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RESEARCH PAPER

Thermodynamic Performances Improvement of Cascade Vapour Compression Refrigeration System using New HFO Eco-Friendly Refrigerant for Reducing Global Warming and Ozone Depletion

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ABSTRACT

The ozone depletion and global warming due to the use of various refrigerants is very serious for environmental degradation which affect living of human standard Therefore, it is essential to search and use new and low GWP and zero ODP eco-friendly refrigerants. Thermodynamic first and second law performances (energy-exergy efficiencies) of cascade vapour compression refrigeration system using new HFO eco-friendly refrigerants for reducing global warming and ozone depletion performance parameters such as COP, exergetic e±ciency and exergy destruction ratio and power required to run whole systems have been presented in this paper. The various combinations of using six different ecofriendly refrigerants used in high temperature cycle in the temperature range of from 50°C to 0°C for which other five ecofriendly low GWP refrigerants in the temperature range of from 0°C to-50°C have been compared. It is found that The first and second law performances of cascade vapour compresson refrigeration system using R1234ze(Z) in higher temperature cycle and R1233zd(E) in low temperature cycle gives best thermodynamic performance as compared to R1234ze(E) and R1224ze(z) and R1243z in high temperature cycle. Moreover lowest performances were found by using R1234yf in high or low temperature cycles as compared to other HFO refrigerants. The comparison was made between HFO-1234yf and HFC-134a in low temperature cycle up to temperature of -50°C and also found the first and second law efficiencies are 3.245% lower than using R-1234yf in low temperature cycle as compared to HFC-134a in low temperature cycle and R1234ze(Z) in high temperature cycle with 5.195% decrement in the exergy destruction ratio.

Key words: *HFO refrigerants in HTC, Thermodynamic Analysis, Cascade vapour compression Refrigeration Systems*

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INTRODUCTION

Refrigeration plays a very significant role in industrial, domestic and commercial sectors for cooling, heating and food preserving applications. There are numerous applications of such systems and they are the major consumer of electricity around the world because energy utilization is directly proportional to the economic development of any nation. However, this area is in huge interest now a day because of increase in the cost of conventional fuels and environmental concerns globally. The scientists are searching for new/alternate renewable energy sources in order to reduce the costs. Due to the ever-increasing energy demand and degradation of environment due to global warming and depletion of ozone layer etc, there is urgent need of efficient energy utilization and waste heat recovery for useful applications. 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 sources besides, efficient utilization of all conventional sources, Anand Tyagi, (2012). Arora and Kaushik, (2008) carried out theoretical analysis of actual VCRS with liquid vapour heat exchanger & also carried out analysis on basis of energy, entropy, & exergy in specific temperature range of evaporator and condenser. Besides, they concluded that R502 fluid was best refrigerant as compared to R404A and R507A fluid. The main objective is to investigate the thermodynamic performances of cascade vapour compression refrigeration systems (VCRS) based on energy-exergy principles. In this investigations , several new HFO refrigerants flowing in the high temperature circuit between temperature range from 50°C to 0°C have been compared in terms of first law efficiency known as coefficient of performance (COP) and second law efficiency commonly known as exergetic efficiency (Exergy Efficiency) and exergy destruction ratio ($EDR_{\_System}$) and other ecofriendly new HFO refrigerants are also compared with HFC-134a, R245fa and R32 in low temperature circuit up to -50°C by doing exergy analysis.

THERMODYNAMIC (ENERGY-EXERGY) PERFORMANCES OF VAPOUR COMPRESSION REFRIGERATION SYSTEM:

First law analysis (energy analysis) is restricted to calculate only coefficient of performance of system but exergy analysis is the one of the most useful analyses to evaluate the plant losses, the actual amount of energy flow through process exergetic efficiency and exergetic destruction Ratio, Anand, *et. al*, (2012). Ahamed *et. al.,* (2011) 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. Ahamed *et. al.,* (2011) 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 occurred 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 thesystem. The experimental analysis of 2TR (ton of refrigeration) vapor compression refrigeration cycle for different percentage of refrigerant charge using exergy analysis is carried out by Anand, *et. al.*, (2012). An experimental setup has been developed and evaluated on different operating conditions using a test rig having R22 as working fluid. The coefficient of performance, exergy destruction, and exergetic efficiency for variable quantity of refrigerant has been calculated. The present investigation has been done by using 2TR window air conditioner. A 2TR window air conditioner equipped with different pressure, temperature and flow measuring devices has been studied experimentally using energy and exergy analysis. The unit is charged with refrigerant R-22 in four steps, i.e., 25, 50, 75, and 100%, respectively, and the system performance is analyzed in each case. The reference temperature is measured to be 25^{o}C. The results indicate that the losses in the compressor are more pronounced, while the losses in the condenser are less pronounced as compared to other components, i.e., evaporator and expansion device. The total exergy destruction is highest when the system is 100% charged, whereas it is found to be least when the system is 25% charged.

Chopra Kapil, *et. al.*, (2014) 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. Getu, *et. al.,* (2008) carried out thermodynamic analysis of an R744–R717 cascade refrigeration system and concluded that by increasing the condenser temperature which increasese 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. Joybari *et al.* (2013) done experimental investigation on a domestic refrigerator and concluded that compressor's exergetic destruction was highest in contrast to other components. Mishra, (2014 a,b,c) 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 use 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. Reddy, *et. al.* (2012) 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.

The above investigators did not carried out detailed thermodynamic first and second law analysis using energy and exergy principles for predicting performances using latest and new ecofriendly of low GWP refrigerants of cascade refrigeration systems for replacing high GWP refrigerants in near future. In this paper, thermodynamic first law efficiency in terms of coefficient of performance (COP) and second law efficiency in terms of exergetic efficiency have been computed for low temperature applications used for bio medical applications and best solution for replacing High GWP refrigerants and important results have been presented in next section.

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-

1. Temperature of low temperature evaporator using eco-friendly refrigerants = -50°C
2. Compressor efficiency of low temperature cycle compressor =80%
3. Temperature overlapping between low temperature condenser and intermediate temperature evaporator =10°C
4. Load on low temperature evaporator = 175 "kW"
5. Compressor efficiency of high temperature cycle compressor =80%
6. Temperature of high temperature evaporator using ecofriendly refrigerants = 0°C,
7. Temperature of high temperature condenser using ecofriendly refrigerants = 50°C,
8. Temperature of intermediate temperature evaporator using following refrigerants = -50°C

Table-1 shows the effect of various ecofriendly refrigerants in high temperature circuit between temperature range of 50°C to 0° C and R134a in the low temperature cycle at-50°C of evaporator with 10 °C temperature overlapping (approach) and found that R1234ze(z) gives best/ highest thermodynamic performances with lowest exergy destruction ratio as compared to R1224yd(Z) and R1234ze(E) and R1243zf.However lowest performances was observed by using R1234yf in high temperature circuit and R134a in low temperature cycle .

Table-2 show the effect of various ecofriendly refrigerants in high temperature circuit between temperature range of 50°C to 0° C and HFO-1234yf in the low temperature cycle at -50°C of evaporator with 10 °C temperature overlapping (approach) and found that R1234ze(z) gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1224yd(Z) and R1234ze(E) and R1243zf. 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 HFC-134a gives better cycle thermodynamic performances 4.845 % higher than R1234yf and overall cascade system thermodynamic first law performances 6.708%. The second law performance (exergetic efficiency) using R134a in low temperature cycle is 6.665% higher than using R1234yf in low temperature cycle.

Table-3 shows the effect of various ecofriendly refrigerants in the low temperature circuit between temperature range of -50°C to 0°C and R1234ze(Z) in the high temperature cycle at 50°C of evaporator with 10 °C temperature overlapping (approach) and found that R1233zd(E)gives best/highest thermodynamic performances with lowest exergy destruction ratio as compared to R1224yd(Z) and HFO1336mzz(Z). However lowest performances was observed by using R1234yf in high temperature circuit and R134a in low temperature cycle. The power required to run both compressors in whole cascade system is lowest by using R1233zd(E)in lower temperature while highest by using R1234yf in low temperature cycle. The second law performance using R1233zd(E) is higher than using HFO-1336mzz(Z) or R1225ye(Z) in lower temperature circuit. It was also observed that the thermodynamic performances using HFO-1336mzz(Z) and R1225ye(Z) are nearly same nearly 0.5% differences. The lowest thermodynamic first and second law performances were found by using R1234yf in the low temperature circuit.

Table 1: Thermodynamic (Energy-Exergy) performance Parameters of- cascade) vapour compression refrigeration system using new HFC (R134a) refrigerant in low temperature circuit and following ecofriendly refrigerant in high temperature circuit for reducing global warming and ozone depletion depletion

First & second Law performances	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1243zf	R1234yf
$COP_{\_HTC}$	3.669	3.215	3.448	3.169	2.986
$COP_{\_LTC}$	2.294	2.294	2.294	2.294	2.294
$COP_{\_Overall\ Cascade}$	1.209	1.133	1.173	1.125	1.091
Second law efficiency	0.4065	0.3811	0.3945	0.3783	0.3668
$EDR_{\_Overall\ Cascade}$	1.46	1.621	1.535	1.644	1.726
Exergy of Fuel (kW)	144.8	154.5	149.2	155.6	160.4

Table 2: Thermodynamic (Energy-Exergy) performance Parameters of- cascade) vapour compression refrigeration system using new HFO (R1234yf) refrigerant in low temperature circuit and following ecofriendly refrigerant in high temperature circuit for reducing global warming and ozone depletion depletion

First & second Law performances	R1234ze(Z)	R1234ze(E)	R1224yd(Z)	R1243zf	R1234yf
$COP_{\_HTC}$	3.669	3.215	3.448	3.169	2.986
$COP_{\_LTC}$	2.188	2.188	2.188	2.188	2.188
$COP_{\_Overall\ Cascade}$	1.171	1.099	1.137	1.091	1.104
Second law efficiency	0.3938	0.3695	0.3824	0.3669	0.3713
$EDR_{\_Overall\ Cascade}$	1.54	1.706	1.615	1.726	1.693
Exergy of Fuel (kW)	149.5	159.3	153.9	160.4	158.5

Table 3: First law performance Parameters of- cascade) vapour compression refrigeration system using new HFO (R1234ze(Z) in high temperature circuit and following ecofriendly refrigerant in low temperature circuit for reducing global warming and ozone depletion

First & second Law performances	HFO-1336mzz(Z)	R1234yf	R1225ye(Z)	R1233zd(E)	R124	R245fa	R32
$COP_{\_HTC}$	3.669	3.669	3.669	3.669	3.669	3.669	3.669
$COP_{\_LTC}$	2.286	2.188	2.289	2.363	2.312	2.349	2.249
$COP_{\_Overall\ Cascade}$	1.206	1.171	1.20	1.233	1.218	1.228	1.193
Second law efficiency	0.4058	0.3998	0.4036	0.4147	0.4087	0.4130	0.4012
$EDR_{\_Overall\ Cascade}$	1.466	1.540	1.478	1.412	1.447	1.421	1.493
Exergy of Fuel (KW)	145.1	149.5	145.8	141.9	144.0	142.5	146.7
Exergy of Product (KW)	58.86	58.86	58.86	58.86	58.86	58.86	58.86

Table-4 shows the effect of various ecofriendly refrigerants in the low temperature circuit between temperature range of -50°C to 0°C and R1234ze(E) in the high temperature cycle at 50°C of evaporator with 10°C temperature overlapping (approach) and found that R1233zd(E) gives best/highest (more than 2.183% thermodynamic performances with lowest exergy destruction ratio as compared to R1225ye(Z) and HFO1336mzz(Z). However lowest performances was observed by using R1234yf in high temperature circuit and R134a in low temperature cycle. The power required to run both compressors in whole cascade system is lowest by using R1233zd(E) in lower temperature while highest by using R1234yf in low temperature cycle. The second law performance using R1233zd(E) is higher than using HFO-1336mzz(Z) or R1225ye(Z) in lower temperature circuit. It was also observed that the thermodynamic performances using HFO-1336mzz(Z) and R1225ye(Z) are nearly same nearly 0.5% differences. The lowest thermodynamic first and second law performance was found by using R1234yf in the low temperature circuit.

Table-5 shows the effect of various ecofriendly refrigerants in the low temperature circuit between temperature range of -50°C to 0°C and R1224zd(Z) in the high temperature cycle at 50°C of evaporator with 10°C temperature overlapping (approach) and found that R1233zd(E)gives best/highest (more than 2.183% thermodynamic performances with lowest exergy destruction ratio as compared to R1225ye(Z) and HFO1336mzz(Z). However lowest performances was observed by using R1234yf in high temperature circuit and R134a in low temperature cycle. The power required to run both compressors in whole cascade system is lowest by using R1233zd(E) in lower temperature while highest by using R1234yf in low temperature cycle. The second law performance using R1233zd(E) is higher than using HFO-1336mzz(Z) or R1225ye(Z) in lower temperature circuit. It was also observed that the thermodynamic performances using HFO-1336mzz(Z) and R1225ye(Z) are nearly same nearly 0.5% differences. The lowest thermodynamic first and second law performances were found by using R1234yf in the low temperature circuit.

Table-6 shows the effect of various ecofriendly refrigerants in the low temperature circuit between temperature range of -50°C to 0°C and R1243zf in the high temperature cycle at 50°C of evaporator with 10°C temperature overlapping (approach) and found that R1233zd(E)gives best/highest (more than 2.183% thermodynamic performances with lowest exergy destruction ratio as compared to R1225ye(Z) and HFO1336mzz(Z). However lowest performances was observed by using R1234yf in high temperature circuit and R134a in low temperature cycle. The power required to run both compressors in whole cascade system is lowest by using R1233zd(E) in lower temperature while highest by using R1234yf in low temperature cycle. The second law performance using R1233zd(E) is higher than using HFO-1336mzz(Z) or R1225ye(Z) in lower temperature circuit. It was also observed that the thermodynamic performances using HFO-1336mzz(Z) and R1225ye(Z) are nearly same nearly 0.5% differences. The lowest thermodynamic first and second law performance was found by using R1234yf in the low temperature circuit.

Table 4: Thermodynamic (Energy-Exergy) performance Parameters of- cascade) vapour compression refrigeration system using new HFO refrigerant (R1234ze(E) in high temperature circuit and following ecofriendly refrigerant in low temperature circuit for reducing global warming and ozone depletion

First & second Law performances	HFO-1336mzz(Z)	R1234yf	R1225ye(Z)	R1233zd(E)	R32	R245fa	R124
$COP_{\_HTC}$	3.215	3.215	3.215	3.215	3.215	3.215	3.215
$COP_{\_LTC}$	2.286	2.188	2.289	2.363	2.249	2.349	2.312
$COP_{\_Overall\ Cascade}$	1.139	1.109	1.125	1.155	1.119	1.151	1.139
Second law efficiency	0.3802	0.3695	0.3784	0.3885	0.3762	0.3870	0.383
$EDR_{\_Overall\ Cascade}$	1.63	1.540	1.642	1.574	1.493	1.421	1.611
Exergy of Fuel (KW)	154.8	159.3	155.5	151.5	156.7	154.1	153.7

Table 5: Thermodynamic (Energy-Exergy) performance Parameters of- cascade) vapour compression refrigeration system using new HFO refrigerant (R1224zd(Z) in high temperature circuit and following ecofriendly refrigerant in low temperature circuit for reducing global warming and ozone depletion

First & second Law performances	HFO-1336mzz(Z)	R1234yf	R1225ye(Z)	R1233zd(E)	R32	R245fa	R124
COP_{HTC}	3.448	3.448	3.448	3.448	3.448	3.448	3.448
COP_{LTC}	2.286	2.188	2.269	2.363	2.249	2.349	2.312
$COP\_{Overall\ Cascade}$	1.142	1.131	1.192	1.196	1.158	1.192	1.179
Second law efficiency	0.4007	0.3824	0.4007	0.4023	0.3894	0.4007	0.3966
$EDR\_{Overall\ Cascade}$	1.495	1.615	1.445	1.486	1.568	1.445	1.521
Exergy of Fuel (kW)	146.9	153.9	146.9	146.3	151.1	146.9	148.4

Table 6: Thermodynamic (Energy-Exergy) performance Parameters of- cascade) vapour compression refrigeration system using new HFO (R1243zf) refrigerant in high temperature circuit and following ecofriendly refrigerant in low temperature circuit for reducing global warming and ozone depletion

First & second Law performances	HFO-1336mzz(Z)	R1234yf	R1225ye(Z)	R1233zd(E)	R32	R245fa	R124
COP_{HTC}	3.169	3.169	3.169	3.169	3.169	3.169	3.169
COP_{LTC}	2.286	2.188	2.269	2.363	2.249	2.349	2.312
$COP\_{Overall\ Cascade}$	1.122	1.091	1.117	1.141	1.111	1.142	1.131
Second law efficiency	0.3774	0.3669	0.3750	0.3856	0.3735	0.3841	0.3802
$EDR\_{Overall\ Cascade}$	1.649	1.726	1.662	1.594	1.677	1.604	1.630
Exergy of Fuel (kW)	155.9	160.4	156.7	152.6	157.6	153.2	154.8

CONCLUSIONS AND RECOMMENDATION

The following conclusions were drawn from present investigation-

1. The first and second law performances of cascade vapour compresson refrigeration system using R1234ze(Z) in higher temperature cycle is highest.
2. The first and second law performances of cascade vapour compresson refrigeration system using R1234ze(Z) in higher temperature cycle and HFO and HFC refrigerants in lower temperature is higher than R1234ze(E) R1224zd(Z) and (R1243zf) in high temperature cycle.
3. The power required to run both compressors in whole cascade system is lowest by using R1233zd(E) in lower temperature while highest by using R1234yf in low temperature cycle while using R1234ze(z), R1234ze(E), R1224ze(Z) and (R1243zf) in high temperature cycle.
4. The thermodynamic performances using HFO-1336mzz(Z) and R1225ye(Z) in low temperature cycle are nearly same nearly 0.5% differences using R1234ze(z) or R-1234ze(E) in high temperature cycle. The lowest thermodynamic first and second law performance was found by using R1234yf in the low temperature circuit.
5. R1243zf gives lower thermodynamic performance as compared to using R1234ze(Z) and R1234ze(E) in high temperature cycle.
6. The thermodynamic performances using R1234yf in higher temperature cycle and even in low temperature cycle gives lower performances as compared to other HFO refrigerants.

REFERENCES

1. Ahemed J.U., Saidur R., Masjuki H.H. and Mehjabin S. (2011a): A review on exergy analysis of vapor compression refrigeration system. Int. J. Renewable and Sustainable Energy Reviews, 15: 1593-1600.
2. Ahemed J.U., Saidur R., Masjuki H.H. and Mehjabin S. (2011b): Prospect of hydrocarbon used based on exergy analysis in the vapour compression refrigeration system. Int. J. Renewable and Sustainable Energy Reviews, 1: 67-70.
3. Anand S. and Tyagi S.K. (2012): Exergy analysis and experimental study of a vapour compression refrigeration cycle, Int J Therm Anal Calorim., 110: 961-971.
4. Arora A. and Kaushik S.C. (2008): Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A. Int J Refrigeration, 31: 998-1005.
5. Chopra Kapil, Sahni V. and Mishra R.S. (2014): Method for improving first and second law efficiencies of vapour compression refrigeration system using flash-intercooler with ecofriendly refrigerants. International journal of advance research and innovation, 1(1): 50-54.
6. Getu H.M. and P.K Bansal (2008): Thermodynamic analysis of an R744–R717 cascade refrigeration system; international journal of refrigeration, 31: 45-54
7. Joybari M.M., Hatamipour M.S., Rahimi A. and Modarres F.G. (2013): Exergy analysis and optimization of R600a as a replacement of R134a in a domestic refrigerator system, International Journal of refrigeration, 36: 1233-1242.
8. Mishra R.S. (2014a): Method for improving exergetic efficiency of multi-evaporators single compressor and single expansion valve in vapour compression refrigeration system using thirteen ecofriendly refrigerants for reducing global warming and ozone depletion", international journal of latest research in science and technology, 3(3):191-196.
9. Mishra R.S. (2014b): Method for improving thermal performance of vapour compression refrigeration system using energy analysis for reducing warming and global warming and ozone depletioning using ecofriendly refrigerants. Nature and environment, 19: 219-231.
10. Mishra R.S. (2014c): Methods for improving thermodynamic performance of vapour compression refrigeration system using twelve eco friendly refrigerants in primary circuit and nano fluid (water- nano particles based) in secondary circuit. International Journal of Emerging Technology and Advanced Engineering, 4(6): 878-891.
11. Reddy V.S., Panwar N.L. and Kaushik S.C. (2012): Exergy analysis of a vapour compression refrigeration system with R134a,R143a,R152a, R404A,R407C, R410A,R502 and R507A, Clean Techn Environ Policy, 14: 47-53.