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

Irreversibility analysis of Two and three stage vapour compression refrigeration systems with multi evaporators and flash-intercooler using new ecofriendly refrigerants (R227ea, R236fa, R245fa, R1234yf, R1234ze) for replacing R134a

R.S. Mishra

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

Abstract

The performance parameters for HFO-1234yf are around ten% lesser than that of HFC-134a, so it can a good alternative to HFC-134a because of its environmental friendly properties. Similarly HFO-1234ze can replace the conventional HFC-134a after having slight modification in the design as the performance parameters are 4% to 5% less than using R134a. However by using liquid vapor heat exchanger, the first law performances improved slightly. The numerical computation have been carried out for ecofriendly refrigerants and hydrocarbons and it is concluded that mixture of hydrocarbon with slightly modification in system design can also replace R134a.

Key words: Thermodynamic Analysis, Vapour compression Refrigeration system, Irreversibility Analysis

1. Introduction

The most commonly used refrigerants in recent past were R11, R12, and R22 which because of their high ODP have been either phased out or under consideration for the same. After the revelation of the harmful effects of CFC and HCFC refrigerants on the ozone layer, search to find alternative working fluids gained more interest in the recent few years. The HFC134a was found to be a suitable candidate for replacing R12 and is being successfully used to date in small equipment like domestic refrigerators and water coolers and in mobile air-conditioning. HFC134a has very high GWP which is a matter of environmental concern [1]. HFO stands for hydro-fluoro-olefin (HFO-1234yf) is a low global warming potential (GWP) 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. They are used in a number of applications today, but have been barely studied just a decade agoHFO-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 1. These refrigerants are used as a "near drop-in replacement" for R-134a, the current product used in automobile AC systems, which has a 100-year GWP of 1430. HFO-1234yf has the lowest cost among the currently proposed alternatives (i.e.R134a). Thermophysical properties of Refrigerants are shown in table-1

Table 1: Thermophysical properties of HFO Refrigerants.

Properties	HFO-1234yf	HFO-1234ze	HFC-134a
Boiling Point, Tb	-29°C	-19°C	-26°C
Critical Point, Tc	94.7°C	109.4°C	101°C
Pvap, MPa at 25°C	0.682	0.500	0.665
Pvap, MPa at 80°C	2.519	2.007	2.635
Liquid Density, kg/m3 at 25°C	1092	1162	1207
Vapour Density, kg/m3 at 25°C	37.94	26.76	32.34

The initial cost of refrigeration and air conditioning system using R1234yf is much higher than that of R-134a and handled in repair shops in the same way as R-134a. Although it would require different, specialized equipment to perform the service due to the mild flammability of HFO-1234yf and another issue affecting the compatibility between HFO-1234yf and R-134a-

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

based systems due to choice of lubricating oil. The current lubricating oil is showing signs of damage to plastic and aluminium, and issues with health, including mouth dryness, rashes, and sore throat, among other effects.

2. Literature Review

HFO-1234yf would be adopted as a replacement of R-134a automotive air-conditioning refrigerant. Mishra [2] 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 5.6%, which decreases with the increase in evaporator temperature, whereas it is 14.5-5% higher than HFO-1234yf. Hence HFO-1234yf can be a good drop-in' replacement of HFC-134a at higher value of evaporator temperature and HFO-1234ze can be a good replacement after certain modification [3]. From the irreversibility or exergy destruction viewpoint, worst component is condenser followed by compressor, throttle valve, evaporator and liquid vapour heat exchanger, the most efficient component. Total efficiency defect is more for HFO-1234yf followed by HFO-1234ze and HFC-134a, but the difference is small. Increase in ambient state temperature has a increasing (positive) effect on second law efficiency in terms of exergetic efficiency and exergy destruction ratio which was computed based on exergy of fuel or based on exergy of product (EDR). When exergy destruction ratio (EDR) reduced, then exergetic efficiency increases. Therefore HFO-1234yf gives lesser values of exergetic efficiency whereas HFO-1234ze gives approximately similar values.4. HFC-134a gives higher COP and exergetic efficiency than HFO-1234yf but lesser value than HFO- 1234ze. However reverse trend is seen when effectiveness of heat exchanger is increased from 0 to 1. Hence, it can be concluded that even though the values of performance parameters for HFO-1234yf are smaller than that of HFC-134a, but the difference is small, so it can a good alternative to HFC-134a because of its environmental friendly properties. HFO-1234ze can replace the conventional HFC-134a after having slight modification in the design as the performance parameters are almost similar.

3. Energy Exergy Analysis of Vapor Compression Refrigeration Systems

The second law analysis (i.e. exergy Computation) is widely accepted as a useful tool for obtaining overall performances of any system for finding various exergy losses occurred in its components Exergy analysis also helps in taking account the important engineering decisions regarding design parameters of a system by finding maximum exergy destruction using entropy generation principle Many researchers have carried out exergy studies of different thermal energy conversion systems describing various approach for exergy analysis and its usefulness for improving existing designs by reducing exergy destruction in a more simple and effective manner [2-3] Padilla et al. [4] computed the exergy performance of a domestic vapor compression refrigeration system (VCRS) by using zeotropic mixture (R413A) for direct replacement of R12 and found that the overall energy and exergy performances of this system working with R413A is far better than R12. Arora and Kaushik [5] presented a detailed exergy analysis of an actual vapour compression refrigeration (VCR) cycle and developed computational model for computing coefficient of performance (COP), exergy destruction, exergetic efficiency and efficiency defects for R502, R404A and R507A and found that the R507A is a better substitute to R502 than R404A. The efficiency defect in condenser is highest, and lowest in liquid vapour heat exchanger for R502, R404A and R507A refrigerants in the range of −50 °C to 0 °C evaporator temperature and in the range and 40 °C to 55 °C condenser temperature respectively. Anand S and Tyagi S. K. [6] presented a detailed experimental analysis of 2 ton of refrigeration capacity vapor compression refrigeration cycle using R22 as working fluid for different percentage of refrigerant charge using exergy analysis and evaluated thermal performances (i.e. coefficient of performance, exergy destruction, and exergetic efficiency) under variable quantity of refrigerant and found that the losses in the compressor are more pronounced, while the losses in the condenser are less pronounced as compared to other components. A computational model based on the exergy analysis is presented by Yumrutas et. al [7] for the investigation of the effects of the evaporating and condensing temperatures on the pressure losses, exergy losses, second law of efficiency, and the COP of a vapour compression cycle. Dincer [8] asserts that conventional energy analysis, based on the first law of thermodynamics, evaluates energy mainly on its quantity but analysis that are based on second law considers not only the quality of energy, but also quantity of energy. Kumar et al. [9] also carried out to carry out the exergetic analysis of a VCR system using R11 and R12 as refrigerants. Nikolaidis and Probert [10] used exergy method for computing thermodynamic performances of R22 in a two-stage compound compression cycle, with flash intercooling. Bejan [11] developed, thermodynamic model by considering heat transfer irreversibility and showed that the exergetic efficiency decreases as evaporator temperature decreases.

Getu and Bansal [12] had optimized the design and operating parameters of like condensing temperature, sub cooling temperature, evaporating temperature, superheating temperature and temperature difference in cascade heat exchanger R744-R717 cascade refrigeration system. A regression analysis was also done to obtain optimum thermodynamic parameters of same system.

From the irreversibility or exergy destruction viewpoint, worst component is condenser followed by compressor, throttle valve, evaporator and liquid vapour heat exchanger, the most efficient component. Total efficiency defect is more for HFO-1234yf followed by HFO-1234ze and HFC-134a, but the difference is small. Increase in ambient state temperature has a increasing (positive) effect on second law efficiency in terms of exergetic efficiency and exergy destruction ratio which was computed based on exergy of fuel or based on exergy of product (EDR). When exergy destruction ratio (EDR) reduced, then the exergetic efficiency increases. Therefore HFO-1234yf gives lesser values of exergetic efficiency whereas HFO-1234ze gives approximately 4% less values. HFC-134a gives higher COP and exergetic efficiency than HFO-1234yf but lesser value than HFO- 1234ze [13].

In this investigation the work input required running the vapour compression refrigeration system reduced by using compound compression and further decreased by flash intercooling between compressors. COP of system can also be enhanced by compressing the refrigerant very close to the saturation line this can be achieved by compressing the refrigerants in more stages with intermediate intercoolers. The refrigeration effect can be increase by maintaining the condition of refrigerants in more liquid stage at the entrance of evaporator which can be achieved by expanding the refrigerant very close to the liquid line. The expansion can be brought close to the liquid line by subcooling the refrigerant and removing the flashed vapours by incorporating the flash chamber in the working cycle. The evaporator size can be reduced because unwanted vapours formed are removed before the liquid refrigerant enters in the evaporator. Multi-stage vapour compression with flash intercooler and individual throttle valves (system-1) consists of three compressors arranged in compound compression, individual throttle valves, condenser and evaporators as shown in Fig.1. Multiple evaporators at different temperatures with compound compression, flash intercooler and multiple throttle valves (system-2) consists of three compressors arranged in compound compression, multiple throttle valves, condenser and evaporators as shown in Fig.2.

4. Energy and exergy analysis

For carrying out energetic and exergetic analysis, computational models of system-1 and system-2 has been developed and impact of chosen refrigerants on these systems has been analyzed using Engineering Equation Solver software[16].In this investigation following assumptions are made:

1. Load on the low, intermediate and high temperature evaporators are 10TR, 20 TR and 30 TR respectively.
2. Dead state temperature (T0): 25^0C
3. Difference between evaporator and space temperature (Tr-Te):5^0C.
4. Adiabatic efficiency of compressor: 76%.
5. Dead state enthalpy (Φ0) and entropy (s0) of the refrigerants have been calculated corresponding to the dead state temperature (T0) of 25^0C.
6. Variation in kinetic and potential energy is negligible.
7. Expansion process is adiabatic
8. Temperature of low, intermediate and high temperature evaporators are -10^0C,0^0 C and 10^0C respectively.
9. Condenser temperature : 40^0C
10. Degree of sub cooling : 10^0C

4.1 Thermodynamic Analysis

First law of thermodynamic gives the idea of energy balance of system.

$$\dot{m}_{c1} = \dot{m}_{e1} = \frac{\dot{Q}_{e1}}{(\Phi_1-\Phi_{10})} \quad (1)$$

$$\dot{m}_{e2} = \frac{\dot{Q}_{e2}}{(\Phi_3-\Phi_9)} \quad (2)$$

$$\dot{m}_{f1} = \frac{\dot{m}_{c1}(\Phi_2-\Phi_3)}{(\Phi_3-\Phi_9)} \quad (3)$$

$$\dot{m}_{c2} = \dot{m}_{c1} + \dot{m}_{e2} + \dot{m}_{f1} \quad (4)$$

$$\dot{m}_{e3} = \frac{\dot{Q}_{e3}}{(\Phi_5-\Phi_8)} \quad (5)$$

$$\dot{m}_{f2} = \frac{\dot{m}_{c2}(\Phi_4-\Phi_5)}{(\Phi_5-\Phi_8)} \quad (6)$$

$$\dot{m}_{c3} = \dot{m}_{c2} + \dot{m}_{e3} + \dot{m}_{f2} \quad (7)$$

Energy consumption for sytem-1

$$P_{c1} = \frac{\dot{m}_{c1}(\Phi_2-\Phi_1)}{60} \quad (8)$$

$$P_{c2} = \frac{\dot{m}_{c2}(\Phi_4-\Phi_3)}{60} \quad (9)$$

$$P_{c3} = \frac{\dot{m}_{c3}(\Phi_6-\Phi_5)}{60} \quad (10)$$

Energetic efficiency of system-1

$$\mathrm{COP} = \frac{\dot{Q}_e}{P_c*60} \quad (11)$$

4.2 Rate of exergy loss due to irreversibility$(T_o\dot{S}_{gen})$ in various components of system-1

The concept of exergy was given by second law of thermodynamics, which always decreases due to thermodynamic irreversibility. Exergy is defined as the measure of usefulness, quality or potential of a stream to cause change and an effective measure of the potential of a substance to impact the environment [12].

Exergy at any state is given as

$$\mathrm{X} = (\Phi - \Phi_0) - \mathrm{T}_0(\mathrm{s} - \mathrm{s}_0) \quad (12)$$

Compressors

$$\left(T_o\dot{S}_{gen}\right)_{c1} = \dot{W}_{c1} + \dot{m}_{c1}(X_2 - X_1) \quad (13)$$

$$(T_o\dot{S}_{gen})_{c2} = \dot{W}_{c2} + \dot{m}_{c2}(X_4 - X_3) \quad (14)$$

$$(T_o\dot{S}_{gen})_{c3} = \dot{W}_{c3} + \dot{m}_{c3}(X_6 - X_5) \quad (15)$$

$$\dot{\Psi}_c = (T_o\dot{S}_{gen})_{c1} + (T_o\dot{S}_{gen})_{c2} + (T_o\dot{S}_{gen})_{c3} \quad (16)$$

Evaporators

$$(T_o\dot{S}_{gen})_{e1} = \dot{m}_{e1}(X_1 - X_{10}) - \dot{Q}_{e1}\left(1 - \frac{T_0}{T_{r1}}\right) \quad (17)$$
$$(T_o\dot{S}_{gen})_{e2} = \dot{m}_{e2}(X_3 - X_9) - \dot{Q}_{e2}\left(1 - \frac{T_0}{T_{r2}}\right) \quad (18)$$
$$(T_o\dot{S}_{gen})_{e3} = \dot{m}_{e3}(X_5 - X_8) - \dot{Q}_{e3}\left(1 - \frac{T_0}{T_{r3}}\right) \quad (19)$$
$$\dot{\Psi}_e = (T_o\dot{S}_{gen})_{e1} + (T_o\dot{S}_{gen})_{e2} + (T_o\dot{S}_{gen})_{e3} \quad (20)$$

Condenser

$$\dot{\Psi}_{cond} = (T_o\dot{S}_{gen})_{cond} = \dot{m}_{c3}(X_6 - X_7) - \dot{Q}_e\left(1 - \frac{T_0}{T_r}\right) \quad (21)$$
$$(T_o\dot{S}_{gen})_{tv1} = \dot{m}_{e1}(X_{77} - X_{10}) \quad (22)$$
$$(T_o\dot{S}_{gen})_{tv2} = (\dot{m}_{e2} + \dot{m}_{f1})(X_{77} - X_9) \quad (23)$$
$$(T_o\dot{S}_{gen})_{tv3} = (\dot{m}_{e3} + \dot{m}_{f2})(X_{77} - X_8) \quad (24)$$
$$\dot{\Psi}_{tv} = (T_o\dot{S}_{gen})_{tv1} + (T_o\dot{S}_{gen})_{tv2} + (T_o\dot{S}_{gen})_{tv3} \quad (25)$$

Liquid subcooler

$$\dot{\Psi}_{lsc} = (T_o\dot{S}_{gen})_{sc} = \dot{m}_{c3}(X_7 - X_{77}) \quad (26)$$

Flash intercoolers

$$(T_o\dot{S}_{gen})_{f1} = \dot{m}_{f1}(X_9 - X_3) + \dot{m}_{c1}(X_2 - X_3) \quad (27)$$
$$(T_o\dot{S}_{gen})_{f2} = \dot{m}_{f2}(X_8 - X_5) + \dot{m}_{c1}(X_4 - X_5) \quad (28)$$
$$\dot{\Psi}_f = (T_o\dot{S}_{gen})_{f1} + (T_o\dot{S}_{gen})_{f2} \quad (29)$$
$$\sum \dot{\Psi}_k = \dot{\Psi}_e + \dot{\Psi}_c + \dot{\Psi}_{cond} + \dot{\Psi}_{tv} + \dot{\Psi}_{lsc} + \dot{\Psi}_f \quad (30)$$
$$\dot{m}_{c1'} = \dot{m}_{e1'} = \frac{\dot{Q}_{e1'}}{(\Phi_{1'} - \Phi_{12'})} \quad (31)$$
$$\dot{m}_{e2'} = \frac{\dot{Q}_{e2'}}{(\Phi_{3'} - \Phi_{10'})} + \dot{m}_{c1'}\left(\frac{x_{10'}}{1 - x_{10'}}\right) \quad (32)$$
$$\dot{m}_{f1'} = \frac{\dot{m}_{c1'}(\Phi_{2'} - \Phi_{3'})}{(\Phi_{3'} - \Phi_{10'})} \quad (33)$$
$$\dot{m}_{c2'} = \dot{m}_{c1'} + \dot{m}_{e2'} + \dot{m}_{f1'} \quad (34)$$
$$\dot{m}_{e3'} = \frac{\dot{Q}_{e3'}}{(\Phi_{5'} - \Phi_{8'})} + \dot{m}_{c2'}\left(\frac{x_{8'}}{1 - x_{8'}}\right) \quad (35)$$
$$\dot{m}_{f2'} = \frac{\dot{m}_{c2'}(\Phi_{4'} - \Phi_{5'})}{(\Phi_{5'} - \Phi_{8'})} \quad (36)$$

Power required for running the compressors

$$P_{c1'} = \frac{\dot{m}_{c1'}(\Phi_{2'} - \Phi_{1'})}{60} \quad (37)$$
$$P_{c2'} = \frac{\dot{m}_{c2'}(\Phi_{4'} - \Phi_{3'})}{60} \quad (38)$$
$$P_{c3'} = \frac{\dot{m}_{c3'}(\Phi_{6'} - \Phi_{5'})}{60} \quad (39)$$
$$\text{Energetic efficiency} = \frac{\dot{Q}_{e'}}{P_{c'} * 60} \quad (40)$$

4.3 Rate of exergy loss due to irreversibility $(T_o\dot{S}_{gen})$ in various components of system-2

$$(T_o\dot{S}_{gen})_{c1'} = \dot{W}_{c1'} + \dot{m}_{c1'}(X_{2'} - X_{1'}) \quad (41)$$
$$(T_o\dot{S}_{gen})_{c2'} = \dot{W}_{c2'} + \dot{m}_{c2'}(X_{4'} - X_{3'}) \quad (42)$$
$$(T_o\dot{S}_{gen})_{c3'} = \dot{W}_{c3'} + \dot{m}_{c3'}(X_{6'} - X_{5'}) \quad (43)$$
$$\dot{\Psi}_{c'} = (T_o\dot{S}_{gen})_{c1'} + (T_o\dot{S}_{gen})_{c2'} + (T_o\dot{S}_{gen})_{c3'} \quad (44)$$

Evaporators

$$(T_o\dot{S}_{gen})_{e1'} = \dot{m}_{e1'}(X_{1'} - X_{12'} - \dot{Q}_{e1'}\left(1 - \frac{T_0}{T_{r1'}}\right) \quad (45)$$
$$(T_o\dot{S}_{gen})_{e2'} = \dot{m}_{e2'}(X_{3'} - X_{10'}) - \dot{Q}_{e2'}\left(1 - \frac{T_0}{T_{r2'}}\right) \quad (46)$$
$$(T_o\dot{S}_{gen})_{e3'} = \dot{m}_{e3'}(X_{5'} - X_{8'}) - \dot{Q}_{e3'}\left(1 - \frac{T_0}{T_{r3'}}\right) \quad (47)$$
$$\dot{\Psi}_{e'} = (T_o\dot{S}_{gen})_{e1'} + (T_o\dot{S}_{gen})_{e2'} + (T_o\dot{S}_{gen})_{e3'} \quad (48)$$

Condenser

$$\dot{\Psi}_{cond'} = (T_o\dot{S}_{gen})_{cond'} = \dot{m}_{c3'}(X_{6'} - X_{7'}) - \dot{Q}_{e'}\left(1 - \frac{T_0}{T_{r'}}\right) \quad (49)$$

Throttle Valves

$$(T_o\dot{S}_{gen})_{tv1'} = \dot{m}_{e1'}(X_{11'} - X_{12'}) \quad (50)$$
$$(T_o\dot{S}_{gen})_{tv2'} = \dot{m}_{c2'}(X_{9'} - X_{10'}) \quad (51)$$
$$(T_o\dot{S}_{gen})_{tv3'} = \dot{m}_{c3'}(X_{77'} - X_{8'}) \quad (52)$$
$$\dot{\Psi}_{tv'} = (T_o\dot{S}_{gen})_{tv1'} + (T_o\dot{S}_{gen})_{tv2'} + (T_o\dot{S}_{gen})_{tv3'} \quad (53)$$

Liquid subcooler

$$\dot{\Psi}_{lsc'} = (T_o\dot{S}_{gen})_{lsc'} = \dot{m}_{c3'}(X_{7'} - X_{77'}) \quad (54)$$

Flash intercoolers

$$(T_o\dot{S}_{gen})_{f1'} = \dot{m}_{f1'}(X_{10'} - X_{3'}) + \dot{m}_{c1'}(X_{2'} - X_{3'}) \quad (55)$$
$$(T_o\dot{S}_{gen})_{f2'} = \dot{m}_{f2'}(X_{8'} - X_{5'}) + \dot{m}_{c2'}(X_{4'} - X_{5'}) \quad (56)$$
$$\dot{\Psi}_{f'} = (T_o\dot{S}_{gen})_{f1'} + (T_o\dot{S}_{gen})_{f2'} \quad (57)$$

Total irreversibility destruction in system-1

$$\sum \dot{\Psi}_{k'} = \dot{\Psi}_{e'} + \dot{\Psi}_{c'} + \dot{\Psi}_{cond'} + \dot{\Psi}_{tv'} + \dot{\Psi}_{lsc'} + \dot{\Psi}_{f'} \quad (58)$$

4. Result and Discussion

Following Data have been assumed in present investigation Evaporator pressure= 2 bar=200 KPa, Condenser Pressure 12 bar, P2= P3= 8 bar and Qeva= 10 TR=35kW, First compressor efficiency=second compressor efficiency =Third compressor efficiency =0.8

Table-2 and table-3 show the effect of eco-friendly refrigerants on following three type of systems, it was observed that R134a gives better thermodynamic first law performance in terms of coefficient of performance (COP) and second law thermal performance in terms of exergetic efficiency (Rational Efficiency) as compared to other new eco-friendly refrigerants. System-3 with multiple expansion valves and flash intercoolers gives best exergetic second law and first law performances than other two systems. Although R245fa also gives similar thermodynamic first law performance (COP) in all systems but and second law exergetic performances using R236fa and R245fa is badly affecting for second system as shown in table-3. Due to higher GWP of R134a R1234ze can be used for replacing R134a for higher temperature applications. R1234yf give better second law exergetic performance than R1234ze for domestic applications. Similarly, Table-4 shows exergy destruction ratio of all three systems using eco-friendly refrigerants. For computations of irreversibility, the exergy destruction ratio was defined by several investigators, in terms of total exergy losses occurred in the system or thermodynamic cycle to the exergy of product while other investigators also defined EDR based on the exergy input in terms of exergy of fuel (i.e. total power required to run the whole system as total power used in the compressors). It was observed that R236fa gives maximum exergy destruction ratio lowering the exergetic efficiency as compared to R134a. As comparing to all systems, system-3 gives lowest EDR using R-134a.

Table-2: Thermodynamic first law thermal performances (COP_{Over_all}) of two stage vapour compression refrigeration system using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	2.886	3.08	3.086
R1234ze	3.038	3.157	3.159
R1234yf	2.551	2.796	2.782
R227ea	3.098	3.134	3.137
R236fa	7.503	6.377	7.916
R245fa	9.03	6.954	9.38

Table-3: Thermodynamic second law thermal performances (exergetic efficiency)of two stage vapour compression refrigeration system using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	0.3833	0.4091	0.4099
R1234ze	0.3095	0.3175	0.3177
R1234yf	0.3686	0.4040	0.4020
R227ea	0.2727	0.2760	0.2762
R236fa	0.2270	0.1921	0.2395
R245fa	0.2533	-19.51	-0.2632

Table-4: Thermodynamic second law thermal losses oftwo stage vapour compression refrigeration system using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	1.609	1.373	1.35
R1234ze	2.231	2.133	2.128
R1234yf	1.713	1.391	1.379
R227ea	2.666	2.618	2.615
R236fa	3.406	4.445	3.065
R245fa	-4.947	-7.672	-4.375

Table-5: *Total Power required to runtwo stage vapour compression refrigeration system using eco-friendly refrigerants*

Eco Friendly Refrigerant	System-1 with water intercoolers (kW)	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	12.13	10.73	17.01
R1234ze	11.37	11.09	16.62
R1234yf	13.72	12.52	18.87
R227ea	11.30	11.7	16.73
R236fa	4.665	5.488	6.632
R245fa	3.876	5.033	5.597

Table-6: Power required to run First Compressor of two stage vapour compression refrigeration system using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers (kW)	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	5.455	4.348	7.224
R1234ze	5.288	5.043	7.565
R1234yf	6.177	5.218	7.828
R227ea	5.409	5.297	7.946
R236fa	4.375	5.11	7.665
R245fa	3.72	4.885	7.327

Table-7: Power required to run second Compressor of two stage vapour compression refrigeration system using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	6.674	6.386	9.791
R1234ze	6.084	6.044	9.056
R1234yf	7.546	7.302	11.05
R227ea	5.89	5.869	8.789
R236fa	0.2899	0.3782	-1.033
R245fa	0.1561	-0.01481	-1.731

Table-8: Thermodynamic first law performances /Overall coefficient of performance ($COP_{\_Over\_All}$)of two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	2.886	3.08	3.086
R152a	3.016	3.134	3.152
R404a	1.943	2.407	2.354
R410a	2.136	2.566	2.582
R407c	2.408	2.782	2.784
R717	3.097	3.26	3.363
R123	9.185	6.468	9.587
R125	1.751	2.296	2.206
R290	2.191	2.492	2.477
R600	7.213	6.164	7.511
R-600a	6.263	5.778	6.624

Table-9: Thermodynamic second law performances (exergetic efficiency) of two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	0.3833	0.4091	0.4099
R152a	0.3676	0.382	0.3842
R404a	0.4436	0.5496	0.5375
R410a	0.5607	0.6734	0.6776
R407c	0.4456	0.5148	0.5150
R717	0.5322	0.5603	0.5779
R123	0.6623	0.4664	-0.6913
R125	0.4231	0.5549	0.5330
R290	0.4449	0.5059	0.5030
R600	0.1497	0.1279	0.1559
R-600a	0.4011	0.3701	0.4242

Table-10: Irreversibility Ratio in terms of exergy destruction ratio based on exergy of product of two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	1.609	1.373	1.35
R152a	1.72	1.58	1.557
R404a	1.254	0.4411	0.3647

R410a	0.7836	0.1386	0.0295
R407c	1.244	0.8263	0.7737
R717	0.8791	0.7110	0.6394
R123	2.51	-4.561	-2.156
R125	1.364	0.2811	0.1882
R290	1.248	0.7853	0.7409
R600	5.68	7.566	5.173
R-600a	1.493	1.726	1.342

Table-11: Power required to run two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	12.13	10.73	17.01
R152a	11.6	11.17	16.66
R404a	18.01	14.54	22.3
R410a	16.39	13.64	20.34
R407c	14.53	12.58	18.86
R717	11.3	10.3	15.61
R123	3.81	5.411	5.476
R125	19.99	15.24	23.80
R290	15.97	14.05	21.19
R600	4.852	5.678	6.99
R-600a	5.588	6.057	7.926

Table-12: Power required to run first compressor of two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	5.455	4.348	7.224
R152a	5.251	4.87	7.305
R404a	7.598	5.053	7.58
R410a	6.708	4.668	7.04
R407c	6.288	4.727	7.091
R717	4.831	4.348	6.522
R123	3.66	5.273	7.909
R125	8.35	5.007	7.511
R290	6.874	5.377	8.065
R600	4.649	5.48	8.219
R-600a	5.267	5.678	8.517

Table-13: Power required to run second compressor of two stage vapour compression refrigeration system with water intercoolers using eco-friendly refrigerants

Eco Friendly Refrigerant	System-1 with water intercoolers	System-2 with flash intercoolers	System-3 with multiple expansion valves and Flash intercoolers
R-134a	6.674	6.386	9.791
R152a	6.354	6.299	9.351
R404a	10.41	9.485	14.72
R410a	9.677	8.975	13.3
R407c	8.245	7.852	11.27
R717	6.471	6.386	9.08
R125	11.64	10.24	16.29
R290	8.101	8.669	13.13

Table-5 shows the exergy of fuel in terms of total power required to run all three compressors in the three stage vapour compression refrigeration systems, it was observed that system-3 required less power consumptions to system-1 and system-2. The By using R134a, the minimum exergy input in terms of exergy of fuel (kW) needed as compared to R1234yf and R1234ze in system-3 as compared to system -1. Similarly, by using R227ea and R236fa eco-friendly refrigerants, the power consumption is higher in the three stage systems by running all compressors as compared to R-134a while R245fa gives lower power consumption as compared to R227ea and R236fa.The power required to run various compressors in the three stage vapour compression refrigeration system using eco-friendly refrigerants are shown in Table-6 to Table-8 respectively. It was observed that R227ea gives maximum power consumptions in all compressors while less power consumptions required to run first compressor using R -134a. It was shown that first compressor used in system-3 gives lowest power consumption as compared to system-1 and system-2. By using new refrigerants, the power consumption is first compressor is more. Similarly, maximum power consumption using R227ea was observed as compared to R-236fa and R245fa. The lowest power consumption was observed using R134a in system -3 as compared to system-1 and system-2. Similarly, R1234yf and R1234ze gives slightly higher power consumption as compared to R1234yf and R1234ze. The power required to run compressor -3 in three stage vapour compression refrigeration system, the same trend was observed because system -3 is always gives better thermodynamic performance and lower power consumption.

5. Conclusion

Following conclusions were drawn from present investigations.

(i) System-3 gives better thermodynamic performance and less power consumption than other two systems.
(ii) The percentage first law improvement in ystem-1 is varying from 14.5% to 16% while power consumption is 13% less as compared to simple saturation cycle working between the pressure limit to 2 bar and 12 bar.
(iii) System-3 gives lowest power consumption (less than 20%) as compared to system -1 (13%) and first law improvement around 20% in system-3 as compared to 15.2%.
(iv) The System-2 required 10% less power required as compared to simple saturation cycle along with 0% of improvement in the first law performance.

References

[1] R. S. Mishra, Appropriate Vapour Compression Refrigeration Technologies for Sustainable Development International Journal of Advance Research & Innovations, 2014, 551-556.

[2] K. Chopra, V. Sahni, R. S. Mishra, Thermodynamic Analysis of Multiple evaporators vapour compression Refrigeration Systems with R-410a, R290, R1234yf, R502, R404a, R152a and R134a, International Journal of Air conditioning and Refrigeration, 22(1), 2014, 14

[3] K. Chopra, V. Sahni, R. S. Mishra, Methods for improving first and second law efficiencies of vapour compression refrigeration systems using flash intercooler with ecofriendly refrigerants, 1, 2014, 50- 64

[4] Padilla M, Revellin R, Bonjour J. Exergy analysis of R413Aas replacement of R12 in a domestic refrigeration system. Energy Convers Manag. 2010;51:2,195–201

[5] Arora A, Kaushik SC. Theoretical analysis of vapor compression refrigeration system with R502, R404A and R507A. Int J Refrig. 2008;31:998–1005

[6] Anand S and Tyagi S. K Exergy analysis and experimental study of a vapor compression refrigeration cycle

[7] Yumrutas et. al Exergy analysis of vapour compression refrigeration systems, Exergy, an Int J, 2 (2002) 266-272

[8] Dincer I. Refrigeration systems and applications. London: Wiley; 2003. pp. 26–27

[9] Kumar S, Prevost M, Bugarel R. Exergy analysis of a compression refrigeration system. Heat Recovery Syst CHP. 1989;9(2):151–7

[10] Nikolaidis C, Probert D. Exergy-method analysis of a two stage vapor compression refrigeration plants performance. Appl Energy. 1998;60:241–56

[11] Bejan A, Theory of heat transfer irreversible refrigeration plants, Int J Heat mass transfer, 32(9), (1989), 1631-39.

[12] H.M Getu, P.K Bansal. Thermodynamic analysis of an R744-R717 cascade refrigeration system. Int J Refrigeration.2008; 31:45-54.

[13] R. S. Mishra, Irriversibility Analysis of MultiEvaporators Vapour Compression Refrigeration Systems Using New and Refrigerants: R134a, R290, R600, R600a, R1234yf,R502, R404a and R152a and R12, R502” International Journal Advance Research & Innovations International Journal of Advance Research & Innovations, 1, 2013, 180-193

[14] R.S. Mishra, Irreversibility analysis of three stage vapour compression refrigeration systems with flash-intercooler using eco-friendly new refrigerants (R134a, R1234yf, R1234ze, R227ea and R245fa), International Journal of Research in Engineering and Innovation, vol-2, issue-2, 136-142, 2018.

[15] R.S. Mishra, Thermodynamic model analysis of vapour compression refrigeration systems by using ecofriendly refrigerant (R1234yf) in primary circuit and R718 in the secondary circuit by mixing Nano particles (Al2O3) for improving thermal efficiencies, International Journal of Research in Engineering and Innovation, vol-2, issue-1, 51-59, 2018.

[16] R.S. Mishra, Thermodynamic performance analysis of two stage vapour compression refrigeration systems with flash-intercooler using eco-friendly new refrigerants (R134a, R1234yf, R1234ze, R227ea and R152a), International Journal of Research in Engineering and Innovation, vol-2, issue-1, 156-161, 2018.