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

Thermal Performance of three stage cascade vapour compression refrigeration systems using new HFO in high and intermediate temperature cycle and R32 ethylene and hydrocarbons in ultra-low temperature cycle refrigerants

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Abstract

This papers mainly deals with the use of ecofriendly HFO refrigerants in the medium temperature range (up to -50ºC) using Low GWP ecofriendly R245fa in Intermediate temperature cycle up to -95ºC and R600a, R290 in ultra-low temperature (-155ºC) of cascade refrigeration system and it was found that Hydrocarbon R-600a gives best thermodynamic first and second law performances with lowest exergy destruction ratio in the ultra-low temperature between -110ºC to -130ºC. The thermodynamic first and second law performances of R32 and ethylene are nearly similar and less than R290. Therefore use of hydrocarbons can also be promising by taking appropriate safety measures because mostly hydrocarbons are flammable in nature.R1234ze(z) gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1224yd(Z) and R1234ze(E) and R1243zf used in intermediate temperature for R1234ze(Z) /R1234ze(E) & R1243zf, R1233zd(E) in high temperature cycle using R600a, R290 and R32 and Ethylene in ultra-low temperature ranges between -110ºC to -130ºC .However lowest performances was observed by using R134a in high temperature circuit and R1234yf in low temperature cycle . the thermodynamic performances of cascade vapour compression refrigeration systems was compared between HFC-134a and HFO-1234yf and it is found that HFO-1236mzz(z) and R1225ye(Z) gives similar results as compared with R134a used in intermediate temperature cycle up to -50ºC of evaporator temperature.

Keywords: New HFO refrigerants, Thermodynamic Performances, Energy-Exergy Analysis, Modified cascade VCRS

1. Introduction

The concept of refrigeration is known by heat rejection from a space at a temperature lesser than temperature of surrounding. Now COP can be defined as ratio of effect of refrigeration produced at section of heat absorption to input work through compressor. Also, COP could be enhanced either by declining compressor's input work by multistage compression process/ cascade refrigeration or by increasing effect of refrigeration. Further, HFO refrigerants (i.e. R1234yf & R1234ze(Z), R1234ze(E), R1243zf, R1224yd(z), R1225ye(z), R1233zd(E), HFO-1336mzz(Z) and hydrocarbons like propane (R290) & isobutene (R600a) refrigerants have a low mass flow rate as competed with R134a refrigerant. As can be seen, both specific volume and temperature of refrigerant decreases as mass flow rate going to be decrease. As a result, compressor work also reduces and COP increases. Besides, R600a is an environmental safety refrigerant, whose ozone depletion potential (ODP) & global warming potential (GWP) is less than 10 [1] . A refrigerant is a substance or mixture, usually a fluid, used in a heat pump and refrigeration cycle. In most cycles it undergoes phase transitions from a liquid to a gas and back again. Many working fluids have been used for such purposes. The researchers are paying attention on the alternate and environment friendly refrigerants, especially HFCs after the Kyoto and the Montreal protocols. However, it is essential to find alternate and environment friendly refrigerants such as HFOs and others in terms of Blends of HFCs with HFOs, for the energy efficiency of the equipment having HFC refrigerants. Although, natural and conventional refrigerants are also very important in the present age of competitive dealing community because the aim of the scientific group of people all over the world is to find out the new and renewable energy

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https://doi.org/10.36037/IJREI.2020.4206

sources besides, efficient utilization of all conventional sources, Reddy et al [2] performed numerical investigation of VCRS by using R134a, R143a, R152a, R404A, R410A, R502, & R507A fluid and reported that temperature of evaporator and condenser have crucial effect on both COP & exergetic efficiency. In addition, they found that R134a fluid has better performance than R407C fluid. Mastani Joybari et al. [3] done experimental investigation on a domestic refrigerator and concluded that compressor's exergetic destruction was highest in contrast to other components. Ahamed et al. [4] carried out exergy based investigation of the VCRS and evaluated thermodynamic performance of hydrocarbons, mixture of hydrocarbons, & R134a. Additionally, they found that higher exergy destruction occurred in compressor as rivaled with other VCRS' components. Kapil chopra,et.al, [5] have carried out the thermodynamic performances of vapour compression refrigeration system using multiple evaporators and compressors with individual or multiple expansion valves have been considered by using first law and second law analysis. Numerical models for parallel and series expansion valves in the VCR. Thermodynamic analysis in terms of energy and exergy analysis of multiple evaporators and compressors with individual expansion valves (system-1) and multiple evaporators and compressors with multiple expansion valves (system-2) have been carried out and following conclusions was drawn from present investigation. For same degree of subcooling, fixed evaporators and condenser temperatures system-2 is the best system with comparisons of system-1. R600, R600a and R152A show better performances than other refrigerants for both systems (system-1 & system-2) but due to inflammable property of R600 and R600a, R134a is preferred for both systems. First law efficiency and second law efficiency of system-2 is 3%- 6% higher than System-1. J. U.Ahamed et. al. [6], were emphasized on the possibilities of researches in the field of exergy analysis in various vapor compression refrigeration systems. Exergy losses, exergetic efficiency, and irreversibility of the system components as well as in the vapour compression system using R134a, R290 and R600a refrigerants. Exergy parameters in the compressor, evaporator, condenser and expansion devices are computed and found that the exergy losses depend on evaporator temperatures, condensing temperature, type of refrigerants and ambient temperature and concluded that maximum exergy destruction occured in the condenser and lowest in the Expansion devices. He also observed the exergy destruction using butane or isobutene are less than using R134a refrigerant in the VCRS. In the higher evaporating temperature exergy loss is decreased for all refrigerants because exergetic efficiency is also higher for butane as compared to isobutene and R-134a as refrigerants. Exergy loss in the compressor is higher than that in the other parts of the system i.e. around 70% of the total exergy loss occurs in the system. R.S.Mishra [1,7,8] carried out the detailed energy and exergy analysis of multi-evaporators at different temperatures with single compressor and single expansion valve using liquid vapour heat exchanger vapour compression refrigeration systems have been done in terms of performance parameter for R507a, R125, R134a, R290, R600, R600a, R1234ze, R1234yf, R410a, R407c, R707, R404a and R152a refrigerants. The numerical computations have been carried out for both systems. It was observed that first law and second law efficiency improved by 20% using liquid vapour heat exchanger in the vapour compression refrigeration systems. The First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using R717 refrigerant is higher but is has toxic nature can be used by using safety measure for industrial applications. COP and exergetic efficiency for R152a and R600 are nearly matching the same values are better than that for R125 at 313K condenser temperature and showing higher value of COP and exergetic efficiency in comparison to R125. For practical applications R-134a is recommended because it is easily available in the market has second law efficiency slightly lesser than R-152a which was not applicable for commercial applications. The increase in dead state temperature has a positive effect on exergetic efficiency and EDR, i.e. EDR decreases and exergetic efficiency increases with increase in dead state temperature.

H.M. Getu et. al. [9] carried out thermodynamic analysis of an R744–R717 cascade refrigeration system and concluded that by increasing the condenser temperature which increases refrigerant mass flow rates and also the decreasing COP. similarly by increasing evaporating temperature increased COP of the system and decreases mass flow ratios. By increasing temperature difference in cascade condenser reduced both COP and mass flow ratios and by increasing isentropic efficiency of compressors also increases COP linearly. This papers mainly deals with the use of ecofriendly HFO refrigerants in the medium temperature range (up to -50ºC) using Low GWP ecofriendly R245fa in Intermediate temperature cycle up to -95ºC and R600a, R290 in ultra-low temperature (-155ºC) of cascade refrigeration system

2. Results and Discussion

Following input data have been chosen for numerical computations in the– cascade vapour compression refrigeration system using new HFO eco-friendly refrigerant for reducing global warming and ozone depletion:

- Temperature of low temperature evaporator using eco-friendly refrigerants = -50ºC,
- Compressor efficiency of low temperature cycle compressor =80%
- Temperature overlapping between low temperature condenser and intermediate
- Evaporator temperature =10ºC
- Load on low temperature evaporator = 175 "kW"
- Compressor efficiency of high temperature cycle compressor =80%
- Temperature of high temperature evaporator using ecofriendly refrigerants = 0ºC,
- Temperature of high temperature condenser using ecofriendly refrigerants = 50ºC,
- Temperature of intermediate temperature evaporator using following refrigerants = -50ºC

Table-1(a) shows the effect of various ecofriendly refrigerants in the high temperature circuit between temperature range of 50ºC to 0º C and R1234yf in the intermediate evaporator temperature cycle at -50ºC of with 10ºC temperature overlapping (approach) and R32 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R1234ze(Z)gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1234ze(E) and R1224yd(Z).However lowest performances was observed by using R1243zf in high temperature circuit and R32 in low temperature cycle .The power required to run both compressors in whole cascade system is lowest by using R1234ze (Z)in high temperature and R1234yf in intermediate low temperature cycleR32 in low temperature cycle. The second law performance using R1234ze(Z) is higher than using R1234ze(E)or R1224yd(Z) for replacing R134a in high temperature circuit. 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Table-1(c) shows the effect of various ecofriendly refrigerants in the high temperature circuit between temperature range of 50ºC to 0º C and R1234yf in the intermediate evaporator temperature cycle at -50ºC of with 10ºC temperature overlapping (approach) and R290 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R1234ze(Z)gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1234ze(E) and R1224yd(Z).However lowest performances was observed by using R1243zf in high temperature circuit and R32 in low temperature cycle .The power required to run both compressors in whole cascade system is lowest by using R1234ze (Z) in high temperature and R1234yf in intermediate low temperature cycleR32 in low temperature cycle. The second law performance using R1234ze(Z) is higher than using R1234ze(E)or R1224yd(Z) for replacing R134a in high temperature circuit..Table-1(d) shows the effect of various ecofriendly refrigerants in the high temperature circuit between temperature range of 50ºC to 0º C and R1234yf in the intermediate evaporator temperature cycle at -50ºC of with 10ºC temperature overlapping (approach) and ethylene in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R1234ze(Z)gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1234ze(E) and R1224yd(Z).However lowest performances was observed by using R1243zf in high temperature circuit and R32 in low temperature cycle .The power required to run both compressors in whole cascade system is lowest by using R1234ze (Z)in high temperature and R1234yf in intermediate low temperature cycleR32 in low temperature cycle. The second law performance using R1234ze(Z) is higher than using R1234ze(E) or R1224yd(Z) for replacing R134a in high temperature circuit. From table1 (a) to Table1(d), It was found that Hydrocarbon R-600a in low temperature cycle between temperature range (-115ºC to -165ºC gives best thermodynamic first and second law performances with lowest exergy destruction ratio. The thermodynamic first and second law performances of R32 and ethylene are nearly similar and less than R290. Therefore use of hydrocarbons can also be promising by taking appropriate safety measures because mostly hydrocarbons are flammable in nature. Table-2(a) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1233zd(E) refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R32 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and R32 in low temperature cycle .The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R32 in low temperature cycle. The second law performance using R124 is higher than using R1234ze(E)or R1224yd(Z) for replacing R134a in intermediate temperature circuit. However the thermodynamic first and second law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30ºC to -50ºC.Table-2(b) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1233zd(E) refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R600a in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and R600a in low temperature cycle .The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R600a in low temperature cycle. 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Table-3(a) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1234ze(Z) refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R32 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and R32in low temperature cycle .The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R32 in low temperature cycle. The second law performance using R124 is higher than using R1234ze(E)or R1224yd(Z) for replacing R134a in intermediate temperature circuit. 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The second law performance using R124 is higher than using R1224yd(Z) for replacing R134a in intermediate temperature circuit. However the thermodynamic first and second law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30ºC to -50ºC. 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However the thermodynamic first and second law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30ºC to -50ºC

Table-4(c) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1234ze(E) refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R290 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z). However lowest performances was observed by using R1234yf in intermediate temperature circuit and R290in low temperature cycle .The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R290 in low temperature cycle. The second law performance using R124 is higher than using R1224yd(Z) for replacing R134a in intermediate temperature circuit. 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Table-5(a) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1243zf refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R32 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and R32in low temperature cycle .The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R32 in low temperature cycle. The second law performance using R124 is higher than using R1224yd(Z) for replacing R134a in intermediate temperature circuit. 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However the thermodynamic 1^{st} and 2^{nd} law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30ºC to -50ºC.Table-5(c) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50ºC and R1243zf refrigerant in the high evaporator temperature cycle at 0ºC of with 10ºC temperature overlapping (approach) and R290 in the low evaporator temperature cycle at -120ºC of with 10ºC temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and R290in low temperature cycle.

Table- 1(a) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234yf) refrigerant in low temperature circuit and using R32 refrigerant in low temperature circuit

Performance Parameters	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1243zf	HFO1336 mzz(z)	R245fa	R134a
High temperature cycle first law efficiency (COP_{HTC})	3.669	3.215	3.448	3.169	3.402	3.459	3.246
Intermediate temperature cycle first law efficiency (COP_{ITC})	2.188	2.188	2.188	2.188	2.188	2.188	2.188
Low temperature cycle first law efficiency (COP_{LTC})	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034
Overall system first law efficiency ($COP_{Overall\ Cascade}$)	0.3441	0.3306	0.3378	0.3291	0.3365	0.3382	0.3316
System second law efficiency	0.3254	0.3127	0.3196	0.311	0.3182	0.3198	0.3137
($EDR_{Overall\ Cascade}$)	2.188	2.198	2.13	2.213	2.142	2.127	2.188
Total work required to run whole system (Exergy of Fuel) (kW)	203.5	211.7	207.2	212.7	208	207	211.8
High temperature Compressor $Work_{HTC}$(kW)	58.67	66.83	62.33	67.81	63.16	62.12	66.19
Intermediate temperature Compressor $Work_{ITC}$(kW)	67.39	67.39	67.39	67.39	67.39	67.39	67.39
Low temperature Compressor $Work_{LTC}$(kW)	77.49	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Fuel (kW)	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 1(b) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234yf) refrigerant in low temperature circuit and using R600a refrigerant in low temperature

Performance Parameters	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1233zd(E)	HFO1336 mzz(z)	R1243zf	R245fa	R134a
High temperature cycle first law efficiency (COP_{HTC})	3.669	3.215	3.448	3.523	3.402	3.169	3.459	3.246
Intermediate temperature cycle first law efficiency (COP_{ITC})	2.188	2.188	2.188	2.188	2.188	2.188	2.188	2.188
Low temperature cycle first law efficiency (COP_{LTC})	1.075	1.075	1.075	1.075	1.075	1.075	1.075	1.075
Overall system first law efficiency ($COP_{Overall\ Cascade}$)	0.3877	0.3721	0.3805	0.383	0.3789	0.3704	0.3809	0.3733
System second law efficiency	0.3667	0.352	0.3599	0.3623	0.3584	0.3503	0.3603	0.3531
($EDR_{Overall\ Cascade}$)	1.721	1.841	1.779	1.761	1.79	1.855	1.776	1.832
Total work required (Exergy of Fuel) (kW)	180.5	188.1	184	182.8	184.7	189	183.8	187.5
High temperature Compressor $Work_{HTC}$(kW)	53.66	61.23	57.1	55.89	52.87	62.12	56.91	60.64
Intermediate temperature Compressor $Work_{ITC}$(kW)	61.74	61.74	61.74	61.74	61.74	61.74	61.74	61.74
Low temperature Compressor $Work_{LTC}$(kW)	65.12	65.12	65.12	65.12	65.12	65.12	65.12	65.12
Exergy of Fuel (kW)	66.21	66.21	66.21	66.21	66.21	66.21	66.21	66.21

The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and R290 in low temperature cycle. The second law performance using R124 is higher than using R1224yd(Z) for replacing R134a in intermediate temperature circuit. However the thermodynamic 1st and 2nd law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30ºC to -50ºC. Table-5(d) shows the effect of various ecofriendly refrigerants in the intermediate temperature circuit at temperature of -50oC and R1243zf refrigerant in the high evaporator temperature cycle at 0°C of with 10°C temperature overlapping (approach) and ethylene in the low evaporator temperature cycle at -120°C of with 10°C temperature overlapping (approach) found that R124gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and ethylene in low temperature cycle. The power required to run both compressors in whole cascade system is highest by using R1234yf in intermediate temperature and ethylene in low temperature cycle. The second law performance using R124 is higher than using R1224yd(Z) for replacing R134a in intermediate temperature circuit. However the thermodynamic first and second law performances of R1225ye(Z) and HFO-1336mzz(Z) is slightly lower than R134a but these low GWP refrigerants can be alternative for replacing R134a in the low temperature range between -30°C to -50°C

Table- 1(c) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234yf) refrigerant in low temperature circuit and using R290 refrigerant in low temperature

Performance Parameters	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1233zd(E)	HFO1336	R1243zf	R245fa	R134a
High temperature cycle first law efficiency (COP_{HTC})	3.669	3.215	3.448	3.523	3.402	3.169	3.459	3.246
Intermediate temperature cycle first law efficiency (COP_{ITC})	2.188	2.188	2.188	2.188	2.188	2.188	2.188	2.188
Low temperature cycle first law efficiency (COP_{LTC})	1.058	1.058	1.058	1.058	1.058	1.058	1.058	1.058
Overall system first law efficiency ($COP_{Overall\ Cascade}$)	0.3836	0.3682	0.3764	0.3789	0.3749	0.3664	0.3768	0.3693
System second law efficiency	0.33628	0.3482	0.356	0.3584	0.3546	0.3466	0.3564	0.3493
($EDR_{Overall\ Cascade}$)	1.756	1.872	1.809	1.79	1.82	1.885	1.806	1.863
Total work required (Exergy of Fuel) (kW)	182.5	190.1	186	184.7	186.7	191	185.8	189.5
High temperature Compressor $Work_{HTC}$(kW)	58.67	66.83	62.33	56.33	58.32	67.81	62.12	66.19
Intermediate temperature Compressor $Work_{ITC}$(kW)	67.39	67.39	67.39	67.39	67.39	67.39	67.39	67.39
Low temperature Compressor $Work_{LTC}$(kW)	77.49	77.49	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Fuel (kW)	66.21	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 1(d) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234yf) refrigerant in low temperature circuit and using ethylene refrigerant in low temperature circuit

Performance Parameters	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1233zd(E)	R1243zf	R245fa	R134a
High temperature cycle first law efficiency (COP_{HTC})	3.669	3.215	3.448	3.523	3.169	3.459	3.246
Intermediate temperature cycle first law efficiency (COP_{ITC})	2.188	2.188	2.188	2.188	2.188	2.188	2.188
Low temperature cycle first law efficiency (COP_{LTC})	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236
Overall system first law efficiency ($COP_{Overall\ Cascade}$)	0.3441	0.3306	0.3378	0.3453	0.3291	0.3382	0.3316
System second law efficiency	0.3254	0.3127	0.3196	0.3266	0.311	0.3198	0.3137
($EDR_{Overall\ Cascade}$)	2.188	2.198	2.13	2.062	2.213	2.127	2.188
Total work required to run whole system (Exergy of Fuel) (kW)	203.5	211.7	207.2	202.7	212.7	207	211.8
High temperature Compressor $Work_{HTC}$(kW)	58.67	66.83	62.33	60.3	67.81	62.12	66.19
Intermediate temperature Compressor $Work_{ITC}$(kW)	67.39	67.39	67.39	67.39	67.39	67.39	67.39
Low temperature Compressor $Work_{LTC}$(kW)	77.49	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Fuel (kW)	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 2(a) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1233zd(E)) refrigerant in high temperature circuit and using new R32 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.523	3.523	3.523	3.523	3.523	2.363
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3462	0.3452	0.3478	0.34	0.3501	0.3467
System second law efficiency	0.3275	0.3265	0.329	0.3216	0.3311	0.3279
($EDR_{\_\ Overall\ Cascade}$)	2.054	2.063	2.04	2.11	2.02	2.05
Total work required to run whole system (Exergy of Fuel) (kW)	202.2	202.8	201.3	205.9	200	201.9
High temperature Compressor $Work_{\_HTC}$(kW)	60.18	60.32	59.988	61	59.69	60.12
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	64.52	64.99	67.39	64.52	62.79	64.3
Low temperature Compressor $Work_{\_LTC}$(kW)	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 2(b) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1233zd(E)) refrigerant in high temperature circuit and using new R600a refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.523	3.523	3.523	3.523	3.523	2.363
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	1.075	1.075	1.075	1.075	1.075	1.075
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3903	0.3891	0.3921	0.383	0.3947	0.3908
System second law efficiency	0.3691	0.368	0.3709	0.3623	0.3733	0.3696
($EDR_{\_\ Overall\ Cascade}$)	1.709	1.718	1.696	1.76	1.679	1.705
Total work required to run whole system (Exergy of Fuel) (kW)	179.4	179.5	178.5	182.81	177.3	179.1
High temperature Compressor $Work_{\_HTC}$(kW)	55.14	55.26	54.95	55.89	54.69	55.08
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	59.11	59.54	58.44	61.74	57.52	58.91
Low temperature Compressor $Work_{\_LTC}$(kW)	65.12	65.12	65.12	65.12	65.12	65.12
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 2(c) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1233zd(E)) refrigerant in high temperature circuit and using new R290 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.523	3.523	3.523	3.523	3.523	2.363
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	1.058	1.058	1.058	1.058	1.058	1.058
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.386	0.3849	0.3879	0.3789	0.3905	0.3866
System second law efficiency	0.3651	0.364	0.3669	0.3584	0.3693	0.3656
($EDR_{\_\ Overall\ Cascade}$)	1.739	1.747	1.726	1.79	1.708	1.735
Total work required to run whole system (Exergy of Fuel) (kW)	181.3	181.9	180.5	184.7	179.3	181.1

High temperature Compressor Work_$_{HTC}$(kW)	55.57	55.7	55.38	56.33	55.12	55.52
Intermediate temperature Compressor Work_$_{ITC}$(kW)	59.57	60.01	58.9	62.23	57.98	59.37
Low temperature Compressor Work_$_{LTC}$(kW)	66.18	66.18	66.18	66.18	66.18	66.18
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 2(d) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1233zd(E)) refrigerant in high temperature circuit and using ethylene refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1234yf	R124	R245fa	R134a
High temperature cycle first law efficiency (COP_$_{HTC}$)	3.523	3.523	3.523	3.523	3.523	3.523
Intermediate temperature cycle first law efficiency (COP_$_{ITC}$)	2.286	2.269	2.188	2.312	2.349	2.294
Low temperature cycle first law efficiency (COP_$_{LTC}$)	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236
Overall system first law efficiency (COP_$_{Overall\ Cascade}$)	0.3506	0.3506	0.3453	0.3533	0.3556	0.3521
System second law efficiency	0.3316	0.3316	0.3266	0.3341	0.3363	0.333
(EDR_ $_{Overall\ Cascade}$)	2.016	2.016	2.062	1.993	1.974	2.003
Total work required to run whole system (Exergy of Fuel) (kW)	199.7	199.7	202.7	198.1	196.9	198.8
High temperature Compressor Work_$_{HTC}$(kW)	59.63	59.63	60.3	59.29	59.01	59.43
Intermediate temperature Compressor Work_$_{ITC}$(kW)	64.24	64.24	66.62	63.06	62.07	66.56
Low temperature Compressor Work_$_{LTC}$(kW)	75.79	75.79	75.79	75.79	75.79	75.79
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 3(a): Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(Z)) refrigerant in high temperature circuit and using new R32 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R245fa	R134a
High temperature cycle first law efficiency (COP_$_{HTC}$)	3.669	3.669	3.669	3.669	3.669	3.669
Intermediate temperature cycle first law efficiency (COP_$_{ITC}$)	2.286	2.188	2.363	2.249	2.363	2.294
Low temperature cycle first law efficiency (COP_$_{LTC}$)	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034
Overall system first law efficiency (COP_$_{Overall\ Cascade}$)	0.3504	0.3493	0.3551	0.3441	0.3543	0.3508
System second law efficiency	0.3314	0.3304	0.3359	0.3254	0.3351	0.3318
(EDR_ $_{Overall\ Cascade}$)	2.018	2.027	1.977	2.073	1.985	2.014
Total work required to run whole system (Exergy of Fuel) (kW)	199.8	200.4	197.1	203.5	197.6	199.6
High temperature Compressor Work_$_{HTC}$(kW)	57.79	57.92	57.27	58.57	57.32	57.73
Intermediate temperature Compressor Work_$_{ITC}$(kW)	64.52	64.99	67.39	62.79	67.39	64.3
Low temperature Compressor Work_$_{LTC}$(kW)	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 3(b) :Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(Z)) refrigerant in high temperature circuit and using new R600a refrigerant in low temperature

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.669	3.669	3.669	3.669	3.669	3.669	3.669
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.363	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	1.075	1.075	1.075	1.075	1.075	1.075	1.075
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3951	0.3939	0.4006	0.397	0.3877	0.3996	0.3957
System second law efficiency	0.3737	0.3725	0.3789	0.3755	0.3667	0.378	0.3742
($EDR_{\_\ Overall\ Cascade}$)	1.676	1.684	1.639	1.663	1.727	1.646	1.672
Total work required to run whole system (Exergy of Fuel) (kW)	177.2	177.7	174.7	176.3	180.5	175.2	176.9
High temperature Compressor $Work_{\_HTC}$(kW)	52.94	53.06	52.42	52.76	53.66	52.51	52.89
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	59.11	59.54	57.18	58.44	61.74	57.52	58.91
Low temperature Compressor $Work_{\_LTC}$(kW)	65.12	65.12	65.12	65.12	65.12	65.12	65.12
Exergy of Product “kW”	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 3(c) :Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(Z)) refrigerant in high temperature circuit and using new R290 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.669	3.669	3.669	3.669	3.669	3.669	3.669
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.363	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	1.058	1.058	1.058	1.058	1.058	1.058	1.058
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3908	0.3896	0.3963	0.3927	0.3836	0.3953	0.3914
System second law efficiency	0.3996	0.3685	0.3748	0.3714	0.3626	0.3739	0.3702
($EDR_{\_\ Overall\ Cascade}$)	1.705	1.714	1.668	1.692	1.756	1.675	1.702
Total work required to run whole system (Exergy of Fuel) (kW)	179.1	179.7	176.6	178.3	182.5	177.1	178.9
High temperature Compressor $Work_{\_HTC}$(kW)	53.36	53.43	52.83	53.18	54.08	52.93	53.31
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	59.57	60.01	57.63	58.9	62.03	57.98	59.37
Low temperature Compressor $Work_{\_LTC}$(kW)	66.18	66.18	66.18	66.18	66.18	66.18	66.18
Exergy of Product “kW”	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 3(d) :Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(Z)) refrigerant in high temperature circuit and using new ethylene refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.669	3.669	3.669	3.669	3.669	3.669	3.669
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.188	2.363	2.312	2.249	2.363	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3504	0.3493	0.3551	0.3575	0.3441	0.3543	0.3508
System second law efficiency	0.3314	0.3304	0.3359	0.3382	0.3254	0.3351	0.3318
($EDR_{\_\ Overall\ Cascade}$)	2.018	2.027	1.977	1.957	2.073	1.985	2.014

Total work required to run whole system (Exergy of Fuel) (kW)	199.8	200.4	197.1	195.8	203.5	197.6	199.6
High temperature Compressor Work_HTC(kW)	57.79	57.92	57.27	56.93	58.57	57.32	57.73
Intermediate temperature Compressor Work_ITC(kW)	64.52	64.99	67.39	63.06	62.79	67.39	64.3
Low temperature Compressor Work_LTC(kW)	77.49	77.49	77.49	75.79	77.49	77.49	77.49
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 4(a) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(E)) refrigerant in high temperature circuit and using R32 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R245fa	R134a
High temperature cycle first law efficiency (COP_HTC)	3.215	3.215	3.215	3.215	3.215	3.215
Intermediate temperature cycle first law efficiency (COP_ITC)	2.286	2.269	2.363	2.186	2.349	2.294
Low temperature cycle first law efficiency (COP_LTC)	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034
Overall system first law efficiency (COP_Overall Cascade)	0.3366	0.3356	0.3412	0.3306	0.3403	0.3371
System second law efficiency	0.3184	0.3174	0.3227	0.3127	0.3219	0.3188
(EDR_ Overall Cascade)	2.141	2.15	2.099	2.198	2.107	2.131
Total work required to run whole system (Exergy of Fuel) (kW)	207.9	208.6	205.2	211.7	205.7	207.7
High temperature Compressor Work_HTC(kW)	65.94	66.09	65.28	66.83	65.4	65.87
Intermediate temperature Compressor Work_ITC(kW)	64.52	64.99	62.41	67.39	62.79	64.3
Low temperature Compressor Work_LTC(kW)	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 4(b) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(E)) refrigerant in high temperature circuit and usingR600a refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency (COP_HTC)	3.215	3.215	3.215	3.215	3.215	3.215	3.215
Intermediate temperature cycle first law efficiency (COP_ITC)	2.286	2.169	2.363	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency (COP_LTC)	1.075	1.075	1.075	1.075	1.075	1.075	1.075
Overall system first law efficiency (COP_Overall Cascade)	0.3791	0.378	0.3844	0.3809	0.372	0.3834	0.3796
System second law efficiency	0.3586	0.3575	0.3636	0.3603	0.352	0.3626	0.3591
(EDR_ Overall Cascade)	1.789	1.797	1.751	1.776	1.841	1.758	1.785
Total work required to run whole system (Exergy of Fuel) (kW)	184.6	185.2	182.1	183.8	188.1	182.6	184.4
High temperature Compressor Work_HTC(kW)	60.41	60.55	59.81	60.2	61.23	59.92	60.35
Intermediate temperature Compressor Work_ITC(kW)	59.11	59.54	57.18	58.44	61.74	57.52	58.81
Low temperature Compressor Work_LTC(kW)	65.12	65.12	65.12	65.12	65.12	65.12	65.12
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 4(c) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(E)) refrigerant in high temperature circuit and using new R290 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R124	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.215	3.215	3.215	3.215	3.215	3.215	3.215
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.169	2.363	2.312	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	1.058	1.058	1.058	1.058	1.058	1.058	1.058
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3751	0.3739	0.3802	0.3768	3682	0.3793	0.3756
System second law efficiency	0.3547	0.3536	0.3596	0.3564	0.3482	0.3587	0.3552
($EDR_{\_ Overall\ Cascade}$)	1.819	1.828	1.781	1.806	1.872	1.787	1.815
Total work required to run whole system (Exergy of Fuel) (kW)	186.6	187.2	184.1	185.8	190.1	184.5	186.4
High temperature Compressor $Work_{\_HTC}$(kW)	60.88	61.02	60.28	60.68	61.71	60.39	60.82
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	59.57	60.01	57.63	658.9	61.71	57.98	59.37
Low temperature Compressor $Work_{\_LTC}$(kW)	66.18	66.18	66.18	66.18	66.18	66.18	66.18
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 4(d) : Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new HFO (R1234ze(E)) refrigerant in high temperature circuit and using ethylene refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R124	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.215	3.215	3.215	3.215	3.215	3.215	3.215
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.363	2.188	2.312	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3419	0.3409	0.3465	0.3358	0.3436	0.3457	0.3423
System second law efficiency	0.3234	0.3224	0.3277	0.3176	0.3249	0.3269	0.3238
($EDR_{\_ Overall\ Cascade}$)	2.093	2.102	2.051	2.149	2.078	2.059	2.088
Total work required to run whole system (Exergy of Fuel) (kW)	204.7	205.4	202	208.5	203.8	202.4	204.5
High temperature Compressor $Work_{\_HTC}$(kW)	65.18	65.33	64.53	66.07	64.96	64.65	65.12
Intermediate temperature Compressor $Work_{\_ITC}$(kW)	63.77	64.24	61.69	66.62	63.06	62.07	63.56
Low temperature Compressor $Work_{\_LTC}$(kW)	75.79	75.79	75.79	75.79	75.79	75.79	75.79
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 5(a) :Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new R1243zf refrigerant in high temperature circuit and using new R32 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R245fa	R134a
High temperature cycle first law efficiency ($COP_{\_HTC}$)	3.169	3.169	3.169	3.169	3.169	3.169
Intermediate temperature cycle first law efficiency ($COP_{\_ITC}$)	2.286	2.269	2.363	2.188	2.349	2.294
Low temperature cycle first law efficiency ($COP_{\_LTC}$)	0.9034	0.9034	0.9034	0.9034	0.9034	0.9034
Overall system first law efficiency ($COP_{\_Overall\ Cascade}$)	0.3351	0.3341	0.3396	0.3291	0.3388	0.3355
System second law efficiency	0.3169	0.316	0.3212	0.3113	0.3204	0.3173
($EDR_{\_ Overall\ Cascade}$)	2.155	2.165	2.144	2.213	2.121	2.151
Total work required to run whole system (Exergy of Fuel) (kW)	208.9	209.5	206.1	212.7	206.6	208.6

High temperature Compressor Work_HTC(kW)	66.9	66.21	66.24	67.81	66.36	66.83
Intermediate temperature Compressor Work_ITC(kW)	64.52	64.99	62.41	67.39	62.79	60.3
Low temperature Compressor Work_LTC(kW)	77.49	77.49	77.49	77.49	77.49	77.49
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21

Table- 5(b):Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using R1243zf refrigerant in high temperature circuit and using new R600a refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R124	R245fa	R134a
High temperature cycle first law efficiency (COP_HTC)	3.169	3.169	3.169	3.169	3.169	3.169	3.169
Intermediate temperature cycle first law efficiency (COP_ITC)	2.286	2.269	2.363	2.249	2.312	2.349	2.294
Low temperature cycle first law efficiency (COP_LTC)	1.075	1.075	1.075	1.075	1.075	1.075	1.075
Overall system first law efficiency (COP_Overall Cascade)	0.3773	0.3762	0.3825	0.3704	0.3791	0.3816	0.3778
System second law efficiency	0.3589	0.3558	0.3618	0.3503	0.3586	0.3609	0.3574
(EDR_ Overall Cascade)	1.802	1.811	1.764	1.855	1.789	1.771	1.798
Total work required to run whole system (Exergy of Fuel) (kW)	185.5	186.1	183	189	184.6	183.4	185.3
High temperature Compressor Work_HTC(kW)	61.29	61.43	60.68	62.12	61.08	60.79	61.23
Intermediate temperature Compressor Work_ITC(kW)	59.11	59.54	57.18	61.74	58.44	57.52	58.91
Low temperature Compressor Work_LTC(kW)	65.12	65.12	65.12	65.12	65.12	65.12	65.12
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

Table- 5(c): Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using new R1243zf refrigerant in high temperature circuit and using new R290 refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R124	R245fa	R134a
High temperature cycle first law efficiency (COP_HTC)	3.169	3.169	3.169	3.169	3.169	3.169	3.169
Intermediate temperature cycle first law efficiency (COP_ITC)	2.286	2.269	2.363	2.188	2.312	2.349	2.294
Low temperature cycle first law efficiency (COP_LTC)	1.058	1.058	1.058	1.058	1.058	1.058	1.058
Overall system first law efficiency (COP_Overall Cascade)	0.3733	0.3721	0.3784	0.3664	0.375	0.3775	0.3508
System second law efficiency	0.353	0.352	0.3579	0.3466	0.357	0.357	0.3318
(EDR_ Overall Cascade)	1.832	1.841	1.794	1.885	1.819	1.801	2.014
Total work required (Exergy of Fuel) (kW)	187.5	188.1	185	191	186.6	185.4	199.6
High temperature Compressor Work_HTC(kW)	61.77	61.91	61.16	62.61	61.56	61.27	61.71
Intermediate temperature Compressor Work_ITC(kW)	59.57	60.01	57.63	62.23	59.9	57.98	59.37
Low temperature Compressor Work_LTC(kW)	66.18	66.18	66.18	66.18	66.18	66.18	66.18
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.18	66.21	66.21

Table- 5(d): Thermodynamic (Energy-Exergy) performance Parameters of cascade) vapour compression refrigeration system using R1243zf refrigerant in high temperature circuit and using ethylene refrigerant in low temperature circuit

Performance Parameters	HFO-1336mzz(Z)	R1225ye(Z)	R1233zd(E)	R1234yf	R124	R245fa	R134a
High temperature cycle first law efficiency (COP_HTC)	3.169	3.169	3.169	3.169	3.169	3.169	3.169

Intermediate temperature cycle first law efficiency (COP_ITC)	2.286	2.269	2.363	2.188	2.312	2.349	2.294
Low temperature cycle first law efficiency (COP_LTC)	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236	0.9236
Overall system first law efficiency (COP_Overall Cascade)	0.3403	0.3393	0.3449	0.3342	0.3419	0.3441	0.3408
System second law efficiency	0.3219	0.3209	0.3262	0.3161	0.3233	0.3254	0.3223
(EDR_ Overall Cascade)	2.107	2.116	2.066	2.163	2.093	2.073	2.103
Total work required to run whole system (Exergy of Fuel) (kW)	205.7	206.3	203	209.4	204.8	203.5	205.4
High temperature Compressor Work_HTC(kW)	66.13	66.28	65.48	67.03	65.91	57.32	57.73
Intermediate temperature Compressor Work_ITC(kW)	63.77	64.24	61.69	66.62	63.06	67.39	64.3
Low temperature Compressor Work_LTC(kW)	75.79	75.79	75.79	75.79	75.79	75.79	75.79
Exergy of Product "kW"	66.21	66.21	66.21	66.21	66.21	66.21	66.21

3. Conclusions

Following conclusions were drawn from present investigation

- Hydrocarbon R-600a in ultra low temperature cycle between temperature range (-115ºC to -165ºC) gives best thermodynamic first and second law performances with lowest exergy destruction rato also higher than R290 hydrocarbon
- The thermodynamic first and second law performances of R32 and ethylene are nearly similar and less than R290.
- The use of hydrocarbons in ultra low temperature cycle between temperature range (-115ºC to -165ºC) can also be promising by taking appropriate safety measures because mostly hydrocarbons are flammable in nature
- shows the effect of various ecofriendly refrigerants In the high temperature circuit between temperature range of 50ºC to 0º C and several ecofriendly HFO and HFC refrigerantsin the intermediate evaporator temperature cycle at -50ºC of with 10ºC temperature overlapping (approach) and four ecofriendly refrigerants such as (R32, R600a , R290 & ethylene)in the low evaporator temperature cycle between -110ºC to -130ºC with 10ºC temperature overlapping in LTC condenser and ITC evaporator (approach) found that R1234ze(Z)gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1234ze(E) and R1224yd(Z).
- The lowest thermodynamic first and second law performances found by using R1243zf in high temperature circuit and and four ecofriendly refrigerants such as *(R32, R600a , R290 & ethylene)* in low temperature cycle .
- The power required to run both compressors in whole cascade system is lowest by using R1234ze (Z)in high temperature and R1234yf in intermediate low temperature cycle using four ecofriendly refrigerants such as (R32, R600a), R290 & ethylene) in ultra low temperature cycle between temperature variation of evaporator is -110ºC to -130ºC. The second law performance using R1234ze(Z) ishigher than using R1234ze(E)or R1224yd(Z) for replacing R134a in high temperature circuit.
- In the intermediate evaporator temperature cycle range from -30ºC to -50ºC, using R-1234ze(Z) or R1234ze€ or R1243zf in high temperature cycle and R-600a, R290, ethylene & R32 refrigerants in low temperature cycle from -30ºC to -50ºC the R124 in intermediate temperature cycle gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to HFO-1336mzz(Z) and R1225ye(Z) .However lowest performances was observed by using R1234yf in intermediate temperature circuit and ethylenein low temperature cycle

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Cite this article as: R.S Mishra, Thermal Performance of three stage cascade vapour compression refrigeration systems using new HFO in high and intermediate temperature cycle and R32 ethylene and hydrocarbons in ultra-low temperature cycle refrigerants, International Journal of Research in Engineering and Innovation Vol-4, Issue-2 (2020), 109-123.
https://doi.org/10.36037/IJREI.2020.4206