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Energy and exergy analysis of multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration system using ecofriendly refrigerants

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Abstract

Lots of literature was available on the thermal performances of vapour compression refrigeration systems and based on the literature it was observed that researchers have gone through detailed first law and second law analysis in terms of coefficient of performance and second law analysis in term of exergetic efficiency of simple vapour compression refrigeration system with single evaporator. Researchers did not go through for finding the irreversibility of system and exergy losses /destruction using entropy generation of simple (double stage and triple stage)VCR and stages in compression and Multiple evaporators systems with multi-stage expansion and compound compression in vapour compression refrigeration systems. In this paper, comparative thermodynamic analysis of system-1 (multiple evaporators and compressors with individual expansion valves) and system-2 (multiple evaporators and compressors with multiple expansion valves) has been presented which is based on energy and exergy principles. The comparison of systems-1 and -2 using eco-friendly R410A, R290, R1234YF, R502, R404A, R152A and R134A refrigerants was done in terms of first law efficiency (COP) known as energetic efficiency, exergetic efficiency and rational efficiency and exergy destruction ratio based on exergy of fuel and total irreversibility occurred in the system (%) Exergy losses in the various components known as system defect. Numerical model has been developed for systems-1 and -2 for finding out irreversibility and it was observed that system-1 is better system in comparison with system-2 for selected refrigerants. It was also found that R123 shows better performances than other considered refrigerants for both systems. The comparison was also done using eighteen eco-friendly refrigerants with R12 and it was found that R600, R600a, R290 and R152A show better performances than other refrigerants for both systems but due to flammable property of R600, R600a and R290 and R152a, HFO refrigerant R1234yf and R1234ze are preferred for both systems.

Keywords: Thermodynamic Analysis, Energy-Exergy Analysis, Entropy Generation principle, Irreversibility Analysis

1. Introduction

Nowadays most of the energy utilize in cooling and air conditioning in industrial as well as for domestic applications. In addition with energy consumption, using of refrigerants in cooling and air conditioning having high GWP and ODP are responsible for global warming and ozone depletion. The primary requirements of ideal refrigerants is having good physical and chemical properties, due to good physical and chemical properties such as non-corrosiveness, non-toxicity, non- flammability, low boiling point, Chlorofluorocarbons (CFCs) have been used over the last many decades. But hydro chlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) having large amount of chlorine content as well as high GWP and ODP, so after 90s refrigerants under these categories are almost prohibited [1].

Most of the study has been carried out for the performance evaluation of vapour compression refrigeration system using energetic analysis. But with the help of first law analysis irreversibility destruction or losses in components of system unable to determined , so that exergetic or second law analysis is the advanced approach for thermodynamic analysis which give a additional practical view of the processes [2]. In addition to this second law analysis also provides new thought for

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development in the existing refrigeration and air conditioning systems [3]

1.1 Energy Exergy Analysis of Vapour Compression Refrigeration Systems

The most commonly-used method for analysis of an energy-conversion process is the first law of thermodynamics. But in the recent decades, the exergetic performance based on the second law of thermodynamics has found as useful method in the design, evaluation, optimization and improvement of vapour compression refrigeration systems.

The exergetic performance analysis can not only determine magnitudes, location and causes of irreversibilities in the vapour compression refrigeration systems, but also provides more meaningful assessment of power plant individual components efficiency. A conventional exergetic analysis reveals irreversibilities within each component of a vapour compression refrigeration systems. Exergetic analysis provides the tool for a clear distinction between energy losses to the environment and internal irreversibilities in the process because exergy analysis is a methodology for the evaluation of the performance of devices and processes, and examining the exergy at different points in a series of energy-conversion steps. With this information, efficiencies can be evaluated, and the process steps having the largest losses (i.e., the greatest margin for improvement) can be identified. For these reasons, the modern approach uses the exergy analysis in the vapour compression refrigeration systems, which provides a more realistic view of the process and a useful tool for engineering evaluation.

The second law analysis (i.e. exergy Computation) is widely accepted as a useful tool for obtaining overall performances of any system for finding various exergy losses occurred in its components Exergy analysis also helps in taking account the important engineering decisions regarding design parameters of a system by finding maximum exergy destruction using entropy generation principle.

Many researchers have carried out exergy studies of different thermal energy conversion systems describing various approach for exergy analysis and its usefulness for improving existing designs by reducing exergy destruction in a more simple and effective manner [2-3]. Cabello et al. [4] studied the effect of condensing pressure, evaporating pressure and degree of superheating was experimentally investigated on single stage vapour compression refrigeration system using R22, R134a and R407C.It was observed that mass flow rate is greatly affected by change in suction conditions of compressor in results on refrigeration capacity because refrigeration capacity depended on mass flow rate through evaporator. It was also found that for higher compression ratio R22 gives lower COP than R407C.Padilla et al. [5] carried out exergy analysis of domestic vapour compression refrigeration system with R12 and R413A was done. They concluded that performance in terms of power consumption, irreversibility and exergy efficiency of R413A is better than R12, so R12 can be replaced with R413A in domestic vapour compression refrigeration system. Kumar et al.[6] did energy and exergy analysis of vapour compression refrigeration system by the use of exergy-enthalpy diagram. They did first law analysis or energy analysis for calculating the coefficient of performance and exergy analysis for evaluation of various losses occurred in different components of vapour compression cycle using R11 and R12 as refrigerants. In this paper great emphasis put on saving of energy and using of ecofriendly refrigerants due to increase of energy crises, global warming and depletion of ozone layer. In this investigation the work input required running the vapour compression refrigeration system reduced by using compound compression and work input.

2. Thermodynamic Analysis

2.1 Models description of multiple evaporators and compressors with individual expansion valves (system-1) and multiple evaporators and compressors with multiple expansion valves (system-2) vapour compression refrigeration systems.

The multiple evaporators and compressors with individual expansion valves vapour compression refrigeration system (system-1) consists of compressors (C_1, C_2,C_3) throttle valves (TV_1, TV_2,TV_3), condenser and evaporators(EP_1, EP_2,EP_3)as shown in Fig.1(a).The pressure versus enthalpy chart for this system is shown in Fig.1(b). In this system all refrigerant coming out at point ‘77’ from sub-cooler distributed by mass $\dot{m}_1$,$\dot{m}_2$, $\dot{m}_3$ to expansion valves TV_1, TV_2, and TV3 respectively. Both liquid and vapour formed by TV_1 ,TV_2 ,TV_3 represented by point ‘10’, ‘9’ and ‘8’ take care the load of EP_1 ,EP_2 and EP_3 respectively. The low pressure vapours formed by EP_1 ,EP_2 and EP_3 supplied to the compressor C_1 ,C_2 and C_3 represented by point ‘1’, ‘3’ and ‘5’ respectively. The high pressure vapours formed by compressor C_1 ,C_2 and C_3 respectively represented by points ‘2’, ‘4’ and ‘6’ .then high pressure vapours coming out from compressor C_1 , C_1 ,C_1 collectively enter through condenser by point ‘7’.The main components of multiple evaporators and compressors with individual expansion valves vapour compression refrigeration system (system-2) are compressors (C_1, C_2,C_3) throttle valves (TV_1, TV_2,TV_3), condenser and evaporators(EP_1, EP_2,EP_3)as shown in Fig. 2(a).The corresponding pressure versus enthalpy chart for this system is shown in Fig. 2(b).In this system all the refrigerant from condenser at point ‘g’ followed by sub-cooler exit at point ‘gg’ flows through the throttle valve TV3 where its pressure is reduced from condenser pressure of the third evaporator. All the vapours formed after leaving the expansion valve TV3 at point ‘h’ plus enough liquid to take care of the load of evaporator EP3.The remaining refrigerant then enter at point ‘i’ through the expansion valve TV2 where its pressure is reduced from pressure of the third evaporator to pressure of the second evaporator. Again all the vapour formed after leaving the expansion valve TV_2 at point ‘j’ plus enough liquid to take care of the load of evaporator EP_2 passes through this evaporator .The remaining liquid now enter at point 'k' through the expansion valve TV_1 and exit at point 'l' which supplied it to the first evaporator EP_1.The vapours formed by EP_1, EP_2 , EP_3 supplied to compressors C_1, C_2 and C_3 shown by point 'a','c' and 'e' respectively. High pressure vapours formed by compressors C_1, $C_2$and C_3 as shown by points 'b','d' and 'f' respectively supplied to the condenser.

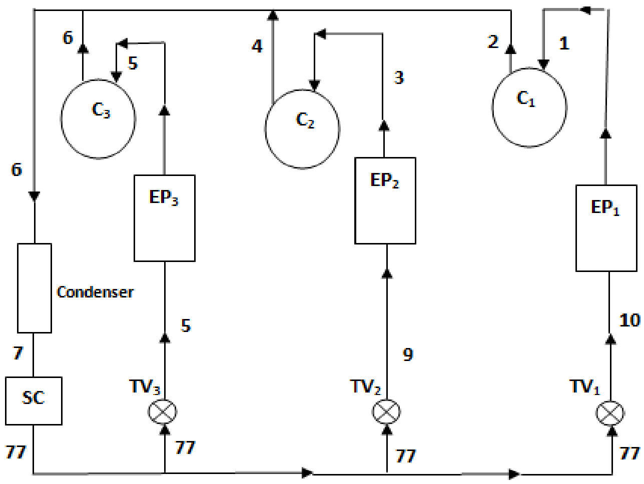

Figure 1 (a) Schematic diagram of multiple evaporators at different temperatures with individual compressors and individual expansion valves

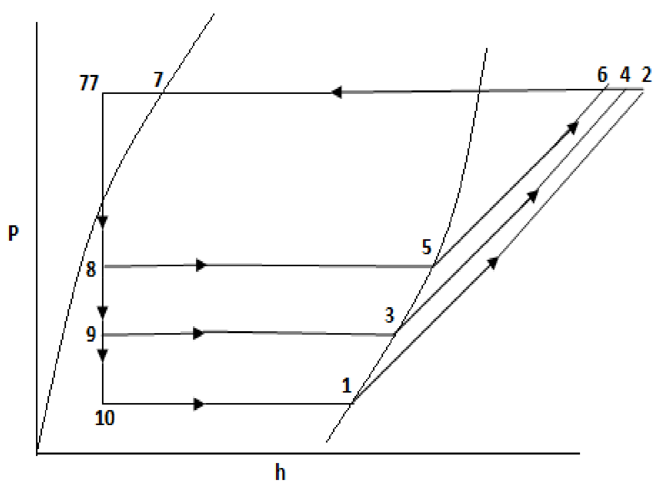

Figure 1 (b): Pressure enthalpy diagram of multiple evaporators at different temperatures with individual compressors and individual expansion valves.

2.2 First law analysis (COP & work input analysis) of multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration systems

The multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration system as shown in Fig.1 and Fig.2 respectively. From the energy analysis point of view first law of thermodynamics, evaluate the performance of the vapour compression systems as given below:

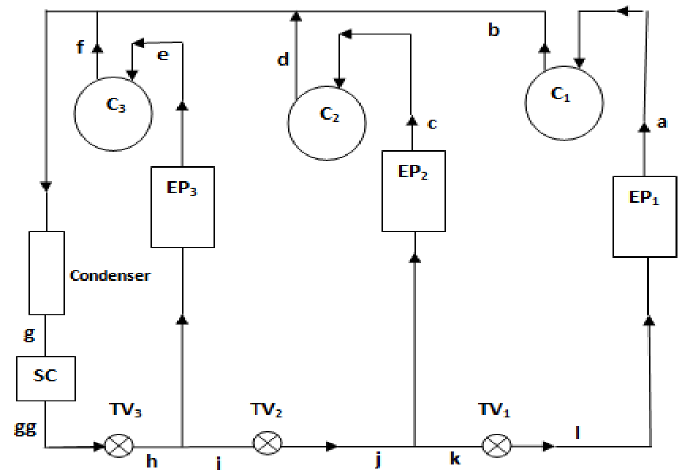

Fig.2 (a) Schematic diagram of multiple evaporators at different temperatures with individual compressors and multiple expansion valves

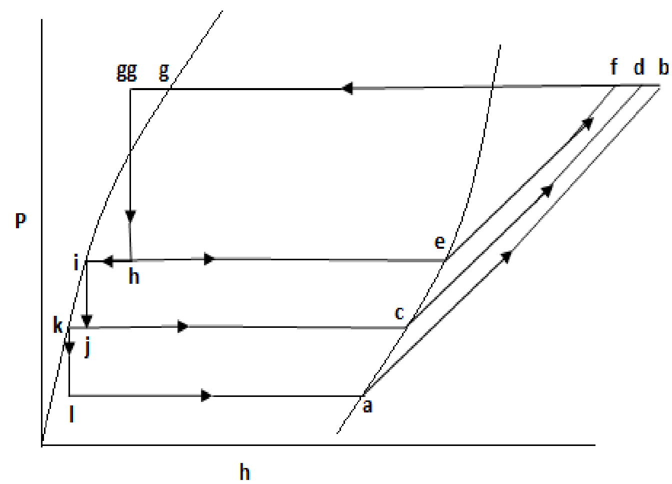

Fig.2 (b) Pressure enthalpy diagram of multiple evaporators at different temperatures with individual compressors and multiple expansion valves

System-1

$$\dot{m}_{e1} = \dot{m}_{c1} \quad (1)$$
$$\dot{m}_{e2} = \dot{m}_{c2} \quad (2)$$
$$\dot{m}_{e3} = \dot{m}_{c3} \quad (3)$$
$$\dot{Q}_{e\_1} = \dot{Q}_{e1} + \dot{Q}_{e2} + \dot{Q}_{e3} \quad (4)$$
$$\dot{W}_{comp1} = \dot{m}_{c1}(\psi_2 - \psi_1) \quad (5)$$
$$\dot{W}_{comp2} = \dot{m}_{c2}(\psi_4 - \psi_3) \quad (6)$$
$$\dot{W}_{comp3} = \dot{m}_{c3}(\psi_6 - \psi_5) \quad (7)$$
$$\dot{W}_{comp\_1} = \dot{W}_{comp1} + \dot{W}_{comp2} + \dot{W}_{comp3} \quad (8)$$
$$COP\_1 = \frac{\dot{Q}_{e\_1}}{\dot{W}_{comp\_1}} \quad (9)$$

System-2

$$\dot{m}_{c1} = \dot{m}_{e1} \quad (10)$$

$$\dot{m}_{c2} = \dot{m}_{e2} = \dot{m}_2 + \dot{m}_{e1}\left(\frac{\varphi_j}{1-\varphi_j}\right) \quad (11)$$

$$\dot{m}_2 = \left(\frac{\dot{Q}_{e2}}{\psi_c-\psi_j}\right) \quad (12)$$

$$\dot{m}_{c3} = \dot{m}_{e3} = \dot{m}_3 + (\dot{m}_{e1} + \dot{m}_{e2})\left(\frac{\varphi_h}{1-\varphi_h}\right) \quad (13)$$

$$\dot{m}_3 = \left(\frac{\dot{Q}_{e3}}{\psi_e-\psi_h}\right) \quad (14)$$

$$\dot{Q}_{e\_2}=\dot{Q}_{e1} + \dot{Q}_{e2} + \dot{Q}_{e3} \quad (15)$$

$$\dot{W}_{comp1} = \dot{m}_{c1}(\psi_b - \psi_a) \quad (16)$$

$$\dot{W}_{comp2} = \dot{m}_{c2}(\psi_d - \psi_c) \quad (17)$$

$$\dot{W}_{comp3} = \dot{m}_{c3}(\psi_f - \psi_e) \quad (18)$$

$$\dot{W}_{comp\_2} = \dot{W}_{comp1} + \dot{W}_{comp2} + \dot{W}_{comp3} \quad (19)$$

$$COP\_2 = \frac{\dot{Q}_{e\_2}}{\dot{W}_{comp\_2}} \quad (20)$$

3. *Second law analysis of multiple evaporators and compressors with individual or multiple expansion valves vapour compression refrigeration system*

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.

3.1 Exergy destruction (ED)

Exergy destruction in each component of the multiple evaporators and compressors with individual expansion valves vapour compression refrigeration system (System-1) is evaluated as per Eqs. (21)– (32) given below:

Evaporators

$(EP_1)_{\text{System-1}}$

$$\dot{ED}_{e1} = \dot{E}_{x10} + \dot{Q}_{e1}\left(1-\frac{T_0}{T_{r1}}\right) - \dot{E}_{x1} = \dot{m}_{e1}(\psi_{10} - T_0 s_{10}) + \dot{Q}_{e1}\left(1-\frac{T_0}{T_{r1}}\right) - \dot{m}_{e1}(\psi_1 - T_0 s_1) \quad (21)$$

$(EP_2)_{\text{System-1}}$

$$\dot{ED}_{e2} = \dot{E}_{x9} + \dot{Q}_{e2}\left(1-\frac{T_0}{T_{r2}}\right) - \dot{E}_{x3} = \dot{m}_{e2}(\psi_9 - T_0 s_9) + \dot{Q}_{e2}\left(1-\frac{T_0}{T_{r2}}\right) - \dot{m}_{e2}(\psi_3 - T_0 s_3) \quad (22)$$

$(EP_3)_{\text{System-1}}$

$$\dot{ED}_{e3} = \dot{E}_{x8} + \dot{Q}_{e3}\left(1-\frac{T_0}{T_{r3}}\right) - \dot{E}_{x5} = \dot{m}_{e3}(\psi_8 - T_0 s_8) + \dot{Q}_{e3}\left(1-\frac{T_0}{T_{r3}}\right) - \dot{m}_{e3}(\psi_5 - T_0 s_5) \quad (23)$$

Compressors

$(C_1)_{\text{System-1}}$

$$\dot{ED}_{comp1} = \dot{E}_{x1} + \dot{W}_{comp1} - \dot{E}_{x2} = \dot{m}_{c1}(T_0(s_2 - s_1)) \quad (24)$$

$(C_2)_{\text{System-1}}$

$$\dot{ED}_{comp2} = \dot{E}_{x3} + \dot{W}_{comp2} - \dot{E}_{x4} = \dot{m}_{c2}(T_0(s_4 - s_3)) \quad (25)$$

$(C_3)_{\text{System-1}}$

$$\dot{ED}_{comp3} = \dot{E}_{x5} + \dot{W}_{comp3} - \dot{E}_{x6} = \dot{m}_{c3}\big(T_0(s_6 - s_5)\big) \quad (26)$$

Condenser

$(\text{Condenser})_{\text{System-1}}$

$$\dot{ED}_c = (\dot{E}_{x2} - \dot{E}_{x7}) + (\dot{E}_{x4} - \dot{E}_{x7}) + (\dot{E}_{x6} - \dot{E}_{x7}) = \dot{m}_{c1}\big((\psi_2 - T_0 s_2) - (\psi_7 - T_0 s_7)\big) + \dot{m}_{c2}\big((\psi_4 - T_0 s_4) - (\psi_7 - T_0 s_7)\big) + \dot{m}_{c3}\big((\psi_6 - T_0 s_6) - (\psi_7 - T_0 s_7)\big) \quad (27)$$

Sub cooler

$(SC)_{\text{System-1}}$

$$\dot{ED}_{sc} = \dot{E}_{x7} - \dot{E}_{x77} = (\dot{m}_{c1} + \dot{m}_{c2} + \dot{m}_{c3})((\psi_7 - T_0 s_7) - (\psi_{77} - T_0 s_{77})) \quad (28)$$

Throttle valves

$TV_1)_{\text{System-1}}$

$$\dot{ED}_{TV_1} = \dot{E}_{x77} - \dot{E}_{x10} = \dot{m}_{c1}(T_0(s_{10} - s_{77})) \quad (29)$$

(TV-2) $_{\text{System-1}}$

$$\dot{ED}_{TV_2} = \dot{E}_{x77} - \dot{E}_{x9} = \dot{m}_{c2}(T_0(s_9 - s_{77})) \quad (30)$$

(TV-3) $_{\text{System-1}}$

$$\dot{ED}_{TV_3} = \dot{E}_{x77} - \dot{E}_{x8} = \dot{m}_{c3}(T_0(s_8 - s_{77})) \quad (31)$$

The total irreversibility (%) in terms of system exergy losses in the system-1 is the sum of irreversibility in each components of the system and is given by

$$\sum \dot{ED}_k = \dot{ED}_{e1} + \dot{ED}_{e2} + \dot{ED}_{e3} + \dot{ED}_{comp1} + \dot{ED}_{comp2} + \dot{ED}_{comp3} + \dot{ED}_c + \dot{ED}_{sc} + \dot{ED}_{TV_1} + \dot{ED}_{TV_2} + \dot{ED}_{TV_3} \quad (32)$$

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 Eqs. (33)– (44) given below:

Evaporators

$(EP1)_{\text{System-2}}$

$$\dot{ED}_{e1} = \dot{E}_{xl} + \dot{Q}_{e1}\left(1-\frac{T_0}{T_{r1}}\right) - \dot{E}_{xa} = \dot{m}_{e1}(\psi_l - T_0 s_l) +$$

$\dot{Q}_{e1}\left(1-\frac{T_0}{T_{r1}}\right)-\dot{m}_{e1}(\psi_a-T_0 s_a)$ (33)

(EP2)System-2

$$E\dot{D}_{e2}=\dot{E}_{xj}+\dot{Q}_{e2}\left(1-\frac{T_0}{T_{r2}}\right)-\dot{E}_{xc}=\dot{m}_{e2}(\psi_j-T_0 s_j)+\dot{Q}_{e2}\left(1-\frac{T_0}{T_{r2}}\right)-\dot{m}_{e2}(\psi_c-T_0 s_c) \quad (34)$$

(EP3)System-2

$$E\dot{D}_{e3}=\dot{E}_{xh}+\dot{Q}_{e3}\left(1-\frac{T_0}{T_{r3}}\right)-\dot{E}_{xe}=\dot{m}_{e3}(\psi_h-T_0 s_h)+\dot{Q}_{e3}\left(1-\frac{T_0}{T_{r3}}\right)-\dot{m}_{e3}(\psi_e-T_0 s_e) \quad (35)$$

Compressors

(C-1)System-2

$$E\dot{D}_{comp1}=\dot{E}_{xa}+\dot{W}_{comp1}-\dot{E}_{xb}=\dot{m}_{c1}(T_0(s_b-s_a)) \quad (36)$$

(C-2)System-2

$$E\dot{D}_{comp2}=\dot{E}_{xc}+\dot{W}_{comp2}-\dot{E}_{xd}=\dot{m}_{c2}(T_0(s_d-s_c)) \quad (37)$$

(C-3)System-2

$$E\dot{D}_{comp3}=\dot{E}_{xe}+\dot{W}_{comp3}-\dot{E}_{xf}=\dot{m}_{c3}(T_0(s_f-s_e)) \quad (38)$$

(Condenser)System-2

$$E\dot{D}_{cond}=(\dot{E}_{xb}-\dot{E}_{xg})+(\dot{E}_{xd}-\dot{E}_{xg})+(\dot{E}_{xf}-\dot{E}_{xg}) =\dot{m}_{c1}\left((\psi_b-T_0 s_b)-(\psi_g-T_0 s_g)\right)+\dot{m}_{c2}\left((\psi_d-T_0 s_d)-(\psi_g-T_0 s_g)\right)+\dot{m}_{c3}\left((\psi_f-T_0 s_f)-(\psi_g-T_0 s_g)\right) \quad (39)$$

(SC)System-2

$$E\dot{D}_{sc}=\dot{E}_{xg}-\dot{E}_{xgg}=(\dot{m}_{c1}+\dot{m}_{c2}+\dot{m}_{c3})\left((\psi_g-T_0 s_g)-(\psi_{gg}-T_0 s_{gg})\right) \quad (40)$$

Throttle valves: (TV-1) System-2

$$E\dot{D}_{TV_1}=\dot{E}_{xk}-\dot{E}_{xl}=\dot{m}_{c1}(T_0(s_l-s_k)) \quad (41)$$

(TV-2)System-2

$$E\dot{D}_{TV_2}=\dot{E}_{xi}-\dot{E}_{xj}=(\dot{m}_{c1}+\dot{m}_{c2})(T_0(s_j-s_i)) \quad (42)$$

(TV-3)System-2

$$E\dot{D}_{TV_3}=\dot{E}_{xgg}-\dot{E}_{xh}=(\dot{m}_{c1}+\dot{m}_{c2}+\dot{m}_{c3})(T_0(s_h-s_{gg})) \quad (43)$$

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

$$\sum E\dot{D}_k=E\dot{D}_{e1}+E\dot{D}_{e2}+E\dot{D}_{e3}+E\dot{D}_{comp1}+E\dot{D}_{comp2}+E\dot{D}_{comp3}+E\dot{D}_c+E\dot{D}_{sc}+E\dot{D}_{TV_1}+E\dot{D}_{TV_2}+E\dot{D}_{TV_3} \quad (44)$$

$$\text{Exergetic efficiency}\ \eta_{ex}=\frac{\text{Exergy in product}}{\text{Exergy of fuel}}=\frac{\dot{EP}}{\dot{EF}} \quad (45)$$

For the multi evaporators vapour compression refrigeration system, product is the exergy of the heat abstracted in to the evaporators' i.e. $Q_e = Q_{e1} + Q_{e2} + Q_{e3}$ from the space to be cooled at temperature T_r, and exergy of fuel is actual compressor work input. Hence, exergetic efficiency is given by

$$\dot{EP}=\dot{Q}_{e1}+\dot{Q}_{e2}\left|\left(1-\frac{T_0}{T_{r2}}\right)\right|+\dot{Q}_{e3}\left|\left(1-\frac{T_0}{T_{r3}}\right)\right| \quad (46)$$

$$\eta_{ex}=\frac{\dot{Q}_{e1}\left|\left(1-\frac{T_0}{T_{r1}}\right)\right|+\dot{Q}_{e2}\left|\left(1-\frac{T_0}{T_{r2}}\right)\right|+\dot{Q}_{e3}\left|\left(1-\frac{T_0}{T_{r3}}\right)\right|}{(\dot{W}_{comp1}+\dot{W}_{comp2}+\dot{W}_{comp3})} \quad (47)$$

3.2 Exergy destruction ratio (EDR)

EDR is the ratio of total exergy destruction in the system to exergy in the product [9] and it is given by Eq. (48). EDR is related to the exergetic efficiency by Eq. (49)

$$EDR=\frac{E\dot{D}_{total}}{\dot{EP}}=\frac{1}{\eta_{ex}}-1 \quad (48)$$

$$\eta_{ex}=\frac{1}{1+EDR} \quad (49)$$

4. Result and Discussion

The method for improving thermal performance of vapour compression refrigeration system using multiple evaporators and compressors with individual or multiple expansion valves have been considered by using first law and second law analysis. Numerical computation was carried out for finding thermal performances vapour compressor refrigeration system with Multiple evaporators at same temperature with single compressor, individual expansion valves of developed models , the following input parameters were considered [9] to verified proposed thermal model.

Table 1(a): System-1: validation of results from developed model Vapour compressor refrigeration system with multiple evaporators at same temperature with single compressor, individual expansion under actual conditions (for compressors efficiency=100%)

Parameters	Model	Ref [9]
First Law Efficiency (COP)	6.196	5.96
Exergy of Fuel (kW)	33.92	35.20

The following data have been taken for numerical computation for table-1(b)

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves with sub coolers (System-1) for energy-exergy- analysis. To validate computational results from developed thermal model of system-1, the following input values have been taken. The computed results of system-1 for 100% compressors efficiency were compared and shown in Table-3(a) respectively. For finding thermal performances in terms of first law efficiency (COP), EDR (Exergy Destruction Ratio based on exergy of input) exergetic efficiency using energy-exergy analysis. For finding various exergetic losses (Exergy defects)in terms of irreversibility of system occurred in the components and total exergy destruction in system along with rational efficiency and second law efficiency of the Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves are shown in Table-2(a) to Table-2 (c) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances and results are shown in Tables-1(a) to (1(b) for system-2 and Table-1(c) for system-2 .respectively. vapour compressor refrigeration system with Multiple evaporators at different temperatures with multiple compressors, individual expansion valves . We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves with sub coolers (System-2) for energy-exergy-analysis table-1(c). To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-2 for 100% compressors efficiency were compared and shown in Table-1(a) respectively. For finding thermal performances in terms of first law efficiency (COP), EDR (Exergy Destruction Ratio based on exergy of input) exergetic efficiency using energy-exergy analysis. For finding various exergetic losses (Exergy defects) in terms of irreversibility of system occurred in the components and total exergy destruction in system along with rational efficiency and second law efficiency of the vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves are shown in Table-2(a) to Table-2 (c) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=80%) T_{EVA}_1=263"K", T_{EVA}_2=278"K", T_{EVA}_3=283"K", T_R_1=268"K", T_R _2=283"K", T_R_3=288"K", Q_{EVA_1}=70 "kW', Q_{EVA_2}=105"kW',Q_{EVA_3}=35"kW',T_subcooled=303"K"under actual conditions for compressors efficiency=0.80)

Table-1.(b)Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system (System-1) using alternative refrigerants

Refrigerants	First Law Efficiency (COP)	Exergy Destruction Ratio (EDR_{System})	Exergetic Efficiency	Exergy_of Fuel (KW)	Exergy of Product (KW)	Second Law Efficiency
R12	4.953	1.844	0.3447	42.4	14.62	0.6591
R134a	4.905	1.867	0.3414	42.81	14.62	0.6528
R1234yf	4.804	1.915	0.3344	43.71	14.62	0.6393
R1234ze	4.919	1.858	0.3424	44.69	14.62	0.6546
R227ea	4.69	1.98	0.3265	44.77	14.62	0.6242
R236fa	4.822	1.878	0.3405	42.93	14.62	0.6510
R245fa	5.07	1.791	0.3529	41.42	14.62	0.6747
R5.07a	4.586	2.024	0.3192	45.79	14.62	0.6103
R407c	4.036	2.501	0.2809	52.03	14.62	0.5372
R404a	4.498	2.087	0.3131	46.68	14.62	0.5986
R125	4.426	2.114	0.3080	47.45	14.62	0.5889
R123	5.116	1.769	0.3561	41.05	14.62	0.6809
R410a	4.67	1.987	0.3250	44.97	14.62	0.6214
R152a	5.003	1.824	0.3482	41.97	14.62	0.6658
R143a	4.613	2.012	0.3211	45.53	14.62	0.6139
R32	4.689	1.996	0.3263	44.79	14.62	0.624
R290	4.829	1.99	0.3361	43.49	14.62	0.6426
R600	5.037	1.807	0.3506	41.69	14.62	0.6704
R600a	4.941	1.853	0.3439	42.51	14.62	0.6575
R717	4.902	1.902	0.3412	42.51	14.62	0.6524

Table-1(c) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system (System-2)using alternative refrigerants.

Refrigerants	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	4.697	2.195	30.58	36.86	11.27	0.7569
R134a	4.654	2.213	30.35	37.14	11.27	0.7524
R1234yf	4.560	2.253	29.85	37.77	11.27	0.740
R1234ze	4.624	2.199	30.49	36.97	11.27	0.7559
R-32	4.445	2.320	29.23	38.56	11.27	0.7247
R227ea	4.461	2.309	29.32	38.45	11.27	0.7268
R236fa	4.664	2.213	30.45	37.08	11.27	0.7538
R245fa	4.832	2.136	31.34	35.97	11.27	0.7769
R123	4.877	2.118	31.55	35.73	11.27	0.7821

Table-2.(a) Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system using alternative refrigerants .

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Total Losses	Rational Efficiency
R12	9.685	8.071	27.33	18.48	63.67	36.43
R134a	9.559	8.881	26.73	18.57	63.74	36.26
R1234yf	7.834	9.914	27.31	18.97	64.02	35.98
R1234ze	9.186	9.330	26.10	18.99	63.61	36.39
R227ea	8.897	11.99	24.74	19.02	64.64	35.36
R236fa	9.566	9.573	25.75	19.04	63.93	36.07
R245fa	9.889	7.34	27.02	18.96	63.21	36.79
R5.07a	8.968	12.6	24.35	18.68	64.6	35.40
R407c	23.18	4.575	24.76	17.76	70.27	29.73
R404a	10.57	12.04	24.13	18.60	65.34	34.66
R125	8.631	14.79	22.92	18.78	65.12	34.88
R123	9.811	6.553	27.93	18.72	63.01	36.99
R410a	9.499	9.563	27.64	17.89	64.59	35.41
R152a	9.775	7.065	28.57	18.10	63.51	36.49
R143a	9.009	12.04	25.04	18.51	64.61	35.39
R32	9.169	7.854	31.05	17.05	65.13	34.87
R290	9.45	9.611	26.28	18.59	63.93	36.07
R600	9.927	7.349	27.11	18.98	63.37	36.63
R600a	9.662	7.754	26.29	19.01	63.72	36.28
R717	9.571	4.122	35.44	15.78	64.91	35.09

Table-2.(b)Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system (System-1)using alternative refrigerants

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	Total % Losses	Rational Efficiency
R12	10.86	6.944	30.67	18.56	67.03	0.3297
R134a	10.74	7.614	30.07	18.63	67.06	0.3294
R1234yf	8.731	8.397	31.0	18.97	67.1	0.3290
R1234ze	10.40	7.931	29.56	19.01	66.9	0.3310
R-32	10.29	6.992	33.73	17.29	68.30	0.3120
R227ea	10.07	10.15	28.22	19.02	67.46	0.3254
R236fa	11.87	8.047	29.25	19.04	67.14	0.3286
R245fa	11.14	6.137	30.53	18.99	66.79	0.3321
R123	11.01	5.501	31.43	18.77	66.72	0.3328

Table-2.(c) Exergy Destruction of various components based on Total exergy destruction of vapour compression refrigeration system (System-2)using alternative refrigerants

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	%Irreversibility	II Law effectiveness
R12	16.20	10.36	45.75	27.68	67.03	0.3297
R134a	16.02	11.35	44.84	27.78	67.06	0.3294
R1234yf	13.01	12.51	46.2	28.27	67.1	0.3290
R1234ze	15.54	11.86	44.19	28.41	66.9	0.3310
R-32	15.06	10.24	49.39	25.31	68.30	0.3120
R227ea	14.93	15.04	41.83	28.2	67.46	0.3254
R236fa	16.09	11.99	43.57	28.36	67.14	0.3286
R245fa	16.68	9.188	45.71	28.42	66.79	0.3321
R123	16.5	8.245	47.11	28.14	66.72	0.3328

4. Conclusion

Numerical models have been developed for parallel and series expansion valves in the VCR. The comparison of above systems have been done in terms of first law efficiency, second law efficiency and exergy destruction ratio by using R410a, R290, R600, R600a, R1234yf, R502, R404a, R1234ze, R134a and R152a.it was observed that for same degree of sub-cooling, fixed evaporators and condenser temperatures multiple evaporators and compressors with multiple expansion valves system is the best system with comparisons of system with individual expansion valves. The following conclusions were drawn:

(i) Use of HFO refrigerants for Replacing HFC -134a is more significant due to low GWP as compared to R134a of 1430.
(ii) Thermal performances using HFO refrigerants is slightly less than by using R134a although R123 refrigerant gives higher first law efficiency (COP).
(iii) Performances of R600, R152a and R717 better with comparison of other selected refrigerants for system-1 and system-2. But hydrocarbons R290, R600a &R600)are highly flammable and R717 is toxic and R152a is limited to industrial application, so R1234yf and R1234ze are recommended for both systems.
(iv) By altering evaporator load effects thermal performances considerably.
(v) The maximum exergy destruction in the system components it is found maximum (i.e. higher) in the condenser and low in the throttle valves.
(vi) The percentage exergy destruction in the evaporator varies with the type of refrigerants. It becomes high when R236fa is used and lower when R32 is used.
(vii) Energetic and exergetic performance of system-1 is higher than system-2 for selected temperature range of condenser and evaporators for chosen ecofriendly refrigerants.
(viii) System defect in sytem-1 is less as compare with system-2, so system-1 is better system than system-2 for selected refrigerants.
(ix) R407C shows minimum performance in terms of first law efficiency, second law efficiency and system defect in terms of exergy losses for both systems

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Nomenclature

COP	coefficient of performance (non-dimensional)
VCR	vapour compression refrigeration
CFC	chlorofluorocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
$\dot{Q}$	rate of heat transfer (kW)
$\dot{W}$	work rate (kW)
T	temperature (K)
ΔT_{sc}	degree of subcooling
$\dot{EP}$	exergy rate of product (kW)
TV	throttle valve

φ	dryness fraction(non-dimensional)
EP	evaporator
Ψ	specific enthalpy (kJ/kg)
$\dot{ED}$	rate of exergy destruction (kW)
E_x	exergy rate of fluid (kW)
$\dot{m}$	mass flow rate (kg/s)
s	specific entropy (kJ/kgK)
$\dot{EF}$	exergy rate of fuel (kW)
η	efficiency (non-dimensional)
c	compressor
sc	sub-cooler
ODP	ozone depletion potential
GWP	global warming potential

Subscript

e	evaporator
comp	compressor
o	dead state
II	second law efficiency
r	refrigerant, space to be cooled
TV	throttle valve
sc	sub-cooler
k	kth component
cond	condenser
ev	expansion valve
ex	exergetic

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