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Thermodynamic analysis of two stage cascade refrigeration systems using R-1234ZE in high temperature circuit and R1234YF in low temperature circuit

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Abstract

This paper present the thermodynamic performance evaluation of two stage cascade vapour compression refrigeration system using Energy-Exergy method. The comparison were made of three systems of stage cascade vapour compression refrigeration in terms of their thermodynamic performances such as first law efficiency in terms of system overall coefficient of performance (COPOverall) and second law efficiency in terms of exergetic efficiency and system exergy destruction ratio (EDR_system) which is the based on exergy of fuel or exergy of product. The comparison were made for above three systems because system-1 (consist of HFO-1234ze in high temperature circuit and R134a in low temperature circuit) while System-2 (consist of HFO-1234ze in high temperature circuit and R1234yf in low temperature circuit) and System-3 (consist of HFO-1234yf in high temperature circuit and R134a in low temperature circuit).

Both HFO refrigerants (R-1234ze and R1234yf) have ultra-low Global Warming Potential (GWP) with zero Ozone Depletion Potential (ODP) and comparison was made of the computed results using HFO refrigerants with HFC-134a refrigerant as possible alternative replacements in low temperature refrigeration circuit in the range evaporator temperature variation between -35oC of -50oC. A numerical computation has been carried out for calculating first law efficiency in terms of system coefficient of performance (SCOP), Second law efficiency in terms of exergetic efficiency, exergy destruction ratio based on exergy of fuel and also exergy destruction ratio based on exergy of product, first law efficiency for high temperature circuit and first law efficiency for low temperature circuit, power required to run whole system and power required for each compressors, mass flow rate in each evaporators with variation of high temperature condenser temperature ranging between 30oC to 55oC and cascade evaporator temperature ranging between -20oC to 20oC using HFO1234ze along with effect of temperature overlapping in terms of approach. It was observed that the two stage cascade refrigeration system HFO-1234yf (2, 3, 3, 3-Tetrafluoropropene) in the low temperature circuit and HFO-1234ze (trans-1, 3, 3, 3-tetrafluoroprop-1-ene) in the high temperature circuit gives comparable thermal performances which can replace HFC-134a in the low temperature applications. The performance of system-2 using HFO-1234ze in HTC and HFO-1234yf in LTC) gives slightly less performance than system-1 (R-1234ze-R134a) and higher performance than system-3 (R1234yf-R134a)
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Keywords: Organic Rankine Cycle, Thermal power plant, Thermodynamic analysis.

1. Introduction

The usually used refrigerants in the cascade refrigeration system in recent past were CFC R12 in high temperature circuit and R22 in intermediate temperature circuit, along with R13in the low temperature circuit. Because of their high ODP and GWP, these refrigerants were either phased out or under consideration for the same for few years. After the revelation of the harmful effects of CFC and HCFC refrigerants on the ozone layer and global warming, there is a search to find alternative working fluids have ultra-low GWO and zero ODP in terms of HFO refrigerants in the recent few years. The HFC134a was found to be a suitable refrigerants for replacing R13 and is being successfully used. HFC134a has very high GWP which is a matter of environmental concern [1], therefore the use of HFO refrigerants in the cascade refrigeration is proposed [1, 2]. HFO stands for hydro-fluoro-olefin (HFO-1234yf) is a low global warming potential (GWP)

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refrigerant for use in automotive air-conditioning systems. HFC-134a is a hydro-fluoro-carbon refrigerant, while (HFO-1234yf) is a hydro-fluoro-olefin refrigerant. Hydro-fluoro-olefin, or in short HFO, is a definition that is familiar to many of us. R1234yf, R1234ze are few examples of HFOs. HFO-1234yf was developed to meet the European directive 2006/40/EC in 2011 requiring use of HFO refrigerant in AC system with a GWP below 150. HFO-1234yf, which has a 100-year GWP lower than 5. These refrigerants are used as a "near drop-in replacement" for R-134a, which has a 100-year GWP of 1430.HFO-1234yf has the lowest cost among the currently proposed alternatives for replacing R134a.

2. Literature Review

Chopra Kapil, Sahni V., Mishra R. S. [1] carried out thermodynamic analysis utilizing first and second law of eight ecofriendly R152a, R600, R600a, R410a, R290, R1234yf, R404a and R134a refrigerants in the two stage vapor compression refrigeration system based on energetic and exergetic performances. The thermal performance parameters, for example, generation of entropy, first law efficiency regarding COP, second-law effectiveness in terms of exergetic efficiency , entropy were explored at various ambient condition and found that both energy and exergy efficiencies of R134a is 8.97% and 5.38% lower than R152a and R600 respectively. To validate the proposed thermal model, numerical calculation was carried out by utilizing ecofriendly refrigerants and found that the irreversibility was negligible at higher evaporator temperatures while condenser temperature was in charge of most noteworthy irreversibility as far as thermal energy losses in the two stage vapour compression refrigeration system.

Mishra R. S. [2] carried out first law and second law analysis, and comparison of eight ecological friendly refrigerants on multiple stage vapour compression refrigerator with flash intercooler and individual throttle valves (system-1) and multiple stage vapour compression refrigerator with flash intercooler and multiple throttle valves (system-2) and observed that irreversibility occurred in the system- 1 is higher than the system-2 for eight chosen ecofriendly refrigerants. The first law effectiveness (i.e. COP) and exergy efficiency of system-1is lower than the sytem-2. It was observed that exergetic performance of R600 and R717 is better in comparison of other chosen ecofriendly refrigerants for the two systems whereas ecofriendly R125 refrigerant indicated lowest thermal performances in terms of first law efficiency (COP) and exergetic effectiveness (second law efficiency) and higher irreversibility as far as exergy destruction ratio (EDR) . As ecofriendly R717 refrigerant is harmful due to toxic in nature and confined to restricted applications and furthermore hydrocarbon R600 is somewhat lower performance than R717 and 2-3% higher performance than R134a refrigerant is additionally incombustible in nature can be utilized with taking of any security safeguards. Along these lines R134a may likewise be utilized for pragmatic applications. Additionally R134A is effectively accessible, the thermal performance of R1234yf (GWP four with zero ozone consumption potential) gives somewhat slightly lower thermal performance than R134a.

Mishra R.S. [3] did the relative computation for performance assessment of sixteen ecofriendly refrigerants utilized as a part of the two stage vapor compression refrigeration system in light of energetic and exergetic performance for finding system and components irreversibility utilizing entropy generation principle. The numerical calculation was done for finding rational exergy destruction ratio(EDR_rational) _ in light of system exergy contribution to terms of total work done by compressors ,exergy destruction ratio exergy destruction ratio (based on exergy of product and first law efficiency in terms of COP)and second law efficiency in terms of exergetic efficiency at different input variations and found that the flash chamber is responsible for highest exergy destruction for all refrigerants taken under consideration . It was observed that the R123 shows best first law efficiency and R125 shows lowest first law performance among selected sixteen ecofriendly refrigerants. It was found that the R123 demonstrates best first law effectiveness in terms of COP and R125 indicates most minimal first law efficiency among chose sixteen ecofriendly refrigerants. The first and second law efficiency of utilizing R1234ze (of GWP =6) is superior to R1234yf (of GWP=4) for higher temperature applications .The global warming potential of R134a is higher than R152a. Therefore R1234yf (GWP = 4) and R1234ze(GWP = 6) refrigerant can be utilized for medium and higher temperature applications, which can replace R134a around 2030 and R152a, R600a, , R290, R600 are combustible in nature can be utilized by utilizing security measures. In this manner R134a prescribed for all sort of applications before 2030 and R1234yf and R1234ze after 2030.Esbri, et al. [4] experimentally analyzed HFO-1234yf as a drop-in replacement for HFC-134a in a vapour compression system and fond that, the cooling capacity of HFO-1234yf is about 9% lower than that of HFC-134a and also the volumetric efficiency was about 5% less than that obtained with HFC-134a. Jung, et al. [5] evaluated the performance of HFO-1234yf and HFO-1234yf/HFC- 134a mixture in three compositions and drawn the results that COP, capacity and discharge temperature of HFO-1234yf and mixture of refrigerants are similar to those of HFC-134a, with decrement in flammability as the content of HFC-134a increases. Mishra R.S. [6] studied vapour compression refrigeration systems and concluded that the first law efficiency in terms of coefficient of performance COP and second law efficiency in terms of exergetic efficiency of HFC-134a and HFO- 1234ze is almost same having a difference of around 3 to 5%, which decreases with the increase in evaporator temperature, whereas it is 4-7% higher than HFO-1234yf. Hence HFO-1234yf can be a good drop-in' replacement of HFC-134a at low value of evaporator temperature and HFO-1234ze can be a good replacement after certain modification for higher temperature applications.

Kerber. et al. [7] evaluated experimentally and compared the performance of HFC-134a to HFO-1234yf and HFO-1234ze, and concluded that HFO-1234yf had 2.7% higher energy consumption than HFC-134a, indicating that HFO-1234yf is a suitable drop-in replacement of HFC-134a in domestic refrigerators. While HFO-1234ze had 6% lower energy consumption than HFC-134a, hence to replace HFC-134a with HFO-1234ze lower capacity refrigerators were required,

Minor et al. [8] performed optimization of beverage cooler using HFO1234yf and found that performance is comparable to HFC-134a.

Reaser et al. [9] investigated and compared the thermo-physical properties of HFO-1234yf to those of HFC-134a and R410a to determine the drop-in replacement potential of HFO-1234yf and concluded that properties were similar to that of HFC-134a and not similar to that of R410a.

Zang et al. [10] developed the non-azeotropic mixtures composed of HFOs (HFO-1234yf, HFO-1234ze (e), HFO-1234ze(z) and HFO-1234zf) as a replacement of HFC-134a and CFC-114 in air- conditioning and high temperature heat pump systems. It investigated theoretical cycle performance and found that COP of mixture of HFO-1234zf/HC-290 (60%/40% in mass) was 1.5% higher than that of HFC-134a, thus a good substitute in air conditioning system.

The literature survey emphasizes that HFO-1234yf and HFO-1234ze can be a promising alternative to HFC- 134a. Secondly, it has been observed that in most of the studies referred above, the analysis of the systems is based on first law of thermodynamics i.e. estimating coefficient of performance. In this study a more comprehensive exergy approach is followed, based on both first and second laws of thermodynamics. Exergy approach is a powerful tool in the design and performance evaluation of the systems, and allows an explicit presentation of thermodynamic processes by quantifying the effect of irreversibility occurring during the processes. Exergy balance applied to processes tells us how much of the exergy input to the system has been consumed (irreversibly in terms of exergy destruction/exergy lost) by the system in terms of system exergy destruction ratio based on the exergy of fuel (i.e. total power required to run whole system including both compressors) or based on the exergy of product.. Exergy analysis takes into account all the losses appearing in the cascade vapour compression refrigeration system for calculating exergetic efficiency. The various parameters in the cascade refrigeration system calculated are first law efficiency in terms of COPs, exergetic efficiency, exergy destruction in the various components. Effects of degree of sub-cooling in the vapour compression two stage cascade refrigeration system as shown in Fig-1.

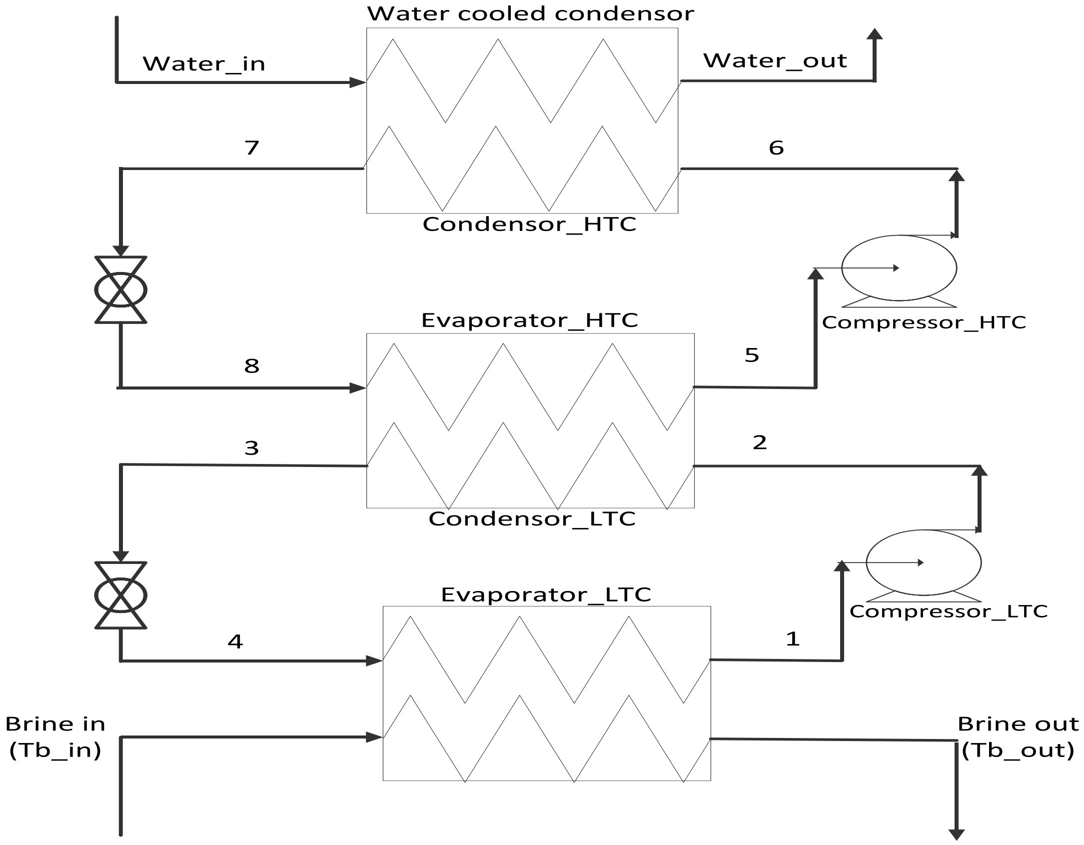

Figure 1: Two stage vapour compression cascade refrigeration system using HFO refrigerants

3. Result and Discussion

Following input data have been used for predicting thermodynamic performances of two stages cascade refrigeration systems using ecofriendly refrigerants.
Condenser temperature=50^{o}C,
Cascade evaporator temperature=0^{o}C,
Low temperature evaporator= -50^{o}C.
Efficiency of HTC Compressor =0.80.
Efficiency of HTC Compressor =0.80.
Load on Evaporator=70 kW
Approach (Temperature overlapping) =10
Fig- 2 shows the variation of First law efficiency (Coefficient of performance: COP_Overall) and second law efficiency (exergetic efficiency) , Exergy Destruction Ratio based on exergy of product HTC first law efficiency (COP_HTC) and LTC first law efficiency (COP_LTC) with varying condenser temperature (^{o}C) from 30^{o}C to 55^{o}C , it was found that increasing condenser temperature , the First law efficiency (Coefficient of performance: COP_Overall) and second law efficiency (exergetic efficiency) , is decreasing and Exergy Destruction Ratio based on exergy of product in also increasing HTC first law efficiency (COP_HTC) and LTC first law efficiency (COP_LTC) in also decreasing with increasing condenser temperature(^{o}C).
Fig- 3 shows the variation of heat rejected by high temperature condenser (kW) , heat rejected by cascade condenser (kW), total power required to run whole system (Exergy of fuel) kW and power required to run HTC Compressor using HFO R1234ze (kW) , power required to run LTC Compressor using HFO R1234yf (kW) with variation of condenser temperature(^{o}C) from 30^{o}C and it was observed that by increasing condenser temperature, the heat rejected in cascade condenser using R1234yf and heat rejected in cascade condenser is increasing while power required to run both compressors and whole system is also increasing. Fig-4 shows the variation of mass flow rate in High temperature evaporator using HFO 1234ze (Kg/sec) and mass flow rate in Low temperature evaporator using HFO 1234yf (Kg/sec) with varying condenser temperature (^{o}C) from 30^{o}C to 55^{o}C and it was found that mass flow rate of HTC is increasing by increasing condenser temperature up to 45^{o}C and then decreasing up to 50^{o}C and then increasing from 50^{o}C to 55^{o}C. While optimum condenser temperature to be found as 45^{o}C where mass flow rate is maximum. Fig-5 shows the variation of first law efficiency of system (Coefficient of performance of system), second law efficiency of system (Exergetic efficiency) and exergy destruction ratio based on exergy of fuel with variation of approach in terms of temperature overlapping (^{o}C) and it was observed that increasing temperature overlapping (approach) the first law efficiency of system (Coefficient of performance of system), second law efficiency of system (Exergetic efficiency) is decreasing while exergy destruction ratio based exergy of fuel (in terms of total power required to run whole system) is increasing.Fig 6 shows the variation of high temperature circuit first law efficiency of system /Coefficient of performance (COP_HTC), Low temperature circuit first law efficiency of system /Coefficient of performance (COP_LTC), and exergy destruction ratio based on exergy of product (EDR_System) with variation of approach in terms of temperature overlapping (^{o}C) in cascade refrigeration system and it was found that by increasing temperature overlapping from 0 to 5 the exergy destruction ratio based on exergy of product is increasing while first law efficiency i.e. circuit coefficient of performance (COP_LTC)is decreasing and from 5^{o}C to 10^{o}C its again increasing and then slightly decreasing .Similarly power required (kW) to run the whole system is also increasing along with Power required to run both compressors as shown in Fig-7 respectively. Fig- 8 shows the variation of mass flow rates in HTC and LTC circuit and heat rejected by high temperature condenser and cascade condenser (kW) with increasing temperature overlapping in terms of approach (^{o}C) and it is found that by increasing temperature overlapping from 0 (^{o}C) to 15 (^{o}C) , the mass flow rate (Kg/sec) in high temperature circuit and mass flow rate (Kg/sec) in the low temperature circuit is also increasing . Similarly heat rejected by condenser (kW) using HFO-1234ze and Heat rejected by cascade condenser using HFO-1234yf is also increasing.
Fig-9 shows the variation of system first law efficiency (overall COP of the system) second law efficiency (Exergetic efficiency) and exergy destruction ratio based on exergy of fuel with the variation of temperature of cascade evaporator temperature (^{o}C), it is found that by increasing temperature of cascade evaporator temperature using HFO-1234ze refrigerant in the high temperature circuit , the overall first law efficiency (System COP) and second law efficiency (exergetic efficiency) is decreasing while exergy destruction ratio based on exergy of fuel (i.e. power required to run whole system including both compressors) (EDR_system) is also increasing of cascade evaporator temperature. Fig- 10 shows the variation of HTC first law efficiency (COP_HTC) and LTC first law efficiency (COP_LTC) and exergy destruction ratio based on exergy of product with variation temperature of cascade evaporator temperature (^{o}C), and it was found that by increasing cascade evaporator temperature using HFO-1234ze refrigerant , first law efficiency of high temperature circuit in terms of COP_{HTC} is increasing while the exergy destruction ratio based on exergy of product is increasing and first law efficiency of low temperature circuit in terms of $COP_{\_LTC}$ is decreasing. Fig-11 shows the variation of power required to run the system/ exergy of fuel (kW), power required to run high temperature compressor (kW)using R1234ze , power required to run low temperature compressor (kW)using R1234yf with variation of temperature of cascade evaporator temperature (^{o}C), it was observed that the power required to run the system/ exergy of fuel (kW) and power required to run high temperature compressor (kW) using R1234ze is increasing by increasing cascade evaporator temperature from -20^{o}C to 20^{o}C while the power required to run low temperature compressor (kW)using R1234yf is decreasing.
Fig- 12 shows the variation of system exergy destruction ratio

based on exergy of fuel (EDR_$_{System}$) and system coefficient of performance (COP _$_{Overall}$)) with temperature of cascade evaporator (^{o}C) and it was found that with variation of cascade evaporator temperature (^{o}C) from -20^{o}C to 20^{o}C, the mass flow rate (Kg/sec) in the high temperature circuit using R1234ze refrigerant and the mass flow rate (Kg/sec) in the low temperature circuit using R1234yf refrigerant are increasing. However, it is found that the heat rejected by condenser using HFO-1234ze refrigerant and heat rejected by cascade condenser using HFO-1234yf refrigerant are increasing with increasing cascade evaporator temperature (^{o}C) from -20^{o}C to 20^{o}C. Fig- 13 : shows the variation of system exergy destruction ratio based on exergy of fuel (EDR_$_{System}$) and first law efficiency of whole cascade refrigeration system in terms of coefficient of performance as defined as the system coefficient of performance (COP_Overall)) with variation temperature of LTC evaporator from -50^{o}C to -35^{o}C , the second law efficiency in terms of exergetic efficiency is decreasing while first law efficiency of whole cascade refrigeration system in terms of coefficient of performance known as the system coefficient of performance (COP_Overall) is increasing . Similarly system exergy destruction ratio based on exergy of fuel (EDR_$_{System}$) is also decreasing as increasing low temperature evaporator temperature .Fig-14 shows the variation of system exergy destruction ratio based on exergy of fuel (EDR_$_{System)}$ and cycle coefficient of performances in terms of Cycle First law efficiency of high temperature circuit using HFO-1234ze and Cycle First law efficiency of low temperature circuit using HFO-1234yf (i.e. COP_$_{HTC}$ and COP_$_{LTC}$) with variation temperature of low temperature evaporator from -50^{o}C to -35^{o}C , the system exergy destruction ratio based on exergy of fuel (EDR_$_{System}$) is increasing along with cycle First law efficiency of low temperature circuit using HFO-1234yf (i.e. COP_$_{LTC}$) while First law efficiency of high temperature circuit is constant. ig-15 shows the variation of power required to run HTC and LTC compressors and Total power required to run whole system (kW) with the variation temperature of low temperature (LTC) evaporator (^{o}C) from -50^{o}C to -35^{o}C and it was found that increasing LTC evaporator temperature from -50^{o}C to-35^{o}C, the total power required to run whole system (kW) and power required to run both compressors decreases.

Fig-16 shows the variation of mass flow rate (Kg/sec) in the high temperature evaporator using HFO R1234ze refrigerant and variation of mass flow rate (Kg/sec) in the low temperature evaporator using HFO R1234yf refrigerant with variation of low temperature circuit from -35^{o}C to -50^{o}C and it was found that mass flow rates in the both circuits are decreasing when temperature of low temperature evaporator is increasing. Similarly heat rejected in the high temperature circuit condenser (kW) using R1234ze refrigerant and heat rejected in the low temperature circuit condenser (kW) using R1234yf refrigerant is decreasing.

Fig-17 shows the variation of first law efficiency in terms of coefficient of performance (COP), second law efficiency (exergetic efficiency) and system exergy destruction ratio which is based on exergy of fuel with variation with condenser temperature between 30^{0}C to 55^{0}C and it was found that increasing condenser temperature in the high temperature circuit using R1234ze ecofriendly refrigerant, the first law efficiency in terms of COP along with second law efficiency is decreasing while exergy destruction ratio is increasing.

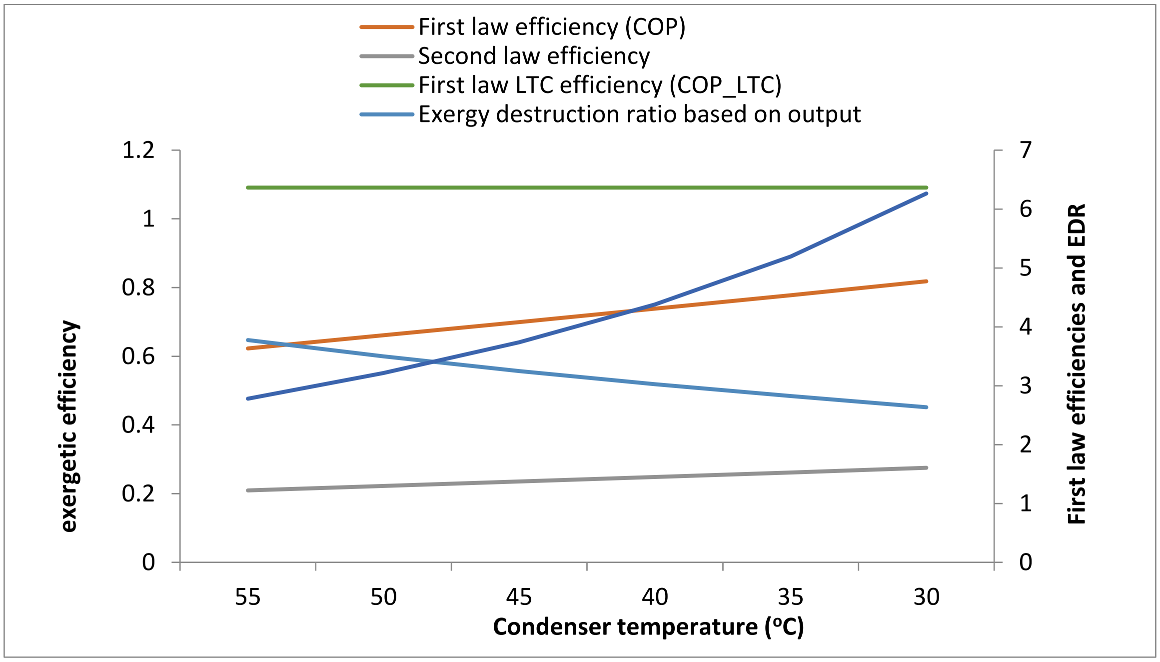

Figure 2 :Variation of First law efficiency (Coefficient of performance: COP_Overall) and second law efficiency (exergetic efficiency) , Exergy Destruction Ratio based on exergy of product HTC first law efficiency (COP_HTC) and LTC first law efficiency (COP_LTC) with condenser temperature(^{o}C)

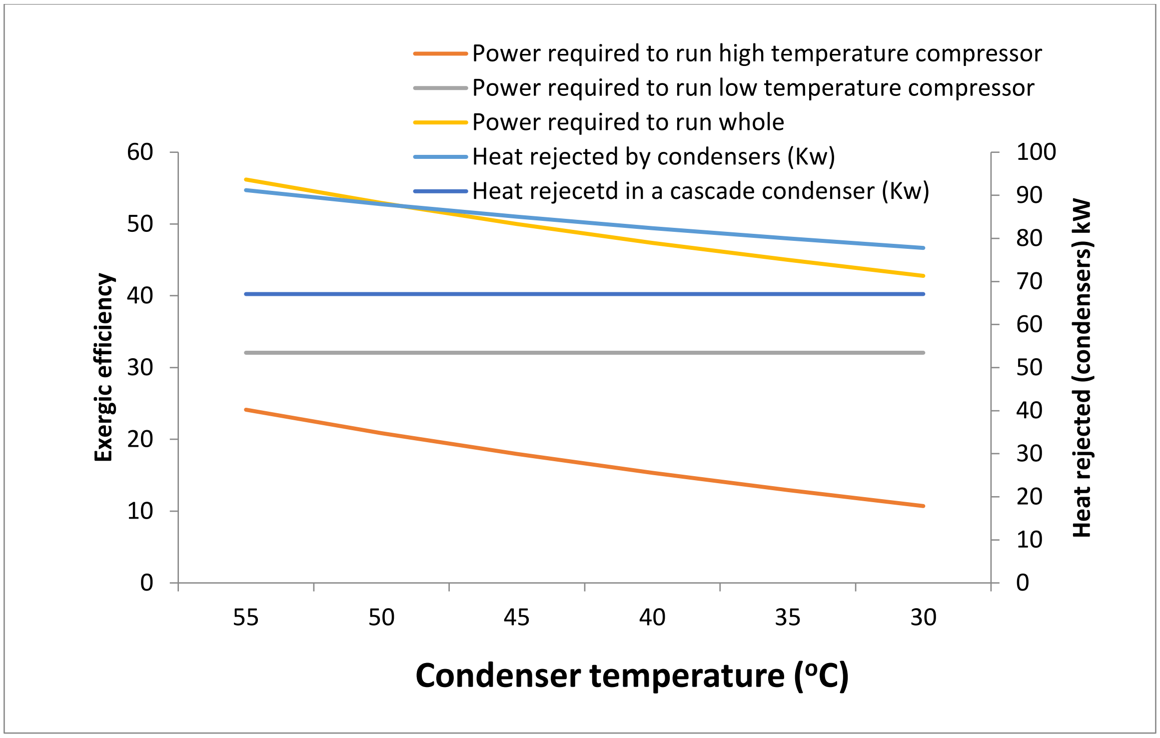

Figure 3 :Variation of heat rejected by high temperature condenser (kW) , heat rejected by cascade condenser (kW), total power required to run whole system (Exergy of fuel) kW and power required to run HTC Compressor using HFO R1234ze (kW) , power required to run LTC Compressor using HFO R1234yf (kW) with condenser temperature(°C)

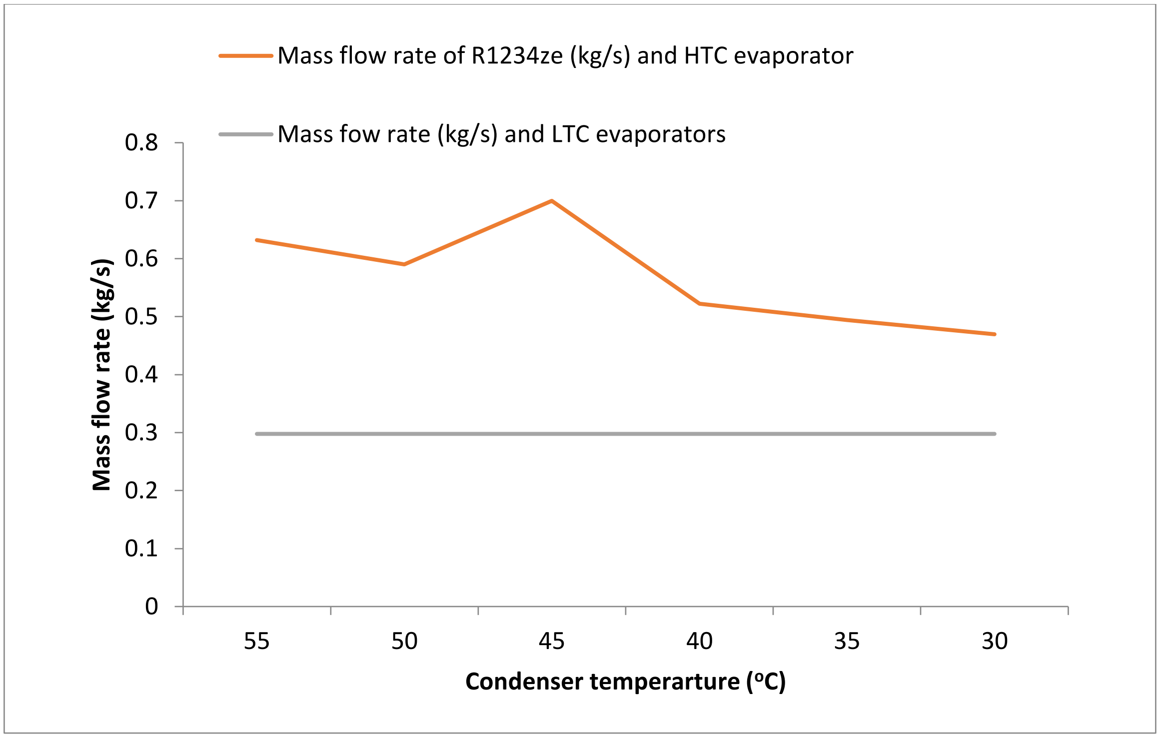

Figure 4: Variation of mass flow rate in High temperature evaporator using HFO 1234ze (Kg/sec) and mass flow rate in Low temperature evaporator using HFO 1234yf (Kg/sec) with condenser temperature(°C).

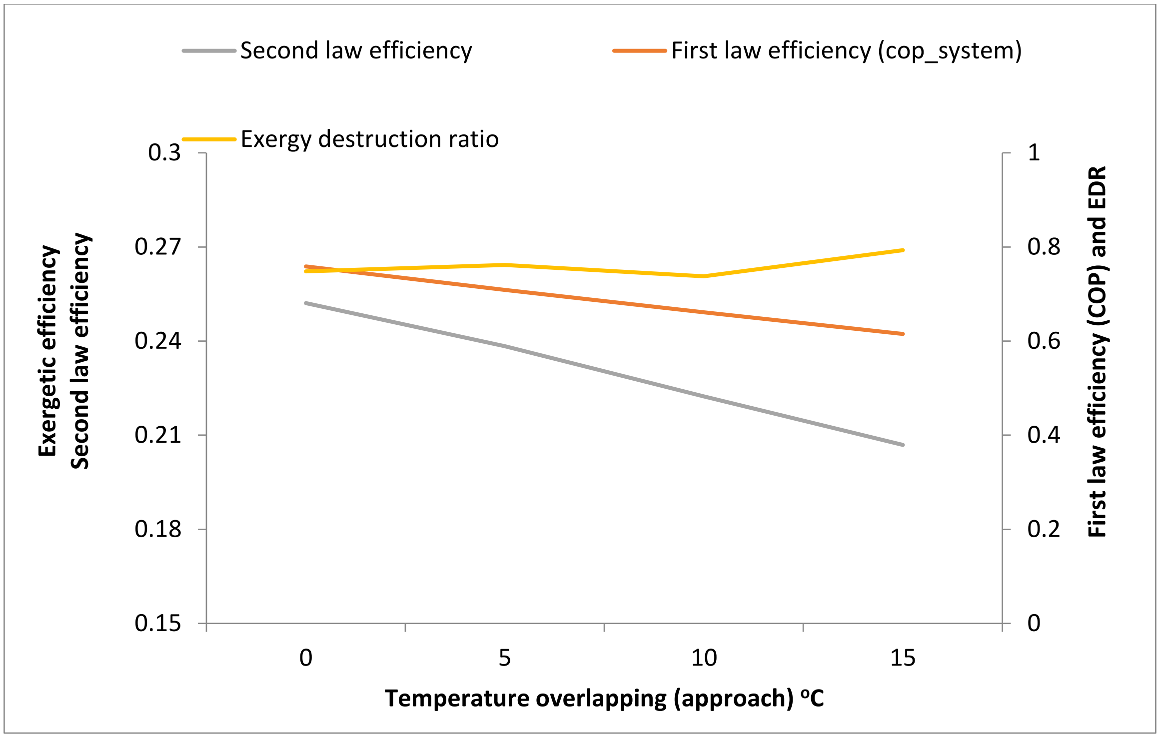

Figure 5: Variation of first law efficiency of system (Coefficient of performance of system), second law efficiency of system (Exergetic efficiency) and exergy destruction ratio based on exergy of fuel with temperature overlapping (ᵒC)

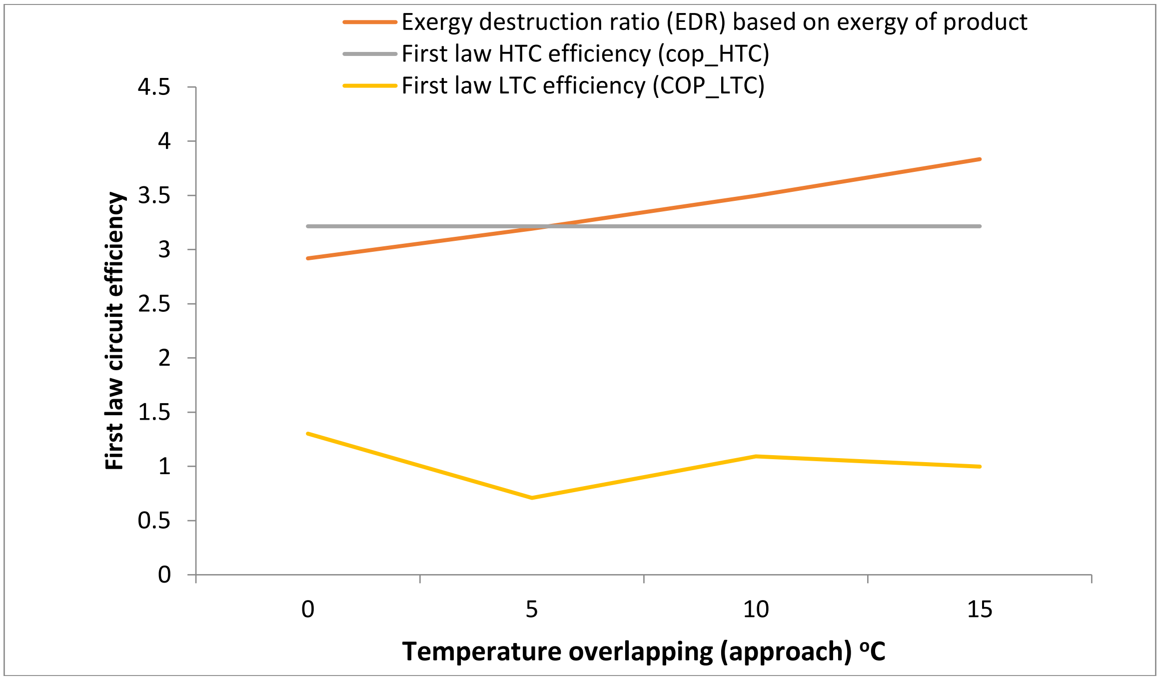

Figure 6 : Variation of High temperature circuit first law efficiency in terms of Coefficient of performance (COP_HTC), Low temperature circuit first law efficiency of system in terms of Coefficient of performance (COP_LTC), and exergy destruction ratio based on exergy of product (EDR_System) with temperature overlapping (ᵒC) in cascade system

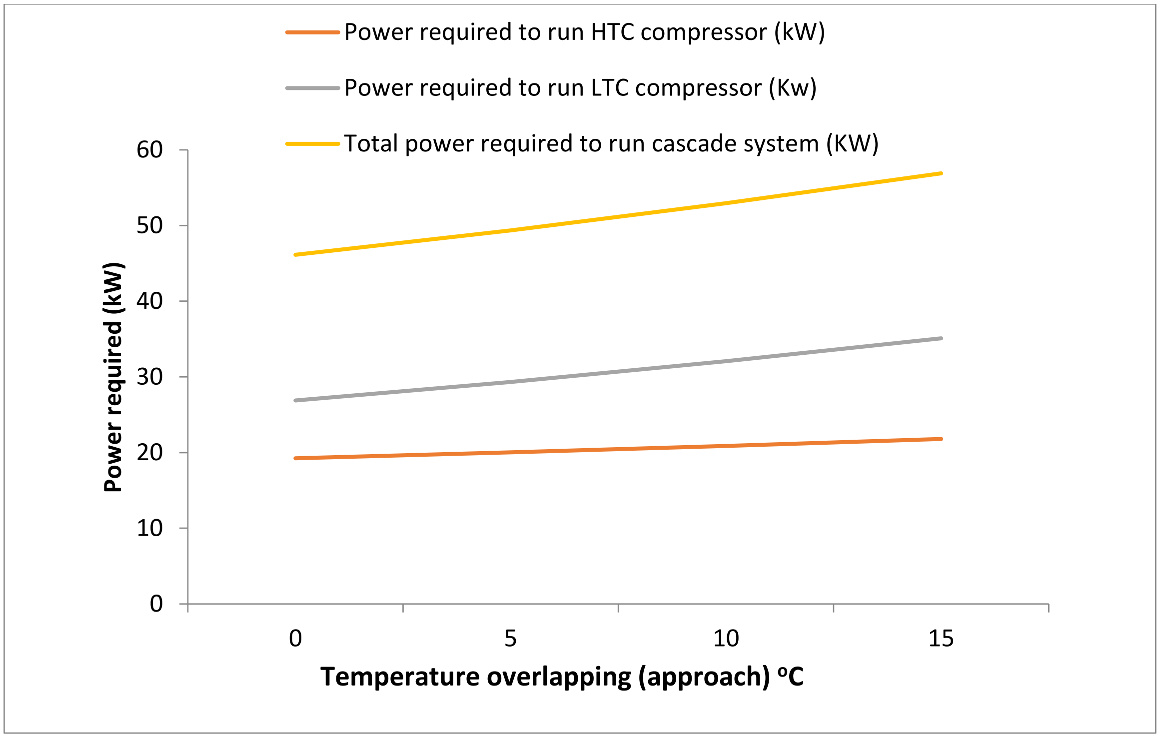

Figure 7 :Variation of power required to derived the system and power required to derived high temperature compressor (kW)using HFO R1234ze and power required to derived low temperature compressor (kW) using HFO R1234yf with temperature overlapping (approach) °C in cascade system

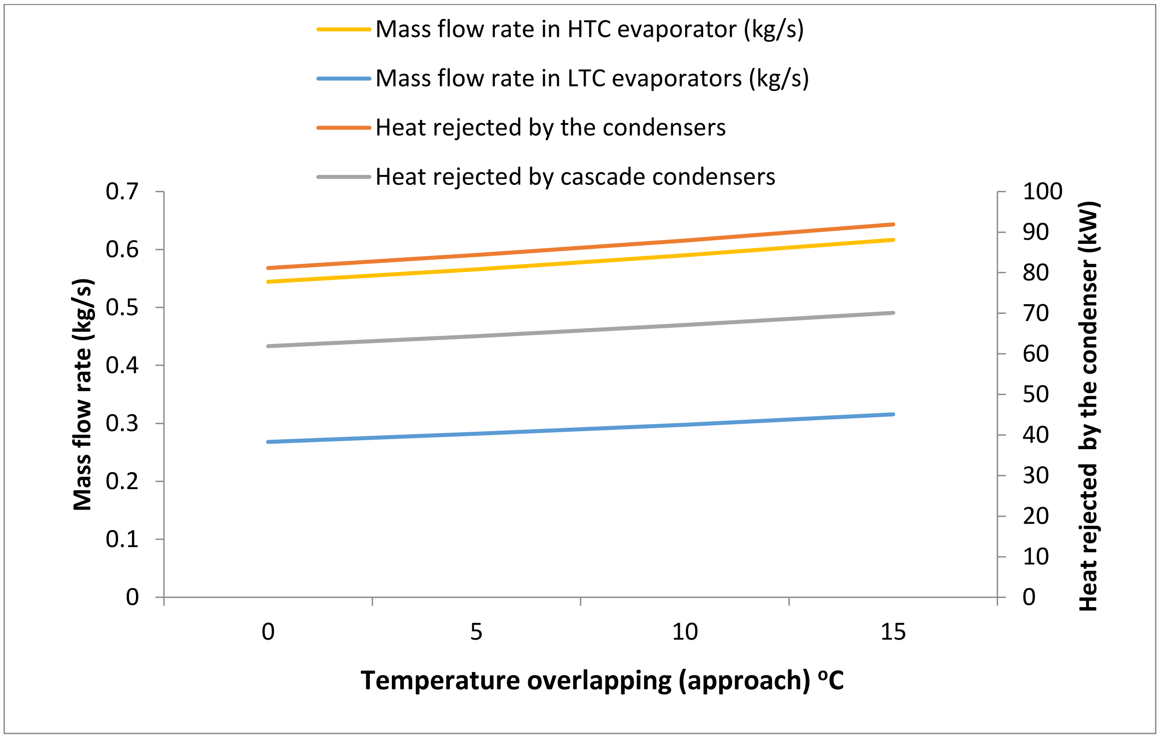

Figure 8: Variation of mass flow rates in HTC and LTC circuit and heat rejected by high temperature condenser and cascade condenser (kW) with temperature overlapping (approach) °C

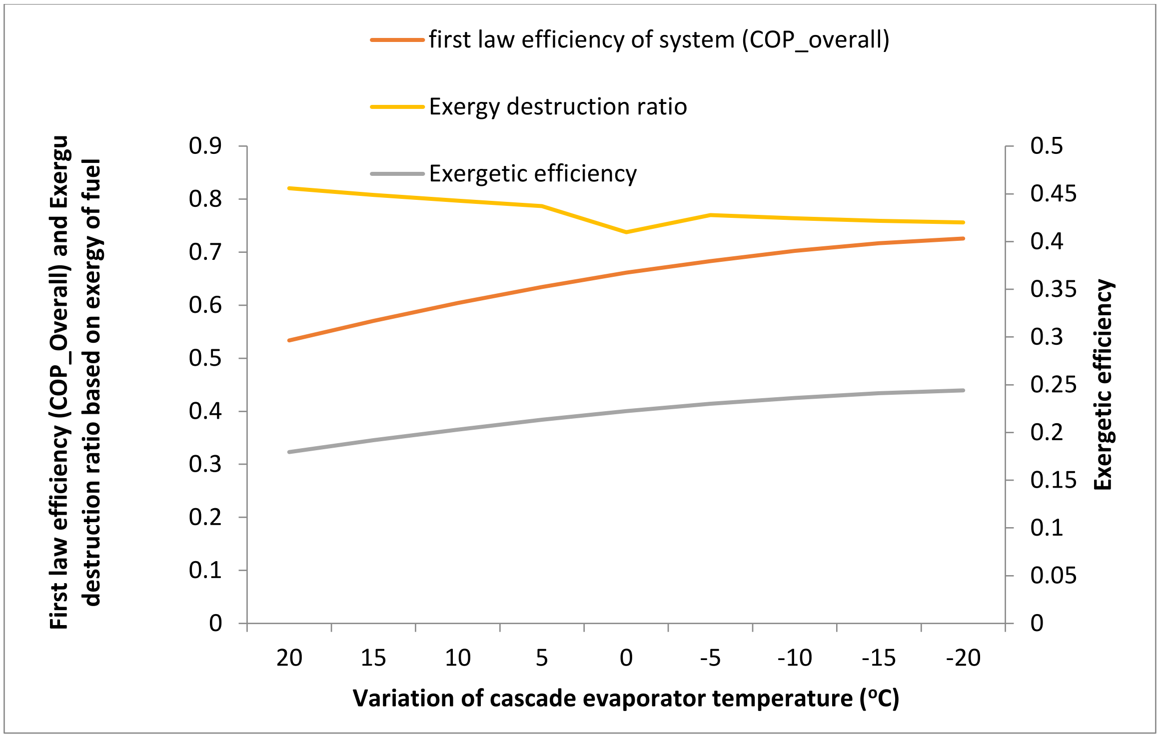

Figure 9 :Variation of first law efficiency (overall cop of the system) second law efficiency (Exergetic efficiency) and exergy destruction ratio based on exergy of fuel with temperature of cascade evaporator temperature (°C)

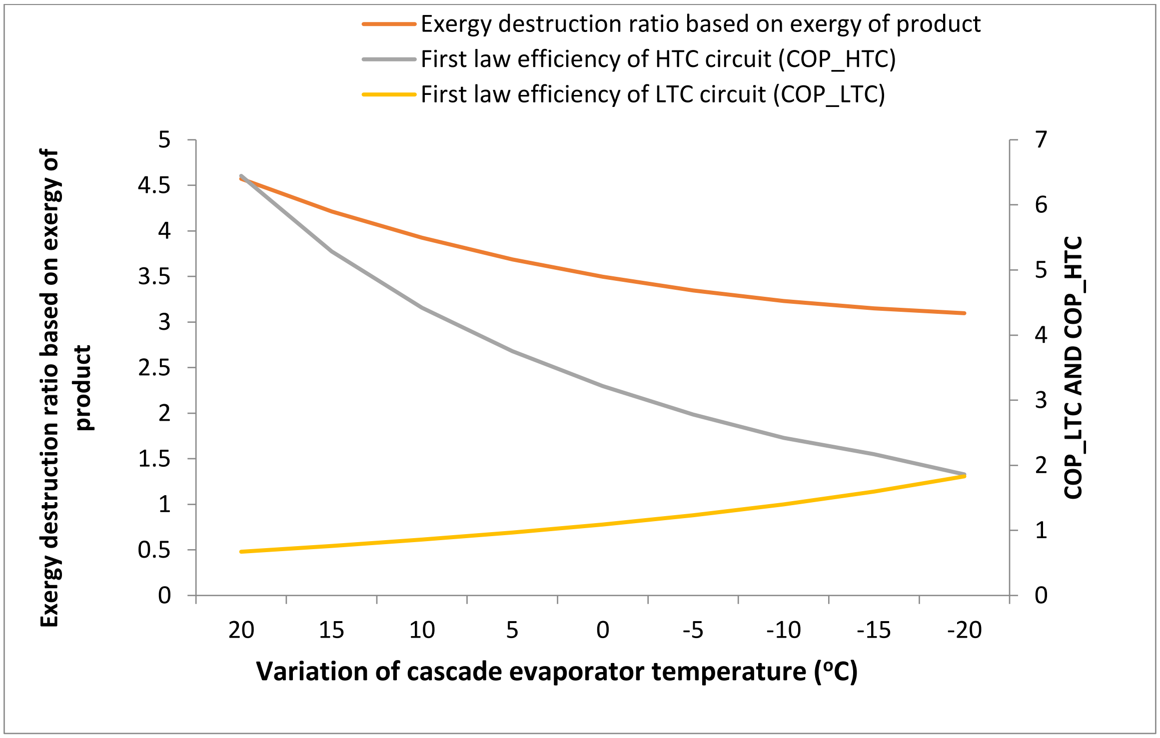

Figure 10:Variation of HTC first law efficiency (COP_HTC) and HTC first law efficiency (COP_LTC) and exergy destruction ratio based on exergy of product with temperature of cascade evaporator temperature (°C)

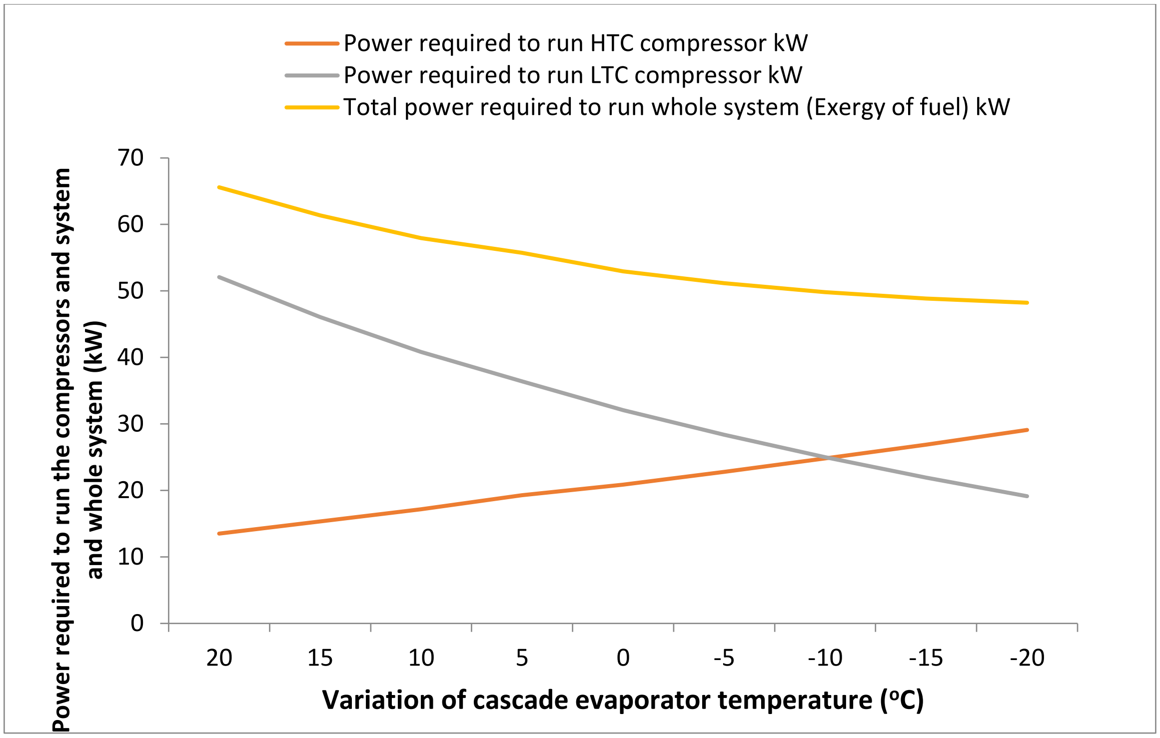

Figure 11:Variation of power required to run the system/ exergy of fuel (kW), power required to run high temperature compressor (kW)using R1234ze , power required to run low temperature compressor (kW)using R1234yf with temperature of cascade evaporator temperature (°C)

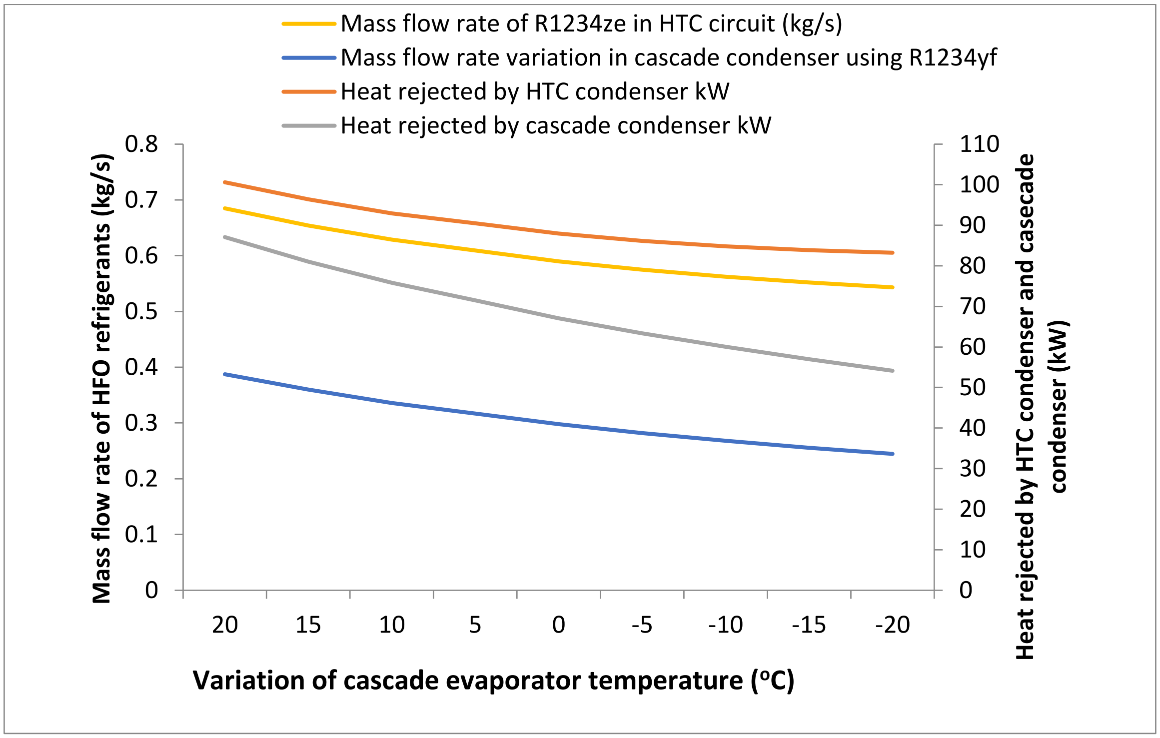

Figure 12 : Variation of system exergy destruction ratio based on exergy of fuel (EDR_{System}) and system coefficient of performance (COP_Overall) with temperature of cascade evaporator (°C)

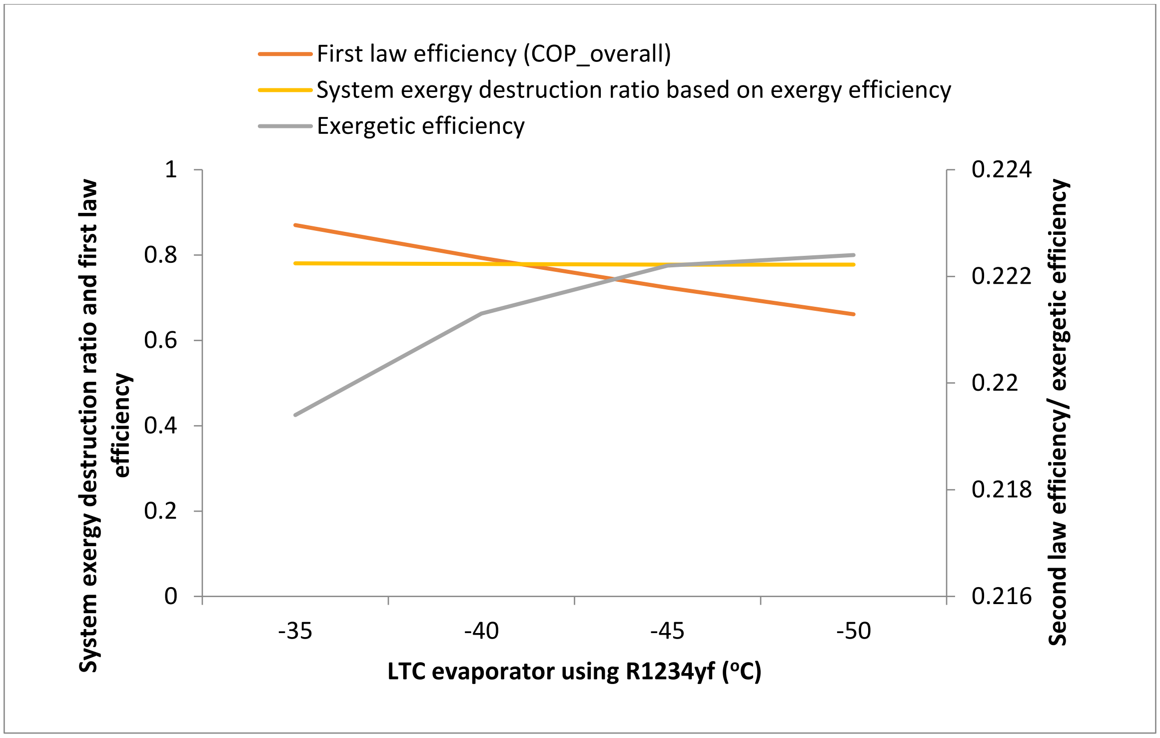

Figure 13 : Variation of system exergy destruction ratio based on exergy of fuel (EDR_$_{System}$) and system coefficient of performance (COP_Overall)) with temperature of LTC evaporator

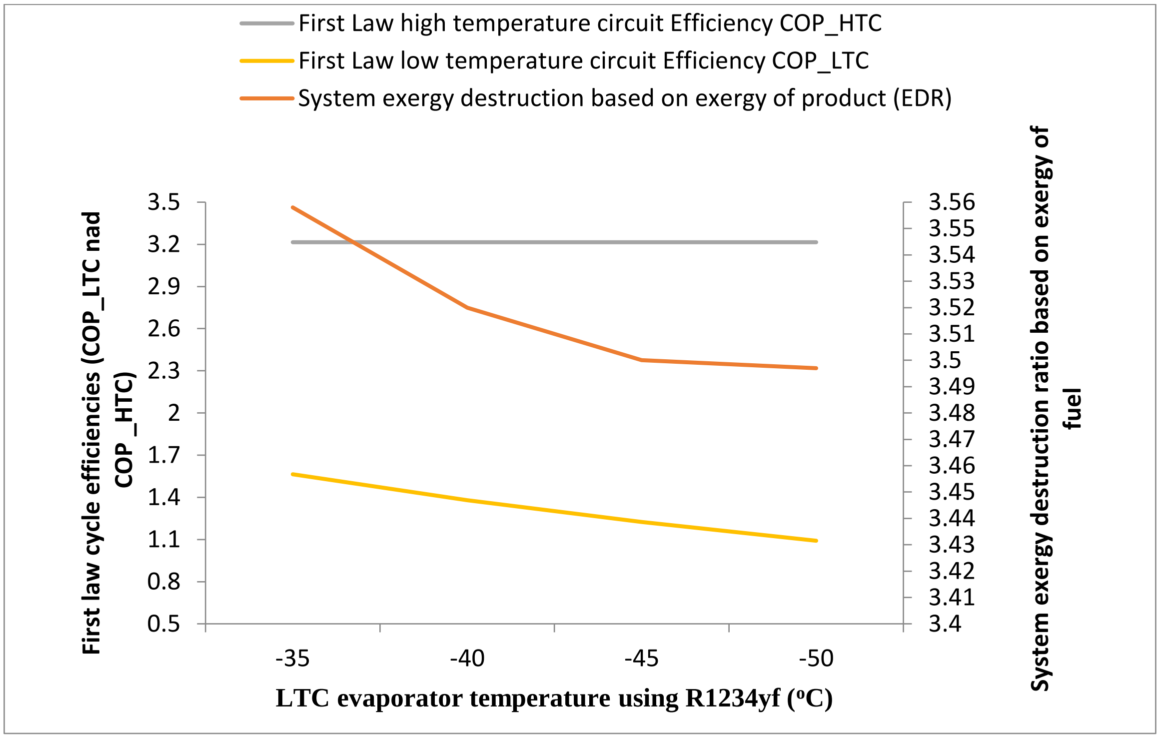

Figure 14 : Variation of system exergy destruction ratio based on exergy of product(EDR_$_{System)}$ and cycle coefficient of performance (Cycle First law efficiency)of HTC and LTC with temperature of low temperature evaporator

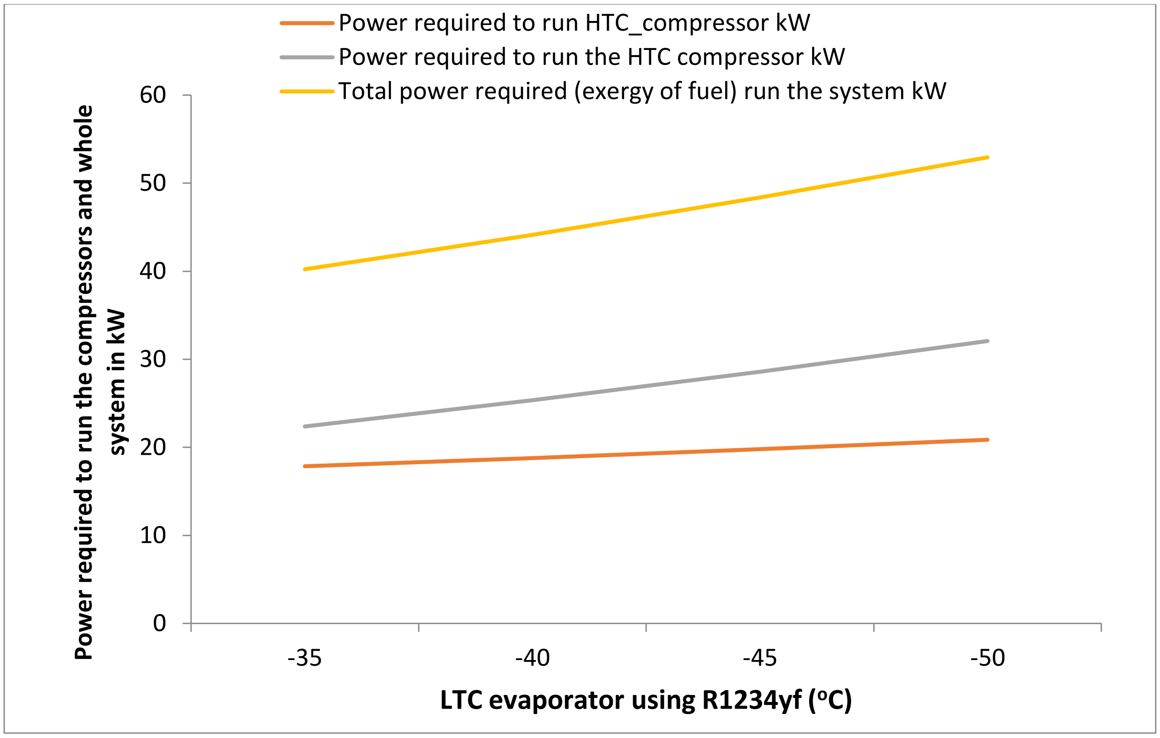

Figure 15: Variation of Power required to run HTC and LTC compressors and Total power required to run whole system (kW) with temperature of low temperature(LTC) evaporator (°C) respectively.

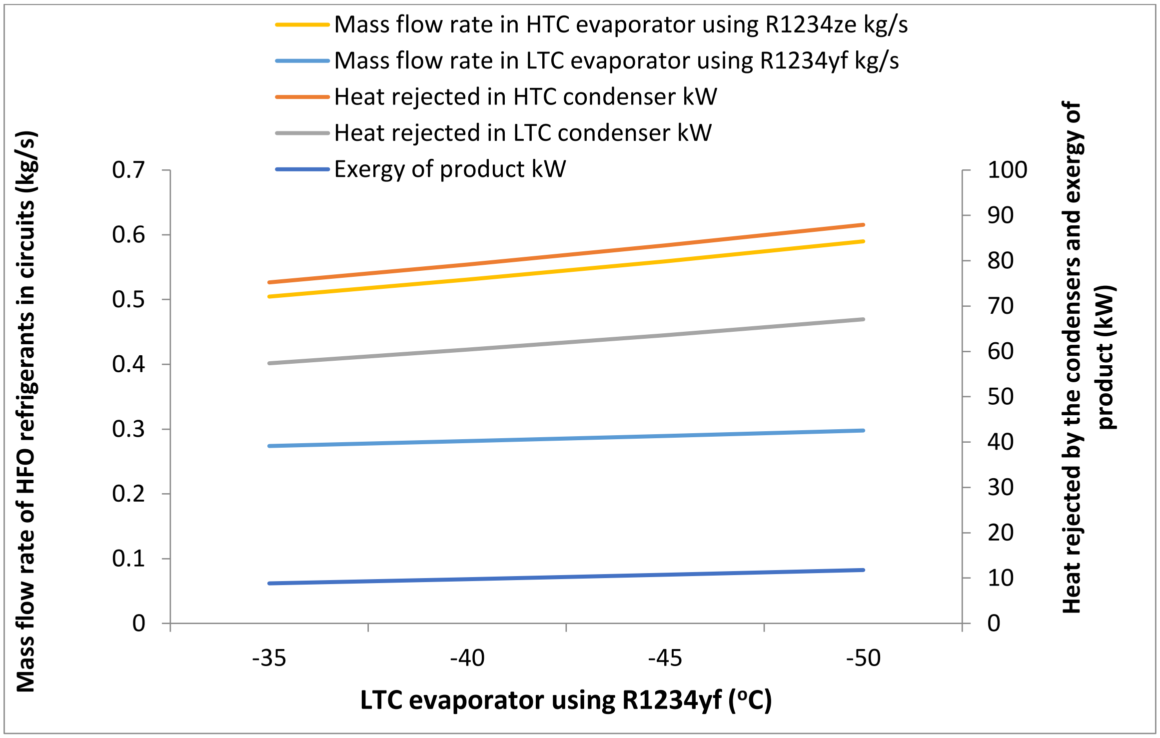

Figure 16 : Variation of system exergy destruction ratio based on exergy of product (EDR_$_{System}$) and Heat rejected by high temperature condenser (kW)) using R-1234ze and Heat rejected by cascade condenser (kW) using R-1234yf with Low temperature evaporator (°C)

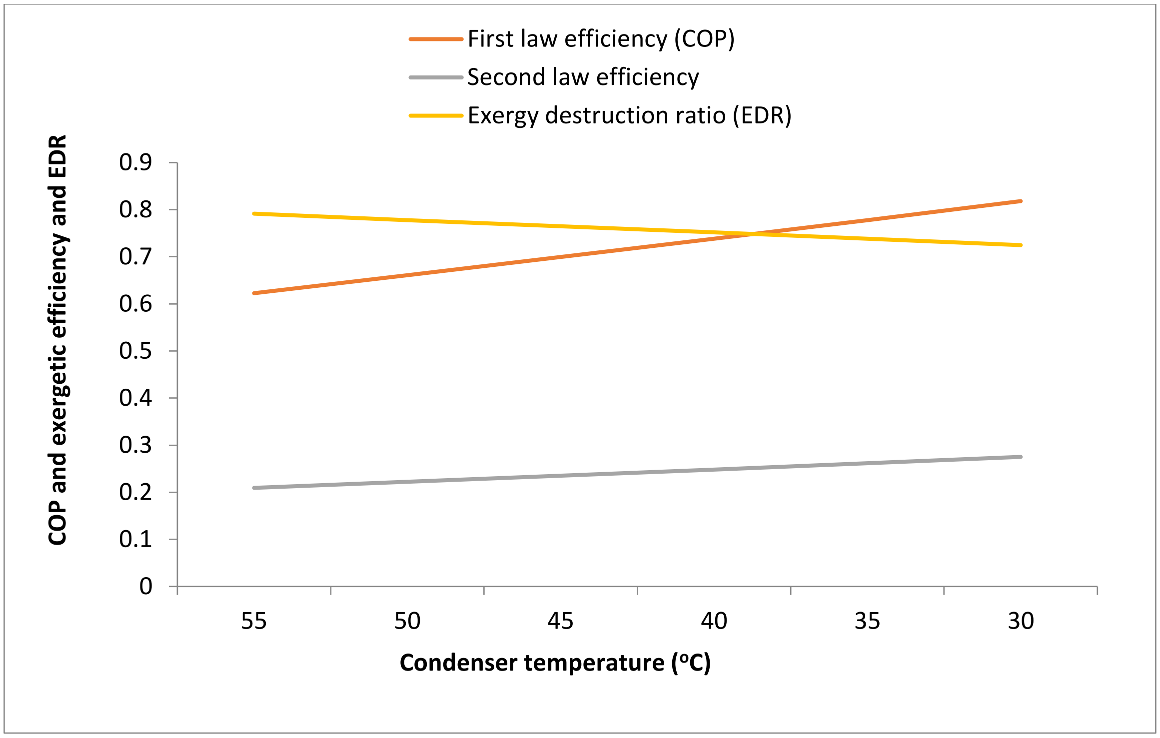

Figure 17 : Variation of system exergy destruction ratio based on exergy of fuel (EDR_System) and cycle coefficient of performance (High temperature Cycle First law efficiency using HFO 1234ze)COP_ HTC and cycle coefficient of performance (Low temperature Cycle First law efficiency using HFO 1234yf) COP_ LTC with high temperature evaporator (°C)

System-1

Table-1 :Effect of Temperature over lapping on the thermal performances of Two stage cascade using HFO (R1234ze -R134a) Refrigerants (for compressors efficiency=0.80)

Temperature Overlapping (Approach) K	COP_{System}	EDR	Exergetic Efficiency	$EDR_{rational}$	COP_{HTC}	COP_{LTC}	$Exergy_{Product}$ kW	$Exergy_{Fuel}$ kW
10.0	1.1133	1.624	0.3811	0.6199	3.215	2.294	23.54	61.77
5.0	1.220	1.437	0.4104	0.5896	3.215	2.579	23.54	57.36
0.0	1.315	1.261	0.4422	0.5578	3.215	2.916	23.54	53.24

Table-2: Effect of Temperature over lapping on the thermal performances of Two stage cascade using HFO (R1234ze -R1234yf) Refrigerants(for compressors efficiency=0.80)

Temperature Overlapping (Approach)K	COP_{System}	EDR	Exergetic Efficiency	EDR_rational	COP_{HTC}	COP_{LTC}	$Exergy_{Product}$ kW	$Exergy_{Fuel}$ kW
10.0	1.104	1.694	0.3712	0.6288	3.215	2.204	23.54	63.42
5.0	1.196	1.486	0.4083	0.5917	3.215	2.497	23.54	58.52
0.0	1.295	1.296	0.4356	0.5644	3.215	2.844	23.54	50.04

Table-3(a):Effect of Temperature over lapping on the thermal performances of Two stage cascade using HFO (R1234yf -R134a) Refrigerants(for compressors efficiency=0.80)

Temperature Overlapping (Approach)K	COP_{System}	EDR	Exergetic Efficiency	$EDR_{rational}$	Loss_ $Exergy_{HTC}$	Loss_ $Exergy_{LTC}$	Loss_ $Exergy_{Total}$	$Exergy_{Fuel}$ kW
10.0	1.104	2,205	0.3120	0.6880	22.33 %	29.59%	51.92%	63.42
5.0	1.196	2.181	0.3144	0.6856	21.51%	29.83%	51.34%	58.52
0.0	1.295	2.167	0.3158	0.6842	20.76%	30.25%	51.01%	50.04

Table-3(b): Effect of Temperature over lapping on the thermal performances of Two stage cascade using HFO (R1234yf -R134a) Refrigerants(for compressors efficiency=0.80)

Temp Over-lapping Approach	Exergetic Efficiency	System EDR based on exergy of product	% Loss Comp_$_{\text{HTC}}$	% LossCond _$_{\text{HTC}}$	% LossEva _$_{\text{HTC}}$	% Loss Valve_$_{\text{HTC}}$	% Loss Comp_ $_{\text{LTC}}$	% Loss Cond_$_{\text{LTC}}$	% LossEva _$_{\text{LTC}}$	% Loss_ Valve _$_{\text{LTC}}$
10	0.3120	2,205	7.721	13.78	0.2018	6.297	8.608	6.376	15.30	8.923
5	0.3144	2.181	7.495	13.7	0.1959	8.054	7.786	8.686	15.21	7.155
0	0.3158	2.167	7.266	12.97	0.1899	7.808	6.99	10.93	17.01	5.643

For three systems (HFO-1234ze_$_{\text{HTC}}$-,HFO-1234yf_$_{\text{LTC}}$, and HFO-1234ze_$_{\text{HTC}}$-HFC-134a $_{\text{LTC}}$) and HFO-1234yf_$_{\text{HTC}}$-HFC-134a $_{\text{LTC}}$) , the thermal performance were performed. During the investigation, condenser temperature is kept at 313K and evaporator temperature is kept in the range from 223K to 273K .Results obtained indicate that HFO-1234yf and HFO-1234ze can be good replacement of R-134a. Among the system components, condenser shows highest efficiency defect value and liquid vapour heat exchanger shows the lowest with liquid vapour heat exchanger (lvhe) refrigerants

Table-1-3 show the comparison between three cascade refrigeration systems in terms of temperature over lapping in terms of approach (ºC) on the thermal performances have been investigated. System-1 consists of two stage cascade vapour compression refrigeration system using R1234ze refrigerant in high temperature circuit and R134a in the low temperature circuit. The effect of temperature overlapping in the cascade refrigeration system on the thermal performances is shown in Table-1 respectively. Similarly system-2 consist of two stage cascade vapour compression refrigeration system using HFO -1234ze in the high temperature circuit and R1234yf Refrigerant in the low temperature circuit. The effect of temperature overlapping in the cascade refrigeration system on the thermal performances is shown in Table-2 respectively. The system-3 consist of two stage cascade vapour compression refrigeration system using HFO -1234yf in the high temperature circuit and R134a Refrigerant in the low temperature circuit. The effect of temperature overlapping in the cascade refrigeration system on the thermal performances is shown in Table-3 Respectively. It is found that by increasing temperature overlapping, the first law efficiency in terms of Overall COP of system, and circuit first law efficiency of low temperature circuit (COP_LTC) and second law efficiency in terms of exergetic efficiency are decreasing while system exergy destruction ratio based on exergy of output is increasing. The system-1 gives better thermal performance in terms of first law efficiency (i.e. overall COP) of the system and second law efficiency (exergetic efficiency) than system-2 and system-3. And system-1 (R1234ze-R234a) also reduced exergy destruction ratio (EDR_System) based on the exergy of product than system-2 using (R1234ze-R1234yf) and system-3 using (R1234yf-R134a). It can be seen that system-2 using HFO refrigerants (R1234ze in HTC and R1234yf in LTC) gives high power required to run the system as compared to system -1 (R1234ze in HTC and R134a in LTC). The Exergy destruction in the various components of system-3 ((R1234yf in HTC and R134a in LTC) is also shown in Table-3(b) respectively. It is seen that maximum exergy destruction occurred in the low temperature evaporator 15.3% and slightly less in condenser around 13.78% and lowest exergy destruction is observed in the valves especially lowest in high temperature valves (6.297%) and 8.6% in low temperature valve for 10ºC of temperature overlapping.

4. Conclusion

Following conclusions were drawn from present investigations**.**

1. System-1 (using HFO-1234ze in high temperature circuit and R134a in low temperature circuit) gives better first law efficiency in terms of system overall coefficient of performance , second law efficiency in terms of exergetic efficiency and lower system exergy destruction ratio as compared to system-2 (using HFO-1234ze in high temperature circuit and R1234yf in low temperature circuit) and system-3(using HFO-1234yf in high temperature circuit and R134a in low temperature circuit)
2. Although the the thermal performance of system-2 (using HFO-1234ze in high temperature circuit and R1234yf in low temperature circuit) is slightly less than System-1 which can replace R134a in the low temperature evaporator circuit with slightly higher power consumption in the system-2.
3. In system-3 (using HFO-1234yf in high temperature circuit and R134a in low temperature circuit) the maximum exergy destruction occurred in the low temperature evaporator and slightly less in condenser around and lowest exergy destruction is observed in the valves, especially lowest in high temperature valves for 10ºC of temperature overlapping

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