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Thermodynamic performances of ejector refrigeration systems (ERS) using low GWP ecofriendly HFO refrigerants

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Abstract

Currently, the refrigeration and air conditioning is looking for energy efficient technologies which will reduce the electric power consumption from causing the damage to the environment. The ejector refrigeration system is found to be energy efficient system which will be able to provide the cooling by utilizing the environment friendly refrigerants. In this paper HFO refrigerants are used in ejector refrigeration system and comparison were made with other HFC and HCFC refrigerants.

Keywords: Energy-Exergy analysis, Ejector refrigeration system, Thermodynamic performances.

1. Introduction

In the context of recent developments in the field of energy, the aspect related to energy consumption is of excessive importance for experts. Many industries trust on refrigeration technologies; a great challenge being stated in energy savings in this sector. In this respect, efforts oriented towards efficient industrial refrigeration systems have revealed the necessity of a proper design. The most commonly used method of cooling is based on vapor compression cycles.

Ejector refrigeration technology is the one which can have utilized the waste heat to compress the refrigerant instead of compressor. Therefore, electrical energy was saved which can have employed to meet the other demand. When ejector is integrated with vapour compression refrigeration system, then system will use less compressor power to provide the natural cooling of products.

2. Ejector Refrigeration system

In the vapour compression refrigeration system, throttle device is used to expand the refrigerant from high pressure prevailing in the condenser to low pressure evaporator. Capillary tube and thermostatic expansion valve, used in the throttling devices in the vapour compression refrigeration system has highly irreversible process which causes larger amount of wastage of the kinetic energy of the refrigerant. Vapour compression refrigeration systems uses CFCs, HFCs and HCFC refrigerants and their leakage from the system causes emissions in the environment hence degrading its air quality. This emission can be direct emission or indirect or both. Therefore, energy efficient technologies which reduced the electric power consumption apart from the causing the damage to the environment. Ejector refrigeration system is an energy efficient device which is able to compress the refrigerant in the system and providing the cooling by utilizing the environment friendly refrigerant

Chen, J, [1] studied theoretically, the application of different nine working fluids in the ejector vapour refrigeration system and found theR600 gives higher first law efficiency (COP) of ejector refrigeration system. Chen, J, [2] had performed exergy analysis of an ejector refrigeration system using ecofriendly R134a refrigerant and found that by reducing the exergy destruction in the parts improves the quality of exergy analysis in terms of exergetic efficiency and concluded the maximum exergy destruction in ejector followed by generator and evaporator and tried for reducing ejector exergy destruction by improving the ejector efficiencies. Similarly, generator (boiler) exergy destruction can be reduced by improving design of other components of the system. Memet and A Preda [3] carried out theoretical analysis of ejector refrigeration system using R134a

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and found that when by increasing the generating temperature, the coefficient of performance(COP) is increasing together and the best COP value being 0.178. also the generating temperature increase leads to the increase of the work input to the pump. Li, H. et.al. [4] had compared thermodynamic performance characteristics of ejector expansion refrigeration cycle using R1234yf and R134a as a refrigerants and found that R1234yf gives better performance than R134a at 40ºC of condenser temperature and 5ºC of evaporator temperature. Trung Kien Nguyen & Chi Hiep Le [5] carried out the first and second law of thermodynamics, an ejector vapour compressor cascade refrigeration system using R134a and R410A refrigerant for the ejector and compressor sub-cycle, respectively. Also an intercooler was inserted for setting temperature at 26.5 °C for minimizing total exergy loss in the system. The effects of generator temperature, evaporator temperature, condenser temperature, intercooler temperature and intercooler temperature difference are studied and found that a combined cycle can improve 30.8% of COP in single compressor cycle and 122% when compared to the single ejector cycle. M Yari, M Sirousazar [6] carried out the first and second law (exergy) analysis of the ejector-vapour compression refrigeration cycle using internal heat exchanger and intercooler for enhancing the performance of the cycle and investigated the effects of the evaporative and condenser temperatures on the coefficient of performance (COP), second law efficiency, exergy destruction rate and entrainment ratio. and found that the COP and second law efficiency values of the new ejector-vapour compression refrigeration cycle are on average 8.6% and 8.15 % higher than that of the conventional ejector-vapour compression refrigeration cycle using R125. It was also observed that the COP of the new ejector-vapour compression cycle is 21 per cent higher than that of the conventional vapour compression cycle.

Yapici and Ersoy [7] had compared the thermodynamic performance of constant pressure and constant area mixing ejector using HR123 refrigerant and found the optimum coefficient of performance and area ratio determined by using the constant area flow model are greater than those of constant pressure model. Yin-Hai Zhu & Peixue Jiang [8] developed refrigeration system which combines a basic vapour compression refrigeration cycle with an ejector cooling cycle. The ejector cooling cycle is driven by the waste heat from the condenser in the vapor compression refrigeration cycle. The additional cooling capacity from the ejector cycle is directly input into the evaporator of the vapor compression refrigeration cycle. The governing equations are derived based on energy and mass conservation in each component including the compressor, ejector, generator, booster and heat exchangers. The system performance was analyzed for the design conditions and found that the COP is improved by 9.1% for R22 system. Chaiwongsa and Wongwishes [9] have carried out experimental investigation on two phase ejector as expansion device using R134a and R12 refrigerants and observed the COP improvement at lower sink temperature because motive mass flow rate is highly dependent on heat sink temperature. Chaiwongsa and Wongwishes [10] have carried out experimental investigation on the effect of throat diameter of the nozzle on the performance on the refrigeration system using ecofriendly R134a refrigerant in the two phase ejector as expansion device and found maximum cooling capacity and COP at 0.8mm throat diameter. by varying the dimension of nozzle diameter with cooling capacity. Da-Wen Sun [11] described a new integrated refrigeration cycle based on the combination of an ejector cycle with a vapour compression cycle for maximizing performance of the conventional ejector cycles and providing high COP for refrigeration and observed that this cycle has a significant increase in system performance over the conventional systems and its COP values are competitive to the absorption machines. In this modified system, the waste heat was used and, higher COP value was observed. The system performance can be further improved if dual refrigerants are used. Lucas and Kochler [12] found experimentally the improvement in COP of the vapour compression refrigeration cycle using R744 (CO_2) as refrigerant and found the entrainment ratio and ejector efficiency increases with increase in high side pressure and also concluded that ejector efficiency is maximum decrement with decreasing evaporator pressure. Kornhauser A.A [13] analyzed thermodynamic performance of the ejector-expansion refrigeration cycle on constant mixing pressure using R12 and found 21% improvement in COP. Nehdi [14] carried out theoretical investigation on the performance of ejector-expansion refrigeration cycle with ecofriendly synthetic refrigerants and found maximum performance of 22% using R141b. Also investigated maximum first law performance (COP) using ejector as expansion device occurred at 9.9 area ratio and found best performance for using R141b and R408A for a given operating condition. Bilir and Ersoy [15] investigated theoretical improvement of ejector refrigeration cycle using two phase ejector using R134a refrigerant and observed that COP increases with decreasing evaporator temperature and also by increasing condenser temperature. Saleh B., [16] had numerical investigated parameter analysis of ejector refrigeration cycle with different refrigerants using ejector refrigeration cycle and found best thermodynamic performance using R245fa. Sarkar [17] carried out optimization of geometric parameters of the ejector expansion refrigeration cycle using natural refrigerant (R717) and hydrocarbon (R600a and R290) refrigerants and observed 21.55% maximum COP improvement using isobutane (R600a), 18% using propane(R290).12% using ammonia(R717).

Lot of work have been done by several investigators using CFCs, HFCs, natural and hydrocarbon refrigerants in the ejector refrigeration systems and still very less work has been done using HFO refrigerant. In this paper the utility of HFO refrigerants in ejector refrigeration system are highlighted for improving thermodynamic performances.

3. Results and Discussion

Following Numerical values have been chosen for numerical computation

Cooling Load(Qeva)	4.75 KW
Boiler temperature(T_boiler)	333 K
Evaporator temperature (T_eva)	273 K
Condenser temperature (T_cond)	303 K
Ambient temperature (To)	300 K
T_ref	T_eva+5

Ejector geometric input

(Length / Diameter} ratio of constant area mixing chamber(L/D)	10
Diameter of primary nozzle throat (D_throat)	0.5/1000
Diameter of mixing chamber(d_m)	1.4/1000
Exit diameter of primary nozzle (d_p)	0.8/1000
Diffuser angle (theta)	3
Diffuser Length (L_d)	112/1000
Refrigerant	R1234zf
Area Ratio	7.84

Table- 1(a): Effect of ecofriendly refrigerants on the variation of thermal performance parameters of vapour compression refrigeration system using ejector

Refrigerant	COP	EDR	2nd law Efficiency
R-1234ze(Z)	6.483	4.007	0.1997
R-1234ze(E)	6.213	3.56	0.2193
HFO-1336 mzz(Z)	4.723	3.573	0.2187
R-1243zf	6.016	3.754	0.2103
R1234yf	5.788	3.298	0.2327
R-1233zd(E)	5.799	3.833	0.2069
R-1224yd(Z)	5.163	3.468	0.2238
R-1225ye(Z)	5.734	3.212	0.2374
R-124	5.333	3.256	0.2349
R123	5.141	3.545	0.220

Table-1(a) shows the variation of first law efficiency (COP) of vapour compression refrigeration system using ejector using ecofriendly refrigerants and it was observed that maximum COP was observed by using R1234ze(Z) and minimum by using R123. Similarly, maximum second law efficiency was observed by using R-1225ye(Z)

Table-1(b) Effect of ecofriendly refrigerants on the variation of thermal performance parameters of vapour compression refrigeration system using ejector

Refrigerant	Entrainment Ratio(shy)	Compression Ratio (Mu_1)	Mu_2
R-1234ze(Z)	1.454	1.942	7.089
R-1234ze(E)	1.383	1.970	6.804
HFO-1336 mzz(Z)	1.535	2.347	5.328
R-1243zf	1.359	1.807	6.543
R1234yf	1.353	1.987	6.313
R-1233zd(E)	1.477	2.07	6.403
R-1224yd(Z)	1.467	2.229	5.714
R-1225ye(Z)	1.386	2.151	5.858
R-124	1.396	2.162	5.827
R123	1.496	2.254	5.648
R125	1.326	2.155	5.32

Table-1(b) shows the variation of Entrainment Ratio (shy) of vapour compression refrigeration system using ejector using ecofriendly refrigerants and it was observed that maximum Entrainment Ratio was observed by using HFO-1336mzz(Z) and minimum by using R125. Similarly, maximum compression Ratio was observed by using R-1225ye(Z).

Table-1(c) Effect of ecofriendly refrigerants on the variation of thermal performance parameters of vapour compression refrigeration system using ejector

Refrigerant	Effective ness	a	b
R-1234ze(Z)	0.07336	2.072	1.02
R-1234ze(E)	0.08521	1.963	1.03
HFO-1336 mzz(Z)	0.1063	2.134	0.9652
R-1243zf	0.08476	1.904	1.035
R1234yf	0.09896	1.891	1.033
R-1233zd(E)	3000.08411	2.097	1.022
R-1224yd(Z)	0.1034	2.063	0.9902
R-1225ye(Z)	0.1094	1.933	1.016
R-124	0.1085	1.959	1.011
R123	0.1030	2.092	0.9832

Table-1(c) shows the variation of Effectiveness of vapour compression refrigeration system using ejector using ecofriendly refrigerants and it was observed that maximum Effectiveness was observed by using R-1225ye(Z).

Table- 2(a): Variation with Generator (Boiler) temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_Boiler (K)	Exergetic efficiency	EDR	shy
333	0.2103	3.754	1.359
338	0.2.091	3.782	1.359
343	0.2080	3.807	1.359
348	0.2071	3.829	1.359
353	0.2062	3.848	1.359
358	0.2056	3.863	1.359
363	0.2053	3.871	1.359

Table-2(a) shows the variation of Exergetic efficiency of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of boiler temperature and it was observed that boiler temperature is increasing, second law efficiency (Exergetic efficiency) is decreasing.

Table- 2(b): Variation with Generator (Boiler) temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_Boiler (K)	a	b	mu_1
333	1.398	0.6952	1.665
338	1.449	0.7046	1.627
343	1.497	0.7132	1.593
348	1.542	0.7218	1.563
353	1.582	0.7296	1.537
358	1.619	0.7373	1.514
363	1.648	0.7444	1.495

Table-2(b) shows the variation of Compression Ratio of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of boiler temperature and it was observed that boiler temperature is increasing, Compression Ratio of ejector coupled vapour compression refrigeration system is decreasing.

Table- 3(a): Variation with condenser temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_Cond(K)	Exergetic efficiency	EDR	shy
300	0.2127	3.701	1.663
303	0.2138	3.676	1.807
306	0.2149	3.651	1.961
308	0.2158	3.634	2.069
309	0.2162	3.625	2.124

Table-3(a) shows the variation of Exergetic efficiency of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of condenser temperature and it was observed that condenser temperature is increasing, second law efficiency (Exergetic efficiency) is increasing. Similarly, entainment ratio is also increasing while exergy destruction ratio is decreasing

Table- 3(b): Variation with condenser temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_Cond(K)	COP	mu1	Mu2
300	1.363	1.807	1.486
303	0.9115	1.807	0.9951
306	0.6283	1.807	0.6867
308	0.4595	1.807	0.5376
309	0.4337	1.807	0.4746

Table-3(b) shows the variation of first law efficiency (COP) of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of condenser temperature and it was observed that condenser temperature is increasing, first law efficiency (COP) is decreasing.
Table-3(c) shows the variation of first law efficiency (COP) of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of condenser temperature and it was observed that condenser temperature is increasing, first law efficiency (COP) is decreasing.

Table- 3(c): Variation with condenser temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_Cond(K)	COP	a	b
300	1.363	1.582	0.8595
303	0.9115	1.489	0.8092
306	0.6283	1.413	0.7676
308	0.4595	1.368	0.7436
309	0.4337	1.348	0.7326

Table-4(a): Variation with evaporator temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_EVA[K]	Exergetic efficiency	EDR	shy
268	0.3826	1.613	3.002
273	0.3347	1.988	2.517
278	0.2791	2.583	2.126
283	0.2138	3.676	1.807

Table-4(a) shows the variation of second law efficiency (exergetic efficiency) of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of evaporator temperature and it was observed that evaporator temperature is increasing, second law efficiency (exergetic efficiency) is decreasing.

Table-4(b): Variation with evaporator temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_EVA[K]	COP	mu1	Mu2
268	0.3692	1.602	0.4163
273	0.4888	1.665	0.5451
278	0.6556	1.732	0.7233
283	0.9115	1.807	0.9950

Table-4(b) shows the variation of first law efficiency (COP) of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of evaporator temperature and it was observed that evaporator temperature is increasing,
first law efficiency (COP) is decreasing and entrainment ratio is also increasing.

Table- 4(c): Variation with evaporator temperature of ejector fitted vapour compression refrigeration system using R1243zf

T_EVA[K]	COP	a	b
268	0.3692	1.359	0.6478
273	0.4888	1.398	0.6952
278	0.6556	1.441	0.7483
283	0.9115	1.489	0.8092

Table-4(c) shows the variation of first law efficiency (COP) of ejector coupled vapour compression refrigeration system using HFO-1243zf with variation of evaporator temperature and it was observed that evaporator temperature is increasing, first law efficiency (COP) is decreasing and entrainment ratio is also increasing.

4. Conclusions

Following conclusions were drawn from this investigation.

- Maximum first law efficiency of ejector coupled vapour compression refrigeration system using HFO-1234ze(Z) while maximum second law efficiency was observed by using R-1225ye(Z)
- maximum Entrainment Ratio of ejector coupled vapour compression refrigeration system was observed by using HFO-1336mzz(Z) and minimum by using R125.
- Maximum Effectiveness of ejector coupled vapour compression refrigeration system was observed by using R-1225ye(Z)
- When boiler temperature of ejector coupled vapour compression refrigeration system is increasing, second law efficiency (Exergetic efficiency) is decreasing.
- When boiler temperature of ejector coupled vapour compression refrigeration system is increasing, compression Ratio of ejector coupled vapour compression refrigeration system is decreasing.
- When condenser temperature of ejector coupled vapour compression refrigeration system is increasing, second law efficiency (exergetic efficiency) is increasing. Similarly, entrainment ratio is also increasing while exergy destruction ratio is decreasing
- condenser temperature of ejector coupled vapour compression refrigeration system using R1243zf is increasing, first law efficiency (COP) is decreasing.

- When evaporator temperature of ejector coupled vapour compression refrigeration system using HFO-1243zf is increasing, first law efficiency (COP) is decreasing and entrainment ratio is also increasing.
- When evaporator temperature of ejector coupled vapour compression refrigeration system using HFO-1243zf is increasing, second law efficiency (exergetic efficiency) is decreasing.

References

[1] Chen J, et.al.{2014] screening of working fluids for the ejector refrigeration system, International journal of refrigeration, Vol-47, page-1-14

[2] Chen J, et.al. [2015] conventional and advanced exergy analysis of an ejector refrigeration system, Applied energy, Vol-144, page-139-151

[3] F Memet[1] and A Preda, [2015] An analysis of the performance of an ejector refrigeration cycle working with R134a IOP Conference Series: Materials Science and Engineering, Volume 95, Modern Technologies in Industrial Engineering (Mod Tech-2015), page-17–20 June 2015, Mammalia, Romania.

[4] Li, H. et.al. [2014] performance characteristics of R1234yf ejector expansion refrigeration cycle, Applied Energy, Vol-121, page-96-103

[5] Trung Kien Nguyen & Chi Hiep Le [2020] Thermodynamic analysis of an ejector–vapour compressor cascade refrigeration system Journal of Thermal Analysis and Calorimetry (2020), Published: 09 April 2020.

[6] M Yari, M Sirousazar[2007]Performance analysis of the ejector-vapour compression refrigeration cycle, Institute of Mechanical Engineers, https://doi.org/10.1243/09576509JPE484

[7] Yapici, R and Ersoy H.K. [2005] performance characteristics of the ejector expansion device, Energy conversion and Management, Vol-46, issue-18-19, page-3117-3135.

[8] Yin-Hai Zhu & Peixue Jiang [2012] Hybrid vapor compression refrigeration system with an integrated ejector cooling cycle International Journal of Refrigeration 35(1) · January 2012.

[9] Disawas S and Wongwishes S .[2004] experimental investigation on the performance of the refrigeration cycle using two phase ejector as expansion device, international journal of refrigeration, Vol-27, issue-6, page-587-594

[10] Chaiwongsa,P and Wongwishes S .[2007] Effect of throat diameters of the ejector on the performance of the refrigeration cycle using two phase ejector as an expansion device, International journal of refrigeration, Vol-30, issue-4, page-601-608

[11] Da-Wen Sun[1998] Evaluation of a combined ejector–vapour-compression refrigeration system, International Journal of energy research Volume22, Issue4, Pages 333-342,

[12] Lucus C and Kochler J [2020] experimental investigation of the COP improvement of a refrigeration cycle by using of an ejector, international journal of refrigeration, Vol-35, issue-6, page-1595-1603.

[13] Kornhauser A.A [1990], the use of an ejector as a refrigerant expander, proceedings of the USN/ IIR- Purdue refrigeration conference, page-10-19.

[14] Nehdi, E et.al., [2007], performance analysis of the vapour compression cycle using ejector as an expander, International journal of Energy Research, Vol-31, No.4, page-364-375

[15] Bilr N, and Ersoy H.K., [2009] Performance improvement of the vapour compression refrigeration cycle by a two phase constant area ejector, International Journal of Energy Research, Vol-33, No.5, page-469-480.

[16] Saleh B., [2016] performance analysis and working fluid selection for ejector refrigeration cycle, Applied Thermal Engineering, Vol-107, page-114-124.

[17] Sarkar J, et.al. [2010] geometric parameter optimization of ejector-expansion refrigeration cycle with natural refrigerants, International Journal of Energy Research, Vol-34, No.1, page-84-94.

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