



## ORIGINAL ARTICLE

# Methods of improving thermal performance of vapour compression based refrigeration system through ecofriendly refrigerants to reduce their environmental impact

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### Abstract

Tetrafluoroethane (CF<sub>3</sub>CH<sub>2</sub>F), an HFC refrigerant, is also known as R134a. It is safe for normal handling because it is neither poisonous, flammable, nor corrosive. After it was discovered recently that R-134a contributes to global warming, the European Union forbade its use in brand-new automobiles starting in 2011. Worked on a vapour compression-based refrigeration system, utilizing hydrocarbon (HC) refrigerants which were examined for their energetic and exergetic performance. In this investigation, pure Tetrafluoroethane (CF<sub>3</sub>CH<sub>2</sub>F) from the R134a family of HFCs was used for a theoretical analysis, along with other refrigerants which were eco-friendly and had a lower environmental impact (low Global Warming Potential and Ozone Depletion Potential): trans-1,3,3,3-Tetrafluoroprop -1-ene(R1234 ze (Z), R1234ze (E), (Z)-1-Chloro-2,3,3,3-Tetrafluoropropane (R1224YD (Z)), Fluoroethene (R1141),3,3,3-Trifluoroprop-1-ene (R1243 ZF). The thermodynamic equations of the refrigerants were solved for analysis using the Engineering equation solver application. It was concluded that R1234ZE (Z) and R1141 are the most effective refrigerants.

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## 1. Introduction

An upgraded version of the air refrigeration cycle used in general refrigeration and commercial applications is the vapour compression cycle. It involves four operations: compression, condensation, expansion, and vaporisation. The thermodynamic cycle is a process in which a liquid refrigerant is condensed into a saturated liquid and stored in the liquid receiver. The low-pressure refrigerant vapour expands before entering the evaporator or refrigerator, where it absorbs heat and creates refrigeration. At point 5 the cold and partially vaporised refrigerant moves towards point 1 passing from the evaporator coils/tubes, Warm air is introduced through the coil or tubes by a fan. The generated refrigerant vapour then flows

back to point 1, the compressor inlet. The vapour compression cycle, which involves compression, condensation, throttling, and evaporation, has been the focus of scientists' attention. EES is a commercial software package used to solve systems of simultaneous nonlinear equations, storing thermodynamic properties and performing iterative problem solving. Code can be input in any order.

### 1.1 Literature Review

R.S. Mishra et al. (2013) Employed several evaporators, compressors, expansion valves, intercoolers, and flash chambers to enhance the vapour compression refrigeration system's thermal efficiency. Results revealed a 22%

improvement in first- and second-law effectiveness. R.S Mishra et al. (2020) found that raising evaporator load or decreasing high grade energy can both increase the thermal performance(COP) of a Vapour compression based refrigeration system utilizing eco-friendly refrigerants.

S C Kaushik et al. (2008) performed a conceptual study of a vapour compression based refrigeration system using R502, R600, R404A, and R507A. R507A was concluded to be a better replacement of R502 than R404A, with minor issues of the liquid vapour heat exchanger efficiency and minor condenser issues. Akhilesh Arora and SC Kaushik et al. (2008) conducted a study to identify the appropriate interstage pressure and temperature of a Refrigeration system with two stages utilising HCFC22, R410A, and R717 refrigerants. Conclusion: R717 is a better HCFC22 replacement refrigerant than R410A. S K Tyagi et al. (2012) found that the system's overall exergy destruction is highest at 100% charge and lowest at 25% charge. Kapil Chopra, V. Sahni et al. (2015) compared the refrigerants used in two-stage vapour compression refrigeration systems. At  $-50^{\circ}\text{C}$  for evaporation and  $45^{\circ}\text{C}$  for condensation, R134a had 8.97% and 5.38% less energy and exergy efficiency than R152a and R600.

Vaibhav Jain et al. (2011) conducted a performance comparison research of R22, R134a, R410A, R407C, and M20-based vapour compression refrigeration systems. R407C can be a viable HFC refrigerant replacement with the least expense and work. Huang et. al. (2017) studied the energetic and exergetic performance of a mini air cooled heat exchanger. Naushad Ahmad Ansari, Akhilesh Arora, Samsher and K. Manjunath et al (2019) investigated the functioning of a Vapour Compression based Refrigeration System with customized Mechanical Subcooling and the Effect of Green Refrigerants. It was found that R1233zd(E), a low GWP refrigerant, performed better than R134a in terms of COP and energy efficiency. Jeyaraj Thavamani & Ramalingam Senthil et al. (2020) had conducted a study on the effectiveness of retrofitting hydrocarbon-based household vapour compression refrigeration systems. Separate tests using HC mix and R134a refrigerants were conducted under no-load conditions. Because of the high latent heat, it was found that the temperature of the HC mix is 3C lower. Bolaji, B.O. et al. (2011) chose environmentally friendly refrigerants from methane derivatives and ethane derivatives based on flammability, toxicity, chemical stability, and atmospheric lifespan.

Neeraj Agrawal, Shriganesh Patil, Prasant Nanda et al. (2017) used R290/R600a Zeotropic Blends to determine the ideal charge for a residential refrigerator, with a 60 g charge and  $-3.5^{\circ}\text{C}$  as the lowest temperature. Piyanut Saengsikhiao, Juntakan Taweekun, Somchai Sae-ung, Thanasak et al. (2020) conducted research to create an energy-efficient and ecologically friendly refrigerant for medium temperature refrigeration systems. The end product is a nontoxic refrigerant with low GWP, 0% ODP, high capacity, and low operating pressure. Kazm Kumaş, Ali Akyüz et al. (2020) conducted a performance investigation of the R450A refrigerant in a vapour compression cooling system. The energy characteristics of R450A and R134a refrigerants were theoretically and

ecologically examined. It was determined that R450A has a larger mass flow rate than R134a due to cooling more slowly. R134a has a greater COP. Alptug Yatanbaba, Ali Kilicarslan, Irfan Kurtbas et al. (2015) found that R1234yf and R1234ze are good alternatives to R134a in terms of their environmental friendliness. Mr. Sandip P. Chavhan, Prof. S. D. Mahajan et al. (2015) conducted a study on the experimental performance assessment of R152a as a potential R134a replacement. R152a has an average refrigerating effect that is 57% higher than R134a's. It is the most energy-efficient refrigerant since it uses the least amount of electricity per tonne of refrigeration of the two refrigerants under study and has the lowest GWP (Global Warming Potential (120)) and ODP (Ozone Depleting Potential (0)) values.

Lalit Mishra, Asst. Prof. Sunil Kumar, Prof. Abhishek Bhandari et al (2019) analysed performance of an ice plant using R-134a eco-friendly refrigerant. Three refrigerants, R32, R152a, and R245a, were combined in a certain ratio to replace R134a. The global warming potential of all three refrigerants was lower than that of R134a. Based on their thermal performance in the given conditions and environmental impact the refrigerant mixes were evaluated. A L Tarish, J Al Douri, and V Apostol et al. (2020) examined effectiveness and efficiency for a vapour compression based refrigeration system (VCRS) employing R1234ze and R1234ze, two ecologically friendly refrigerants. studied how performance and energy destruction were affected by subcooling temperature in all VCRS components. The thermodynamic properties of the refrigerant were obtained using the Engineering Equation Solver (EES) software programme. The findings showed that R1234yf demonstrated the biggest COP gain (16.7%) as a result of subcooling, followed by R1234ze (14%), and R134a (12.8%). Uma Shankar Prasad, R.S Mishra, R.K Das et al. (2020) investigated the thermal performance of a vapour compression based refrigeration system utilising R134a refrigerant with nanofluids and an  $\text{Al}_2\text{O}_3$  base. They concluded that nanoparticles with R134a refrigerant can improve heat transfer qualities.

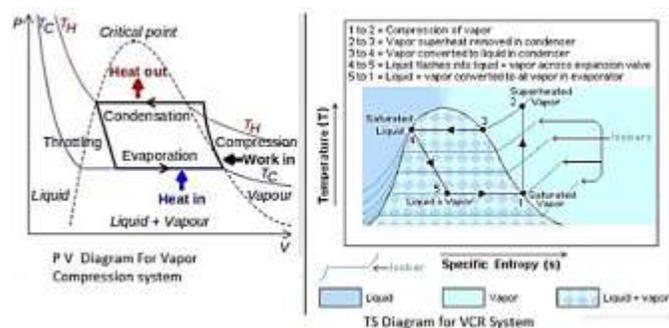


Figure 1: PV and TS Diagram for Vapour Compression System

## 1.2 Advantages and disadvantages

Benefits of a vapour compression system include its smaller size and cheaper running costs for a given refrigeration capacity. It may be used in a wide variety of temperatures. The

vapour compression system offers the following benefits: It is smaller in size for the same refrigeration capacity, and it costs less to operate. Disadvantages of Vapour Compression System: The system's primary difficulty is controlling refrigerant leakage, and the initial cost is rather high. Moving Parts cause more wear and tear and noise. Liquid droplets in the suction line could be harmed.

### 1.3 System description

#### 1.3.1 Compressor

In order to maintain a constant flow of refrigerant throughout the system, compressors pull refrigerant vapour from the evaporator and increase its temperature and pressure so that it condenses.

#### 1.3.2 Condenser

It is a heat exchanger device used for condensation which employs a cooling medium to transfer heat from the refrigerant. The cooling system of the apparatus generally utilises atmospheric air or water as the medium which receives the system's rejected heat. The cooling medium ultimately ejects the heat to the universe or the outside atmosphere. The heat rejected in the condenser is the sum total of heat equivalent to the compressor work and absorbed evaporator heat. Due to heat transfer, the refrigerant going through the condenser is first superheated, then condensed, and occasionally somewhat sub-cooled.

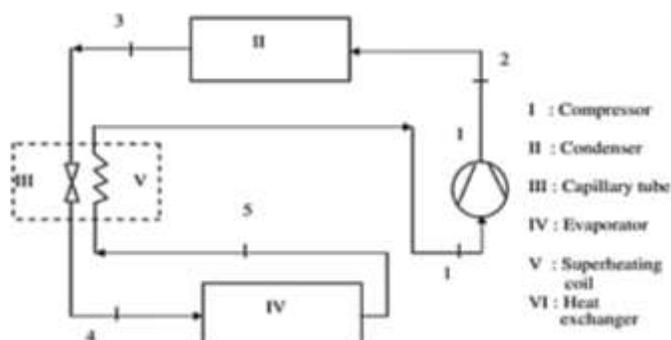


Figure 2: System Description

#### 1.3.3 Capillary Tube

Because the capillary tube is not adjustable and cannot alter the flow of the refrigerant, it is built for certain environmental circumstances. However, if correctly chosen, it can perform pretty effectively under a variety of scenarios. Because of the capillary's short diameter, the pressure of the refrigerant decreases.

#### 1.3.4 Evaporator

The evaporator also acts as a heat exchanger in a typical refrigeration circuit apart from the condenser, it functions at

the "business end" of the refrigeration cycle. The evaporator's fins absorb heat from the air as it is forced past them, cooling the air by collecting heat from space. Since it transfers heat from the objects in the cold room to the refrigerant, it is the main part of the refrigeration system.

#### 1.3.5 Super Heating

The process of turning saturated or wet steam into superheated or dry steam, which is subsequently used in steam turbines, steam engines, and procedures like steam reforming, is known as a superheater coil. Before the liquid reaches the evaporator coil, it evaporates, absorbing heat that is then released as superheated vapour. The operational superheat controls how much of the evaporator is used.

#### 1.3.6 Heat Exchanger

Heat is transferred using heat exchangers from one flowing substance to another that is flowing and has a lower initial temperature. Heat exchangers are employed as evaporators and condensers in refrigeration engineering, where the refrigerant goes through a phase shift. As a counter-flow heat exchanger, the capillary tube and suction line move refrigerant vapour from the evaporator to the condenser and maintain its condensed state throughout the process. Throughout the procedure, which uses a non-adiabatic throttling technique, heat is transferred from the capillary tube to the suction line, keeping it apart from the evaporator. The thermal performance of this system is boosted due to heat transfer.

## 2. Materials and Methods

These mentioned numerical values were employed for the numerical calculation to verify the thermal model:

Reference temperature ( $T_0$ ) = 298.15 K

Reference pressure ( $P_0$ ) = 110 kilo Pascal

Refrigeration capacity ( $Q_{\text{evap}}$ ) = 10 kilo Watt

Evaporator temperature range ( $T_{\text{evap}}$ ) = 250–273.15 K

Condenser temperature range ( $T_{\text{condenser}}$ ) = 313–333.15 K

Sub cooling temperature (DTSC) = 0 Kelvin

Superheating temperature (DTSH) = 3 Kelvin

Compressor isentropic efficiency = 80%

Electric motor efficiency = 90%

Mass flow rate range of refrigerants:

R134a = 0.06905 kg s<sup>-1</sup>

R600 = 0.0042 kg s<sup>-1</sup>

R600a = 0.0050 kg s<sup>-1</sup>

### 2.1 Energy and Exergy Analysis

For the simple vapour compression refrigeration cycle, energy and exergy analyses require some mathematical formulations. The compressor receives external energy (power), and the evaporator adds heat to the system while the condenser rejects heat. The energy efficiency of the refrigerants changes as a

result of changes in heat rejection and heat addition for various refrigerants. The different parts of the system's components experience different exergy losses.  $T_0$  and  $P_0$  represent the surrounding ambient temperature and pressure. Exergy is consumed or destroyed as a result of the entropy generated by the associated processes.

Second law efficiency (Exergy):

$$\Psi = (h - h_0) - T_0 (s - s_0) \tag{1}$$

For Evaporator: Heat addition in evaporator

$$Q_{ev} = m (h_1 - h_4) \tag{2}$$

Exergetic losses:

$$I_{ev} = m (\psi_4 - \psi_1) + Q_{ev} (1 - T_0 / T_{evap}) = m [(h_4 - h_1) - T_0 (s_4 - s_1)] + Q (1 - T_0 / T_{evap}) \tag{3}$$

For Vapour Compressor:

Exergetic losses:

$$I_{compressor} = m (\psi_1 - \psi_2) + W_{el} = m [(h_1 - h_2) - T_0 (s_1 - s_2)] + W_{el} \tag{4}$$

For Condenser:

$$Q_{condenser} = m (h_2 - h_3) \tag{5}$$

Exergetic losses:

$$I_{condenser} = m (\psi_2 - \psi_3) - Q_{condenser} (1 - T_0 / T_{condenser}) = m [(h_2 - h_3) - T_0 (s_2 - s_3)] - Q_{condenser} (1 - T_0 / T_{condenser}) \tag{6}$$

For Expanding through valve: cooling the condensed refrigerant Exergetic destruction:

$$I_{exp} = m (\psi_4 - \psi_3) = m (s_4 - s_3) [Throttling, h_4 = h_3] \tag{7}$$

For thermal efficiency: coefficient of performance

$$COP = Q_{ev} / W_{el} \tag{8}$$

aggregate system destruction:

$$Total = I_{condenser} + I_{exp} + I_{compressor} + I_{ev} \tag{9}$$

Exergetic efficiency (2<sup>nd</sup> law efficiency)

$$\eta_x = (\Psi_1 - \Psi_4) / W_{el}$$

## 2.2 Engineering Equation Solver (EES)

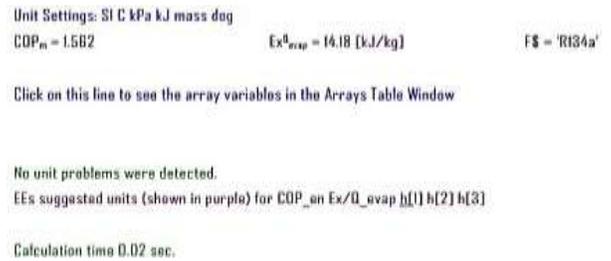


Figure 3: Settings of EES Code

## 3. Results and Discussions

### 3.1 R134a

Table 1(a): Variation of evaporating temperature with thermal performance for R134a

| Temp Evap (°C) | -20   | -15   | -10   | -5    | 0     |
|----------------|-------|-------|-------|-------|-------|
| COP            | 2.10  | 2.36  | 2.68  | 3.06  | 3.54  |
| Efficiency     | 0.3   | 0.29  | 0.27  | 0.26  | 0.23  |
| Q(cond)        | 14.66 | 14.46 | 14.28 | 14.12 | 13.96 |
| W(comp)        | 4.25  | 3.8   | 3.38  | 2.97  | 2.58  |
| Exergy Product | 1.85  | 1.65  | 1.45  | 1.25  | 1.04  |
| Q(evap)        | 10.41 | 10.66 | 10.9  | 11.14 | 11.37 |
| EDR(sys)       | 2.28  | 2.4   | 2.57  | 2.83  | 3.2   |

Table 1(b): Variation of condensing temperature with thermal performance for R134a

| Temp Cond (°C) | 60    | 55    | 50    | 45    | 40    |
|----------------|-------|-------|-------|-------|-------|
| COP            | 1.89  | 2.16  | 2.46  | 2.81  | 3.22  |
| Efficiency     | 0.16  | 0.18  | 0.21  | 0.24  | 0.28  |
| Q(cond)        | 12.85 | 13.24 | 13.61 | 13.96 | 14.28 |
| W(comp)        | 7.44  | 4.19  | 3.93  | 3.66  | 3.38  |
| Exergy Product | 1.12  | 1.2   | 1.29  | 1.37  | 1.45  |
| Q(evap)        | 8.41  | 9.05  | 9.68  | 10.3  | 10.9  |
| EDR(sys)       | 5.18  | 4.41  | 3.73  | 3.13  | 2.57  |

### 3.2 R1234ze (Z)

Table 2(a): Variation of evaporating temperature with thermal performance for R1234ze(Z)

| Temp Evap (°C) | -20   | -15   | -10   | -5    | 0     |
|----------------|-------|-------|-------|-------|-------|
| COP            | 2.61  | 3.01  | 3.32  | 3.72  | 4.33  |
| Efficiency     | 0.29  | 0.27  | 0.26  | 0.24  | 0.24  |
| Q(cond)        | 12.82 | 13.14 | 13.57 | 13.84 | 14.55 |
| W(comp)        | 4.12  | 3.84  | 3.67  | 3.39  | 2.99  |
| Exergy Product | 1.91  | 1.83  | 1.8   | 1.7   | 1.62  |
| Q(evap)        | 10.77 | 11.57 | 12.2  | 12.61 | 12.93 |
| EDR(sys)       | 2.34  | 2.48  | 2.6   | 2.94  | 3.31  |

Table 2(b): Variation of condensing temperature with thermal performance for R1234ze(Z)

| Temp Cond (°C) | 60    | 55    | 50    | 45    | 40    |
|----------------|-------|-------|-------|-------|-------|
| COP            | 1.99  | 2.26  | 2.67  | 2.92  | 3.34  |
| Efficiency     | 0.26  | 0.28  | 0.31  | 0.34  | 0.38  |
| Q(cond)        | 12.98 | 13.41 | 13.82 | 13.96 | 14.32 |
| W(comp)        | 7.74  | 4.28  | 3.93  | 3.56  | 3.23  |
| Exergy Product | 1.42  | 1.61  | 1.7   | 1.47  | 1.58  |
| Q(evap)        | 8.61  | 9.15  | 9.88  | 10.45 | 10.92 |
| EDR(sys)       | 5.38  | 4.81  | 3.48  | 3.22  | 2.87  |

3.3 R1234ze (E)

Table 3(a): Variation of evaporating temperature with thermal performance for R1234ze(E)

| Temp Evap (°C) | -20   | -15   | -10   | -5     | 0     |
|----------------|-------|-------|-------|--------|-------|
| COP            | 2.42  | 2.872 | 3.325 | 3.67   | 4.322 |
| Efficiency     | 0.311 | 0.28  | 0.27  | 0.2611 | 0.23  |
| Q(cond)        | 14.86 | 14.61 | 14.2  | 14.13  | 14    |
| W(comp)        | 4.29  | 3.884 | 3.31  | 2.88   | 2.56  |
| Exergy Product | 1.9   | 1.711 | 1.46  | 1.23   | 1.11  |
| Q(evap)        | 10.38 | 11.15 | 11.01 | 10.61  | 11.08 |
| EDR(sys)       | 2.25  | 2.42  | 2.6   | 2.84   | 3.211 |

Table 3(b): Variation of condensing temperature with thermal performance for R1234ze(E)

| Temp Cond (°C) | 60     | 55    | 50    | 45     | 40     |
|----------------|--------|-------|-------|--------|--------|
| COP            | 1.887  | 2.17  | 2.47  | 2.82   | 3.23   |
| Efficiency     | 0.1623 | 0.187 | 0.211 | 0.2431 | 0.2981 |
| Q(cond)        | 12.82  | 13.31 | 13.65 | 13.98  | 14.35  |
| W(comp)        | 7.5    | 4.13  | 3.97  | 3.65   | 3.33   |
| Exergy Product | 1.18   | 1.2   | 1.27  | 1.34   | 1.52   |
| Q(evap)        | 8.4    | 9.05  | 9.633 | 10.32  | 10.8   |
| EDR(sys)       | 5.232  | 4.41  | 3.78  | 3.445  | 2.456  |

3.4 R1224YD (Z)

Table 4(a): Variation of evaporating temperature with thermal performance for R1224YD

| Temp Evap (°C) | -20   | -15   | -10   | -5    | 0     |
|----------------|-------|-------|-------|-------|-------|
| COP            | 2.41  | 2.85  | 3.34  | 3.69  | 4.29  |
| Efficiency     | 0.3   | 0.29  | 0.28  | 0.27  | 0.23  |
| Q(cond)        | 14.81 | 14.59 | 14.23 | 14.05 | 13.91 |
| W(comp)        | 4.22  | 3.88  | 3.31  | 2.8   | 2.59  |
| Exergy Product | 1.91  | 1.76  | 1.76  | 1.72  | 1.7   |
| Q(evap)        | 10.17 | 11.05 | 11.08 | 10.32 | 11.1  |
| EDR(sys)       | 2.23  | 2.44  | 2.53  | 2.85  | 3.12  |

3.6 Comparison between refrigerants

Table 6(a): Comparison between Refrigerants at T\_cond (50)

| T_cond(50) | COP  | Exergy Product | EDR  | Q(cond) | Comp Work | Q(evap) | Efficiency |
|------------|------|----------------|------|---------|-----------|---------|------------|
| R134a      | 2.46 | 1.29           | 3.73 | 13.61   | 3.93      | 9.68    | 0.21       |
| R1234ze(Z) | 2.67 | 1.7            | 3.48 | 13.82   | 3.93      | 9.88    | 0.31       |
| R1234ze(E) | 2.47 | 1.27           | 3.78 | 13.65   | 3.99      | 9.633   | 0.2112     |
| R1224YD(Z) | 2.56 | 1.28           | 3.78 | 13.79   | 3.96      | 9.69    | 0.21       |
| R1141      | 2.68 | 1.7            | 3.46 | 13.93   | 3.98      | 9.89    | 0.31       |

Table 6(b): Comparison between Refrigerants at T\_evap(0)

| T_evap(0)  | COP   | Exergy Product | EDR   | Q(evap) | Comp Work | Q(cond) | Efficiency |
|------------|-------|----------------|-------|---------|-----------|---------|------------|
| R134a      | 3.54  | 1.04           | 3.2   | 11.37   | 2.58      | 13.96   | 0.23       |
| R1234ze(Z) | 4.33  | 1.62           | 3.31  | 12.93   | 2.99      | 14.55   | 0.24       |
| R1234ze(E) | 4.322 | 1.11           | 3.211 | 11.08   | 2.56      | 14      | 0.23       |
| R1224YD(Z) | 4.29  | 1.7            | 3.12  | 11.1    | 2.59      | 13.91   | 0.23       |
| R1141      | 4.33  | 1.62           | 3.31  | 12.93   | 2.99      | 14.55   | 0.24       |

Table 4(b): Variation of condensing temperature with thermal performance for R1224YD

| Temp Cond (°C) | 60    | 55    | 50    | 45    | 40    |
|----------------|-------|-------|-------|-------|-------|
| COP            | 1.86  | 2.14  | 2.56  | 2.9   | 3.25  |
| Efficiency     | 0.16  | 0.19  | 0.21  | 0.24  | 0.3   |
| Q(cond)        | 12.86 | 13.57 | 13.79 | 13.98 | 14.56 |
| W(comp)        | 7.46  | 4.13  | 3.96  | 3.64  | 3.33  |
| Exergy Product | 1.14  | 1.23  | 1.28  | 1.38  | 1.67  |
| Q(evap)        | 8.45  | 9.08  | 9.69  | 10.56 | 10.78 |
| EDR(sys)       | 5.28  | 4.48  | 3.78  | 3.42  | 2.43  |

3.5 R1141

Table 5(a): Variation of evaporating temperature with thermal performance for R1141

| Temp Evap (°C) | -20   | -15   | -10   | -5    | 0     |
|----------------|-------|-------|-------|-------|-------|
| COP            | 2.61  | 3.01  | 3.32  | 3.72  | 4.33  |
| Efficiency     | 0.29  | 0.27  | 0.26  | 0.24  | 0.24  |
| Q(cond)        | 12.82 | 13.14 | 13.57 | 13.84 | 14.55 |
| W(comp)        | 4.12  | 3.84  | 3.67  | 3.39  | 2.99  |
| Exergy Product | 1.91  | 1.83  | 1.8   | 1.7   | 1.62  |
| Q(evap)        | 10.77 | 11.57 | 12.2  | 12.61 | 12.93 |
| EDR(sys)       | 2.34  | 2.48  | 2.6   | 2.94  | 3.31  |

Table 5(b): Variation of condensing temperature with thermal performance for R1141

| Temp Evap (°C) | 60    | 55    | 50    | 45    | 40    |
|----------------|-------|-------|-------|-------|-------|
| COP            | 1.99  | 2.28  | 2.68  | 2.96  | 3.36  |
| Efficiency     | 0.26  | 0.29  | 0.31  | 0.34  | 0.38  |
| Q(cond)        | 12.93 | 13.56 | 13.93 | 13.99 | 14.48 |
| W(comp)        | 7.77  | 4.28  | 3.98  | 3.84  | 3.27  |
| Exergy Product | 1.46  | 1.68  | 1.7   | 1.45  | 1.55  |
| Q(evap)        | 8.63  | 9.17  | 9.89  | 10.59 | 10.97 |
| EDR(sys)       | 5.38  | 4.82  | 3.46  | 3.23  | 2.84  |

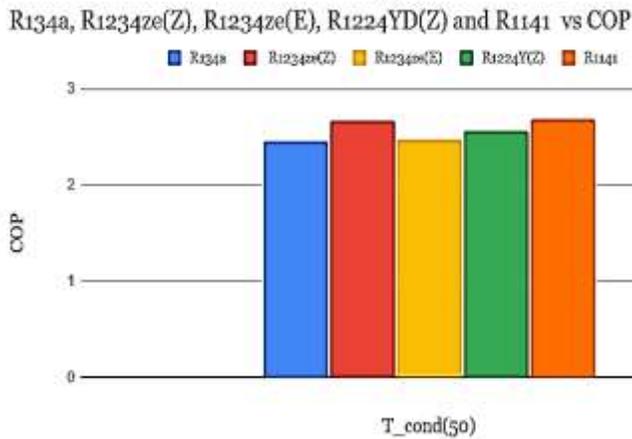


Figure 1: The graph compares the refrigerants based on their COP at  $T_{cond}(50)$ . The results demonstrate that R1234ze(Z), R1234ze(E), R1224YD(Z), and R1141 have higher COP than R134a.

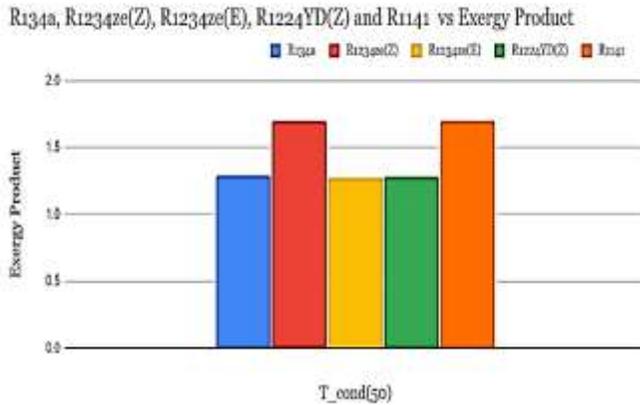


Figure 2: The graph compares the refrigerants based on their Exergy Product at  $T_{cond}(50)$ . The results demonstrate that R1234ze(Z) and R1141 have higher Exergy Product than R134a whereas R1234ze(E) and R1224YD(Z) have lower Exergy Product than R134a.

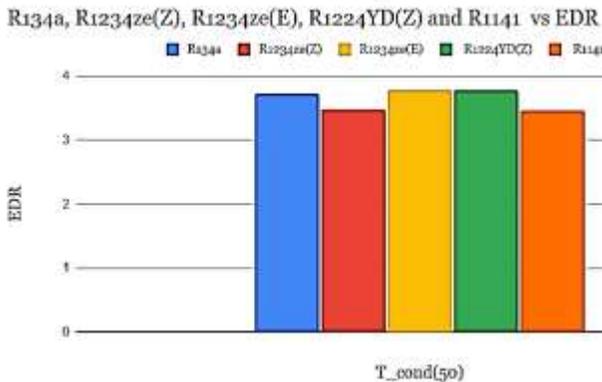


Figure 3: The graph compares the refrigerants based on their EDR at  $T_{cond}(50)$ . The results demonstrate that R1234ze(Z) and R1141 have lower EDR than R134a whereas R1234ze(E) and

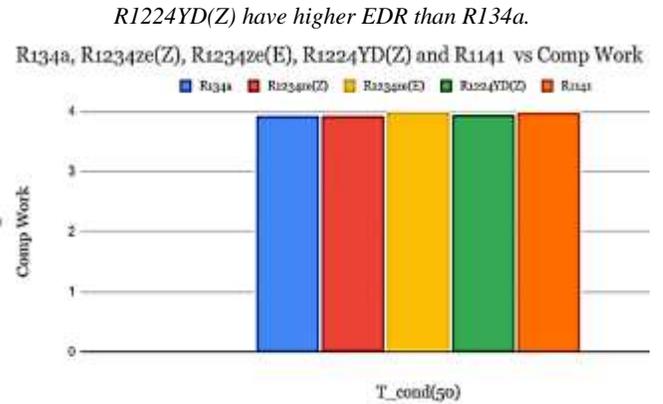


Figure 4: The graph compares the refrigerants based on their Comp Work at  $T_{cond}(50)$ . The results demonstrate that R1234ze(E), R1224YD(Z) and R1141 have higher Comp work than R134a whereas R1234ze(Z) have the same Comp work as R134a.

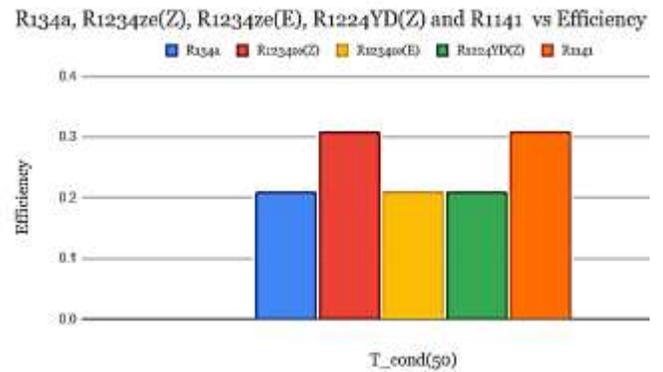


Figure 5: The graph compares the refrigerants based on their Efficiency at  $T_{cond}(50)$ . The results demonstrate that R1234ze(Z) and R1141 have higher Efficiency than R134a whereas R1234ze(E) and R1224YD(Z) have the same Efficiency than R134a.

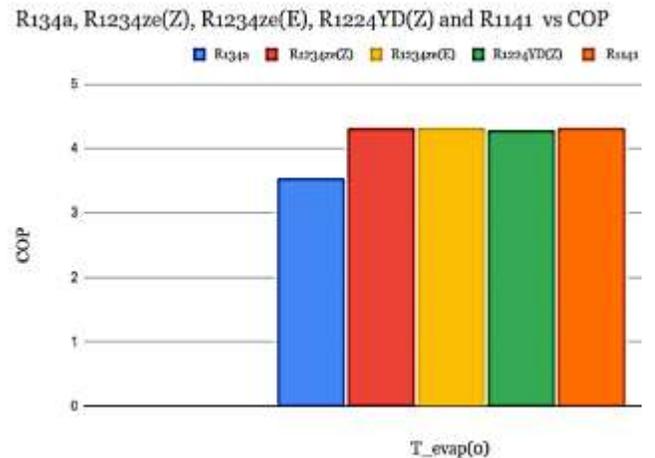


Figure 6: The graph compares the refrigerants based on their COP at  $T_{evap}(0)$ . The results demonstrate that R1234ze(Z), R1234ze(E), R1224YD(Z), and R1141 have higher COP than R134a.

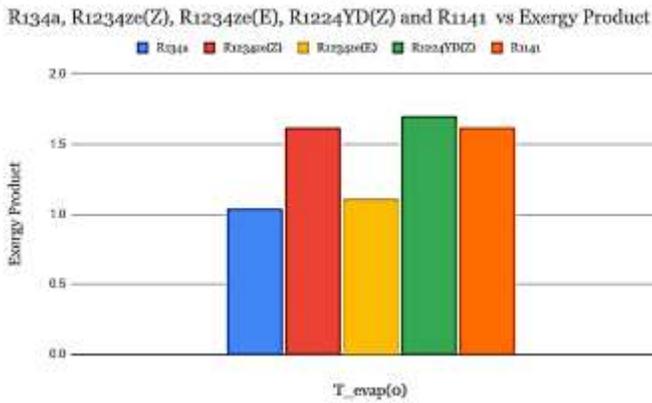


Figure 7: The graph compares the refrigerants based on their Exergy Product at  $T_{evap}(0)$ . The results demonstrate that R1234ze(Z), R1234ze(E), R1224YD(Z), and R1141 have higher Exergy Product than R134a.

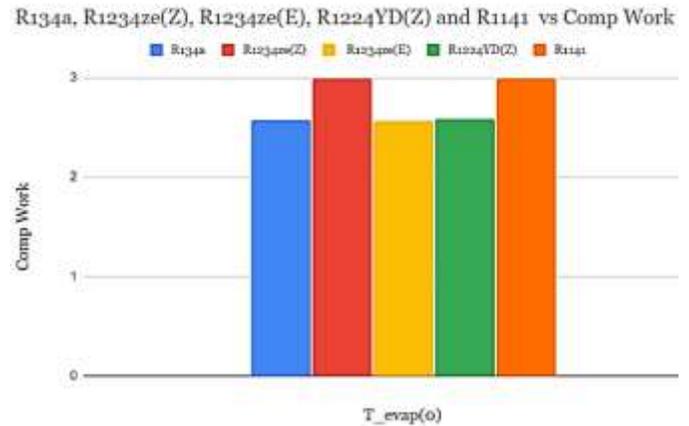


Figure 10: The graph compares the refrigerants based on their Comp Work at  $T_{evap}(0)$ . The results demonstrate that R1234ze(Z), R1224YD(Z), and R1141 have higher Comp Work than R134a whereas R1234ze(E) have lesser Comp Work than R134a.

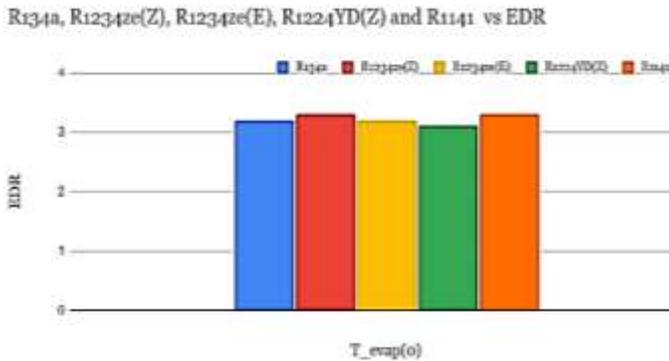


Figure 8: The graph compares the refrigerants based on their EDR at  $T_{evap}(0)$ . The results demonstrate that R1234ze(Z), R1234ze(E) and R1141 have higher EDR than R134a whereas R1224YD(Z) have lower EDR than R134a.

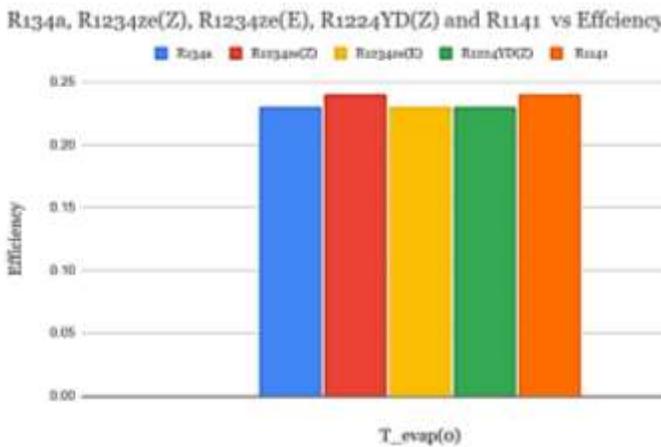


Figure 9: The graph compares the refrigerants based on their Efficiency at  $T_{evap}(0)$ . The results demonstrate that R1234ze(Z) and R1141 have higher Efficiency than R134a whereas R1234ze(E) and R1224YD(Z) have the same Efficiency than R134a.

Based on comprehensive investigation and comparison, it has been shown that R1234 ze (Z) and R1141 are the most efficient refrigerants when compared to R134a.

#### 4. Conclusions

To improve the overall performance of the vapour compression system, the temperature differential between the evaporator and condenser must be reduced. In order to enhance the performance of the compressor, it is necessary to boost the motor's efficiency and the lubrication system. Operating the system at low condensing and high evaporating temperature ranges will result in a high coefficient of performance (COP) and minimal energy loss.

The following findings were reached as a result of the current investigation:

- R1234ZE(Z) and R1141 are the most efficient refrigerants.
- 2.Exergy, also known as availability, is the greatest amount of work that a fluid stream may do during a cyclic mechanism before achieving thermal equilibrium with its surroundings. Second law analysis evaluates the effectiveness in a thermodynamic system. Unlike energy, exergy is not conserved and may be destroyed. Energy efficiency declines as evaporator temperature rises. This is brought on by the components' increased irreversibility as the evaporator temperature rises.
- Eco-friendly refrigerants have better thermodynamic properties than traditional refrigerants, resulting in improved energy efficiency. This means that the system will require less energy to operate, resulting in lower operating costs and energy bills over time.

- Improved energy efficiency, reduced maintenance costs, and compliance with regulations can result in significant cost savings and improved profitability over time. Additionally, the environmental benefits of using eco-friendly refrigerants can also result in positive social and economic impacts that are difficult to quantify but are nonetheless valuable.

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