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# Energy-exergy performance evaluation of new HFO refrigerants in the modified vapour compression refrigeration systems using liquid vapour heat exchanger

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## Abstract

In this paper thermodynamic analysis ofvapour compression refrigeration systems using liquid vapour heat exchanger by using ten ecofriendly low GWP HFO refrigerants studies in detail and it was found that The R1234ze(z) gives better thermodynamic performances than R1234ze(E) and R1243zf. The thermodynamic performance of R1224yd (Z) and HFO-1336mzz(Z) is nearly similar and higher than R1234ze(E) but lower than R1224yd(Z).However R1234yf gives lowest thermodynamic performances. The effect of condenser temperature and evaporator temperature of modified vapour compression refrigeration systems were studied in detail and it was found that first law efficiency decreases' with increasing condenser temperature and also increases with evaporator temperature. However by increasing condenser and evaporator temperatures, the exergetic efficiency decreases, It was found that maximum exergy destruction takes place in the compressor which have external irreversibilities and exergy destruction ratio is lower in the throttling valves. However second higher exergy destruction takes place in the evaporator even higher than condenser and throttle valve. Therefore for reducing higher exergy destruction in evaporator, the detailed thermodynamic analysis using nano mixed particles in the secondary evaporator circuit is required.


*Keywords:* New HFO Refrigerants, Modified VCRS, Performance improvement, Thermodynamic Analysis, Energy Exergy Analysis

## 1. Introduction

In the refrigeration and air conditioning industry, hydro fluorocarbons (HFC) refrigerants, such as HFC-134a, R-410A, and R-404A, were developed as alternatives for chlorofluorocarbons (CFCs) or hydro-chlorofluorocarbons (HCFCs) with low ozone depletion potential (ODP). However, HFCs have high global warming potential (GWP) and, thus, there is an urgent need to replace them to reduce HFC emissions [1]. At the 28th Meeting of the Parties to the Montreal Protocol (MOP 28) held in Kigali Rwanda, in October 2016, an amendment proposal was adopted to regulate HFCs under the Montreal Protocol (UNEP 2016 United Nations Environment Program (UNEP). 2016. Report of the twenty-eighth meeting of the parties to the Montreal protocol on substances that deplete the ozone layer. Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, Kigali, October 10–15, 2016 [Google Scholar]). In the United States, the Environmental Protection Agency's (EPA) Significant New Alternatives Policy (SNAP) Program rules delist certain uses of HFCs (EPA 2016 Environmental Protection Agency (EPA). 2016. Protection of stratospheric ozone: New listings of substitutes; changes of listing status; and reinterpretation of unacceptability for closed cell foam products under the significant new alternatives policy program; and revision of Clean Air Act Section 608 Venting Prohibition for Propane. Federal Register 81(231):86778–895. In Europe, HFCs are regulated by the F-gas regulation and Mobile Air-Conditioning systems (MAC) Directive (The European Parliament and the Council of the European Union 2006 The European Parliament and the Council of the European Union. 2006. Directive 2006/40/EC of the European parliament and of the council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC In Japan, the revised Recovery and Destruction of Fluorocarbons Act restrictions for Designated Products was implemented on April 1, 2015 (Ministry of the Environment, Government of Japan 2016 United Nations Environment Program (UNEP). 2016. Report of the twenty-eighth meeting of the parties to the Montreal protocol on substances that deplete the ozone layer. Twenty-

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Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, Kigali, October 10–15, 2016.Low-GWP refrigerants are currently being developed to replace High-GWP refrigerants. One alternative Low-GWP refrigerant, HFC-32, has a GWP value of 675 versus 2,088 for R-410A and serves as an alternative for R-410A in domestic and small commercial air conditioning units (IPCC 2007 Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: The scientific basis Contribution of Working Group I to the IPCC Fourth Assessment Report, World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), IPCC Secretariat, Geneva Switzerland. [Google Scholar]). The GWP value of HFC-32 barely meets current regulations. Thus, a new refrigerant with a substantially lower GWP value is needed in the future. In order to achieve smooth transition to refrigerants with even lower GWP values, we set the following goals.

### *1.1 Global Warming Potential*

Global Warming Potential, or GWP, is a measure of how destructive a climate pollutant is. Refrigerants today are often thousands of times more polluting than carbon dioxide ($CO_2$). The GWP of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, $CO_2$, which is assigned a value of 1. GWPs can also be used to define the impact greenhouse gases will have on global warming over different time periods or time horizons. These are usually 20 years, 100 years, and 500 years. A time horizon of 100 years is used by regulators .The most common refrigerant today, R-22, has a 100-year GWP of 1,810, almost 2,000 times the potency of carbon dioxide. The most common replacement for R-22 in supermarket systems, R-404A, is more than twice as potent a greenhouse gas than R-22. The common replacements for R-22, such as R134a , R-404A and R-507A, but the future restrictions is because of their high GWP values and the availability of alternatives that pose a lower overall risk to human health and/or the environment. In addition, national and international efforts to phase-down the global use of these and other high-GWP refrigerants may affect future price and availability. New low-GWP technologies and solutions are advancing rapidly and are available today. Refrigerants regulated under the Refrigerant Management Program (RMP) include any refrigerant that is an ozone depleting substance (ODS) as defined in the Code of Federal Regulation, Part 82, and any compound with a global warming potential (GWP) value equal to or greater than 150 according to the GWPs specified in IPCC's fourth Assessment Report of 2007.

### *1.2 Future HFO Refrigerants*

HFO refrigerants are the future refrigerants are are used in near future. HFO refrigerants, or Hydrofluro-Olefins, are a new class of refrigerants that have a much lessened global warming potential than it's HFC alternatives. One example being the 134a alternative, 1234yf, which is 335 times lower on the global warming potential scale and only four times higher than standard carbon dioxide.

Honeywell [20] is one of the three big refrigerant manufactures in the world Honeywell announced that they have begun production on several HFO refrigerants under their Solstice brand name. For replacing the use of HFCs and creating various alternative refrigerants. Few new refrigerants are shown below.

#### *1.2.1 Solstice zd*

A nonflammable HFO refrigerant with a GWP equal to 1, for use in low pressure centrifugal chillers, which are most often used to cool large buildings. Several leading air conditioner manufacturers, has already using Solstice zd in its new Series E CenTraVac large capacity centrifugal chillers in Europe, the Middle East and other 50hz markets. Solstice zd is also called the R-1234zd(E) known as Trans-1-chloro-3,3,3-trifluoropropene .Solstice ze offers a GWP of less than 1, which is 99.9 percent lower than the GWP of R134a. R1243zf also has GWP less than 10.

#### *1.2.2 Solstice ze*

*HFO refrigerant that can be used in equipment that traditionally used R134a (i.e., chillers and refrigeration equipment).*

#### *1.2.3 Amoleatm-1224yd*

It is also known as R-1224yd(Z) (Z)-1-Chloro-2,3,3,3-Tetrafluoropropane has GWP is 1.

#### *1.2.4 Opteon YF*

It is known as R-1234yf has a GWP of 4 based on a 100-year time horizon, and more than meets the EU MAC directive regulation of GWP of 150. Not only is it is 97 percent lower than the EU mandate, it is also 99.7 percent better than HFC-134a, which has a GWP of 1430. Compared to alternative refrigerants, it has the most favorable climate footprint over its entire life cycle.

#### *1.2.5 Solstice N13*

It is also known as (R-450A ) constituted by R-134a/R-1234ze(E) (42/58)an HFO blend for chillers, as well as medium-temperature applications such as supermarket display cases and self-contained refrigeration units that require a non-flammable refrigerant solution. Solstice N13 is designed to replace R134a and offers a 601 GWP , that is 60 percent lower than the GWP of R134a.

#### *1.2.6 Solstice N40*

It is known as R-448A constituted by R-32/R-125/R-134a/R-1234ze/R-1234yf (26/26/21/7/20) an HFO blend for low- and medium-temperature refrigeration equipment such as supermarket freezer cases. Solstice N40 is designed to replace HCFC R22 and HFC R404A, and offers a GWP that is 66 percent lower than R404A. In supermarket trials conducted in the U.S. and Europe, Solstice N40 has GWP 1387 is demonstrated three percent lower energy consumption in low-temperature applications and 5 to 16 percent lower energy consumption in medium-temperature applications as compared to R404A

### *1.2.7 Forane (FBA 1233zd)*

FBA 1233zd) is known as (R-1233zd) is not a volatile organic compound which has good thermal, environmental, safety and cost performances, It has Low global warming potential, and Non-ozone depleting, Non-flammable, has Low vapor pressure, and also improved energy efficiency in refrigerators and freezers

## 2. Energy_Exergy Analysis of Vapour 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 [2-4] Padilla et al. [5] 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 [6] 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. [7] 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 [8] 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.

R.S. Mishra [2015] carried out for the performance evaluation of vapour compression refrigeration system using energetic analysis, but with the help of first law analysis irreversibility destruction or losses in components of system unable to determine that second law thermodynamics. Most of the study has been carried out for the performance evaluation of vapour compression refrigeration system using energetic analysis, but with the help of first law analysis irreversibility destruction or losses in components of system unable to determined [9-13], so that second law thermodynamic analysis is the advanced approach for thermodynamic analysis which gives an additional practical view of the processes. The utility of second law analysis on vapour compression refrigeration systems is well defined because it gives the idea for improvements in efficiency due to modifications in existing design in terms of reducing exergy destructions in the components. The second law exergetic analysis also provides new thought for development in the existing systems. Mishra [2] developed theoretical model of vapour compression refrigeration using eco-friendly refrigerants and observed that the coefficient of performance (COP) of the vapour compression refrigeration system, increases with increasing evaporator in the range of (-20ºC to +5ºC) temperature for a constant condensing temperature (40ºC) and decreases with increasing condenser temperature (30ºC to 60ºC) for constant evaporator -20ºC [14]

From the irreversibility or exergy destruction viewpoint, Mishra [3] worst component is compressor followed by evaporator and condenser, throttle valve, 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 HFO1234ze [12-19]

Based on the literature it was observed that Researchers have gone through detailed first law analysis in terms of coefficient of performance and second law analysis in term of exergetic efficiency of simple vapour compression refrigeration system using HFO-1234yf and R1234ze refrigerants

Researchers did not go through the irreversibility analysis or second law analysis of modified vapour compression refrigeration systems using vapour liquid heat exchanger using ten new ecofriendly low GWP refrigerants. In the next section the detailed computational results are presented.

## 3. Results and Discussion

Table-2 shows the effect of ecofriendly HFO refrigerants on thermodynamic energy-exergy performances of modified vapour compression refrigeration system using liquid vapour heat exchanger and it was found that the low GWP HFO refrigerant HFO-1234ze(z) gives best (optimum ) thermodynamic first and second law performances the HFO-1234ze(z) gives best first law performances. However R-1233zd (E) is slightly lower thermodynamic performances than R1234ze (Z) but slightly higher than R1234ze (E). The lowest performances was observed while using R1234yf in the modified. Systems. Tables-3 show, the percentage of exergy destruction in modified VCRS using following ecofriendly HFO refrigerants using liquid vapour heat exchanger and it was found that the maximum exergy destruction occurred in compressor and then evaporator however exergy destruction in throttle valves is lowest due to only inter visibility takes place in the throttle valve. The maximum exergy destruction also occurred by using R1234yf which lowered exergetic efficiency of modified vapour compression refrigeration systems. Table- 4(a)& Table-4(b) show, the variation of condenser temperature with thermodynamic first law performance (COP) of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when condenser temperature increasing, the first law efficiency in terms of coefficient of performance is also decreasing for all HFO refrigerants.Table-5(a) &Table-5(b) show, the variation of condenser temperature with thermodynamic second law efficiency of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when condenser temperature increasing, the first law efficiency in terms of coefficient of performance is also decreasing for all HFO refrigerants Table-6(a)& Table-6(b) show, the variation of condenser temperature with thermodynamic exergy destruction ratio ($EDR_{\_system}$) of the modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when condenser temperatiure increasing, the exergy destruction ratio ($EDR_{\_system}$)is also increasing for all HFO refrigerants. Table-7(a) & table-7(b) show, the variation of evaporator temperature with thermodynamic first law performance (COP) of modified vapour compression refrigeration system using liquid vapour heat exchanger and also using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when evaporator temperature is increasing, the first law efficiency in terms of coefficient of performance is also increasing for all HFO refrigerants

Table-8(a)-& Table-8(b) show, the variation of evaporator temperature with thermodynamic second law performance of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when evaporator temperature is increasing, the second law efficiency is also decreasing for all HFO refrigerants

Table-9(a-b) show, the variation of evaporator temperature with the exergy destruction ratio ($EDR_{\_system}$) of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion and it was found that when evaporator temperature is increasing, the exergy destruction ratio ($EDR_{\_system}$) of the modified system is also increasing for all HFO refrigerants

*Table- 2 : Performance parameters of modified vapour compression refrigeration system using liquid vapour heat exchanger new HFO ecofriendly refrigerants for reducing global warming and ozone depletion for following input values: Condenser temperature= 323"K", Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%*

| Ecofriendly refrigerants | First Law Efficiency $COP_{\_VCRS}$ | System Exergy Destruction Ratio( $EDR_{\_System}$) | Rational Exergy Destruction Ratio(Rational $_{\_EDR}$) | Exergetic Efficiency |
|---|---|---|---|---|
| HFO1336mzz(Z) | 4.564 | 7.069 | 0.8761 | 0.1239 |
| R1234ze(E) | 4.395 | 7.299 | 0.8795 | 0.1205 |
| R1234ze(Z) | 4.782 | 6.808 | 0.8720 | 0.1280 |
| R1243zf | 4.295 | 7.455 | 0.8817 | 0.1183 |
| R1224yd(Z) | 4.596 | 7.032 | 0.8755 | 0.1245 |
| R1234yf | 4.195 | 7.593 | 0.8836 | 0.1164 |
| R1225ye(z) | 4.339 | 7.374 | 0.8806 | 0.1194 |
| R1233zd(E) | 4.648 | 6.369 | 0.8745 | 0.1255 |
| R152a | 4.522 | 7.142 | 0.8747 | 0.1228 |
| R134a | 4.376 | 7.336 | 0.880 | 0.120 |

*Table- 3(a) : Percentage of exergy destruction in components in the modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion for following input values: Condenser temperature= 323"K", Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C, Degree of super heating=10°C, Heat exchanger effectiveness= 80%*

| Percentage exergy destruction (%) | HFO-1336mzz(Z) | R1243zf | R1233zd(E) | R1234yf | R134a |
|---|---|---|---|---|---|
| Compressor (%) | 53.38 | 54.13 | 53.07 | 54.53 | 53.88 |
| Evaporator (%) | 23.75 | 23.0 | 24.05 | 22.3 | 22.98 |
| Condenser (%) | 7.878 | 7.561 | 7.839 | 7.43 | 7.785 |
| Throttle valve (%) | 2.776 | 3.477 | 2.493 | 4.102 | 3.361 |
| Total exergy destruction (%) | 87.61 | 88.17 | 87.45 | 88.36 | 88.0 |
| Exergetic Efficiency (%) | 12.39 | 11.83 | 12.55 | 11.64 | 12.0 |

*Table -3(b) :Percentage of exergy destruction in components in the modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion for following input values: Condenser temperature= 323"K", Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C, Degree of super heating=10°C, Heat exchanger effectiveness= 80%*

| Percentage exergy destruction (%) | R1234ze(Z) | R1234ze(E) | R1224yd(Z) | R1225ye(Z) | R124 | R152a |
|---|---|---|---|---|---|---|
| Compressor (%) | 52.64 | 53.89 | 53.25 | 54.10 | 53.62 | 53.39 |
| Evaporator (%) | 24.14 | 22.97 | 23.86 | 22.88 | 23.32 | 23.53 |
| Condenser (%) | 8.162 | 7.631 | 7.765 | 7.585 | 7.712 | 8.143 |
| Throttle valve (%) | 2.20 | 3.459 | 2.682 | 3.496 | 3.134 | 2.655 |
| Total exergy destruction (%) | 87.19 | 87.95 | 87.55 | 88.06 | 87.57 | 87.72 |
| Exergetic Efficiency (%) | 12.80 | 12.05 | 12.45 | 11.94 | 12.21 | 12.28 |

*Table-4(a) :Effect of condenser temperature on thermodynamic first law performance(i.e. coefficient of performance) of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletionfor following input values: Evaporator temperature= 263"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%*

| Condenser temperature (K) | HFO-1336mzz (Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1234yf | R152a | R134a |
|---|---|---|---|---|---|---|---|
| 333 | 2.592 | 2.70 | 2.825 | 2.45 | 2.269 | 2.63 | 2.47 |
| 328 | 2.933 | 3.033 | 3.165 | 2.799 | 2.626 | 2.96 | 2.812 |
| 323 | 3.336 | 3.429 | 3.570 | 3.210 | 3.043 | 3.352 | 3.215 |
| 318 | 3.825 | 3.904 | 4.061 | 3.705 | 3.541 | 3.825 | 3.70 |
| 313 | 4.427 | 4.502 | 4.671 | 4.314 | 4.153 | 4.411 | 4.297 |
| 308 | 5.195 | 5.261 | 5.451 | 5.089 | 4.927 | 5.158 | 5.057 |
| 303 | 6.212 | 6.267 | 6.487 | 6.111 | 5.946 | 6.146 | 6.06 |

*Table-4(b) :Effect of condenser temperature on thermodynamic first law performance (COP) of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletionfor following input values: (Evaporator temperature= 263"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Condenser temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 333 | 2.64 | 2.408 | 2.532 | 2.409 | 2.63 | 2.47 |
| 328 | 2.979 | 2.754 | 2.876 | 2.746 | 2.96 | 2.812 |
| 323 | 3.381 | 3.169 | 3.282 | 3.141 | 3.352 | 3.215 |
| 318 | 3.866 | 3.662 | 3.772 | 3.615 | 3.825 | 3.70 |
| 313 | 4.466 | 4.269 | 4.376 | 4.199 | 4.411 | 4.297 |
| 308 | 5.23 | 5.662 | 5.146 | 4.94 | 5.158 | 5.057 |
| 303 | 6.242 | 6.052 | 6.162 | 5.917 | 6.149 | 6.06 |

*Table- 5(a) :Effect of condenser temperature on thermodynamic exergetic performance (i.e. exergetic efficiency) of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion for following input value (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of sub cooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80% )*

| Condenser temperature (K) | HFO-1336mzz(Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1234yf | R152a | R134a |
|---|---|---|---|---|---|---|---|
| 333 | 0.1072 | 0.1105 | 0.1143 | 0.1025 | 0.0964 | 0.1081 | 0.103 |
| 328 | 0.1180 | 0.1210 | 0.1249 | 0.1159 | 0.1080 | 0.1187 | 0.1142 |
| 323 | 0.1360 | 0.1329 | 0.1367 | 0.1267 | 0.1217 | 0.1305 | 0.1267 |
| 318 | 0.1442 | 0.1463 | 0.1502 | 0.1410 | 0.1380 | 0.1439 | 0.1407 |
| 313 | 0.1672 | 0.1678 | 0.1657 | 0.1573 | 0.1518 | 0.1592 | 0.1567 |
| 308 | 0.1786 | 0.1793 | 0.1872 | 0.1780 | 0.1725 | 0.1774 | 0.1753 |
| 303 | 0.2003 | 0.1990 | 0.2053 | 0.1980 | 0.1952 | 0.1987 | 0.1971 |

*Table- 5(b) :Effect of condenser temperature on exergetic performance (exergetic efficiency)of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion( Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Condenser temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 333 | 0.1086 | 0.1010 | 0.1050 | 0.1010 | 0.1081 | 0.103 |
| 328 | 0.1157 | 0.1127 | 0.1162 | 0.1121 | 0.1187 | 0.1142 |
| 323 | 0.1315 | 0.1255 | 0.1287 | 0.1245 | 0.1305 | 0.1267 |
| 318 | 0.1470 | 0.1322 | 0.1428 | 0.1384 | 0.1439 | 0.1407 |
| 313 | 0.1610 | 0.1562 | 0.1588 | 0.1542 | 0.1592 | 0.1567 |
| 308 | 0.1772 | 0.1789 | 0.1750 | 0.1726 | 0.1774 | 0.1753 |
| 303 | 0.2068 | 0.1973 | 0.1983 | 0.1942 | 0.1987 | 0.1971 |

*Table- 6(a) :Effect of condenser temperature on thermodynamic exergy destruction Ratio ($EDR\_{System}$) of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletionfor following input values: (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Condenser temperature (K) | HFO-1336mzz(Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1234yf | R152a | R134a |
|---|---|---|---|---|---|---|---|
| 333 | 8.332 | 8.049 | 7.746 | 8.760 | 9.372 | 8.249 | 8.708 |
| 328 | 7.467 | 7.262 | 7.009 | 7.777 | 8.22 | 7.426 | 7.756 |
| 323 | 6.671 | 6.526 | 6.314 | 6.893 | 7.215 | 6.662 | 6.894 |
| 318 | 5.933 | 5.834 | 5.657 | 6.091 | 6.324 | 5.947 | 6.107 |
| 313 | 5.245 | 5.18 | 5.034 | 5.355 | 5.523 | 5.274 | 5.381 |
| 308 | 4.60 | 4.561 | 4.439 | 4.675 | 4.794 | 4.638 | 4.705 |
| 303 | 3.992 | 3.97 | 3.871 | 4.041 | 4.124 | 4.033 | 4.073 |

*Table-6(b) :Effect of condenser temperature on thermodynamic exergy destruction Ratio ($EDR\_{System}$) of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Condenser temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 333 | 8.206 | 8.888 | 8.51 | 8.901 | 8.249 | 8.708 |
| 328 | 7.372 | 7.873 | 7.598 | 7.919 | 7.426 | 7.756 |
| 323 | 6.602 | 6.967 | 6.767 | 7.033 | 6.662 | 6.894 |
| 318 | 5.884 | 6.148 | 6.003 | 6.227 | 5.947 | 6.107 |
| 313 | 5.212 | 5.40 | 5.296 | 5.484 | 5.274 | 5.381 |
| 308 | 4.58 | 6.148 | 4.637 | 4.794 | 4.638 | 4.705 |
| 303 | 3.98 | 4.069 | 4.017 | 4.148 | 4.033 | 4.073 |

*Table-7(a) :Effect of evaporator temperature on thermodynamic performance of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | HFO-1336mzz(Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1243zf | R1234yf | R134a |
|---|---|---|---|---|---|---|---|
| 253 | 2.527 | 2.623 | 2.767 | 2.428 | 2.381 | 2.284 | 2.449 |
| 258 | 2.894 | 2.988 | 3.131 | 2.783 | 2.725 | 2.628 | 2.796 |
| 263 | 3.336 | 3.429 | 3.570 | 3.210 | 3.141 | 3.043 | 3.215 |
| 268 | 3.880 | 3.970 | 4.108 | 3.736 | 3.652 | 3.553 | 3.730 |
| 273 | 4.564 | 4.648 | 4.782 | 4.395 | 4.295 | 4195 | 4.376 |
| 278 | 5.446 | 5.523 | 5.652 | 5.246 | 5.124 | 5.024 | 5.210 |
| 283 | 6.626 | 6.692 | 6.815 | 6.384 | 6.234 | 6.133 | 6.325 |

*Table-7(b) :Effect of evaporator temperature on thermodynamic performance of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 253 | 2.578 | 2.399 | 2.495 | 2.381 | 2.577 | 2.449 |
| 258 | 2.942 | 2.748 | 2.852 | 2.725 | 2.929 | 2.796 |
| 263 | 3.381 | 3.169 | 3.282 | 3.141 | 3.352 | 3.215 |
| 268 | 3.920 | 3.688 | 3.811 | 3.652 | 3.871 | 3.730 |
| 273 | 4.596 | 4.339 | 4.475 | 4.295 | 4.522 | 4.376 |
| 278 | 5.469 | 5.18 | 5.332 | 5.124 | 5.362 | 5.210 |
| 283 | 6.637 | 6.307 | 6.478 | 6.234 | 6.484 | 6.325 |

*Table-8(a) :Effect of evaporator temperature on thermodynamic performance of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | HFO-1336mzz(Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1243zf | R1234yf | R134a |
|---|---|---|---|---|---|---|---|
| 253 | 0.1322 | 0.1357 | 0.1410 | 0.1283 | 0.1262 | 0.1225 | 0.1289 |
| 258 | 0.1317 | 0.1347 | 0.1383 | 0.1279 | 0.1258 | 0.1220 | 0.1282 |
| 263 | 0.1304 | 0.1329 | 0.1367 | 0.1267 | 0.1245 | 0.1217 | 0.1267 |
| 268 | 0.1279 | 0.130 | 0.1331 | 0.1244 | 0.1221 | 0.1198 | 0.1241 |
| 273 | 0.1239 | 0.1255 | 0.1287 | 0.1205 | 0.1183 | 0.1164 | 0.120 |
| 278 | 0.1177 | 0.1188 | 0.1208 | 0.1154 | 0.1122 | 0.1107 | 0.1137 |
| 283 | 0.1078 | 0.1085 | 0.1099 | 0.1047 | 0.1027 | 0.1015 | 0.1038 |

*Table-8(b) :Effect of evaporator temperature on thermodynamic exergy destruction Ratio ($EDR\_{System}$) of modified vapour compression refrigeration system usingliquidvapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 253 | 0.1344 | 0.1272 | 0.1309 | 0.1262 | 0.1338 | 0.1289 |
| 258 | 0.1332 | 0.1267 | 0.1302 | 0.1258 | 0.1326 | 0.1282 |
| 263 | 0.1315 | 0.1255 | 0.1287 | 0.1245 | 0.1305 | 0.1267 |
| 268 | 0.1288 | 0.1232 | 0.1262 | 0.1221 | 0.1274 | 0.1241 |
| 273 | 0.1245 | 0.1194 | 0.1221 | 0.1183 | 0.1228 | 0.120 |
| 278 | 0.1180 | 0.1134 | 0.1158 | 0.1122 | 0.1160 | 0.1137 |
| 283 | 0.1078 | 0.1089 | 0.1059 | 0.1027 | 0.1058 | 0.1038 |

*Table-9(a) :Effect of evaporator temperature on thermodynamic exergy destruction Ratio ($EDR_{System}$) of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | HFO-1336mzz(Z) | R1233zd(E) | R1234ze(Z) | R1234ze(E) | R1243zf | R1234yf | R134a |
|---|---|---|---|---|---|---|---|
| 253 | 6.566 | 6.368 | 6.092 | 6.795 | 6.921 | 7.1161 | 6.755 |
| 258 | 6.594 | 6.423 | 6.181 | 6.818 | 6.952 | 7.16 | 6.799 |
| 263 | 6.671 | 6.526 | 6.314 | 6.893 | 7.033 | 7.215 | 6.894 |
| 268 | 6.817 | 6.695 | 6.5711 | 7.041 | 7.188 | 7.346 | 7.06 |
| 273 | 7.069 | 6.969 | 6.808 | 7.299 | 7.455 | 7.593 | 7.336 |
| 278 | 7.499 | 7.419 | 7.279 | 7.742 | 7.91 | 8.032 | 7.799 |
| 283 | 8.278 | 8.22 | 8.096 | 8.549 | 8.737 | 8.848 | 8.629 |

*Table- 9(b) :Effect of evaporator temperature on thermodynamic performance of modified vapour compression refrigeration system using liquid vapour heat exchanger using new HFO ecofriendly refrigerants for reducing global warming and ozone depletion (Evaporator temperature= 273"K", Compressor Efficiency= 80%, Degree of subcooling=10°C,Degree of super heating=10°C, Heat exchanger effectiveness= 80%)*

| Evaporator Temperature (K) | R1224yd(Z) | R1225ye(Z) | R124 | R1243zf | R152a | R134a |
|---|---|---|---|---|---|---|
| 253 | 6.459 | 6.864 | 6.641 | 6.921 | 8.454 | 6.755 |
| 258 | 6.507 | 6.890 | 6.679 | 6.952 | 6.544 | 6.799 |
| 263 | 6.602 | 6.967 | 6.767 | 7.033 | 6.662 | 6.894 |
| 268 | 6.765 | 7.116 | 6.925 | 7.188 | 6.849 | 7.06 |
| 273 | 7.032 | 7.374 | 7.191 | 7.455 | 7.142 | 7.336 |
| 278 | 7.477 | 7.819 | 7.639 | 7.910 | 7.617 | 7.799 |
| 283 | 8.273 | 8.629 | 8.445 | 8.737 | 8.454 | 8.629 |

## 4. Conclusions and Recommendation

Following conclusions were drawn from present investigations

- Thermodynamic performance using R1234ze (z) gives better first and second law performances than R1234yf, R152a and, R134a.
- The performance of HFO refrigerants is slightly less than HF1234ze (E), however it has similar refrigerating properties and can easily replace HFC-134a in all vapour compression refrigeration systems.
- The exergy destruction in compressor is highest for all HFO refrigerants.
- The exergy destruction in evaporator is second highest
- The exergy destruction in throttle valve is lowest.
- Exergy destruction ratio is increasing as evaporator and condenser temperatures is increasing.
- Coefficient of performance of modified vapour compression system is increasing when evaporator temperature is increasing for all HFO refrigerants.
- Coefficient of performance of modified vapour compression system is decreasing when condenser temperature is increasing for all HFO refrigerants.

## References


[1] Official Journal of the European Union L161:12–18.

[2] Johnson. E. Global warming from HFC. Environ. Impact Asses.1998; 18:485-492.

[3] Kapil Chopra, V.Sahni, R.S Mishra. Thermodynamic analyses of multiple evaporators vapour compression refrigeration systems with R410A, R290, R1234YF, R502, R404A and R152A.International Journal of Airconditioning and Refrigeration 21(1) (2014) 1-14.

[4] Qiyu Chen,R.C Prasad. Simulation of a vapour compression refrigeration cycles HFC134A and CFC12.Int Comm.Heat Mass Transfer.1999; 26:513-521.

[5] M. Padilla, R. Revellin, J. Bonjour. Exergy analysis of R413A as replacement of R12 in a domestic refrigeration system. Int J Energy Conversion and Management.2010; 51:2195-2201.

[6] Akhilesh Arora, S.C. Kaushik. Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A. Int J Refrigeration.2008; 31:998-1005.

[7] S.Anand ,S.KTyagi, Exergy analysis and experimental study of a vapour compression refrigeration cycle, Int J Therm Anal Calorim.2012; 110:961-971.

[8] RecepYumrutas, Mehmet Kunduz, Mehmet Kanoglu, Exergy analysis of vapor compression refrigeration systems. Exergy, An International Journal.2002; 2:266-272.

[9] R.S. Mishra [2015] Vapour compression refrigeration technology for sustainable development International Journal of Advance Research and Innovation ISSN 2347 – 3258, Volume 3, Issue 4 (2015) 647-652

[10] R.S. Mishra [2015] Irreversibility reduction in vapour compression refrigeration systems using Al2O3 nano material mixed in R718 as secondary fluid, International Journal of Advance Research and Innovation, ISSN 2347 – 3258, Volume 3, Issue 2 (2015) 321-327

[11] R. S. Mishra [2015] Energy-exergy performance comparison of vapour compression Refrigeration Systems using three nano materials mixed in R718 as secondary fluid and R-1234yf and R-1234ze eco-friendly refrigerants in the primary circuit , International Journal of Advance Research and Innovation, ISSN 2347 – 3258, Volume 3, Issue 4, page607-610

[12] R. S. Mishra, R. K. Jaiswal,[2015] Methods for improving thermodynamic performance of variable speed vapour compression refrigeration systems using nano-refrigerent in primary circuit, Nature & Environment, 20 (2), , 26-47

[13] R. S. Mishra, Kapil Chopra, V. Sahni, [2015] irreversibility optimization using energy-exergy analysis of three stage vapour compression refrigeration systems with flash-intercooler using ecofriendly refrigerants (R410a, R290, R600, R600a, R1234yf, R125, R717 And R134A) for reducing global warming and ozone depletion, Nature & Environment, 20(2), page. 73-89

[14] Kapil Chopra, V.Sahni , R.S Mishra - Energy and exergy analysis of multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration system using ecofriendly refrigerants. International Conference on Smart Technologies for Mechanical Engineers.2013.Paper No-121.systems
[15] Kapil Chopra, V.Sahni , R.S Mishra -Thermodynamic analysis of a multievaporatorsvapour compression refrigeration system using ecofriendly refrigerants (R1234yf, R1234ze and R134a). International Conference on Smart Technologies for Mechanical Engineers.2013.Paper No-42. [13]
[16] R.S. Mishra [2015] Vapour compression refrigeration technology for sustainable development International Journal of Advance Research and Innovation ISSN 2347 – 3258, Volume 3, Issue 4 (2015) 647-652.
[17] R.S. Mishra [2019] Evaluation of thermodynamic energy-exergy performances in modified vapour compression refrigeration, International Journal of Research in Engineering and Innovation Vol-3, Issue-6 (2019), 364-376 systems
[18] Kapil Chopra, V.Sahni , R.S Mishra -Thermodynamic analysis of a multievaporatorsvapour compression refrigeration system using ecofriendly refrigerants (R1234yf, R1234ze and R134a). International Conference on Smart Technologies for Mechanical Engineers.2013.Paper No-42.
[19] Kapil Chopra, V.Sahni , R.S Mishra - Energy and exergy analysis of multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration system using ecofriendly refrigerants. International Conference on Smart Technologies for Mechanical Engineers.2013.Paper No-121
[20] www.honeywellnow.com.

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