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Thermodynamic analysis of vapour compression refrigeration systems using multiple evaporators at different temperatures with compound compression, individual and compound expansion valves with flash intercoolers

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Abstract

In this investigation comparison and impact of environmental friendly refrigerants (R1234yf, , R1234ze, R227ea, R134a, R236fa, R245fa and R-32) on multiple evaporators at different temperature with compound compression and flash intercooler with individual and multiple throttle valves was carried out on the basis of energetic -exergetic approach. The Numerical computation was done for both systems and Comparison was done in terms of coefficient of performance, rational efficiency and total system defect. It was observed that for all considered refrigerants second law & first law efficiency of system-1 is higher (approximately 6.29% to 7.2%) than system-2 conversely system defect of system-2 is higher than system-1.In terms of energetic efficiency, rational efficiency and system defect for both systems, R32 shows minimum performance and performances of R123, R245fa and R236fa better with comparison of other selected refrigerants for system-1 and system-2. The performance of HFC-134a and HFO refrigerants were compared and it was observed that the performance of HFC134a and HFO-1234ze are similar with the 1% performance differences while HFO-1234yf has slightly less around 2 to 3% lower than HFC-134a which can replace HFC-134a in near future.

Keywords: Thermodynamic performances, Energy-Exergy Method, Irreversibility Analysis, Vapour Compression Refrigeration System

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 hydrochlorofluorocarbons (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 [2], so exergetic or second law analysis is the advanced approach for thermodynamic analysis which give an additional practical view of the processes [3,4,5]. In addition to this second law analysis also provides new thought for development in the existing system [6].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 further decrease by flash intercooling between two compressors using of ecofriendly refrigerants.

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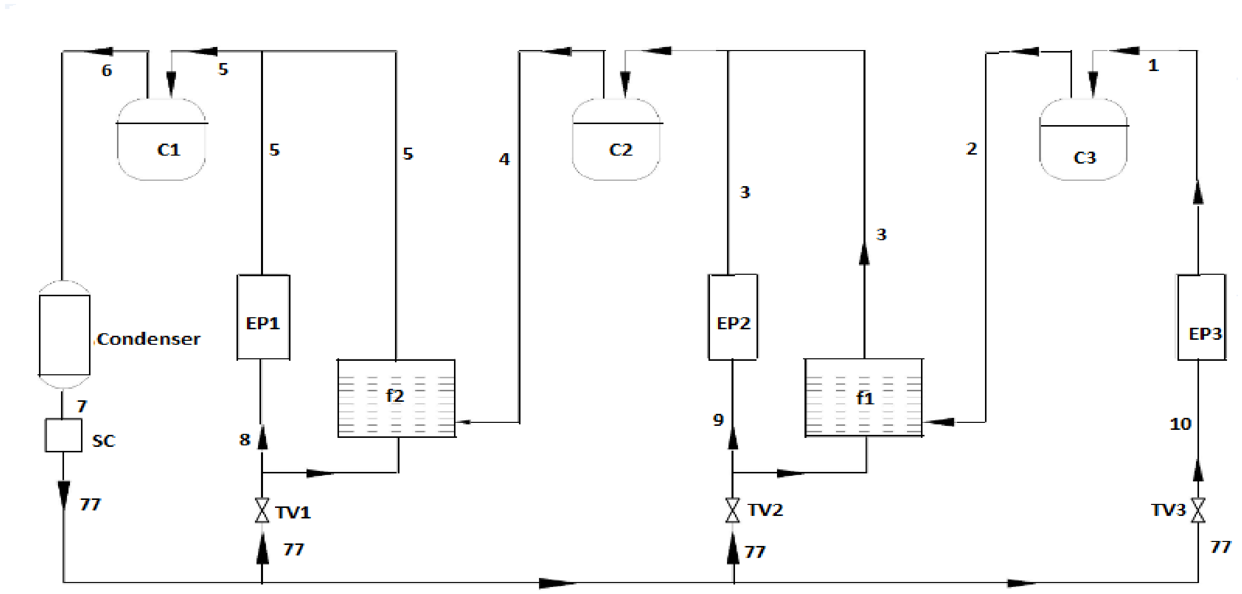

Figure 1: Multiple evaporators with compound compression and flash intercooler with individual throttle valves

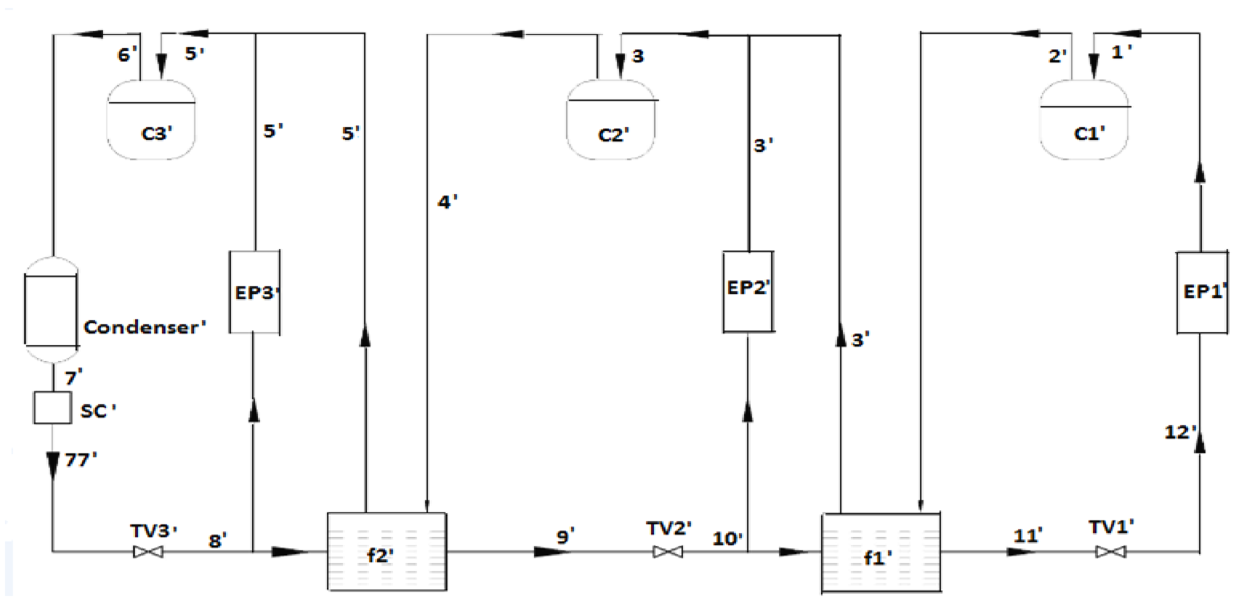

Figure 2: Multiple evaporators with compound compression and flash intercooler with multiple throttle valves

2. Thermodynamic modelling Energy –Exergy analysis of Vapour compression refrigeration systems using multiple evaporators at different temperatures with compound compression, flash intercooler and individual throttle valves (system-1)

Multiple evaporators at different temperatures with compound compression, flash intercooler and individual throttle valves (system-1) consists of compressors (C1, C2, C3) throttle valves (TV1, TV2, TV3), condenser and evaporators(EP1, EP2, EP3) as shown in Fig.1.

Exergy at any state is given as

$$X = (\Phi - \Phi_0) - T_0(s - s_0) \quad (2.1)$$

2.1 Energetic analysis

2.1.1 Mass flow analysis

$$\dot{m}_{c1} = \dot{m}_{e1} = \frac{\dot{Q}_{e1}}{(\Phi_1 - \Phi_{10})} \quad (2.2)$$

$$\dot{m}_{e2} = \frac{\dot{Q}_{e2}}{(\Phi_3 - \Phi_9)} \quad (2.3)$$

$$\dot{m}_{f1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_3)}{(\Phi_3 - \Phi_9)} \quad (2.4)$$
$$\dot{m}_{c2} = \dot{m}_{c1} + \dot{m}_{e2} + \dot{m}_{f1} \quad (2.5)$$
$$\dot{m}_{e3} = \frac{\dot{Q}_{e3}}{(\Phi_5 - \Phi_8)} \quad (2.6)$$
$$\dot{m}_{f2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_5)}{(\Phi_5 - \Phi_8)} \quad (2.7)$$
$$\dot{m}_{c3} = \dot{m}_{c2} + \dot{m}_{e3} + \dot{m}_{f2} \quad (2.8)$$

2.1.2 Power required running the compressors

$$P_{c1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_1)}{60} \quad (2.9)$$
$$P_{c2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_3)}{60} \quad (2.10)$$
$$P_{c3} = \frac{\dot{m}_{c3}(\Phi_6 - \Phi_5)}{60} \quad (2.11)$$

2.1.3 Energetic performance

$$\text{Energetic performance} = \frac{\dot{Q}_e}{P_c * 60} \quad (2.12)$$

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

Compressors

$$(\mathrm{T_o\dot{S}_{gen}})_{c1} = \dot{\mathrm{W}}_{c1} + \dot{\mathrm{m}}_{c1}(\mathrm{X}_2 - \mathrm{X}_1) \quad (2.13)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{c2} = \dot{\mathrm{W}}_{c2} + \dot{\mathrm{m}}_{c2}(\mathrm{X}_4 - \mathrm{X}_3) \quad (2.14)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{c3} = \dot{\mathrm{W}}_{c3} + \dot{\mathrm{m}}_{c3}(\mathrm{X}_6 - \mathrm{X}_5) \quad (2.15)$$

Total irreversibility due to compressors

$$\dot{\Psi}_c = (\mathrm{T_o\dot{S}_{gen}})_{c1} + (\mathrm{T_o\dot{S}_{gen}})_{c2} + (\mathrm{T_o\dot{S}_{gen}})_{c3} \quad (2.16)$$

Evaporators

$$(\mathrm{T_o\dot{S}_{gen}})_{e1} = \dot{\mathrm{m}}_{e1}(\mathrm{X}_1 - \mathrm{X}_{10}) - \dot{\mathrm{Q}}_{e1}\left(1 - \frac{\mathrm{T_o}}{\mathrm{T_{r1}}}\right) \quad (2.17)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{e2} = \dot{\mathrm{m}}_{e2}(\mathrm{X}_3 - \mathrm{X}_9) - \dot{\mathrm{Q}}_{e2}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r2}}}\right) \quad (2.18)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{e3} = \dot{\mathrm{m}}_{e3}(\mathrm{X}_5 - \mathrm{X}_8) - \dot{\mathrm{Q}}_{e3}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r3}}}\right) \quad (2.19)$$

Total irreversibility due to evaporators

$$\dot{\Psi}_e = (\mathrm{T_o\dot{S}_{gen}})_{e1} + (\mathrm{T_o\dot{S}_{gen}})_{e2} + (\mathrm{T_o\dot{S}_{gen}})_{e3} \quad (2.20)$$

Condenser

$$\dot{\Psi}_{\mathrm{cond}} = (\mathrm{T_o\dot{S}_{gen}})_{\mathrm{cond}} = \dot{\mathrm{m}}_{c3}(\mathrm{X}_6 - \mathrm{X}_7) - \dot{\mathrm{Q}}_{\mathrm{e}}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_r}}\right) \quad (2.21)$$

Throttle Valves

$$(\mathrm{T_o\dot{S}_{gen}})_{tv1} = \dot{\mathrm{m}}_{e1}(\mathrm{X}_{77} - \mathrm{X}_{10}) \quad (2.22)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{tv2} = (\dot{\mathrm{m}}_{e2} + \dot{\mathrm{m}}_{f1})(\mathrm{X}_{77} - \mathrm{X}_9) \quad (2.23)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{tv3} = (\dot{\mathrm{m}}_{e3} + \dot{\mathrm{m}}_{f2})(\mathrm{X}_{77} - \mathrm{X}_8) \quad (2.24)$$

Total irreversibility due to throttle valves

$$\dot{\Psi}_{tv} = (\mathrm{T_o\dot{S}_{gen}})_{tv1} + (\mathrm{T_o\dot{S}_{gen}})_{tv2} + (\mathrm{T_o\dot{S}_{gen}})_{tv3} \quad (2.25)$$

Subcooler

$$\dot{\Psi}_{sc} = (\mathrm{T_o\dot{S}_{gen}})_{sc} = \dot{\mathrm{m}}_{c3}(\mathrm{X}_7 - \mathrm{X}_{77}) \quad (2.26)$$

Flash intercoolers

$$(\mathrm{T_o\dot{S}_{gen}})_{f1} = \dot{\mathrm{m}}_{f1}(\mathrm{X}_9 - \mathrm{X}_3 + \dot{\mathrm{m}}_{c1}(\mathrm{X}_2 - \mathrm{X}_3) \quad (2.27)$$
$$(\mathrm{T_o\dot{S}_{gen}})_{f2} = \dot{\mathrm{m}}_{f2}(\mathrm{X}_8 - \mathrm{X}_5) + \dot{\mathrm{m}}_{c1}(\mathrm{X}_4 - \mathrm{X}_5) \quad (2.28)$$

Total irreversibility due to flash intercoolers

$$\dot{\Psi}_f = (\mathrm{T_o\dot{S}_{gen}})_{f1} + (\mathrm{T_o\dot{S}_{gen}})_{f2} \quad (2.29)$$

Total irreversibility destruction in system-1

$$\sum \dot{\Psi}_{\mathrm{k}} = \dot{\Psi}_{\mathrm{e}} + \dot{\Psi}_{\mathrm{c}} + \dot{\Psi}_{\mathrm{cond}} + \dot{\Psi}_{\mathrm{tv}} + \dot{\Psi}_{\mathrm{sc}} + \dot{\Psi}_{\mathrm{f}} \quad (2.30)$$

3. Energy–Exergy analysis of Vapour compression refrigeration systems using multiple evaporators at different temperatures with compound compression, flash intercooler and multiple throttle valves (system-2)

The main components of Multiple evaporators at different temperatures with compound compression, flash intercooler and multiple throttle valves (system-2) are compressors ($C1', C2', C3'$) throttle valves ($TV1', TV2', TV3'$), condenser (cond$'$) and evaporators ($EP1', EP2', EP3'$) as shown in Fig. 2. Exergy at any state is given as

$$\mathrm{X} = (\Phi - \Phi_0) - \mathrm{T}_0(\mathrm{s} - \mathrm{s}_0) \quad (3.1)$$

3.1 Energetic analysis

3.1.1 Mass flow analysis

$$\dot{m}_{c1'} = \dot{m}_{e1'} = \frac{\dot{Q}_{e1'}}{(\Phi_{1'} - \Phi_{12'})} \quad (3.2)$$
$$\dot{m}_{e2'} = \frac{\dot{Q}_{e2'}}{(\Phi_{3'} - \Phi_{10'})} + \dot{m}_{c1'}\left(\frac{x_{10'}}{1 - x_{10'}}\right) \quad (3.3)$$
$$\dot{m}_{f1'} = \frac{\dot{m}_{c1'}(\Phi_{2'} - \Phi_{3'})}{(\Phi_{3'} - \Phi_{10'})} \quad (3.4)$$
$$\dot{m}_{c2'} = \dot{m}_{c1'} + \dot{m}_{e2'} + \dot{m}_{f1'} \quad (3.5)$$
$$\dot{m}_{e3'} = \frac{\dot{Q}_{e3'}}{(\Phi_{5'} - \Phi_{8'})} + \dot{m}_{c2'}\left(\frac{x_{8'}}{1 - x_{8'}}\right) \quad (3.6)$$
$$\dot{m}_{f2'} = \frac{\dot{m}_{c2'}(\Phi_{4'} - \Phi_{5'})}{(\Phi_{5'} - \Phi_{8'})} \quad (3.7)$$

3.1.2 Power required for running the compressors

$$P_{c1'} = \frac{\dot{m}_{c1'}(\Phi_{2'} - \Phi_{1'})}{60} \quad (3.8)$$
$$P_{c2'} = \frac{\dot{m}_{c2'}(\Phi_{4'} - \Phi_{3'})}{60} \quad (3.9)$$
$$P_{c3'} = \frac{\dot{m}_{c3'}(\Phi_{6'} - \Phi_{5'})}{60} \quad (3.10)$$

3.1.3 Energetic performance

$$\text{Energetic performance} = \frac{\dot{Q}_{e'}}{P_{c'} * 60} \quad (3.11)$$

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

Compressor

$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c1'}} = \dot{\mathrm{W}}_{\mathrm{c1'}} + \dot{\mathrm{m}}_{\mathrm{c1'}}(\mathrm{X_{2'}} - \mathrm{X_{1'}}) \quad (3.12)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c2'}} = \dot{\mathrm{W}}_{\mathrm{c2'}} + \dot{\mathrm{m}}_{\mathrm{c2'}}(\mathrm{X_{4'}} - \mathrm{X_{3'}}) \quad (3.13)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c3'}} = \dot{\mathrm{W}}_{\mathrm{c3'}} + \dot{\mathrm{m}}_{\mathrm{c3'}}(\mathrm{X_{6'}} - \mathrm{X_{5'}}) \quad (3.14)$$

Total irreversibility due to compressors

$$\dot{\Psi}_{\mathrm{c'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c1'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c2'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c3'}} \quad (3.15)$$

Evaporators

$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{e1'}} = \dot{\mathrm{m}}_{\mathrm{e1'}}(\mathrm{X_{1'}} - \mathrm{X_{12'}}) - \dot{\mathrm{Q}}_{\mathrm{e1'}}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r1'}}}\right) \quad (3.16)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{e2'}} = \dot{\mathrm{m}}_{\mathrm{e2'}}(\mathrm{X_{3'}} - \mathrm{X_{10'}}) - \dot{\mathrm{Q}}_{\mathrm{e2'}}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r2'}}}\right) \quad (3.17)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{e3'}} = \dot{\mathrm{m}}_{\mathrm{e3'}}(\mathrm{X_{5'}} - \mathrm{X_{8'}}) - \dot{\mathrm{Q}}_{\mathrm{e3'}}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r3'}}}\right) \quad (3.18)$$

Total irreversibility due to evaporators

$$\dot{\Psi}_{\mathrm{c'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c1'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c2'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{c3'}} \quad (3.19)$$

$$\dot{\Psi}_{\mathrm{cond'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{cond'}} = \dot{\mathrm{m}}_{\mathrm{c3'}}(\mathrm{X_{6'}} - \mathrm{X_{7'}}) - \dot{\mathrm{Q}}_{\mathrm{e'}}\left(1 - \frac{\mathrm{T_0}}{\mathrm{T_{r'}}}\right) \quad (3.20)$$

Throttle Valves

$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv1'}} = \dot{\mathrm{m}}_{\mathrm{e1'}}(\mathrm{X_{11'}} - \mathrm{X_{12'}}) \quad (3.21)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv2'}} = \dot{\mathrm{m}}_{\mathrm{c2'}}(\mathrm{X_{9'}} - \mathrm{X_{10'}}) \quad (3.22)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv3'}} = \dot{\mathrm{m}}_{\mathrm{c3'}}(\mathrm{X_{77'}} - \mathrm{X_{8'}}) \quad (3.23)$$

Total irreversibility due to throttle valves

$$\dot{\Psi}_{\mathrm{tv'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv1'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv2'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{tv3'}} \quad (3.24)$$

$$\dot{\Psi}_{\mathrm{sc'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{sc'}} = \dot{\mathrm{m}}_{\mathrm{c3'}}(\mathrm{X_{7'}} - \mathrm{X_{77'}}) \quad (3.25)$$

Flash intercoolers

$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{f1'}} = \dot{\mathrm{m}}_{\mathrm{f1'}}(\mathrm{X_{10'}} - \mathrm{X_{3'}}) + \dot{\mathrm{m}}_{\mathrm{c1'}}(\mathrm{X_{2'}} - \mathrm{X_{3'}}) \quad (3.26)$$
$$(\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{f2'}} = \dot{\mathrm{m}}_{\mathrm{f2'}}(\mathrm{X_{8'}} - \mathrm{X_{5'}}) + \dot{\mathrm{m}}_{\mathrm{c2'}}(\mathrm{X_{4'}} - \mathrm{X_{5'}}) \quad (3.27)$$

Total irreversibility due to flash intercoolers

$$\dot{\Psi}_{\mathrm{f'}} = (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{f1'}} + (\mathrm{T_o}\dot{\mathrm{S}}_{\mathrm{gen}})_{\mathrm{f2'}} \quad (3.28)$$

Total irreversibility destruction in system-1

$$\sum \dot{\Psi}_{\mathrm{k'}} = \dot{\Psi}_{\mathrm{e'}} + \dot{\Psi}_{\mathrm{c'}} + \dot{\Psi}_{\mathrm{cond'}} + \dot{\Psi}_{\mathrm{tv'}} + \dot{\Psi}_{\mathrm{sc'}} + \dot{\Psi}_{\mathrm{f'}} \quad (3.29)$$

3.3 Computation of Rational Efficiency

$$\text{Rational efficiency} = \frac{\text{Exergy of cooling load of evaporators}}{\text{Compressors work}} = \frac{\dot{\mathrm{EP}}}{\dot{\mathrm{W}}} \quad (3.30)$$

For System-1, the rational efficiency or exergetic efficiency can be expressed as

$$\text{Rational efficiency} = \frac{(\dot{\mathrm{Q}}_{\mathrm{e1}} + \dot{\mathrm{Q}}_{\mathrm{e2}} + \dot{\mathrm{Q}}_{\mathrm{e3}}) - \mathrm{T_o}\left(\frac{\dot{\mathrm{Q}}_{\mathrm{e1}}}{\mathrm{T_{r1}}} + \frac{\dot{\mathrm{Q}}_{\mathrm{e2}}}{\mathrm{T_{r2}}} + \frac{\dot{\mathrm{Q}}_{\mathrm{e3}}}{\mathrm{T_{r3}}}\right)}{P_c * 60} \quad (3.31)$$

For System-2, the rational efficiency or exergetic efficiency can be expressed as

$$\text{Rational efficiency} = \frac{(\dot{\mathrm{Q}}_{\mathrm{e1'}} + \dot{\mathrm{Q}}_{\mathrm{e2'}} + \dot{\mathrm{Q}}_{\mathrm{e3'}}) - \mathrm{T_o}\left(\frac{\dot{\mathrm{Q}}_{\mathrm{e1}}}{\mathrm{T_{r1'}}} + \frac{\dot{\mathrm{Q}}_{\mathrm{e2}}}{\mathrm{T_{r2'}}} + \frac{\dot{\mathrm{Q}}_{\mathrm{e3}}}{\mathrm{T_{r3'}}}\right)}{\mathrm{P_{c'}} * 60} \quad (3.32)$$

4. Result and Discussion

For carrying out the energetic and exergetic analysis a numerical model has been developed. Comparison of multiple evaporators at different temperatures with compound compression and flash intercooler with individual and multiple throttle valves and impact of chosen refrigerants on these systems was made using Engineering Equation Solver software [7].In this investigation following assumptions were made

1. Loads ($\dot{Q}_{e1}$, $\dot{Q}_{e2}$ and $\dot{Q}_{e3}$) on the evaporators EP_1, EP_2 and EP_3 are 35KW, 70KW and 105KW respectively.
2. Dead state temperature (T_0): 298K
3. Difference between evaporator and space temperature (T_r-T_e):5K.
4. Adiabatic efficiency of compressor (η_c):76%.
5. Dead state enthalpy (Φ_0) and entropy (s_0) of the refrigerants have been calculated corresponding to the dead state temperature (T_0) of 298K.
6. Temperature of evaporators EP_1, EP2 and EP3 are 263K, 273K and 283K respectively.
7. Condenser Temperature (T_c): 313 K
8. Degree of sub cooling (ΔT_{sc}): 10K.

Analysis of multi-stage vapour compression refrigerator and flash intercooler with individual or multiple throttle valves has been done in terms of COP, second law efficiency and irreversibility destruction. Energetic and exergetic performance of system-1 is higher than system-2 for selected temperature range of condenser and evaporators with chosen ecofriendly refrigerants. For both systems M 32 shows minimum thermal performance in terms of COP, second law efficiency and irreversibility. The validation of results for system-1 is given Table-1(a) respectively.

4.1 For System-1: Vapour compression refrigeration systems using multiple evaporators at different temperatures with compound compression, flash intercooler and individual throttle valves

Table-1(a): Validation of Results of VCRS for 100% compressor efficiency:Q_EVA_1=35"kW" Q_EVA_2=70"kW" Q_EVA_3=105 "kW"

Parameter	Program	Ref [12]
COP	6.44	6.50
Total Work (KW)	32.61	32.77

The performance of actual systems were carried out and shown in Table-1(b) & table-1(c) respectively. It was observed that system-2 gives less thermodynamic performance than system-1 for all refrigerants.

Table-1(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	COP	EDR	% ETA_II	Exergy_Fuel (KW)	Exergy_ Product (KW)	Rational efficiency	Second Law efficiency
R12	5.134	1.963	0.3375	40.9	13.81	0.3375	0.5747
R134a	5.091	1.988	0.3347	41.25	13.81	0.3347	0.5699
R1234yf	5.0	2.042	0.3287	42.0	13.81	0.3287	0.5597
R1234ze	5.112	1.975	0.3361	41.08	13.81	0.3361	0.5722
R-32	4.89	2.111	0.3215	42.95	13.81	0.3215	0.5473
R227ea	4.902	2.103	0.3223	42.84	13.81	0.3223	0.5488
R236fa	5.093	1.986	0.3346	41.23	13.81	0.3348	0.5701
R245fa	5.26	1.892	0.3458	39.93	13.81	0.3458	0.5888
R123	5.299	1.87	0.3484	39.63	13.81	0.3484	0.5932

Table-1.(c) Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Loss_ Subcooler	% Loss_ (F1+F2)	% Loss_ Total
R12	10.34	7.058	27.91	18.87	2.039	0.02573	66.25
R134a	10.26	7.744	27.35	18.94	2.208	0.0240	66.53
R1234yf	8.505	8.545	28.21	19.23	2.632	0.00107	67.13
R1234ze	9.905	8.066	26.91	19.27	2.231	0.00393	66.39
R-32	9.892	7.104	30.63	17.76	2.366	0.1042	67.85
R227ea	9.733	10.28	25.67	19.29	2.806	0.0059	67.77
R236fa	10.30	8.199	26.62	19.30	2.095	0.000753	66.52
R245fa	10.51	6.29	27.8	19.25	1.553	0.009836	65.42
R123	10.38	5.634	28.63	19.06	1.429	0.02436	65.16

4.2 System-2 :Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers

Table-2(a): Validation of Results of VCRS for 100% compressor efficiency using following loads Q_EVA_1=105"kW" Q_EVA_2=70"kW" Q_EVA_3=35"kW"

Parameter	Program	Ref [13]
COP	6.193	5.56
Total Work (KW)	33.91	38.4

The performance of actual systems were carried out and shown in Table-2(b) & table-2(c) respectively. It was observed that system-2 gives less thermodynamic performance than system-1 for all refrigerants. Although eco-friendly alternative nine refrigerants can replace R12 for domestic application because R12 has high GWP and ODP. It was observed that R123 gives better thermodynamic performances and also R245fa give similar (slightly less) performance than R123 refrigerant.

Table-2(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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", T_sub Cooler=303 "K" T_Cond=313"K"

Refrigerants	COP	EDR	ETA_II	Exergy_Fuel (KW)	Exergy_Product (KW)	Rational efficiency	II Law efficiency
R12	4.913	1.925	0.3419	42.75	14.62	0.3419	0.6538
R134a	4.864	1.954	0.3315	43.18	14.62	0.3315	0.6473
R1234yf	4.763	2.074	0.3395	44.09	14.62	0.3395	0.6338
R123456	4.877	1.946	0.3395	43.06	14.62	0.3395	0.6491
R-32	4.718	2.045	0.3284	44.51	14.62	0.3284	0.6279
R227ea	4.654	2.087	0.324	45.12	14.62	0.324	0.6194
R236fa	4.852	1.961	0.3377	43.28	14.62	0.3377	0.6457
R245fa	5.028	1.857	0.350	41.77	14.62	0.350	0.6691
R123	5.073	1.832	0.3531	41.39	14.62	0.3531	0.6752
R507a	4.541	2.164	0.3161	46.24	14.62	0.3161	0.6044

Table-2.(c) Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Loss_ Sub-cooler	% Loss_ (F1+F2)	% Loss_ Total	Rational efficiency
R12	8.514	9.223	26.74	19.29	1.984	0.06303	65.81	0.3419
R134a	8.261	10.15	26.19	19.35	2.144	0.0472	66.15	0.3315
R1234yf	6.386	11.27	27.09	19.59	2.534	0.0001	66.85	0.3395
R1234ze	7.822	10.6	25.86	19.62	2.152	0.0001	66.05	0.3395
R-32	8.194	9.226	28.58	18.84	2.355	0.4131	68.39	0.3284
R227ea	7.195	13.47	24.61	19.65	2.673	0.0001	67.6	0.324
R236fa	8.143	10.85	25.57	19.74	2.01	0.001834	66.23	0.3377
R245fa	8.748	8.398	26.75	19.70	1.501	0.03014	65.0	0.350
R123	8.792	7.499	27.53	19.55	1.385	0.07858	64.69	0.3531
R507a	7.275	9.226	23.89	19.42	3.517	0.0122	68.39	0.3161

The thermodynamic analysis developed in section 2 have been modified for finding the performances of systems-3.

4.3 System-3 : Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers

Table-3(a) :Validation of Results of VCRS for 100% compressor efficiency using following loads Q_EVA_1=105"kW" Q_EVA_2=70"kW" Q_EVA_3=35"kW"

Parameter	Program	Ref [13]
COP	5.7940	4.90
Total Work (KW)	36.25	42.64

Table-3(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of ofvapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	COP	EDR	ETA_II	Exergy_Fuel (KW)	Exergy_Product (KW)	Rational efficiency	Second Law efficiency
R12	4.332	1.296	0.4588	48.48	22.24	0.4445	0.5765
R134a	4.28	1.336	0.4532	49.07	22.24	0.4382	0.5696
R1234yf	4.177	1.405	0.4423	50.23	22.24	0.4293	0.5559
R-32	4.151	1.383	0.4395	50.6	22.24	0.4289	0.5524
R227ea	4.08	1.849	0.4321	51.47	22.24	0.4145	0.543
R236fa	4.272	1.357	0.4524	49.15	22.24	0.4347	0.5686
R245fa	4.44	1.244	0.4702	47.3	22.24	0.4544	0.5908
R123	4.485	1.207	0.475	46.2	22.24	0.4608	0.5969

Table-3.(c) Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Loss_ Subcooler	% Loss_ (F1+F2)	% Loss_ Total
R12	5.297	8.778	25,89	19.37	1.876	0.08344	57.54
R134a	5.843	9.616	25.61	19.41	2.039	0.06972	56.17
R1234yf	5.076	10.54	26.92	19.62	2.438	0.00255	57.03
R-32	4.741	9.463	27.61	18.84	2.223	0.4131	57.01
R227ea	7.302	12.52	24.85	19.65	2.596	0.0001	58.55
R236fa	6.626	9.795	25.27	19.69	1.926	0.001834	56.53
R245fa	5.455	7.434	25.91	19.61	1.419	0.03014	54.56
R123	4.65	6.687	26.42	19.51	1.302	0.07858	53.91

The thermodynamic analysis developed in section 3 have been modified for finding the performances of systems-4.

4.4 System-4 : Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers

Table-4(a) :Validation of Results of VCRS for 100% compressor efficiency using following loads Q_EVA_1=105"kW" Q_EVA_2=70"kW" Q_EVA_3=35"kW"

Parameter	Program	Ref [13]
COP	5.797	5.56
Total Work (KW)	36.25	38.4

Table-4(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	COP	EDR	% ETA_II	Exergy_Fuel (KW)	Exergy_Product (KW)	Rational efficiency	Second Law efficiency
R12	4.589	1.143	0.4860	45.76	22.24	0.4445	0.6107
R134a	4.576	1.159	0.4846	45.89	22.24	0.4382	0.6089
R1234yf	4.537	1.188	0.4805	46.29	22.24	0.4293	0.6038
R-32	4.396	1.227	0.4656	47.77	22.24	0.4289	0.5851
R227ea	4.492	1.231	0.4757	46.75	22.24	0.4145	0.5978
R236fa	4.616	1.159	0.4877	45.60	22.24	0.4347	0.6129
R245fa	4.70	1.096	0.4977	44.68	22.24	0.4544	0.6255
R123	4.709	1.081	0.4986	44.6	22.24	0.4608	0.6266

Table-4.(c) Exergy Destruction of various components based on exergy of fuel of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) 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",

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Loss_ Subcooler	% Loss_ (F1+F2)	% Loss_ Total
R12	4.146	4.748	25,27	19.41	1.876	0.08344	55.55
R134a	4.599	5.092	24.91	19.46	2.039	0.06972	56.19
R1234yf	3.686	5.247	26.03	19.68	2.438	0.00255	57.07
R-32	3.66	5.193	26.97	18.84	2.223	0.4131	57.11
R227ea	5.872	6.463	23.90	19.72	2.596	0.0001	58.55
R236fa	5.294	3.837	24.5	19.74	1.926	0.001834	56.53
R245fa	4.272	5.066	25.3	19.70	1.419	0.03014	54.56
R123	3.574	3.535	25.87	19.55	1.302	0.07858	53.92

5. Conclusion

Analysis multiple evaporators at different temperature with compound compression and flash intercooler with individual throttle valves and multiple evaporators at different temperature with compound compression and flash intercooler with multiple throttle valves have been made in terms of energetic efficiency, exergetic efficiency and irreversibility destruction and from the current study following conclusions were made:

(i) Energetic and exergetic performance of system-1 is higher than system-2 for selected temperature range of condenser and evaporators for chosen ecofriendly refrigerants.
(ii) System defect in sytem-1is less as compare with system-2, therefore system-1 is better system than system-2 for

selected ecofriendly refrigerants.

(iii) R32 shows minimum performance in terms of first law efficiency, second law efficiency and system defect for both systems.

(iv) Performances of R245fa are slightly lower than R123 however it's higher than R236fa and R134a better with comparison of other selected refrigerants for system-1 and system-2. But R123 containing chrine content although has lower GWP and R227ef, R236fa and R245fa are high GWP than R134aand limited to industrial application, therefore R1234yf is recommended for both systems for replacing HFC-134a refrigerant in near future.

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Nomenclature

COP	coefficient of performance (non-dimensional)
VCR	vapour compression refrigeration
CFC	chlorofluorocarbon
HCFC	hydrochlorofluorocarbon
$\dot{Q}$	rate of heat transfer (kW)
$\dot{W}$	work rate (kW)
T	temperature (K)
ΔT_{sc}	degree of subcooling
$\dot{E}P$	exergy rate of product (kW)
TV	throttle valve
φ	dryness fraction(non-dimensional)
EP	evaporator
Ψ	specific enthalpy (kJ/kg)
$\dot{E}D$	rate of exergy destruction (kW)
E_x	exergy rate of fluid (kW)
$\dot{m}$	mass flow rate (kg/s)
s	specific entropy (kJ/kgK)
$\dot{E}F$	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
r	refrigerant, space to be cooled
TV	throttle valve
sc	subcooler
k	kth component
cond	condenser
ev	expansion valve
ex	exergetic

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