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ORIGINAL ARTICLE

Thermodynamic performances evaluations of modified vapour compression refrigeration systems using blends of HFO+HFC refrigerants

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Abstract

Exergy analysis is a useful way for determining the real thermodynamic losses and optimising environmental and economic performance in the systems such as vapour compression refrigeration Systems Performance computations of modified vapour compression refrigeration system have been carried out using exergy method it was found that R454C shows lowest exergetic performance among selected HFO+HFC refrigerants blends However HFO+HFC blends R515A gives best thermodynamic performances Similarly exergetic and energetic performances of R515A is slightly higher than R513A refrigerants. R454C shows lowest first and second law exergetic performances among selected HFO+HFC refrigerants blends. The percentage exergy destruction in expansion valves is lower as compared to compressor and condenser for all HFO & HFC refrigerants.

1. Introduction

The refrigerant is the heat-carrying medium during vapour compression refrigeration cycle in the refrigeration system that absorbs heat from a low-temperature system and discards the heat so absorbed to a higher temperature system. The natural ice and mixture and salt were used the first refrigerant. In 1834, ammonia, sulphur dioxide, methyl chloride and carbon dioxide were used as refrigerants in the vapour compression refrigeration system. The chloro-fluoro derivatives of methane (CH4) and ethane (C2H6) are the most commonly used halo-carbon or organic refrigerants. The fully halogenated refrigerants with chlorine (Cl) atoms in their molecules are referred to as chloro-fluoro-carbon (CFC) refrigerants. The refrigerants such as R11, R12, R13, R113, R114, and R115 are CFC refrigerants. The refrigerants which contain hydrogen(H) atoms in their molecules are referred to as Hydro-chloro-fluoro-carbon (HCFC) refrigerants. The refrigerants such as R22 and R123 are HCFC refrigerants. The refrigerants which contain no chlorine atoms in their molecules are referred to as Hydro-fluoro-carbon (HFC) refrigerants. The refrigerants such as R134a, and R152a are HFC refrigerants. The refrigerants which contain no chlorine and fluorine atoms in their molecules are referred to as Hydrocarbon (HC) refrigerants. The refrigerants such as R290, R600a, etc are HC refrigerants. It was found that the fluorine(F) atom in the molecule of the refrigerants makes them physiologically more favourable. The chlorine (Cl) atom in the molecules of the refrigerants is considered to be responsible for the depletion of this layer in the upper atmosphere, which allows harmful ultra-violet rays from the sun to penetrate through the atmosphere and reach the earth's surface causing skin cancer. The chloro-fluoro-carbon(CFC) refrigerants have been linked to the depletion of this ozone layer. They have a varying degree of ozone depletion potential (ODP). In addition to the ozone depletion effect on the environment, the halo-carbon refrigerants have a

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global warming effect, which may cause serious environmental changes. According to an international agreement, s Montrel Protocol-1987, halogenated chloro-fluoro-carbon (CFC) refrigerants that are considered to have high ozone depletion potential ozone depletion, such as R11, R12, R13, R113, R114, R502, have been phased out. The refrigerant R22, a hydro-chloro-fluoro-carbon (HCFC) refrigerant, is not covered under the original Montreal Protocol as its ODP is one-twentieth of R11 & R12. But because of its GWP, it has to be phased out. Nevertheless, R22 is found to be of greater use these days as it is being employed not only in its existing R22 applications but also as a substitute for R11 in extensive capacity air conditioning applications with screw or centrifugal compressors. The hydrocarbon(HC)& hydro-fluoro-carbon(HFC) refrigerants provide an alternative to fully halogenated chloro-fluoro-carbon (CFC) refrigerants. Since they contain no chlorine atom at all. Therefore, they have the lowest ODP. Refrigerants. Even hydro-chloro-fluoro-carbon (HCFC) refrigerants, which contain some chlorine (Cl) atoms but in association with hydrogen (H) atoms, have much reduced ODP; however, the hydro- fluoro-carbons (HFCs), because of their hydrogen (H) content, may be slightly flammable. The degree of flammability depends upon the number of H atoms in the molecules. Pure hydrocarbon(HCs) are, of course, highly flammable.

1.1 Substitutes for chloro-fluoro-carbon (CFC) refrigerants

Currently, the following substitutes are available for replacement. CFC refrigerants

- The HCFC refrigerant R123 (CF3CHCl2) in place of R11 (CCl3F).
- The HFC refrigerant R134a (CF3CH2F) & R152a (CH3CHF2) in place of R12.
- The HFC refrigerant R143a (CH3CF3) & R125 (CHF2 CF3) in place of R502 (a mixture of R22 & R115)
- The HC refrigerants, propane (R290), C3H8 and R600a (C4H10) may also be used in place of R12.

1.2 HFO+HFC blend as a substitute for chloro-fluoro-carbon (HFC) refrigerants

Accordingly, HFCs that do not destroy the ozone layer were developed to replace HCFCs. In Japan, companies first replaced CFC refrigerants with HCFC refrigerants and then later on with HFC refrigerants in consideration of the environment, ahead of other countries, earlier than the regulation timetable set up in the Montreal Protocol.

HFC refrigerants do not destroy the ozone layer and are non-flammable and low toxic, which makes HFC safe and reliable. But the GWP of HFC is high. Therefore, a new movement was started to implement legal regulations on HFCs. In 2006, the EU F-gas Regulation was established first and then the proposal to phase down HFCs under the Montreal Protocol on substances that deplete the ozone layer was issued through the leadership of the U.S. These new endeavors led to the amendment of the "Law Concerning the Recovery and Destruction of Fluorocarbons" to the "Act on Rational Use and Proper Management of Fluorocarbons" (commonly known as "Fluorocarbon Emission Control Law") and came into effect from April 2015, in Japan. As for the global scene, the Parties to the Montreal Protocol reached an agreement at their 28th Meeting of the Parties (MOP-28) in October 2016 in Kigali, Rwanda, to phase down HFCs (Kigali Amendment) [2]. It was decided that the developed countries should gradually reduce their production and consumption of HFCs (on a CO2 equivalent basis) by 10% by 2019, by 40% by 2024, and then by 70% by 2029, and eventually by 85% by 2036. The developing countries, on the other hand, would have to reduce HFC production and consumption with a time delay of approximately 10 to 13 years. As a whole, all parties are required to minimize HFCs over 30 years. This transition mechanism is similar to past efforts toward reducing HCFCs. As a consequence of the Kigali Amendment, the Fluorocarbon Emission Control Law regulations in Japan have been gradually strengthened further). In December 2017, the government announced proposals to add a centrifugal chiller to the designated product category, which demands that equipment manufacturers replace existing refrigerants with lower GWP refrigerants. Centrifugal chiller manufacturers must regulate GWP values to 100 or less from 2025 onwards. The properties of refrigerants change inevitably to achieve low-GWP levels. Although substances called natural refrigerants have a very low GWP, they have downsides too. For example, hydrocarbons are highly flammable, whereas ammonia is both highly flammable and toxic. To find a way around these hurdles, hydrofluoroolefins (HFOs) with a carbon-carbon double bond have been developed recently as another candidate for a low-GWP refrigerant. HFOs decompose when exposed to ultraviolet rays and thus has a short atmospheric lifetime and a low GWP. As an inherent trade-off for reducing GWP, however, substances tend to become flammable because molecules' stability is reduced to increase the speed of decomposition. Although different types of low GWP refrigerants have been developed for various refrigeration and air-conditioning equipment, we can summarize that non-flammability is not necessarily-achieved property in the effort to achieve low GWP. But in many applications like large hotels, food storage and food processing plants, food items are stored in a different compartment and at different temperatures. Therefore, there is need of multi evaporator vapour compression refrigeration system. The systems under vapour compression technology consume an enormous amount of electricity, this problem can be solved by improving performance of system. The thermodynamic Performances of Cascaded Vapour compression refrigeration systems theoretically investigated the energy parameters (i.e., cooling capacity COP, exergetic efficiency) using R1234yf, R1234ze(E), R513A, R445A and R450A alternative refrigerants with low GWP value instead of R134a of three different vapour compression refrigeration system (i.e. basic cycle, basic cycle with liquid-to-suction heat exchanger and

two-stage cascade cycle) and found similar thermodynamic behavior using these refrigerants. The exergetic efficiency of the systems was also compared. The comparison of the energy parameters was carried out for two different evaporation temperatures (-30 and 0°C) and two condensing temperatures (40 and 55°C). According to the calculation results and found that the R450A has almost same COP values as R134a comes with 58% lower GWP value compared to R134a. and suggested from the studies, by using LSHEX refrigeration cycles, system with gives a better effect in terms of COP for the considered refrigerants and temperature cases as well as assumed system parameters. It was seen for the investigated cycles that the highest exergetic efficiency by using R445A

Adrián Mota-Babiloni [8] carried out analysis of the feasibility of R454C and R455A, two new low global warming potential (GWP of 148) refrigerants, in vapour compression refrigeration systems as alternatives to R404A for warm countries and found that the R454C and R455A will be the most viable low GWP options to perform a direct replacement of R404A due to similar uniqueness and found experimental results show that the cooling capacity of the reserves is slightly lower than R404A, being the Coefficient of Performance (COP) of the new mixtures 10–15% higher than that of R404A, especially at more increased condensation.

1.3 Thermodynamic analysis of vapour compression refrigeration systems refrigeration

Technology is based on the rejection of heat to the surrounding at higher temperatures and absorption of heat at low temperatures [1], evaporator, expansion valve, condenser and compressor are the four main components of the single-stage vapour compression system. Vapour compression refrigeration systems consume a large amount of electricity. This difficulty can be removed by improving the performance parameters of the system. Therefore, the thermodynamic performances of techniques based on vapour compression refrigeration technology can be improved by following. First law efficiency (Coefficient of performance) and second law performance (exergetic efficiency) are the main two parameters to calculate the performance of refrigeration systems.

The Coefficient of performance can be enhanced by minimizing the compressor's power consumption or increasing the refrigeration effect. The adoption of multi-stage throttling can increase the refrigeration effect. On the other hand, compressor power consumption can be enhanced by incorporating multi-stage compression and flash chamber. The collective impact of these two factors improves the overall performance of vapour compression system.

It is presented that system components' Irreversibility occurs due to significant temperature differences between the system and its surrounding. To improve the system performance, Irreversibility should be measured in the cycle because exergy losses are responsible for the degradation of system performance. The Coefficient of performance is commonly used to calculate the performance of vapour compression system but COP provides no information regarding thermodynamic losses in the system components.

One can quantify the exergy losses in vapour compression refrigeration systems using exergy analysis. Exergy losses increase with increasing of the temperature difference between systems and surroundings.

Exergy is the available or useful energy and loss of energy means loss of exergy in the system. Exergy losses are useful to improve the performance of the system and better utilization of energy input given to the system, which is beneficial for environmental conditions and economics of energy technologies. The utilization of green energy can be increased by this method.

2. Thermodynamic modeling of vapour compression refrigeration systems using multi evaporators & multi compressors

In past decades, refrigerants such as R11, R12, R22 etc. used in vapour compression refrigeration systems have been responsible for increasing of global warming and ozone depletion potential. An international society named Montreal protocol discussed and signed on the refrigerants having higher global warming and ozone depletion potential values for all countries. To control the emission of greenhouse gases, one more committee was formed named as Kyto protocol [2]. After 90's a program was run to phase out the higher GWP and ODP refrigerants (CFC and HCFC) for environmental problems. To replace "old" refrigerants with "new" refrigerants, lots of research has been conducted, and lots of research has been carried out.

Saravanakumar and Selladurai [3], evaluated thermal performance parameters such as COP and exergetic efficiency with R290/R600 hydrocarbon mixture on a domestic refrigerator designed to work with R134a and observed that the performance of the same system is higher with R290/R600a hydrocarbon mixture compared to R134a. In their analysis, the condenser, expansion valve, and evaporator show lower exergy destruction than the compressor. Reddy et al.[4]carried out a theoretical analysis of R134a, R143a, R152a, R404A, R410A, R502 and R507A in vapour compression refrigeration system and effect on Coefficient of performance and second law efficiency with a variation of superheating of evaporator outlet, evaporator temperature and degree of sub-cooling at condenser outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature was observed and concluded that COP and exergetic efficiency significantly affected with change of evaporator and condenser temperatures and also observed that R134a and R407C show highest and lowest performance in all respect. Kumar et al. [5] carried out energy and exergy analysis of single-stage vapour compression refrigeration system using R11 and R12 as working fluids.

Nikolaidis and Probert [6] observed the effect of condenser and evaporator temperatures on a two-stage vapour compression refrigeration system using R22. They suggested that there is a

requirement to optimize the condenser and evaporator conditions.

The above literature found that energy, exergy analysis of single-stage and multi stages vapour compression refrigeration systems have been done. But no literature contributed for exergy analysis of the two-stage vapour compression refrigeration system using HFO refrigerants.

Adrián Mota-Babiloni [8] carried out an analysis of the feasibility of R454C and R455A, two new low global warming potential (GWP of 148) refrigerants, in vapour compression refrigeration systems as alternatives to R404A for warm countries and found that the R454C and R455A will be the most viable low GWP options to perform a direct replacement of R404A due to similar uniqueness and found experimental results show that the cooling capacity of the replacements is slightly lower than R404A, being the Coefficient of Performance (COP) of the new mixtures 10–15% higher than that of R404APresent works analyze the system in terms of energy and exergy efficiencies and explain the effect of exergy losses occurred on two-stage vapour compression refrigeration system with ecofriendly HFO +HFC refrigerant blends.

2.1 Energy-Exergy analysis of vapour compression refrigeration systems multi evaporator & multi compressor systems

Energy analysis is concerned with the conservation of energy, but it gives no information on how, where, and how much the system performance is degraded or evaluation of actual irreversibility losses that occurred in the system. Therefore, exergy analysis which is based on the first law and the second law of thermodynamics, is a powerful tool in the design, optimization, and performance evaluation of energy systems. Exergy analysis (second law analysis) helps identify the processes' thermal losses and energy transfer. As per earlier research, exergetic efficiency, energetic efficiency and Irreversibility in each component of the VCR system are not the same for different refrigerants [20]. In this paper, numerical models have been developed for the comparison of performance parameters of systems (system-1 & system-2) based on selected refrigerants using EES software. The performance parameters are evaluated by considering the following operating conditions of the systems.

- Adiabatic efficiency of each compressor (ηc):75%.
- Negligible pressure drop in pipelines
- Negligible change in potential and kinetic energy
- Expansion of refrigerant in expansion valves is isenthalpic.
- Temperatures of first, second and third evaporators are 263K ,273K and 283K, respectively for system-1 and system-2
- Condenser temperature (T_{cond}): 313K
- Dead state temperature (T_0): 298K
- Dead state enthalpy (ψ_0) and entropy (s_0) of the refrigerants have been calculated, corresponding to the dead state temperature (T_0) of 298K.

2.2 First law and second law analysis

System-1 consists of compressors (Comp1, Comp2, Comp3), throttle valves (tv1, tv2, tv3), condenser and evaporators (EP1, EP2, EP3) as shown in Fig.1. The pressure versus enthalpy chart for system-1 is shown in Fig. 2. The main components of system-2 are compressors (Comp1*, Comp2*, Comp3*), throttle valves (tv1*, tv2*, tv3*), condenser and evaporators (EP1*, EP2*, EP3*) as shown in Fig. 2. This system's corresponding pressure versus enthalpy chart is shown in Fig. 2. According to the first law of thermodynamics energetic efficiency /COP is defined as the ratio of net refrigeration effect to the per unit of power consumed. First law analysis is restricted to calculating only the Coefficient of performance of the vapour compression systems as given below:

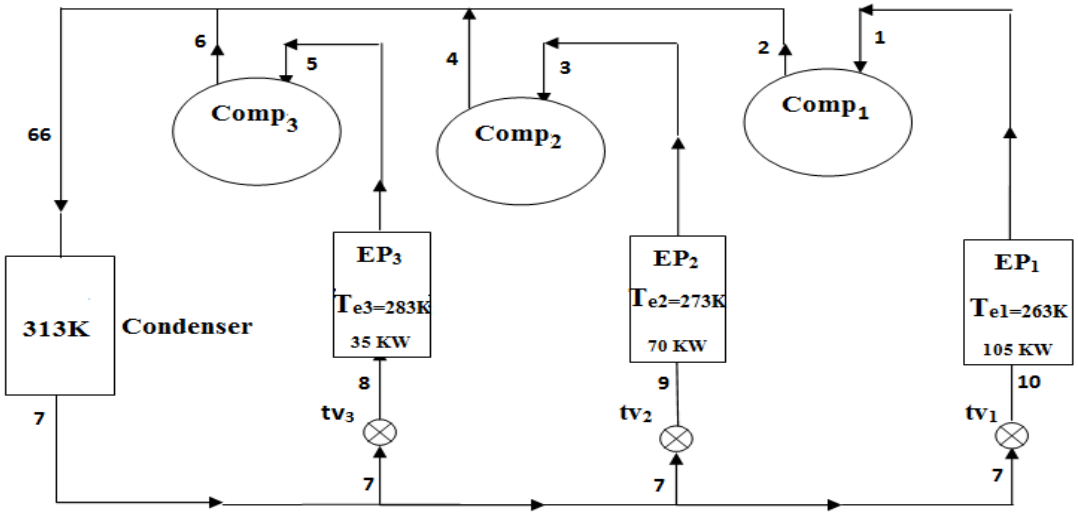

Figure 1: Schematic diagram of multiple evaporators at different temperatures with individual compressors and individual expansion valves

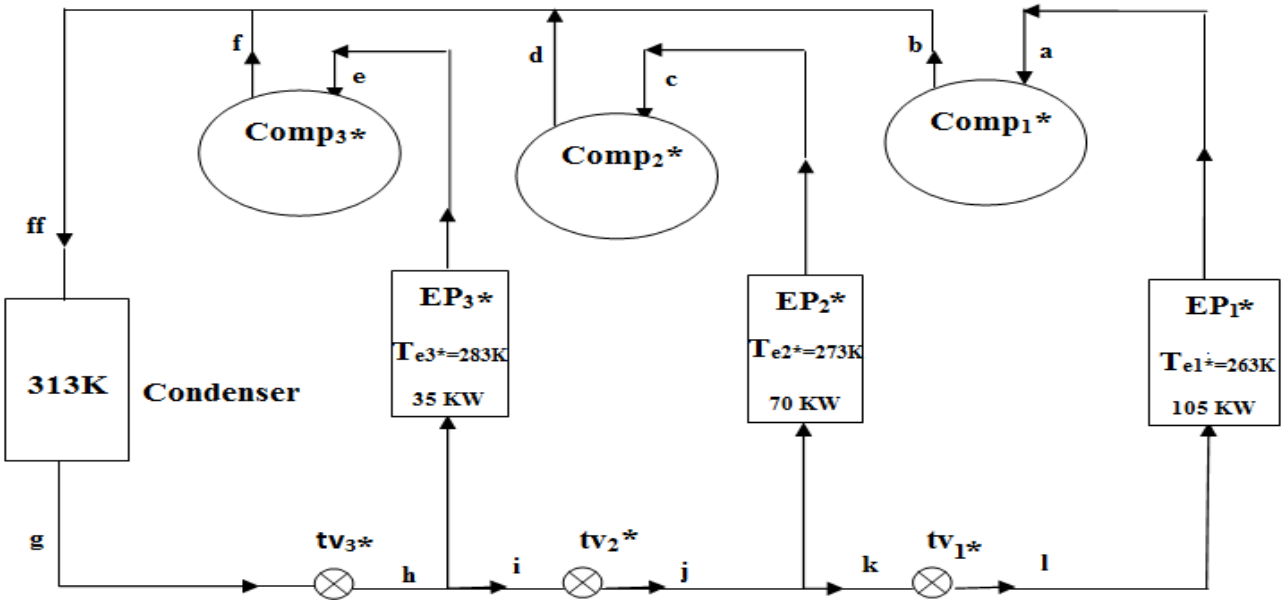

Figure 2: Schematic diagram of multiple evaporators at different temperatures with individual compressors and multiple expansion valves X

The concept of exergy was given by second law of thermodynamics. Exergy is 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. Irreversibility (exergy destruction) in each component of the system-1 evaluated as per Equations (7) to (17) given below

The total compressor work, refrigerating & coefficient of performance capacity of system-7 can be expressed as

$$\dot{W}_c = \dot{m}_{c1}(\psi_2 - \psi_1) + \dot{m}_{c2}(\psi_4 - \psi_3) + \dot{m}_{c3}(\psi_6 - \psi_5) \quad (1)$$

$$\dot{Q}_e = \dot{m}_{e1}(\psi_1 - \psi_{10}) + \dot{m}_{e2}(\psi_3 - \psi_9) + \dot{m}_{e3}(\psi_5 - \psi_8) \quad (2)$$

$$COP = \frac{\dot{Q}_e}{\dot{W}_c} \quad (3)$$

Similarly, the total compressor work, refrigerating & coefficient of performance capacity of system-8 can be expressed as

$$\dot{W}_{c^*} = \dot{m}_{c1^*}(\psi_b - \psi_a) + \dot{m}_{c2^*}(\psi_d - \psi_c) + \dot{m}_{c3^*}(\psi_f - \psi_e) \quad (4)$$

$$\dot{Q}_{e^*} = \dot{m}_{e1^*}(\psi_a - \psi_l) + \dot{m}_{e2^*}(\psi_c - \psi_j) + \dot{m}_{e3^*}(\psi_e - \psi_h) \quad (5)$$

$$COP^* = \frac{\dot{Q}_{e^*}}{\dot{W}_{c^*}} \quad (6)$$

System-1

Evaporators

$$E\dot{D}_{e1} = \dot{E}_{x10} + \dot{Q}_{e1}\left(1 - \frac{T_0}{T_{r1}}\right) - \dot{E}_{x1} \quad (7)$$

$$= \dot{m}_{e1}(\psi_{10} - T_0 s_{10}) + \dot{Q}_{e1}\left(1 - \frac{T_0}{T_{r1}}\right) - \dot{m}_{e1}(\psi_1 - T_0 s_1)$$

$$E\dot{D}_{e2} = \dot{E}_{x9} + \dot{Q}_{e2}\left(1 - \frac{T_0}{T_{r2}}\right) - \dot{E}_{x3} \quad (8)$$

$$= \dot{m}_{e2}(\psi_9 - T_0 s_9) + \dot{Q}_{e2}\left(1 - \frac{T_0}{T_{r2}}\right) - \dot{m}_{e2}(\psi_3 - T_0 s_3)$$

$$E\dot{D}_{e3} = \dot{E}_{x8} + \dot{Q}_{e3}\left(1 - \frac{T_0}{T_{r3}}\right) - \dot{E}_{x5} \quad (9)$$

$$= \dot{m}_{e3}(\psi_8 - T_0 s_8) + \dot{Q}_{e3}\left(1 - \frac{T_0}{T_{r3}}\right) - \dot{m}_{e3}(\psi_5 - T_0 s_5)$$

Compressors

$$E\dot{D}_{c1} = \dot{E}_{x1} + \dot{W}_{c1} - \dot{E}_{x2} = \dot{m}_{c1}(T_0(s_2 - s_1)) \quad (10)$$

$$E\dot{D}_{c2} = \dot{E}_{x3} + \dot{W}_{c2} - \dot{E}_{x4} = \dot{m}_{c2}(T_0(s_4 - s_3)) \quad (11)$$

$$E\dot{D}_{c3} = \dot{E}_{x5} + \dot{W}_{c3} - \dot{E}_{x6} = \dot{m}_{c3}(T_0(s_6 - s_5)) \quad (12)$$

Condenser

$$E\dot{D}_{cond} = (\dot{E}_{x66} - \dot{E}_{x7}) \quad (13)$$

$$E\dot{D}_{cond} = (\dot{E}_{x66} = \dot{m}_c((\psi_{66} - T_0 s_{66}) - (\psi_7 - T_0 s_7))$$

Throttle valves

$$E\dot{D}_{t1} = \dot{E}_{x7} - \dot{E}_{x10} = \dot{m}_{c1}(T_0(s_{10} - s_7)) \quad (14)$$

$$E\dot{D}_{t2} = \dot{E}_{x7} - \dot{E}_{x9} = \dot{m}_{c2}(T_0(s_9 - s_7)) \quad (15)$$

$$E\dot{D}_{t3} = \dot{E}_{x7} - \dot{E}_{x8} = \dot{m}_{c3}(T_0(s_8 - s_7)) \quad (16)$$

The total system defect in the system-1 is the sum of irreversibility in each components of the system and is given by

$$\sum \dot{E}D_n = \dot{E}D_e + \dot{E}D_c + \dot{E}D_{cond} + \dot{E}D_t \quad (17)$$

Similarly, exergy destruction in each component of the multiple evaporators and compressors with multiple expansion valves vapour compression refrigeration system (System-2) is evaluated as per Equations (18) – (28) given below:

System-2

Evaporators

$$\dot{E}D_{e1^*} = \dot{m}_{e1^*}((\psi_l - T_0 s_l) - (\psi_a - T_0 s_a)) + \dot{Q}_{e1^*}\left(1 - \frac{T_0}{T_{r1^*}}\right) \quad (18)$$

$$\dot{E}D_{e2^*} = \dot{m}_{e2^*}((\psi_j - T_0 s_j) - (\psi_c - T_0 s_c)) + \dot{Q}_{e2^*}\left(1 - \frac{T_0}{T_{r2^*}}\right) \quad (19)$$

$$\dot{E}D_{e3^*} = \dot{m}_{e3^*}((\psi_h - T_0 s_h) - (\psi_e - T_0 s_e)) + \dot{Q}_{e3^*}\left(1 - \frac{T_0}{T_{r3^*}}\right) \quad (20)$$

Compressors

$$\dot{E}D_{c1^*} = \dot{E}_{xa} + \dot{W}_{c1^*} - \dot{E}_{xb} = \dot{m}_{c1^*}(T_0(s_b - s_a)) \quad (21)$$

$$\dot{E}D_{c2^*} = \dot{E}_{xc} + \dot{W}_{c2^*} - \dot{E}_{xd} = \dot{m}_{c2^*}(T_0(s_d - s_c)) \quad (22)$$

$$\dot{E}D_{c3^*} = \dot{E}_{xe} + \dot{W}_{c3^*} - \dot{E}_{xf} = \dot{m}_{c3^*}(T_0(s_f - s_e)) \quad (23)$$

Condenser

$$\dot{E}D_{cond^*} = (\dot{E}_{xff} - \dot{E}_{xg}) \quad (24)$$

$$\dot{E}D_{cond^*} = \dot{m}_c\left((\psi_{ff} - T_0 s_{ff}) - (\psi_g - T_0 s_g)\right)$$

Throttle valves

$$\dot{E}D_{t1^*} = \dot{E}_{xk} - \dot{E}_{xl} = \dot{m}_{c1^*}(T_0(s_l - s_k)) \quad (25)$$

$$\dot{E}D_{t2^*} = \dot{E}_{xi} - \dot{E}_{xj} = (\dot{m}_{c1^*} + \dot{m}_{c2^*})(T_0(s_j - s_i)) \quad (26)$$

$$\dot{E}D_{t3^*} = \dot{E}_{xgg} - \dot{E}_{xh} = (\dot{m}_{c1^*} + \dot{m}_{c2^*} + \dot{m}_{c3^*})(T_0(s_h - s_{gg})) \quad (27)$$

System defect

The total system defect in the system-2 is the sum of irreversibility in each components of the system and is given by

$$\sum \dot{E}D_{n^*} = \dot{E}D_{e^*} + \dot{E}D_{c^*} + \dot{E}D_{cond^*} + \dot{E}D_{t^*} \quad (28)$$

Exergetic efficiency

For the multi evaporators vapour compression refrigeration system, product is the exergy of the heat abstracted in to the evaporators from the space to be cooled and exergy of fuel is actual compressor work input. Hence, exergetic efficiency is given by

$$\eta_{ex} = \frac{\text{Exergy in product}}{\text{Exergy of fuel}} = \frac{\dot{E}P}{\dot{E}F}$$

3. Results and Discussion

Following modified vapour compression refrigeration systems using HFO+HFC refrigerant blends have been used in the present investigation.

System-1

Thermodynamic performances of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends. The following numerical values have been taken for numerical computations. Thermodynamic performances ***of*** vapour compression refrigeration system using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends have been computed for different blends of HFC+HFO refrigerants for replacing HFC-134a refrigerant is shown in Table 1-7 respectively. Similarly the percentage of exergy destruction in components based on exergy of fuel and rational exergetic efficiency of vapour compression refrigeration systems using different blends of HFC+HFO refrigerants at different load conditions respectively and found that first law efficiency (COP) of vapour compression refrigeration systems using HFC +HFO blends at dead state temperature of 298K (25ºC)and it was found that vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio.

Table 1:Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	5.293	4.654	4.616	4.623	5.083	4.306	5.482
EDR	2.625	3.108	3.151	3.168	2.747	3.462	2.496
Exergetic Efficiency	0.2842	0.2499	0.2478	0.2482	0.2729	0.2312	0.2943
Second Law Efficiency	0.7044	0.6194	0.6143	0.6152	0.6764	0.5730	0.7296
Rational Efficiency	0.2542	0.2234	0.2191	0.2137	0.2504	0.1998	0.2655
Exergy of Fuel "kW"	39.67	45.12	45.49	45.42	41.32	48.77	38.31
Exergy of Product "kW"	11.27	11.27	11.27	11.27	11.27	11.27	11.27
Effectiveness_Second	0.2759	0.2434	0.2404	0.2399	0.2669	0.2241	0.2861
% Total System Exergy Destruction	74.58	77.66	78.09	78.63	74.96	80.02	73.45
% Total Compressor Exergy Destruction	23.90	22.97	23.09	23.45	22.75	23.10	24.12
% Total condenser Exergy Destruction	28.22	32.02	30.71	27.29	33.26	29.52	29.62
% Total Exergy evaporator Destruction	14.43	14.03	14.98	16.24	10.55	17.54	12.32
% Total Valve Exergy Destruction	5.661	6.01	6.551	8.245	5.483	7.169	5.068
% Total subcooler Exergy Destruction	2.336	2.525	2.657	3.331	2.81	2.567	2.319
% Total Flash intercooler Exergy Destruction	0.03382	0.7008	0.01129	0.079	0.1147	0.1147	0.004344
% Rational Efficiency	25.42	22.34	21.91	21.37	25.04	19.98	26.55

Table 2: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	5.160	4.546	4.509	4.514	4.958	4.210	5.343
EDR	2.542	3.003	3.048	3.071	2.653	3.349	2.416
Exergetic Efficiency	0.2927	0.2579	0.2558	0.2561	0.2813	0.2388	0.3031
Second Law Efficiency	0.6867	0.6050	0.60	0.6007	0.6599	0.5602	0.7110
Rational Efficiency	0.2559	0.2254	0.2205	0.2136	0.2537	0.2001	0.2679
Exergy of Fuel "kW"	40.7	46.19	46.58	46.52	0.2537	49.89	39.31
Exergy of Product "kW"	11.27	11.27	11.27	11.27	11.27	11.27	11.27
Effectiveness_Second	0.2824	0.2498	0.2471	0.2457	0.2737	0.2299	0.2928
% Total System Exergy Destruction	74.41	77.46	77.95	77.64	74.63	79.99	73.21
% Total Compressor Exergy Destruction	23.95	23.04	23.41	23.51	22.82	23.15	24.17
% Total condenser Exergy Destruction	27.62	31.41	30.12	26.76	32.58	28.98	28.97
% Total Exergy evaporator Destruction	14.77	14.32	15.30	16.64	10.81	17.87	12.67
% Total Valve Exergy Destruction	5.737	6.114	6.665	8.379	5.555	7.331	5.121
% Total subcooler Exergy Destruction	2.287	2.477	2.606	3.267	2.753	2.521	2.269
% Total Flash intercooler Exergy Destruction	0.0364	0.01089	0.1225	0.08724	0.0114	0.1266	0.0037
% Rational Efficiency	25.59	22.54	22.05	21.36	25.37	20.01	26.79

System-2

Thermodynamic performances (exergy destruction in components and rational exergetic efficiency of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends

Thermodynamic performances of vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends have been computed for different blends of HFC+HFO refrigerants for replacing HFC-134a refrigerant is shown in Table 8 to 15 respectively. Similarly the percentage of exergy destruction in components based on exergy of fuel and rational exergetic efficiency of vapour compression refrigeration systems using different blends of HFC+HFO refrigerants at different load conditions respectively and found that first law efficiency (COP) of VCRS using HFC +HFO blends at dead state temperature of 298K (25^{o}C)and it was found that vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio.

Table 3: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=273K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.536	4.034	4.0	3.996	4.375	3.3752	4.690	4.636
EDR	2.153	2.531	2.239	2.60	2.238	2.82	2.045	2.089
Exergetic Efficiency	0.3294	0.2930	0.2906	0.2903	0.3178	0.2725	0.3407	0.3367
Second Law Efficiency	0.6036	0.5368	0.5324	0.5318	0.5822	0.4993	0.6242	0.6170
Rational Efficiency	0.2905	0.2585	0.2532	0.2453	0.2888	0.2313	0.3034	0.2965
Exergy of Fuel "kW"	30.87	34.71	35.0	35.03	32.0	37.31	29.85	30.20
Exergy of Product "kW"	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17
Effectiveness_Second	0.3171	0.2832	0.2801	0.2778	0.3088	0.2618	0.3284	0.3237
% Total System Exergy Destruction	70.95	74.15	74.68	75.47	71.12	76.87	69.66	70.35
% Total Compressor Exergy Destruction	24.21	23.33	23.43	23.77	23.12	23.43	24.41	24.31
% Total condenser Exergy Destruction	24.82	28.5	27.34	24.25	29.39	26.43	26.0	24.84
% Total Exergy evaporator Destruction	14.41	14.16	15.10	16.51	10.77	17.58	12.47	13.08
% Total Valve Exergy Destruction	5.325	5.73	6.246	7.837	5.154	6.915	4.734	5.671
% Total subcooler Exergy Destruction	2.054	2.248	2.366	2.960	2.483	2.299	2.036	2.418
% Total Flash intercooler Exergy Destruction	0.06136	0.1852	0.2066	0.1482	0.2084	0.2113	0.0101	0.0278
% Rational Efficiency	29.05	25.85	25.32	24.53	28.88	23.13	30.34	29.65

Table 4: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=273K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.34	3.870	3.840	3.838	4.187	3.409	4.487
EDR	2.042	2.394	2.432	2.465	2.116	2.648	1.937
Exergetic Efficiency	0.3437	0.3074	0.3050	0.3048	0.3326	0.2866	0.3564
Second Law Efficiency	0.5776	0.5150	0.5110	0.5103	0.5573	0.4802	0.5971
Rational Efficiency	0.2962	0.2642	0.2583	0.2488	0.2962	0.2342	0.3097
Exergy of Fuel "kW"	48.38	54.26	54.69	54.72	50.15	58.20	46.90
Exergy of Product "kW"	10.17	10.17	10.17	10.17	10.17	10.17	10.17
Effectiveness_Second	0.3288	0.2947	0.2914	0.2886	0.3209	0.2726	0.3405
% Total System Exergy Destruction	70.38	73.58	74.17	75.12	70.38	76.48	69.03
% Total Compressor Exergy Destruction	24.29	23.42	23.51	23.86	23.2	23.52	24.49
% Total condenser Exergy Destruction	23.96	27.59	26.47	23.49	28.37	25.65	25.08
% Total Exergy evaporator Destruction	14.60	14.27	15.21	16.66	10.87	17.67	12.63
% Total Valve Exergy Destruction	5.475	5.921	6.455	8.088	5.278	7.176	4.842
% Total subcooler Exergy Destruction	1.983	2.176	2.291	2.867	2.397	2.230	1.964
% Total Flash intercooler Exergy Destruction	0.07183	0.2159	0.2404	0.1621	0.2772	0.2382	0.01253
% Rational Efficiency	29.62	26.42	25.83	24.88	29.62	23.42	30.97

Table 5: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105kW, second evaporator load is 35 kW, third evaporator load is 70 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=273K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

. Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.434	3.948	3.918	3.916	4.276	3.679	4.585
EDR	2.08	2.443	2.480	2.509	2.161	2.721	1.974
Exergetic Efficiency	0.3387	0.3015	0.2992	0.2991	0.3266	0.2810	0.3502
Second Law Efficiency	0.5901	0.5254	0.5414	0.5212	0.5690	0.4895	0.6101
Rational Efficiency	0.2956	0.2633	0.2579	0.2496	0.2943	0.2356	0.3087
Exergy of Fuel "kW"	47.36	53.19	53.60	53.62	49.11	57.09	45.80
Exergy of Product "kW"	16.04	16.04	16.04	16.04	16.04	16.04	16.04
Effectiveness_Second	0.3247	0.2904	0.2873	0.2850	0.3164	0.2688	0.3062

% Total System Exergy Destruction	70.44	73.67	74.21	75.04	70.57	76.44	69.13
% Total Compressor Exergy Destruction	24.25	23.37	23.47	23.82	23.15	23.48	24.46
% Total condenser Exergy Destruction	23.38	28.03	26.89	23.87	28.85	26.04	25.53
% Total Exergy evaporator Destruction	14.32	14.02	14.93	16.32	10.65	17.38	12.34
% Total Valve Exergy Destruction	5.405	5.829	6.354	7.967	5.211	7.051	4.791
% Total subcooler Exergy Destruction	2.028	2.21	2.327	2.914	2.438	2.264	1.999
% Total Flash intercooler Exergy Destruction	0.07048	0.2112	0.2347	0.1566	0.2815	0.2301	0.01328
% Rational Efficiency	29.56	26.33	25.79	24.96	29.43	23.56	30.87

Table 6: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW)at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.661	4.137	4.104	4.104	4.490	3.846	4.821
EDR	2.2240	2.615	2.656	2.687	2.31	2.197	2.122
Exergetic Efficiency	0.3244	0.2879	0.2856	0.2856	0.3125	0.2677	0.3256
Second Law Efficiency	0.6203	0.5505	0.5461	0.5462	0.5976	0.5119	0.6416
Rational Efficiency	0.2784	0.2470	0.2412	0.2324	0.2779	0.2190	0.2914
Exergy of Fuel "kW"	45.05	50.76	51.17	51.17	46.77	54.6	43.56
Exergy of Product "kW"	14.62	14.62	14.62	14.62	14.62	14.62	14.62
Effectiveness_Second	0.3101	0.2766	0.2735	0.2712	0.3021	0.2553	0.3214
% Total System Exergy Destruction	72.16	75.3	75.88	76.76	72.21	78.1	70.86
% Total Compressor Exergy Destruction	24.15	23.27	23.37	23.72	23.05	23.37	24.36
% Total condenser Exergy Destruction	25.39	29.09	27.91	24.78	30.02	26.97	26.61
% Total Exergy evaporator Destruction	14.83	14.42	15.39	16.83	10.96	17.91	12.80
% Total Valve Exergy Destruction	5.630	6.057	6.603	8.283	5.439	7.311	4.995
% Total subcooler Exergy Destruction	2.102	2.295	2.415	3.024	2.537	2.345	2.083
% TotalFlash intercooler Exergy Destruction	0.0565	0.1697	0.1897	0.1310	0.201	0.1914	0.0814
% Rational Efficiency	27.84	24.70	24.12	23.24	27.79	21.90	29.14

Table 7: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, individual expansion valves and flash inter cooler using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=273K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.883	3.678	3.633	4.288	4.698	4.010	5.054
EDR	2.334	2.384	2.422	2.815	2.437	3.066	2.218
Exergetic Efficiency	0.3101	0.2743	0.2721	0.2723	0.2984	0.2546	0.3209
Second Law Efficiency	0.6499	0.5748	0.5703	0.5706	0.6252	0.5336	0.6725
Rational Efficiency	0.2761	0.2443	0.2397	0.2334	0.2729	0.2192	0.2882
Exergy of Fuel "kW"	43.0	48.62	49.01	48.98	44.70	52.58	41.55
Exergy of Product "kW"	13.34	13.34	13.34	13.34	13.34	13.34	13.34
Effectiveness Second	0.2999	0.2663	0.2636	0.2621	0.2910	0.2459	0.3108
% Total System Exergy Destruction	72.39	75.57	76.03	76.66	72.71	78.08	71.18
% Total Compressor Exergy Destruction	24.07	23.16	23.27	23.63	22.94	23.28	24.28
% Total condenser Exergy Destruction	26.39	30.13	28.9	25.67	31.16	27.87	27.67
% Total Exergy evaporator Destruction	14.21	13.89	14.8	16.09	10.47	17.29	12.16
% Total Valve Exergy Destruction	5.484	5.862	6.389	8.029	5.299	7.046	4.89
% Total subcooler Exergy Destruction	2.184	2.376	2.501	3.133	2.633	2.424	2.166
% Total Flash intercooler Exergy Destruction	0.0528	0.1573	0.175	0.1176	0.175	0.175	0.175
% Rational Efficiency	27.61	24.43	23.97	23.34	27.29	21.92	28.82

Table 8: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

. Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.216	3.777	3.732	3.682	4.10	3.499	4.357
EDR	2.087	2.437	2.475	2.503	2.163	2.707	1.988
Exergetic Efficiency	0.3176	0.2846	0.2811	0.2774	0.3088	0.2636	0.3282
Second Law Efficiency	0.4719	0.4229	0.4178	0.4122	0.4589	0.3917	0.4878
Rational Efficiency	0.3371	0.3064	0.3042	0.3056	0.3322	0.2863	0.3473
Exergy of Fuel "kW"	49.81	55.59	56.27	57.03	51.22	60.01	48.19
Exergy of Product "kW"	15.82	15.82	15.82	15.82	15.82	15.82	15.82
Mass flow rate flowing in first compressor (kg/sec)	0.4942	0.4398	0.4570	0.6084	0.3279	0.490	0.5150
Mass flow rate flowing in second compressor (kg/sec)	1.223	1.096	1.140	1.510	0.8231	1.218	1.272
Mass flow rate flowing in third compressor (kg/sec)	1.470	1.328	1.380	1.822	1.003	1.471	1.526
% Total System Exergy Destruction	66.29	69.36	69.58	69.44	66.78	71.37	65.27
% Total Compressor Exergy Destruction	24.0	23.02	23.14	23.55	22.71	23.18	24.22
% Total condenser Exergy Destruction	23.47	27.44	26.23	22.93	28.65	25.29	24.51
% Total Exergy evaporator Destruction	9.901	10.07	10.66	11.12	7.415	12.61	8.163
% Total Valve Exergy Destruction	8.914	8.832	9.554	11.83	8.002	10.29	8.365
% Rational Efficiency	33.71	30.64	30.42	30.56	33.22	28.63	34.73

Table 9: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.216	3.777	3.732	3.682	4.10	3.499	4.357
Exergy of Fuel "kW"	49.81	55.59	56.27	57.03	51.22	60.01	48.19
% Total Compressor Exergy Destruction	36.21	33.19	33.26	33.92	34.01	32.48	37.11
% Total condenser Exergy Destruction	35.41	39.57	37.70	33.02	42.09	35.44	37.56
% Total Exergy evaporator Destruction	14.94	14.51	15.31	16.02	11.10	17.66	12.51
% Total Valve Exergy Destruction	13.45	12.73	13.73	17.03	11.98	14.42	12.82
Mass flow rate flowing in first compressor (kg/sec)	0.4942	0.4398	0.4570	0.6084	0.3279	0.490	0.5150
Mass flow rate flowing in second compressor (kg/sec)	1.223	1.096	1.140	1.510	0.8231	1.218	1.272
Mass flow rate flowing in third compressor (kg/sec)	1.470	1.328	1.380	1.822	1.003	1.471	1.526
% Rational Efficiency	33.71	30.64	30.42	30.56	33.22	28.63	34.73

Table 10: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.453	3.974	3.928	3.884	4.317	3.678	4.604
EDR	2.188	2.564	2.601	2.621	2.275	2.848	2.084
Exergetic Efficiency	0.3073	0.2743	0.2711	0.2681	0.2980	0.2539	0.3177
Second Law Efficiency	0.4984	0.4448	0.4397	0.4348	0.4833	0.4117	0.5153
Rational Efficiency	0.3276	0.2968	0.2948	0.2973	0.3222	0.2771	0.3377
Exergy of Fuel "kW"	47.16	52.85	53.47	54.07	48.64	57.09	45.61
Exergy of Product "kW"	14.49	14.49	14.49	14.49	14.49	14.49	14.49
Mass flow rate flowing in first compressor (kg/sec)	0.4942	0.4398	0.4570	0.6084	0.3279	0.490	0.5150
Mass flow rate flowing in second compressor (kg/sec)	0.7404	0.6637	0.690	0.9148	0.4981	0.7377	0.7701
Mass flow rate flowing in third compressor (kg/sec)	1.455	1.314	1.366	1.802	0.9932	1.455	1.511
% Total System Exergy Destruction	67.24	70.32	70.52	70.27	67.78	72.29	66.23
% Total Compressor Exergy Destruction	23.88	22.87	23.0	23.42	22.55	23.04	24.10
% Total condenser Exergy Destruction	24.54	28.57	27.32	23.92	29.88	26.30	25.64
% Total Exergy evaporator Destruction	10.31	10.43	11.05	11.57	7.669	13.09	8.514
% Total Valve Exergy Destruction	8.515	8.456	9.154	11.37	7.678	9.863	7.972

Table 11: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-54C	R515A
COP	4.453	3.974	3.928	3.884	4.317	3.678	4.604
Exergy of Fuel "kW"	47.16	52.85	53.47	54.07	48.64	57.09	45.61
% Total Compressor Exergy Destruction	35.51	32.52	32.61	33.33	33.28	31.87	36.39
% Total condenser Exergy Destruction	36.49	40.43	38.74	34.04	44.08	36.38	38.72
% Total Exergy evaporator Destruction	15.33	14.83	15.67	16.46	11.32	18.10	12.86
% Total Valve Exergy Destruction	12.66	12.02	12.98	16.17	11.33	13.64	12.04
Mass flow rate flowing in first compressor (kg/sec)	0.4942	0.4398	0.4570	0.6084	0.3279	0.490	0.5150
Mass flow rate flowing in second compressor (kg/sec)	0.7404	0.6637	0.690	0.9148	0.4981	0.7377	0.7701
Mass flow rate flowing in third compressor (kg/sec)	1.455	1.314	1.366	1.802	0.9932	1.455	1.511
% Rational Efficiency	32.76	29.68	29.48	29.73	32.22	27.71	33.77

Table 12: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW)at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.593	4.409	4.043	4.005	4.445	3.784	4.75
EDR	2.243	2.634	2.671	2.685	2.337	2.925	2.136
Exergetic Efficiency	0.3020	0.2689	0.2658	0.2633	0.2922	0.2488	0.3123
Second Law Efficiency	0.5142	0.4578	0.4526	0.4483	0.4976	0.4236	0.5318
Rational Efficiency	0.3228	0.2918	0.2899	0.2931	0.3170	0.2724	0.3328
Exergy of Fuel "kW"	45.72	51.35	51.94	52.44	47.24	55.50	44.21
Exergy of Product "kW"	13.81	13.81	13.81	13.81	13.81	13.81	13.81
Mass flow rate flowing in first compressor (kg/sec)	0.2471	0.2199	0.2285	0.3042	0.1639	0.2450	0.2575
Mass flow rate flowing in second compressor (kg/sec)	0.7323	0.6563	0.6822	0.9038	0.4928	0.7291	0.7618
Mass flow rate flowing in third compressor (kg/sec)	1.447	1.306	1.358	1.791	0.9879	1.447	1.503
% Total System Exergy Destruction	67.72	70.82	71.01	70.69	68.30	72.76	66.72
% Total Compressor Exergy Destruction	23.79	22.77	22.90	23.33	22.45	22.95	24.02
% Total condenser Exergy Destruction	25.17	29.24	27.97	23.33	30.59	26.89	26.31
% Total Exergy evaporator Destruction	10.55	10.64	11.29	11.83	7.818	13.37	8.723
% Total Valve Exergy Destruction	8.205	8.177	8.86	11.2	7.44	9.551	7.664
% Rational Efficiency	32.28	29.18	28.99	29.31	31.70	27.24	33.28

Table 13: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , compressors efficiency=0.75)usingfollowing HFO+HFC refrigerants Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.593	4.409	4.043	4.005	4.445	3.784	4.75
Exergy of Fuel "kW"	45.72	51.35	51.94	52.44	47.24	55.50	44.21
% Total Compressor Exergy Destruction	35.13	32.15	32.25	33.0	32.87	31.54	36.0
% Total condenser Exergy Destruction	37.17	41.28	39.37	34.67	44.79	36.96	39.44
% Total Exergy evaporator Destruction	15.58	15.02	15.90	16.74	11.45	18.38	13.07
Mass flow rate flowing in first compressor (kg/sec)	0.2471	0.2199	0.2285	0.3042	0.1639	0.2450	0.2575
Mass flow rate flowing in second compressor (kg/sec)	0.7323	0.6563	0.6822	0.9038	0.4928	0.7291	0.7618
Mass flow rate flowing in third compressor (kg/sec)	1.447	1.306	1.358	1.791	0.9879	1.447	1.503
% Total Valve Exergy Destruction	12.12	11.55	12.48	15.59	10.89	13.13	11.49
% Rational Efficiency	32.28	29.18	28.99	29.31	31.70	27.24	33.28

Table 14: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (f*or first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

. Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A
COP	4.097	3.678	3.633	3.58	3.991	3.409	4.234
EDR	2.046	2.384	2.422	2.455	2.115	2.648	1.949
Exergetic Efficiency	0.3220	0.2891	0.2856	0.2814	0.3137	0.2629	0.3328
Second Law Efficiency	0.4586	0.4118	0.4067	0.4008	0.4467	0.3816	0.4739
Rational Efficiency	0.3412	0.3107	0.3083	0.3092	0.3366	0.2904	0.3514
Exergy of Fuel "kW"	51.26	57.09	57.80	58.66	52.62	61.60	49.60
Exergy of Product "kW"	16.51	16.51	16.51	16.51	16.51	16.51	16.51
Mass flow rate flowing in first compressor (kg/sec)	0.7413	0.6597	0.6855	0.9126	0.4918	0.7350	0.7725
Mass flow rate flowing in second compressor (kg/sec)	1.321	1.104	1.147	1.521	0.8284	1.227	1.281
Mass flow rate flowing in third compressor (kg/sec)	1.478	1.335	1.388	1.833	1.009	1.480	1.535
% Total System Exergy Destruction	65.88	68.93	69.17	69.08	66.34	70.96	64.86
% Total Compressor Exergy Destruction	24.07	23.10	23.22	23.63	22.81	23.26	24.29
% Total condenser Exergy Destruction	22.94	38.99	37.13	32.47	42.27	34.92	36.92
% Total Exergy evaporator Destruction	9.694	9.885	10.45	10.90	7.288	12.36	7.991
% Total Valve Exergy Destruction	9.179	9.073	9.808	12.120	8.207	10.560	8.628
% Rational Efficiency	34.12	31.07	30.83	30.92	33.66	29.04	35.14

Table 15: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (f*or first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-54C	R515A
COP	4.097	3.678	3.633	3.58	3.991	3.409	4.234
Exergy of Fuel "kW"	51.26	57.09	57.80	58.66	52.62	61.60	49.60
% Total Compressor Exergy Destruction	36.54	33.51	33.57	34.21	34.34	32.78	37.45
% Total condenser Exergy Destruction	34.82	38.99	37.13	32.47	42.27	34.92	36.92
% Total Exergy evaporator Destruction	14.71	14.34	15.11	15.77	10.99	17.42	12.32
% Total Valve Exergy Destruction	13.93	13.16	14.18	17.55	12.37	14.88	13.30
Mass flow rate flowing in first compressor (kg/sec)	0.7413	0.6597	0.6855	0.9126	0.4918	0.7350	0.7725
Mass flow rate flowing in second compressor (kg/sec)	1.321	1.104	1.147	1.521	0.8284	1.227	1.281
Mass flow rate flowing in third compressor (kg/sec)	1.478	1.335	1.388	1.833	1.009	1.480	1.535
% Rational Efficiency	34.12	31.07	30.83	30.92	33.66	29.04	35.14

System-3

Thermodynamic performances (exergy destruction in components and rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends.

The thermodynamic performances of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends have been computed for different blends of HFC+HFO refrigerants for replacing HFC-134a refrigerant is shown in Table 16 to 27 respectively. Similarly the percentage of exergy destruction in components based on exergy of fuel and rational exergetic efficiency of vapour compression refrigeration systems using different blends of HFC+HFO refrigerants at different load conditions respectively and found that first law efficiency (COP) of vapour compression refrigeration systems using HFC +HFO blends at dead state temperature of 298K (25^{o}C)and it was found that vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio. The thermodynamic performances of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly using R413a of HFO+HFC refrigerant blends have slightly less (nearly similar) thermodynamic performances using using R413a of HFO+HFC refrigerant blends

Table 16: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-52A	R-454B	R-454C	R515A	R513A
COP	5.132	4.529	4.484	4.459	4.937	4.183	5.312	5.234
EDR	2.548	3.013	3.048	3.044	2.671	3.343	2.428	2.465
Exergetic Efficiency	0.2755	0.2432	0.2407	0.2394	0.2651	0.2245	0.2852	0.2810
Second Law Efficiency	0.6829	0.6028	0.5967	0.5933	0.6571	0.5566	0.7069	0.6955
Rational Efficiency	0.2981	0.2675	0.2662	0.2713	0.2919	0.2493	0.3076	0.3073
Exergy of Fuel "kW"	40.92	46.36	46.84	47.10	42.53	50.21	39.54	40.13
Exergy of Product "kW"	11.27	11.27	11.27	11.27	11.27	11.27	11.27	11.27
First compressor mass flow rate (kg/sec)	0.2532	0.2532	0.2325	0.3113	0.1655	0.2501	0.2642	0.2722
Second compressor mass flow rate (kg/sec)	0. 470	0.4261	0.4428	0.5831	0.3225	0.4714	0.4905	0.5077
Third compressor mass flow rate (kg/sec)	0.6928	0.6302	0.6546	0.8581	0.4805	0.6947	0.7191	0.7454
Mass flow rate flowing in the condenser (kg/sec)	1.418	1.280	1.330	1.753	0.9685	1.416	1.474	1.525
% Total System Exergy Destruction	70.19	73.25	73.38	72.87	70.81	75.07	69.24	69.25
% Total Compressor Exergy Destruction	23.43	22.33	22.47	22.93	21.92	22.54	23.68	23.55
% Total condenser Exergy Destruction	27.63	31.86	30.5	26.78	33.58	29.2	28.90	27.6
% Total Exergy evaporator Destruction	11.47	11.46	12.17	12.81	8.396	14.43	9.503	9.842
% Total Valve Exergy Destruction	7.666	7.606	8.242	10.33	6.915	8.891	7.154	8.259
% Rational Efficiency	29.81	26.75	26.62	27.13	29.19	24.93	30.76	30.73

Table 17: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	5.132	4.529	4.484	4.459	4.937	4.183	5.312	5.234
Exergy of Fuel "kW"	40.92	46.36	46.84	47.10	42.53	50.21	39.54	40.13
% Total Compressor Exergy Destruction	33.38	30.48	30.62	31.47	30.95	30.03	34.20	34.01
% Total condenser Exergy Destruction	39.36	43.50	41.56	36.76	47.43	38.90	41.74	39.85
% Total Exergy evaporator Destruction	16.34	15.64	16.59	17.60	11.86	19.23	13.72	14.21
% Total Valve Exergy Destruction	10.92	10.38	11.23	14.18	9.765	11.84	10.33	11.93
First compressor mass flow rate (kg/sec)	0.2532	0.2532	0.2325	0.3113	0.1655	0.2501	0.2642	0.2722
Second compressor mass flow rate (kg/sec)	0. 470	0.4261	0.4428	0.5831	0.3225	0.4714	0.4905	0.5077
Third compressor mass flow rate (kg/sec)	0.6928	0.6302	0.6546	0.8581	0.4805	0.6947	0.7191	0.7454
Mass flow rate flowing in the condenser (kg/sec)	1.418	1.280	1.330	1.753	0.9685	1.416	1.474	1.525
% Rational Efficiency	29.81	26.75	26.62	27.13	29.19	24.93	30.76	28.10

Table 18: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.430	3.955	3.911	3.866	4.282	3.665	4.578	4.505
EDR	2.179	2.555	2.591	2.612	2.277	2.834	2.076	2.115
Exergetic Efficiency	0.3083	0.2753	0.2722	0.2691	0.2980	0.2551	0.3187	0.3135
Second Law Efficiency	0.5895	0.5263	0.5205	0.5145	0.5698	0.4878	0.6093	0.5995
Rational Efficiency	0.3282	0.2967	0.2948	0.2972	0.3214	0.2771	0.3384	0.3368
Exergy of Fuel "kW"	47.41	53.10	53.70	54.32	49.04	57.30	45.87	46.62
Exergy of Product "kW"	14.62	14.62	14.62	14.62	14.62	14.62	14.62	14.62
Massflow rate flowing in first compressor(kg/sec)	0.5063	0.4476	0.4649	0.6226	0.3310	0.5003	0.5285	0.5443
Mass flow rate flowing in second compressor (kg/sec)	0.7080	0.6391	0.6641	0.8747	0.4838	0.7071	0.7358	0.7616
Mass flow rate flowing in third compressor (kg/sec)	0.2309	0.2101	0.2182	0.2860	0.1602	0.2316	0.2397	0.2485
Mass flow rate flowing in condenser (kg/sec)	1.445	1.297	1.347	1.783	0.9749	1.439	1.504	1.554
Work done by first compressor "kW"	21.7	23.83	24.14	24.71	22.25	25.66	21.06	21.46
Work done by second compressor "kW"	20.15	22.87	23.10	23.18	20.99	24.77	19.47	19.75

Work done by third compressor "kW"	5.545	6.401	6.455	6.430	5.805	6.973	5.343	5.411
% Total System Exergy Destruction	67.18	70.33	70.52	70.28	67.86	72.29	66.16	66.32
% Total Compressor Exergy Destruction	23.38	22.20	22.35	22.87	21.70	22.46	23.65	23.51
% Total condenser Exergy Destruction	24.57	28.95	27.69	24.09	30.7	26.56	25.59	24.46
% Total Exergy evaporator Destruction	10.28	10.42	11.03	11.54	7.634	13.06	8.481	8.745
% Total Valve Exergy Destruction	8.953	8.747	9.451	11.78	7.831	10.20	8.435	9.605
% Rational Efficiency	32.82	29.76	29.48	29.72	32.14	27.71	33.84	33.68

Table 19: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.430	3.955	3.911	3.866	4.282	3.665	4.578	4.505
Exergy of Fuel "kW"	47.41	53.10	53.70	54.32	49.04	57.30	45.87	46.62
% Total Compressor Exergy Destruction	34.80	31.57	31.69	32.54	31.97	31.07	35.75	35.44
% Total condenser Exergy Destruction	36.58	41.17	39.27	34.28	45.24	36.7	38.68	36.89
% Total Exergy evaporator Destruction	15.30	14.82	15.64	16.42	11.25	18.07	12.82	13.19
% Total Valve Exergy Destruction	13.33	12.44	13.40	16.76	11.54	14.11	12.75	14.48
First compressor mass flow rate (kg/sec)	0.5063	0.4476	0.4649	0.6226	0.3310	0.5003	0.5285	0.5443
Second compressor mass flow rate (kg/sec)	0.7080	0.6391	0.6641	0.8747	0.4838	0.7071	0.7358	0.7616
Third compressor mass flow rate (kg/sec)	0.2309	0.2101	0.2182	0.2860	0.1602	0.2316	0.2397	0.2485
Mass flow rate flowing in condenser(kg/sec)	1.445	1.297	1.347	1.783	0.9749	1.439	1.504	1.554
% Rational Efficiency	32.82	29.76	29.48	29.72	32.14	27.71	33.84	33.68

Table 20: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW)at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.074	3.659	3.617	3.563	3.882	3.419	4.207	4.137
EDR	2.033	2.372	2.408	2.441	2.172	2.608	1.937	1.978
Exergetic Efficiency	0.3236	0.2906	0.2872	0.283	0.3084	0.2715	0.3342	0.3286
Second Law Efficiency	0.5422	0.4869	0.4813	0.4741	0.5167	0.4550	0.5599	0.5505
Rational Efficiency	0.3421	0.3106	0.3083	0.3092	0.3303	0.2918	0.3526	0.3502
Exergy of Fuel "kW"	51.54	57.40	58.07	58.95	54.09	61.43	49.91	50.76
Exergy of Product "kW"	16.68	16.68	16.68	16.68	16.68	16.68	16.68	16.68
Mass flow rate flowing in first compressor (kg/sec)	0.7595	0.6714	0.6974	0.9339	0.5034	0.7371	0.7927	0.8165
second compressor Mass flow rate (kg/sec)	0.4720	0.4261	0.4428	0.5831	0.3272	0.4636	0.4905	0.5007
Mass flow rate flowing in third compressor (kg/sec)	0.2309	0.2101	0.2182	0.286	0.1625	0.2278	0.2397	0.2485
Mass flow rate flowing in condenser(kg/sec)	1.462	1.308	1.358	1.803	0.9931	1.428	1.523	1.573
Work done by first compressor "kW"	32.56	35.75	36.21	37.06	33.95	38.06	31.59	32.9
Work done by second compressor "kW"	13.43	15.24	15.40	15.46	14.23	16.43	12.98	13.16
Work done by third compressor "kW"	5.545	6.401	6.455	6.43	5.906	6.942	5.343	5.411
% Total System Exergy Destruction	65.79	68.94	69.17	69.08	70.82	66.97	64.74	64.98
% Total Compressor Exergy Destruction	23.35	22.13	22.28	22.83	22.45	22.95	24.02	23.48
% Total condenser Exergy Destruction	23.03	27.47	26.27	22.72	30.59	26.89	26.31	22.89
% Total Exergy evaporator Destruction	9.066	9.891	10.44	10.88	7.818	13.37	8.723	8.188
% Total Valve Exergy Destruction	9.747	9.442	10.18	12.65	7.44	9.551	7.664	10.43
% Rational Efficiency	34.21	31.06	30.83	30.92	33.03	29.18	35.26	35.02

Table 21: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerants Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.074	3.659	3.617	3.563	3.882	3.419	4.207	4.137
Exergy of Fuel "kW"	51.54	57.40	58.07	58.95	54.09	61.43	49.91	50.76
% Total Compressor Exergy Destruction	35.49	32.10	32.21	33.05	32.23	31.65	36.5	36.13
% Total condenser Exergy Destruction	35.0	39.86	37.98	32.89	43.29	37.55	36.95	35.22
% Total Exergy evaporator Destruction	14.69	14.35	15.09	15.75	11.46	16.16	12.29	12.60
% Total Valve Exergy Destruction	14.81	13.70	14.72	18.31	13.01	14.65	14.25	16.05
Mass flow rate flowing in first compressor (kg/sec)	0.7595	0.6714	0.6974	0.9339	0.5034	0.7371	0.7927	0.8165
Mass flow rate flowing in second compressor (kg/sec)	0.4720	0.4261	0.4428	0.5831	0.3272	0.4636	0.4905	0.5007
Mass flow rate flowing in third compressor (kg/sec)	0.2309	0.2101	0.2182	0.286	0.1625	0.2278	0.2397	0.2485
Mass flow rate flowing in condenser (kg/sec)	1.462	1.308	1.358	1.803	0.9931	1.428	1.523	1.573
% Rational Efficiency	34.21	31.06	30.83	30.92	33.03	29.18	35.26	35.02

Table 22: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.660	4.145	4.101	4.06	4.50	3.837	4.819	4.743
EDR	2.309	2.713	2.749	2.764	2.413	3.010	2.20	2.239
Exergetic Efficiency	0.2960	0.2633	0.2605	0.2578	0.2858	0.2437	0.3060	0.3012
Second Law Efficiency	0.6202	0.5517	0.5458	0.5403	0.5989	0.5106	0.6413	0.6312
Rational Efficiency	0.3167	0.2857	0.2840	0.2872	0.3103	0.2666	0.3267	0.3256
Exergy of Fuel "kW"	45.06	50.66	51.21	51.72	46.66	54.73	43.58	44.27
Exergy of Product "kW"	13.34	13.34	13.34	13.34	13.34	13.34	13.34	13.34
Mass flow rate flowing in first compressor (kg/sec)	0.5063	0.4476	0.4649	0.6226	0.3310	0.5003	0.5285	0.5443
Mass flow rate flowing in second compressor (kg/sec)	0.2360	0.2130	0.2214	0.2916	0.1613	0.2357	0.2453	0.2539
Mass flow rate flowing in third compressor (kg/sec)	0.6928	0.6302	0.6546	0.8581	0.4805	0.6947	0.7191	0.7454
Mass flow rate flowing in condenser (kg/sec)	1.435	1.291	1.341	1.772	0.9727	1.431	1.493	1.544
% Total System Exergy Destruction	71.6	71.43	71.6	71.28	68.97	73.34	67.33	67.44
% Total Compressor Exergy Destruction	23.39	22.23	22.37	22.88	21.74	22.48	23.66	23.51
% Total condenser Exergy Destruction	25.59	29.94	28.65	24.98	31.71	27.45	26.68	25.5
% Total Exergy evaporator Destruction	10.66	10.77	11.40	11.96	7.89	13.51	8.811	9.10
% Total Valve Exergy Destruction	8.691	8.490	9.176	11.46	7.624	9.896	8.181	9.333
% Rational Efficiency	31.67	28.57	28.40	28.72	31.03	26.66	32.67	32.56

Table 23: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.660	4.145	4.101	4.06	4.50	3.837	4.819	4.743
Exergy of Fuel "kW"	45.06	50.66	51.21	51.72	46.66	54.73	43.58	44.27
% Total Compressor Exergy Destruction	34.23	31.12	31.25	32.10	31.52	30.65	35.14	34.86
% Total condenser Exergy Destruction	37.45	41.91	40.01	35.05	45.98	37.43	39.63	37.81
% Total Exergy evaporator Destruction	15.61	15.08	15.93	16.77	11.44	18.42	13.09	13.49
% Total Valve Exergy Destruction	12.72	11.89	12.81	16.07	11.05	13.49	12.15	13.84
Mass flow rate flowing in first compressor (kg/sec)	0.5063	0.4476	0.4649	0.6226	0.3310	0.5003	0.5285	0.5443
Mass flow rate flowing in second compressor (kg/sec)	0.2360	0.2130	0.2214	0.2916	0.1613	0.2357	0.2453	0.2539
Mass flow rate flowing in third compressor (kg/sec)	0.6928	0.6302	0.6546	0.8581	0.4805	0.6947	0.7191	0.7454
Mass flow rate flowing in condenser (kg/sec)	1.435	1.291	1.341	1.772	0.9727	1.431	1.493	1.544
% Rational Efficiency	31.67	28.57	28.40	28.72	31.03	26.66	32.67	32.56

Table 24: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.169	3.738	3.696	3.643	4.040	3.469	4.306	4.235
EDR	2.081	2.431	2.467	2.498	2.169	2.695	1.983	2.024
Exergetic Efficiency	0.3184	0.2855	0.2823	0.2782	0.3085	0.2650	0.3289	0.3234
Second Law Efficiency	0.5584	0.4975	0.4918	0.4848	0.5376	0.4617	0.5731	0.5635
Rational Efficiency	0.3373	0.3060	0.3037	0.3050	0.3307	0.2859	0.3476	0.3455
Exergy of Fuel "kW"	50.34	56.17	56.82	57.65	51.99	60.54	48.77	48.77
Exergy of Product "kW"	16.04	16.04	16.04	16.04	16.04	16.04	16.04	16.04
Work done by first compressor "kW"	32.56	35.75	36.21	37.06	33.38	38.54	31.59	32.19
Work done by second compressor "kW"	6.717	7.622	7.70	7.728	6.995	8.255	6.488	6.582
Work done by third compressor "kW"	11.09	12.80	12.91	12.86	11.61	13.95	10.69	10.82
First compressor mass flow rate (kg/sec)	0.7595	0.6714	0.6974	0.9339	0.4964	0.7504	0.7927	0.8165
Second compressor mass flow rate (kg/sec)	0.2360	0.2130	0.2214	0.2916	0.1613	0.2357	0.2453	0.2539
Third compressor mass flow rate (kg/sec)	4619	0.4201	0.4364	0.572	0.3203	4631	0.4794	0.4969
Mass flow rate flowing in condenser (kg/sec)	1.457	1.305	1.355	1.798	0.9781	1.449	1.517	1.567
% Total System Exergy Destruction	66.27	69.4	69.63	69.5	66.93	71.41	65.24	65.45
% Total Compressor Exergy Destruction	23.35	22.14	22.29	22.83	21.58	22.41	23.64	23.48
% Total condenser Exergy Destruction	23.45	27.89	26.67	23.09	29.70	25.58	24.37	23.31
% Total Exergy evaporator Destruction	9.825	10.04	10.60	11.05	7.355	12.51	8.095	8.333
% Total Valve Exergy Destruction	9.647	9.341	10.08	12.53	8.302	10.87	9.133	10.33
% Rational Efficiency	33.73	30.60	30.37	30.50	33.07	28.59	34.76	34.55

Table 25: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.169	3.738	3.696	3.643	4.040	3.469	4.306	4.235
Exergy of Fuel "kW"	50.34	56.17	56.82	57.65	51.99	60.54	48.77	48.77
% Total Compressor Exergy Destruction	35.244	31.9	32.01	32.85	32.24	31.39	36.23	35.87
% Total condenser Exergy Destruction	35.38	40.18	38.3	33.22	44.37	35.83	37.36	35.62
% Total Exergy evaporator Destruction	14.82	14.46	15.22	15.90	10.99	17.56	12.41	12.73
% Total Valve Exergy Destruction	14.56	13.46	14.47	18.03	12.40	15.23	14.0	15.78
First compressor mass flow rate (kg/sec)	0.7595	0.6714	0.6974	0.9339	0.4964	0.7504	0.7927	0.8165
Second compressor mass flow rate (kg/sec)	0.2360	0.2130	0.2214	0.2916	0.1613	0.2357	0.2453	0.2539
Third compressor mass flow rate (kg/sec)	4619	0.4201	0.4364	0.572	0.3203	4631	0.4794	0.4969
Mass flow rate flowing in condenser (kg/sec)	1.457	1.305	1.355	1.798	0.9781	1.449	1.517	1.567
% Rational Efficiency	33.73	30.60	30.37	30.50	33.07	28.59	34.76	34.55

Table 26: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.989	4.413	4.368	4.339	4.803	4.234	5.162	5.085
EDR	2.456	2.899	2.935	2.936	2.574	3.217	2.34	2.377
Exergetic Efficiency	0.2830	0.2504	0.2478	0.2462	0.2725	0.2314	0.2929	0.2885
Second Law Efficiency	0.6639	0.5873	0.5812	0.5774	0.6392	0.5428	0.6870	0.6767
Rational Efficiency	0.3050	0.2741	0.2727	0.2773	0.2986	0.2556	0.3148	0.3143
Exergy of Fuel "kW"	42.1	47.59	48.08	48.40	43.72	51.49	40.68	41.30
Exergy of Product "kW"	11.91	11.91	11.91	11.91	11.91	11.91	11.91	11.91
Work done by first compressor "kW"	10.85	11.92	12.07	12.35	11.13	12.78	10.53	10.73
Work done by second compressor "kW"	20.15	22.87	23.10	23.18	20.99	24.77	19.47	19.75
Work done by third compressor "kW"	11.09	12.80	12.91	12.86	11.61	13.95	10.69	10.82

First compressor mass flow rate (kg/sec)	0.2532	0.2238	0.2325	0.3113	0.1665	0.2501	0.2642	0.2722
Second compressor mass flow rate (kg/sec)	0.7080	0.6391	0.6641	0.8747	0.4838	0.7071	0.7358	0.7616
Third compressor mass flow rate (kg/sec)	0.4619	0.4201	0.4364	0.572	0.3203	0.4631	0.4794	0.4969
Mass flow rate flowing in condenser (kg/sec)	1.423	1.283	1.333	1.758	0.9696	1.420	1.479	1.531
% Total system Exergy Destruction	69.5	72.59	72.73	72.27	70.14	74.44	68.52	68.57
% Total compressor Exergy Destruction	23.42	22.31	22.45	22.92	21.89	22.53	23.68	23.55
% Total condenser Exergy Destruction	27.0	31.26	29.92	26.24	32.96	28.66	28.22	26.96
% Total Exergy evaporator Destruction	11.23	11.25	11.94	12.57	8.329	14.16	9.297	9.620
% Total Valve Exergy Destruction	7.842	7.772	8.42	10.54	7.05	9.086	7.326	8.444
% Rational Efficiency	30.50	27.41	27.27	27.73	29.86	25.56	31.48	31.43

Table 27: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=268K, $T_{\_eva2}$=273K, $T_{\_eva3}$=278K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-448A	R-449A	R-452A	R-454B	R-454C	R515A	R513A
COP	4.989	4.413	4.368	4.339	4.803	4.234	5.162	5.085
Exergy of Fuel "kW"	42.1	47.59	48.08	48.40	43.72	51.49	40.68	41.30
% Total Compressor Exergy Destruction	33.7	30.37	30.87	31.72	31.2	30.27	34.56	34.34
% Total condenser Exergy Destruction	38.85	43.07	41.14	36.30	47.0	38.51	41.19	39.31
% Total Exergy evaporator Destruction	16.16	15.49	16.42	17.39	11.75	19.02	13.57	14.03
% Total Valve Exergy Destruction	11.28	10.71	11.58	14.58	10.05	12.21	10.69	12.31
First compressor mass flow rate (kg/sec)	0.2532	0.2238	0.2325	0.3113	0.1665	0.2501	0.2642	0.2722
Second compressor mass flow rate (kg/sec)	0.7080	0.6391	0.6641	0.8747	0.4838	0.7071	0.7358	0.7616
Third compressor mass flow rate (kg/sec)	0.4619	0.4201	0.4364	0.572	0.3203	0.4631	0.4794	0.4969
Mass flow rate flowing in condenser (kg/sec)	1.423	1.283	1.333	1.758	0.9696	1.420	1.479	1.531
% Rational Efficiency	30.50	27.41	27.27	27.73	29.86	25.56	31.48	31.43

System-4

Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends

The thermodynamic performances of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends have been computed for different blends of HFC+HFO refrigerants for replacing HFC-134a refrigerant is shown in Table 28 to 39 respectively. Similarly the percentage of exergy destruction in components based on exergy of fuel and rational exergetic efficiency of vapour compression refrigeration systems using different blends of HFC+HFO refrigerants at different load conditions respectively and found that first law efficiency (COP) of vapour compression refrigeration systems using HFC +HFO blends at dead state temperature of 298K (25^{o}C)and it was found that vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio. The thermodynamic performances of vapour compression refrigeration systems using multiple evaporators at the different temperatures with individual compressors, individual expansion valves using low GWP ecofriendly using R413a of HFO+HFC refrigerant blends have slightly less (nearly similar) thermodynamic performances using using R413a of HFO+HFC refrigerant blends.

Table 28: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

. Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	5.33	4.757	5.108	5.498	5.434
EDR	2.507	2.915	2.619	2.394	2.427
Exergetic Efficiency	0.2862	0.2554	0.2742	0.2952	0.2917
Second Law Efficiency	0.7094	0.6330	0.6797	0.7317	0.7231
Rational Efficiency (by second Method)	0.2827	0.2556	0.2818	0.2932	0.2919
Exergy of Fuel "kW"	39.40	44.15	41.11	38.19	38.65
Exergy of Product "kW"	11.27	11.27	11.27	11.27	11.27
First compressor work done "kW"	8.664	9.142	9.214	8.45	8.461
Second compressor work done "kW"	11.47	12.29	12.14	11.17	11.18
Third compressor work done "kW"	19.26	22.82	19.76	18.57	19.0

Mass flow rate flowing in first compressor (kg/sec)	0.2021	0.2304	0.1370	0.2120	0.2146
Mass flow rate flowing in second compressor (kg/sec)	0.3964	0.4598	0.2798	0.4224	0.4313
Mass flow rate flowing in third compressor (kg/sec)	0.6928	1.015	0.5453	0.8331	0.8727
Mass flow rate flowing in condenser(kg/sec)	1.407	1.705	0.9622	1.468	1.519
% Total System Exergy Destruction	71.73	74.44	71.82	70.68	70.81
% Total Compressor Exergy Destruction	23.44	22.95	21.96	23.69	23.56
% Total condenser Exergy Destruction	28.42	27.66	34.22	29.74	28.46
% Total Exergy evaporator Destruction	14.50	16.45	10.57	12.35	12.94
% Total Valve Exergy Destruction	5.374	7.386	5.07	4.898	5.486
% Rational Efficiency	28.27	25.56	28.18	29.32	29.19

Table 29: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 70 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	5.33	4.757	5.108	5.498	5.434
Exergy of Fuel “kW”	39.40	44.15	41.11	38.19	38.65
% Total Compressor Exergy Destruction	32.68	30.83	30.58	33.52	33.28
% Total condenser Exergy Destruction	39.62	37.15	47.64	42.08.56	40.20
% Total Exergy evaporator Destruction	20.21	22.10	14.72	17.47	18.27
% Total Valve Exergy Destruction	7.492	9.921	7.059	6.929	8.257
Mass flow rate flowing in first compressor (kg/sec)	0.2021	0.2304	0.1370	0.2120	0.2146
Mass flow rate flowing in second compressor (kg/sec)	0.3964	0.4598	0.2798	0.4224	0.4313
Mass flow rate flowing in third compressor (kg/sec)	0.6928	1.015	0.5453	0.8331	0.8727
Mass flow rate flowing in condenser(kg/sec)	1.407	1.705	0.9622	1.468	1.519
% Rational Efficiency	28.27	25.56	28.18	29.32	29.19

Table 30: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.712	4.293	4.523	4.843	4.788
EDR	2.109	2.415	2.194	2.017	2.05
Exergetic Efficiency	0.3280	0.2988	0.3148	0.3371	0.3333
Second Law Efficiency	0.6270	0.5714	0.6020	0.6445	0.6372
Rational Efficiency(by second Method)	0.3085	0.2783	0.3093	0.3201	0.3170
Exergy of Fuel “kW”	44.57	48.91.	46.43	43.36	43.86
Exergy of Product “kW”	14.62	14.62	14.62	14.62	14.62
First compressor work done “kW”	17.33	18.28	18.43	16.90	16.92
Second compressor work done “kW”	17.30	18.31	18.27	16.87	16.89
Third compressor work done “kW”	9.942	12.32	9.723	9.592	10.05
Mass flow rate flowing in first compressor (kg/sec)	0.4012	0.4608	0.2741	0.4241	0.4292
Mass flow rate flowing in second compressor (kg/sec)	0.6078	0.6909	0.4213	0.6376	0.7701
Mass flow rate flowing in third compressor (kg/sec)	0.4141	0.5479	0.2683	0.4304	0.4615
Mass flow rate flowing in condenser (kg/sec)	1.426	1.699	0.9637	1.492	1.542
% Total System Exergy Destruction	69.15	72.17	69.07	67.99	68.30
% Total Compressor Exergy Destruction	23.40	22.9	21.76	23.66	23.52
% Total condenser Exergy Destruction	25.68	25.27	31.57	26.79	25.64
% Total Exergy evaporator Destruction	14.82	17.0	10.89	12.74	8.514
% Total Valve Exergy Destruction	5.256	6.998	4.847	4.798	5.720
% Rational Efficiency	30.85	29.88	30.93	32.71	31.70

Table 31: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 70 kW, second evaporator load is 35 kW, third evaporator load is 105 kW) at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R-515A	R-513A
COP	4.712	4.293	4.523	4.843	4.788
Exergy of Fuel "kW"	44.57	48.91.	46.43	43.36	43.86
% Total Compressor Exergy Destruction	33.84	31.73	31.51	34.80	34.44
% Total condenser Exergy Destruction	37.14	35.01	45.71	39.40	37.60
% Total Exergy evaporator Destruction	21.43	23.56	15.77	18.74	19.59
% Total Valve Exergy Destruction	7.60	9.697	7.017	7.056	8.374
Mass flow rate flowing in first compressor (kg/sec)	0.4012	0.4608	0.2741	0.4241	0.4292
Mass flow rate flowing in second compressor (kg/sec)	0.6078	0.6909	0.4213	0.6376	0.7701
Mass flow rate flowing in third compressor (kg/sec)	0.4141	0.5479	0.2683	0.4304	0.4615
Mass flow rate flowing in condenser (kg/sec)	1.426	1.699	0.9637	1.492	1.542
% Rational Efficiency	30.85	29.88	30.93	32.71	31.70

Table 32: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.391	4.033	4.218	4.507	4.457
EDR	1.926	2.188	2.005	1.844	1.874
Exergetic Efficiency	0.3487	0.3203	0.3350	0.3580	0.3540
Second Law Efficiency	0.5843	0.5367	0.5613	0.5998	0.5931
Rational Efficiency(by second Method)	0.3284	0.2990	0.3283	0.3399	0.3365
Exergy of Fuel "kW"	47.83	52.07	49.79	46.59	47.12
Exergy of Product "kW"	16.68	16.68	16.68	16.68	16.68
First compressor work done "kW"	25.99	27.43	27.64	27.43	27.43
Second compressor work done "kW"	11.85	12.31	12.41	11.60	11.63
Third compressor work done "kW"	9.988	12.34	9.734	9.643	10.10
Mass flow rate flowing in first compressor (kg/sec)	0.6062	0.6911	0.4111	0.6361	0.6438
Mass flow rate flowing in second compressor (kg/sec)	0.4162	0.4643	0.2862	0.4385	0.4487
Mass flow rate flowing in third compressor (kg/sec)	0.4160	0.5487	0.2686	0.4327	0.4638
Mass flow rate flowing in condenser (kg/sec)	1.430	1.704	0.9659	1.507	1.556
% Total System Exergy Destruction	67.16	70.10	67.17	66.01	66.35
% Total Compressor Exergy Destruction	23.37	22.86	21.64	23.65	23.50
% Total condenser Exergy Destruction	24.28	24.04	30.26	25.27	24.26
% Total Exergy evaporator Destruction	14.26	16.31	10.5	12.28	12.88
% Total Valve Exergy Destruction	5.257	6.881	7.777	4.807	5.715
% Rational Efficiency	32.84	29.90	32.83	33.99	33.65

Table 33: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K, $T_{\_surrounding}$=298K , compressors efficiency=0.75)using following HFO+HFC refrigerants Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R515A
COP	4.391	4.033	4.218	4.507	4.457
Exergy of Fuel "kW"	47.83	52.07	49.79	46.59	47.12
% Total Compressor Exergy Destruction	34.79	32.61	32.21	35.82	36.57
% Total condenser Exergy Destruction	36.15	34.29	45.05	38.29	39.44
% Total Exergy evaporator Destruction	21.23	23.27	15.63	18.30	19.41
% Total Valve Exergy Destruction	7.827	9.824	7.112	7.283	8.612
Mass flow rate flowing in first compressor (kg/sec)	0.6062	0.6911	0.4111	0.6361	0.6438
Mass flow rate flowing in second compressor (kg/sec)	0.4162	0.4643	0.2862	0.4385	0.4487
Mass flow rate flowing in third compressor (kg/sec)	0.4160	0.5487	0.2686	0.4327	0.4638
Mass flow rate flowing in condenser (kg/sec)	1.430	1.704	0.9659	1.507	1.556

Table 34: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.923	4.439	4.726	5.069	5.011
EDR	2.217	2.554	2.317	2.12	2.15
Exergetic Efficiency	0.3127	0.2819	0.2999	0.3219	0.3182
Second Law Efficiency	0.6552	0.5908	0.6283	0.6746	0.6669
Rational Efficiency(by second Method)	0.3069	0.2798	0.3052	0.3176	0.3158
Exergy of Fuel "kW"	42.65	47.36	44.48	41.43	41.91
Exergy of Product "kW"	13.34	13.34	13.34	13.34	13.34
First compressor work done "kW"	17.33	18.28	18.43	16.90	16.92
Second compressor work done "kW"	6.018	6.183	6.276	5.906	5.93
Third compressor work done "kW"	19.31	27.84	19.77	18.62	19.06
Mass flow rate flowing in first compressor (kg/sec)	0.4041	0.4608	0.2741	0.4241	0.4292
Mass flow rate flowing in second compressor (kg/sec)	0.2114	0.2333	0.1447	0.2233	0.2287
Mass flow rate flowing in third compressor (kg/sec)	0.8042	1.016	0.5456	0.8354	0.8751
Mass flow rate flowing in condenser (kg/sec)	1.420	1.71	0.9644	1.483	1.533
% Total System Exergy Destruction	69.31	72.02	69.48	68.24	68.42
% Total Compressor Exergy Destruction	23.40	22.91	21.81	23.67	23.53
% Total condenser Exergy Destruction	26.64	26.14	32.54	27.81	26.65
% Total Exergy evaporator Destruction	13.90	15.73	10.15	11.86	12.41
% Total Valve Exergy Destruction	5.367	7.237	4.974	4.901	5.831
% Rational Efficiency	30.69	27.98	30.52	31.76	31.58

Table 35: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.923	4.439	4.726	5.069	5.011
Exergy of Fuel "kW"	42.65	47.36	44.48	41.43	41.91
% Total Compressor Exergy Destruction	33.77	31.81	31.39	34.68	34.39
% Total condenser Exergy Destruction	38.44	36.30	46.84	40.76	38.95
% Total Exergy evaporator Destruction	20.05	21.84	14.62	17.38	18.14
% Total Valve Exergy Destruction	7.743	10.05	7.159	7.182	8.522
Mass flow rate flowing in first compressor (kg/sec)	0.4041	0.4608	0.2741	0.4241	0.4292
Mass flow rate flowing in second compressor (kg/sec)	0.2114	0.2333	0.1447	0.2233	0.2287
Mass flow rate flowing in third compressor (kg/sec)	0.8042	1.016	0.5456	0.8354	0.8751
Mass flow rate flowing in condenser(kg/sec)	1.420	1.71	0.9644	1.483	1.533
% Rational Efficiency	30.69	27.98	30.52	31.76	31.58

Table 36: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 105 kW, second evaporator load is 35 kW, third evaporator load is 70 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.481	4.096	4.302	4.603	4.551
EDR	1.964	2.237	2.049	1.88	1.909
Exergetic Efficiency	0.3422	0.3129	0.3286	0.3515	0.3476
Second Law Efficiency	0.5963	0.5451	0.5725	0.6125	0.6067
Rational Efficiency(by second Method)	0.3280	0.30	0.3269	0.3392	0.3363
Exergy of Fuel "kW"	46.87	51.27	57.25	45.63	46.14
Exergy of Product "kW"	16.04	16.04	16.04	16.04	16.04
First compressor work done "kW"	25.99	27.43	27.64	25.35	25.38
Second compressor work done "kW"	6.206	6.242	6.414	6.118	6.156
Third compressor work done "kW"	14.67	17.60	14.76	14.16	14.60

Mass flow rate flowing in first compressor (kg/sec)	0.6062	0.6911	0.4111	0.6361	0.6438
Mass flow rate flowing in second compressor (kg/sec)	0.2180	0.2355	0.1479	0.2313	0.2374
Mass flow rate flowing in third compressor (kg/sec)	0.6111	0.7827	0.4072	0.6352	0.6706
Mass flow rate flowing in condenser (kg/sec)	1.431	1.709	0.9662	1.503	1.552
% Total System Exergy Destruction	67.2	70.0	67.31	66.08	66.37
% Total Compressor Exergy Destruction	23.37	22.87	21.65	23.71	23.5
.% Total condenser Exergy Destruction	24.69	24.82	30.67	25.71	24.67
% Total Exergy evaporator Destruction	13.83	15.72	10.15	11.87	12.43
% Total Valve Exergy Destruction	5.307	6.995	4.833	4.854	5.765
% Rational Efficiency	32.80	30.0	32.69	33.92	33.62

Table 37: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 105 kW, second evaporator load is 35kW, third evaporator load is 70 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K, $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	4.481	4.096	4.302	4.603	4.551
Exergy of Fuel "kW"	46.87	51.27	57.25	45.63	46.14
% Total Compressor Exergy Destruction	34.78	32.67	32.17	35.79	35.41
% Total condenser Exergy Destruction	36.74	34.89	45.57	38.91	37.18
% Total Exergy evaporator Destruction	20.58	22.45	15.08	17.86	18.73
% Total Valve Exergy Destruction	7.898	9.993	7.181	7.346	8.686
Mass flow rate flowing in first compressor (kg/sec)	0.6062	0.6911	0.4111	0.6361	0.6438
Mass flow rate flowing in second compressor (kg/sec)	0.2180	0.2355	0.1479	0.2313	0.2374
Mass flow rate flowing in third compressor (kg/sec)	0.6111	0.7827	0.4072	0.6352	0.6706
Mass flow rate flowing in condenser(kg/sec)	1.431	1.709	0.9662	1.503	1.552
% Rational Efficiency	32.80	30.0	32.69	33.92	33.62

Table 38: Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (for *first evaporator load is 35 kW, second evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures ($T_{\_eva1}$=263K, $T_{\_eva2}$=278K, $T_{\_eva3}$=283K $T_{\_cond}$=313K, $T_{\_Subcooled\ Liquid\ cond}$=303K , $T_{\_surrounding}$=298K) at compressors efficiency=0.75using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	5.204	4.672	4.989	5.363	5.30
EDR	2.425	2.810	2.527	2.317	2.351
Exergetic Efficiency	0.2952	0.2650	0.2831	0.3042	0.3007
Second Law Efficiency	0.6925	0.6217	0.6640	0.7137	0.7053
Rational Efficiency(by second Method)	0.2841	0.2552	0.2846	0.2952	0.2932
Exergy of Fuel "kW"	40.35	44.95	42.09	39.16	39.62
Exergy of Product "kW"	11.91	11.91	11.91	11.91	11.91
First compressor work done "kW"	8.664	9.142	9.214	8.45	8.461
Second compressor work done "kW"	17.11	18.25	18.14	16.66	16.66
Third compressor work done "kW"	14.58	17.56	14.74	14.05	14.50
Mass flow rate flowing in first compressor (kg/sec)	0.2221	0.2304	0.137	0.2120	0.2146
Mass flow rate flowing in second compressor (kg/sec)	0.6011	0.6886	0.4181	0.6296	0.6426
Mass flow rate flowing in third compressor (kg/sec)	0.6073	0.7810	0.4066	0.6306	0.6659
Mass flow rate flowing in condenser (kg/sec)	1.41	1.70	0.9618	1.472	1.523
% Total System Exergy Destruction	71.59	74.48	71.54	70.48	70.68
% Total Compressor Exergy Destruction	23.43	22.94	21.94	23.69	23.56
% Total condenser Exergy Destruction	27.85	27.16	33.64	29.13	27.88
% Total Exergy evaporator Destruction	14.99	17.13	10.97	12.83	13.46
% Total Valve Exergy Destruction	5.313	7.253	4.998	4.841	5.785
% Rational Efficiency	28.41	25.52	28.46	29.52	29.32

Table 39: Thermodynamic performances (Exergy Destruction in components based on total exergy destruction in system and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different temperatures with individual compression, multiple expansion valves using low GWP ecofriendly HFO+HFC refrigerant blends (*for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)at evaporator temperatures (T_{eva1}=263K, T_{eva2}=278K, T_{eva3}=283K, T_{cond}=313K, $T_{Subcooled\ Liquid\ cond}$=303K , $T_{surrounding}$=298K , compressors efficiency=0.75) using following HFO+HFC refrigerant Blends.*

Performance Parameters	R450A	R-452A	R-454B	R515A	R513A
COP	5.204	4.672	4.989	5.363	5.30
Exergy of Fuel "kW"	40.35	44.95	42.09	39.16	39.62
% Total Compressor Exergy Destruction	32.73	30.8	30.66	33.61	33.33
% Total condenser Exergy Destruction	38.9	36.46	47.02	41.33	39.44
% Total Exergy evaporator Destruction	20.95	23.0	15.33	18.2	19.04
% Total Valve Exergy Destruction	7.422	9.738	6.985	6.868	8.184
Mass flow rate flowing in first compressor (kg/sec)	0.2221	0.2304	0.137	0.2120	0.2146
Mass flow rate flowing in second compressor (kg/sec)	0.6011	0.6886	0.4181	0.6296	0.6426
Mass flow rate flowing in third compressor (kg/sec)	0.6073	0.7810	0.4066	0.6306	0.6659
Mass flow rate flowing in condenser(kg/sec)	1.41	1.70	0.9618	1.472	1.523
% Rational Efficiency	28.41	25.52	28.46	29.52	29.32

4. Conclusions

Energetic and exergetic analysis of refrigeration system was carried out with different HFO+HFC blends refrigerants and following conclusion and recommendation are presented below:

- R454C shows lowest first and second law exergetic performances among selected HFO+HFC refrigerants blends.
- The percentage exergy destruction in expansion valves is lower as compared to compressor and condenser for all HFO & HFC refrigerants.
- The percentage exergy destruction in compressors using is higher than using refrigerants of HFO+HFC blends
- Exergetic and energetic efficiency of R515A is slightly higher than R513A refrigerants.
- Flash chamber responsible for lowest exergy destruction for all HFO+HFC blends refrigerants.
- The vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio.

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