The performance parameters have been compared with the half effect vapour absorption system with half effect vapour absorption-compression refrigeration system cascaded with vapour compression refrigeration system using ecofriendly HFC-134a and it was observed that 44.65% first law efficiency enhancement and 42.876% using HFO-1234yf for -50^{o}C of evaporator temperature of vapour compression cycle as shown in table-4(a) & table-4(b) respectively. Similarly 155% enhancement in second law efficiency using half effect vapour absorption system cascaded with vapour compression refrigeration cycle using HFC-134a and 146.726% using HFO-1234yf in the vapour compression cycle as shown in table-4(a-b) respectively. Similarly exergy reduction is 72.024% using HFC-134a and 146.726% using HFO-1234yf in the vapour compression cycle as shown in table-4(a) & table-4(b) respectively. The performance parameters have been compared with the half effect vapour absorption system with half effect vapour absorption-compression refrigeration system cascaded with vapour compression refrigeration system using ecofriendly HFC-134a, single effect vapour absorption system with half effect vapour absorption-compression refrigeration system cascaded with vapour compression refrigeration system using ecofriendly HFC-134a, double effect vapour absorption system with half effect vapour absorption-compression refrigeration system cascaded with vapour compression refrigeration system using ecofriendly HFC-134a, tripplel effect vapour absorption system with half effect vapour absorption-compression refrigeration system cascaded with vapour compression refrigeration system using ecofriendly HFC-134a respectively and it is found that first law efficiency (COP) and second law efficiency (exergetic efficiency) performance increases while exergy destruction based on exergy of product is decreases

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Table 4(b) : Performance comparison of single effect vapour absorption refrigerated cascaded with vapour compression refrigeration system using HFO-1234yf at evaporator temperature of -50^{o}C .

Performance Parameters	Half effect Vapour Absorption System	Half effect Cascade VARS_VCRS	% improvement
COP	0.4255	0.6079	42.876
Exergetic Efficiency	0.1558	0.3844	146.726
EDR	5.419	1.602	70.44

Table-5 : Performance comparison of single effect vapour absorption refrigerated cascaded with vapour compression refrigeration system using HFO-1234yf at evaporator temperature of -50ºC .

Performance Parameters	Half effect simple vapour absorptin refrigeration system	Half effect cascaded vapour Absorption System	Single effect Cascaded vapour absorption System	Double Effect cascaded vapour absorption System	Triple effect cascaded vapour absorption System
COP	0.4255	0.6155	1.126	1.822	2.151
Exergetic Efficiency	0.1558	0.3974	0.3271	0.4131	0.4910
EDR	5.519	2.057	1.516	1.421	1.037

3. Conclusions

The following conclusions were drawn.

(i) The thermodynamic performances in the case of cascaded half effect vapour absorption refrigeration system coupled with vapour compression cycle is improved.

(ii) 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.

(iii) The 44.65% increment of first law efficiency (i.e. over all COP) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

(iv) The 42.867% increment of first law efficiency (i.e. over all COP) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

(v) The 172.867% increment of second law efficiency (i.e. exergetic efficiency) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

(vi) The 142.7267% increment of second law efficiency (i.e. exergetic efficiency) of the half effect vapour absorption refrigeration cascaded with vapour compression cycle using HFC-134a ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

(vii) The 72.024% 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 ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

(viii) The 70.44% 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 ecofriendly refrigerant for -50ºC of evaporator temperature of VCRS.

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