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Thermodynamic analysis of vapour compression refrigeration systems using alternative refrigerants

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Abstract

Two methods for predicting thermal performances of various vapour compression refrigeration systems have been considered in this paper. The numerical computation was carried out for fifteen multiple and compressor systems refrigeration systems for different loads on various evaporators using (i) first method known as energy – exergy analysis for finding exergy destruction ratio and exergetic efficiency and first law efficiency in terms of COP (coefficient of performance) and second method is known as irreversibility prediction using entropy generation principle considered the exergy defects (losses) in the various components and computing total exergy destruction ratio and rational efficiency and second law efficiency. It was observed that by altering the load on the evaporators, the thermal performances effects significantly.

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

1. Introduction

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 irreversibility in the vapour compression refrigeration systems, but also provides more meaningful assessment of power plant individual components efficiency.

A conventional exergetic analysis reveals irreversibility 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 irreversibility 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 system components using energy-conversion concept. With this concept, various efficiencies can be evaluated in the VCRS, and the process steps having the largest losses (i.e., the greatest margin for improvement) can be identified. For these reasons, the modern entropy generation principles 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.

2. Energy Exergy Analysis of Vapour Compression Refrigeration Systems

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

Many researchers have carried out exergy studies of different thermal energy conversion systems describing various approach for exergy analysis and its usefulness for improving existing designs by reducing exergy destruction in a more simple and effective manner [1-3]. Yumrutas et. al [4,7] investigated of the effects of the evaporating and

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condensing temperatures on the pressure losses, exergy losses, second law of efficiency, and the COP of a vapour compression cycle. Dincer [5] asserts that conventional energy analysis, based on the first law of thermodynamics, evaluates energy mainly on its quantity but analysis that are based on second law considers not only the quality of energy, but also quantity of energy. Kumar et al. [6] also computed the exergetic analysis of a VCR system using R11 and R12 as refrigerants. Nikolaidis and Probert [7] used exergy method for calculating ting thermodynamic performances of R22 in a two-stage compound compression cycle, with flash intercooling. Bejan [8] developed, thermodynamic model by using heat transfer irreversibility and showed that the exergetic efficiency decreases as evaporator temperature decreases.

3. Results and Discussion

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 .By using R245fa it becomes 20% while using R123 it has 20.43% .In the case comparing R134a, R1234yf and R1234ze , it becomes 16.15% by using R134a and when R1234yf is used it becomes less around 15.8% as 16.16% by using R134a.and 18.3% by using R1234ze. The maximum exergy destruction in the system components it is found maximum (i.e. higher) in the condenser and low in the throttle valves. By comparing alternative refrigerants, the exergy destruction is low by using R227ea around 35.4% and maximum by using R32 In the case of using HFO refrigerants for replacing HFC-134a and other Refrigerants, it is around similar trends with slightly less by using R1234yf, around 41.22% as compared to R134a is 41.94%. In case of compressors it is almost similar trends, however, it is higher 35.49% when R1234yf is used and 34.8% when R1234ze is used as compared to 34.5% when R134a is used. It becomes 34.8% when R227ea is used and 34.07% when R245fa is used as compared to R134a is used it becomes 35.5%. Still it is also varying by using different alternative refrigerants. It gives higher exergy destruction by using R227ea and lowest by using R23. By comparing exergy destruction by using HFO refrigerants for replacing R134a, it gives 7.624% by using R1234yf as higher as comparing with R134a but 7.457% by using R1234ze as compared to R134a around 7.402%.The first law efficiency in terms of COP (coefficient of performance)by using alternative refrigerants , the maximum COP is found 3.766 by using R123 while by using R245fa it becomes slightly less around 3.727. Similarly exergetic efficiency is higher by using M-32 and slightly less by using HFO refrigerants 28.59% by using R1234yf and 28.82% by using R1234ze as compared to R134a is 29.97%. The total power required to run whole system in terms of exergy of fuel is high by using M-32 is 61.52 "kW' and low by using R123 is 55.76 "kW' for 210 kW of total load of evaporator.

Vapour compressor refrigeration system with multiple evaporators at different temperatures with single compressor, individual expansion valves using following data:

Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35 kW, T_EVA_1=268 "K",T_EVA_2=273 "K" ,T_EVA_3=28 3"K"

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves (System-1) for energy-exergy- analysis. To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-1 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-1(b) to Table-1 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table-1(a) Validation of results of vapour compressor refrigeration system with Multiple evaporators at different temperatures with single compressor for 100% compressor efficiency

Parameter	*Program*	*Ref [13]*
COP	*5.232*	*4.80*
Total Work (KW)	*40.14*	*43.73*

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=0.80) , $T_{\_EVA\_1}$=268"K", $T_{\_EVA\_2}$=273"K", $T_{\_EVA\_3}$=280"K", Effect of superheating= 5°C , T_R=T_EVA+5, (i.e. T_R_1=273"K", T_R _2=278"K", T_R_3=285"K"), Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_Cond=303"K", T_subcooled=303"K"

Refrigerants	First law Efficiency (System COP)	System EDR	Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	4.185	1.823	0.3204	50.18	16.08	0.4033
R134a	4.140	1.861	0.3155	50.71	16.0	0.3974
R1234yf	4.061	1.946	0.3041	51.71	15.73	0.3843
R1234ze	4.164	1.917	0.3092	50.43	15.59	0.3913
R227ea	3.966	2.152	0.2842	52.95	15.05	0.3620
R236fa	4.14	2.093	0.2921	50.73	14.82	0.3731
R245fa	4.297	1.911	0.3120	48.87	15.25	0.3964

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=0.80) , $T_{\_EVA\_1}$=268"K", $T_{\_EVA\_2}$=273"K", $T_{\_EVA\_3}$=280"K", Effect of superheating= 5°C , T_R=T_EVA+5, (i.e. T_R_1=273"K", T_R _2=278"K", T_R_3=285"K"), Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_Cond=303"K", T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	Total % Losses	Second Law effectiveness
R12	11.20	4.495	24.49	18.21	64.57	0.3543
R134a	11.68	4.834	23.9	18.31	65.05	0.3495
R1234yf	11.21	5.114	24.03	18.82	66.05	0.3303
R1234ze	12.47	4.969	23.10	18.74	65.72	o.3228
R227ea	14.22	6.22	21.69	19.02	68.27	0.3173
R236fa	14.62	4.93	22.57	19.01	67.67	0.3233
R245fa	13.24	3.767	23.93	18.69	65.65	0.3435

Table-1.(d) Exergy Destruction of various components based on Total exergy destruction of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1=0.80) , $T_{\_EVA\_1}$=268"K", $T_{\_EVA\_2}$=273"K", $T_{\_EVA\_3}$=280"K", Effect of superheating= 5°C , T_R=T_EVA+5, (i.e. T_R_1=273"K", T_R _2=278"K", T_R_3=285"K"), Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_Cond=303"K", T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	Second law Effectiveness	% Irreversibility= Total Exergy Losses to the Exergy of Fuel
R12	19.18	7.696	41.93	31.17	0.3543	64.57
R134a	19.89	8.239	40.7	31.18	0.3495	65.05
R1234yf	18.95	8.642	40.61	31.8	0.3303	66.05
R1234ze	21.04	8.381	38.96	31.62	o.3228	65.72
R227ea	23.26	10.17	35.46	31.11	0.3173	68.27
R236fa	23.92	8.066	36.92	31.09	0.3233	67.67
R245fa	22.21	6.317	40.13	31.34	0.3435	65.65

System-2 : vapour compressor refrigeration system with Multiple evaporators at different temperatures with multiple compressors, individual expansion valves ($Q_{\_EVA\_1}$=105"kW" $Q_{\_EVA\_2}$=70"kW" $Q_{\_EVA\_3}$=35"kW"). We considered vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves (System-2) for energy-exergy- analysis . To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-6 for 100% compressors efficiency were compared and shown in Table-2(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(b) to Table-2 (c) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-2(a) Thermal Performances (First law efficiency and Second law efficiency, etc.) of 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", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Q_EVA_3=105"kW',T_subcooled=303"K"

Refrigerants	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	5.697	2.195	30.58	36.86	11.27	0.7569
R134a	5.654	2.213	30.35	37.14	11.27	0.7524
R1234yf	5.560	2.253	29.85	37.77	11.27	0.740
R1234ze	5.624	2.199	30.49	36.97	11.27	0.7559
R-32	5.445	2.320	29.23	38.56	11.27	0.7247
R227ea	5.461	2.309	29.32	38.45	11.27	0.7268
R236fa	5.664	2.213	30.45	37.08	11.27	0.7538
R245fa	5.832	2.136	31.34	35.97	11.27	0.7769
R123	5.877	2.118	31.55	35.73	11.27	0.7821

T*able-2.(b)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", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Q_EVA_3=105"kW',T_subcooled=303"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	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 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", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Q_EVA_3=105"kW',T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	%Irreversibility	Second 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

System-3: Vapour compressor refrigeration system with multiple evaporators at different temperatures with multiple compression, individual expansion valves

(*Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35"kW" T_EVA_1=268"K", T_EVA_2=273"K", T_EVA_3=278"K")*

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves (System-3) for energy-exergy- analysis. To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-3 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-3(b) to Table-3 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-3(a) Validation of Results of Vapour compressor refrigeration system with Multiple evaporators at different temperatures with multiple compression, individual expansion valves for 100% compressor efficiency (Q_{EVA_1}=70"kW" Q_{EVA_2}=105"kW" Q_{EVA_3}=35"kW"T_{EVA_1}=268"K", T_{EVA_2}=273"K", T_{EVA_3}=278"K)

Parameter	Program	Ref [13]
COP	6.128	5.56
Total Work (KW)	34.27	38.4

Table-3(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at different temperatures with multiple compression, individual expansion valves Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35"kW"T_{EVA_1}=268"K", T_{EVA_2}=273"K", T_{EVA_3}=278"K using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) T_{EVA_1}=268"K", T_{EVA_2}=273"K", T_{EVA_3}=278"K", T_R_1=273"K", T_R_2=278"K", T_R_3=283"K", Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_subcooled=303"K"

Refrigerants	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Second Law Efficiency
R12	4.902	1.798	36.98	42.89	15.82	
R134a	4.877	1.824	36.74	43.06	15.82	
R1234yf	4.815	1.866	36.27	43.61	15.82	
R1234ze	4.908	1.816	36.97	42.79	15.82	
R-32	4.629	1.937	34.87	45.37	15.82	0.7247
R227ea	4.744	1.935	35.74	44.26	15.82	
R236fa	4.895	1.837	36.88	42.9	15.82	
R245fa	5.023	1.749	37.84	41.81	15.82	
R123	5.046	1.722	0.3801	41.62	15.82	0.7821

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}=268"K", T_{EVA_2}=273"K", T_{EVA_3}=278"K", T_R_1=273"K", T_R_2=278"K", T_R_3=283"K", Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Total Exergy Destruction	Second Law effectiveness
R12	14.95	5.868	27.07	18.51	66.40	0.3360
R134a	15.47	6.386	26.57	18.59	67.01	0.3299
R1234yf	14.46	6.892	27.36	18.97	67.68	0.3232
R1234ze	15.51	6.599	26.04	19.0	67.15	0.3285
R-32	13.75	6.013	30.66	17.11	67.53	0.3247
R227ea	16.73	8.431	24.97	19.02	69.15	0.3085
R236fa	16.33	6.624	25.76	19.04	67.75	0.3225
R245fa	16.38	5.013	26.8	18.98	66.17	0.3383
R123	14.58	4.536	27.58	18.74	65.44	0.3456

Table-3.(d) Exergy Destruction of various components based on Total exergy destruction 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", Q_{EVA_1}=35 "kW', Q_{EVA_2}=70"kW', Q_{EVA_3}=105"kW',T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Irreversibility	Second Law effectiveness
R12	22.52	8.837	40.77	27.83	66.40	0.3360
R134a	23.08	9.529	39.65	27.75	67.01	0.3299
R1234yf	21.37	10.18	40.42	28.03	67.68	0.3232
R1234ze	23.10	9.828	38.78	28.30	67.15	0.3285
R-32	20.36	8.903	45.4	25.34	67.53	0.3247
R227ea	24.2	12.19	36.11	27.51	69.15	0.3085
R236fa	24.10	9.776	38.02	28.10	67.75	0.3225
R245fa	23.24	7.577	40.5	28.68	66.17	0.3383
R123	22.28	6.931	42.15	28.64	65.44	0.3456

System-4 : Vapour compressor refrigeration system with Multiple evaporators at different temperatures with multiple compression with individual expansion valves **(**Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35 "kW", T_EVA_1=268 "K", T_EVA_2=273"K", T_EVA_3=278 "K") We considered vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves (System-4) for energy-exergy- analysis . To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-4 for 100% compressors efficiency were compared and shown in Table-4(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-4(b). It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

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Table-4(a) Validation of Results of vapour compression refrigeration system with multiple evaporators at different temperatures with multiple compression with individual expansion valves for 100% compressor efficiency

Parameter	Program	Ref [13]
COP	5.938	5.56
Total Work (KW)	35.37	38.4

Table-4(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) $T_{\_EVA}\_1$=268"K", $T_{\_EVA}\_2$=273"K", $T_{\_EVA}\_3$=278"K", T_R_1=273"K", T_R _2=278"K", T_R_3=283"K", Q_EVA_1=70 "kW', Q_EVA_2=105"kW', Q_EVA_3=35"kW',T_subcooled=303"K"

Refrigerants	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy of Fuel (KW)	Exergy of Product (KW)	% Exergy Losses	Rational Efficiency	Second Law effectiveness
R12	4.723	2.195	35.58	44.47	15.82	64.42	0.3558	0.5266
R134a	4.676	2.213	35.23	44.91	15.82	64.77	0.3523	0.5235
R1234yf	4.582	2.253	34.51	45.83	15.82	65.49	0.3451	0.5123
R1234ze	4.691	2.199	35.34	44.74	15.82	64.66	0.3534	0.5261
R227ea	4.48	1.963	33.75	46.87	15.82	66.25	0.3375	0.5016
R236fa	4.668	1.844	35.16	44.99	15.82	64.84	0.3516	0.5225
R245fa	4.835	1.746	36.42	43.43	15.82	63.58	0.3642	0.5412

System-5: Vapour compressor refrigeration system with Multiple evaporators at different temperatures with single compressor, multiple expansion valves and back pressure valves for Q_EVA_1=105"kW" Q_EVA_2=70"kW" Q_EVA_3=35"kW"

Table-5(a) Validation of Results of vapour compressor refrigeration system with multiple evaporators at different temperatures with single compressor, multiple expansion valves and back pressure valves for 100% compressor efficiency

Parameter	Program	Ref [13]
COP	4.530	4.53
Total Work (KW)	46.36	46.7

Table-5(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	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	3.624	1.709	30.56	57.95	17.74	0.3784
R134a	3.579	1.747	29.97	58.68	17.59	0.3715
R1234yf	3.509	1.842	28.59	59.85	17.91	0.356
R1234ze	3.603	1.846	28.82	58.28	16.8	0.360
R-32	3.414	1.328	35.86	61.52	22.06	0.4298
R227ea	3.419	2.088	26.18	61.41	16.08	0.3295
R236fa	3.582	2.074	26.67	58.62	15.64	0.3374
R245fa	3.727	1.871	28.90	56.35	16.28	0.3629

R123	3.766	1.934	28.43	55.76	15.85	0.3587

Table-5.(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	Total % Losses	Second Law efficiency
R12	8.06	3.638	22.58	17.94	0.6216	0.3784
R134a	8.462	3.875	21.96	18.06	0.6285	0.3715
R1234yf	8.317	4.015	21.71	18.62	0.6440	0.356
R1234ze	9.74	3.968	20.99	18.51	0.640	0.360
R-32	0.3281	3.796	27.23	16.47	0.5792	0.4208
R227ea	11.37	4.915	19.35	19.03	0.6705	0.3295
R236fa	12.25	3.916	20.35	18.33	0.6626	0.3374
R245fa	10.84	3.004	21.81	18.42	0.6371	0.3629
R123	11.24	2.782	22.94	18.05	0.6413	0.3587

Table-5.(d) Exergy Destruction of various components based on Total exergy destruction 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
R12	15.44	6.968	43.24	34.36
R134a	16.16	7.402	41.94	34.49
R1234yf	15.79	7.624	41.22	35.36
R1234ze	18.30	7.457	39.45	34.79
R-32	12.23	7.972	56.75	34.59
R227ea	10.58	7.078	35.4	34.81
R236fa	12.12	8.991	36.78	34.04
R245fa	20.04	7.078	40.33	34.07
R123	20.43	5.057	41.70	32.81

System-6: Vapour compressor refrigeration system with multiple evaporators at different temperatures with individual compressors, individual expansion valves

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves (System-6) for energy-exergy- analysis. To validate computational results from developed thermal model of system-6, the following input values have been taken. The computed results of system-6 for 100% compressors efficiency were compared and shown in Table-6(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-6(b) to Table-6 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-6(a): Validation of Results of vapour compressor refrigeration system with multiple evaporators at different temperatures with individual compressors, individual expansion valves for 100% compressor efficiency using following loads Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35"kW"

Parameter	Program	Ref [12]
COP	5.938	5.88
Total Work (KW)	35.37	35.72

Table-6(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	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Second Law efficiency
R12	4.505	2.186	31.36	46.62	14.62	0.5995
R134a	4.399	2.264	30.72	47.74	14.62	0.5854

R1234yf	4.204	2.418	29.26	49.96	14.62	0.5594
R1234ze	4.379	2.281	30.48	47.95	14.62	0.5828
R-32	4.336	2.298	30.18	48.43	14.62	0.5770
R227ea	4.018	2.575	27.97	52.26	14.62	0.5348
R236fa	4.329	2.319	30.13	48.51	14.62	0.5761
R245fa	4.612	2.114	32.10	45.53	14.62	0.6138

Table-6.(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	Total % Losses	Second Law efficiency
R12	8.81	13.73	26.23	19.29	58.64	31.36
R134a	8.572	15.2	26.18	19.35	69.38	30.72
R1234yf	6.854	17.24	27.06	19.59	70.74	29.26
R1234ze	8.178	15.87	25.84	19.63	69.52	30.48
R-32	8.479	13.89	28.60	18.38	69.82	30.18
R227ea	7.622	20.2	24.55	19.66	72.03	27.97
R236fa	8.465	16.21	25.54	19.65	69.87	30.13
R245fa	8.996	12.54	26.74	19.59	67.90	32.10

Table-6.(d) Exergy Destruction of various components based on Total exergy destruction 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
R12	12.85	20.02	38.99	26.14
R134a	12.27	21.93	37.78	27.92
R1234yf	9.685	24.36	38.25	27.69
R1234ze	11.76	22.83	37.17	28.23
R-32	12.23	20.03	41.27	26.51
R227ea	10.58	28.05	34.08	27.29
R236fa	12.12	23.2	36.55	28.13
R245fa	13.26	18.48	39.4	28.81

System-7: Vapour compressor refrigeration system with Multiple evaporators at different temperatures with individual compressors, individual expansion valves for different evaporator loads.

($Q_{\_EVA\_1}$=70"kW" $Q_{\_EVA\_2}$=105"kW" $Q_{\_EVA\_3}$=35"kW" $T_{\_EVA\_1}$=263"K", $T_{\_EVA\_2}$=278"K", $T_{\_EVA\_3}$=283"K).

Thermal analysis of vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves (System-7) is carried out . To validate computational results from developed thermal model of system-7, the following input values have been taken. The computed results of system-7 for 100% compressors efficiency were compared and shown in Table-7(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-7(b) to Table-7 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-7(a) : Validation of Results of vapour compressor refrigeration system with Multiple evaporators at different temperatures with individual compressors, individual expansion valves($Q_{\_EVA\_1}$=70"kW" $Q_{\_EVA\_2}$=105"kW" $Q_{\_EVA\_3}$=35"kW" for 100% compressor efficiency

Parameter	Program	Ref [12]
COP	5.683	5.96
Total Work (KW)	36.95	35.24

Table-7(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system using alternative refrigerants for actual conditions: 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	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	4.505	2.186	0.3136	46.62	14.62	0.5995
R134a	4.399	2.264	0.3062	47.74	14.62	0.5854
R1234yf	4.204	2.418	0.2926	49.96	14.62	0..5594
R1234ze	4.379	2.281	0.3048	47.95	14.62	0.5828
R-32	4.336	2.298	0.3018	48.43	14.62	0.5770
R227ea	4.018	2.575	0.2797	52.26	14.62	0.5348
R236fa	4.329	2.319	0.3013	48.51	14.62	0.5761
R245fa	4.612	2.114	0.3210	45.53	14.62	0.6138
R123	4.714	2.045	0.3281	44.55	14.62	0.6273

Table-7.(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	Total % Losses	Second Law efficiency
R12	8.81	13.73	26.73	19.29	68.56	0.3144
R134a	8.572	15.20	26.18	19.35	69.31	0.3069
R1234yf	6.854	17.24	27.06	19.59	70.75	0.2925
R1234ze	8.1781	15.87	25.84	19.63	69.51	0.3049
R-32	8.479	13.89	28.60	18.38	69.35	0.3065
R227ea	7.622	20.20	24.55	19.66	72.03	0.2797
R236fa	8.465	16.21	25.54	19.65	69.87	0.3013
R245fa	8.996	12.54	26.74	19.59	67.87	0.3213
R123	9.039	11.13	27.52	19.42	67.11	0.3289

Table-7.(d) Exergy Destruction of various components based on Total exergy destruction of vapour compression refrigeration system using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80)

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp
R12	12.85	20.02	38.99	28.14
R134a	12.37	21.93	37.78	27.92
R1234yf	9.689	24.36	38.25	27.69
R1234ze	11.76	22.83	37.17	28.23
R-32	12.23	20.03	41.24	26.51
R227ea	10.58	28.05	34.08	27.29
R236fa	12.12	23.20	36.55	28.13
R245fa	13.26	18.48	39.4	28.87
R123	13.47	16.59	41.0	28.94

System-8(a): Vapour compressor refrigeration system with multiple evaporators at different temperatures with individual compressors, multiple expansion valves

We considered vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves (System-8). To validate computational results from developed thermal model of system-8, the following input values have been taken. The computed results of system-8 for 100% compressors efficiency were compared and shown in Table-8(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-8(b) to Table-8 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table-8(a): Validation of Results of VCRS for 100% compressor efficiency (Q_EVA_1=70"kW" Q_EVA_2=105"kW" Q_EVA_3=35"kW")

Parameter	*Program*	*Ref [13]*
COP	*6.485*	*6.25*
Total Work (KW)	*32.38*	*33.6*

Table-8(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compression refrigeration system using alternative refrigerants for actual conditions(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	First law Efficiency (System COP)	EDR	% Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	5.188	1.81	36.11	40.48	14.62	0.6904
R134a	5.113	1.825	36.01	40.59	14.62	0.6885
R1234yf	5.127	1.848	35.69	40.96	14.62	0.6824
R1234ze	5.213	1.810	36.26	40.29	14.62	0.6937
R-32	4.894	1.958	34.06	42.91	14.62	0.6515
R227ea	5.072	1.898	35.30	41.40	14.62	0.675
R236fa	5.207	1.824	36.24	40.33	14.62	0.693
R245fa	5.318	1.758	37.02	40.48	14.62	0.7078
R123	5.331	1.742	37.61	39.49	14.62	0.7095

Table-8 (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	Total % Losses	Second Law efficiency
R12	13.66	4.847	28.35	18.5	65.35	0.3465
R134a	14.02	5.219	27.88	18.59	65.70	0.3430
R1234yf	12.69	5.475	28.30	18.97	65.96	0.3404
R1234ze	13.95	5.337	27.39	19.0	65.67	0.3437
R-32	12.85	5.116	31.80	17.12	66.68	0.3332
R227ea	14.83	6.765	26.4	19.02	67.01	0.3299
R236fa	14.68	5.273	27.13	19.04	66.12	0.3388
R245fa	14.04	5.116	28.11	18.97	65.09	0.3491
R123	13.41	3.634	28.88	18.73	64.66	0.3534

Table-8.(d) Exergy Destruction of various components based on Total exergy destruction 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
R12	20.90	7.416	43.37	28.31
R134a	21.33	7.941	42..34	28.30
R1234yf	19.21	8.301	43.71	28.76
R1234ze	21.24	8.127	41.70	28.93
R-32	18.96	7.671	47.69	25.67
R227ea	22.12	10.09	39.40	28.38
R236fa	22.2	7.975	41.03	28.80
R245fa	21.57	6.096	43.19	29.15
R123	20.74	5.057	41.70	28.31

System-9: Vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-9) for thermal (energy-exergy analysis. To validate computational results from developed thermal model of system-9, the following input values have been taken. The computed results of system-9 for 100% compressors efficiency were compared and shown in Table-9(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, multiple expansion valves and flash intercoolers are shown in Table-9(b) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table-9(a): Validation of Results of Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers for 100% compressor efficiency (Q_{EVA_1}=70"kW" Q_{EVA_2}=105"kW" Q_{EVA_3}=35"kW

Parameter	Program	Ref [10]
COP	5.683	5.960
Total Work (KW)	36.95	35.24

Table 9-.(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	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_ Fuel (KW)	Exergy_ Product (KW)	% Exergetic Efficiency_II	Second Law Efficiency	%Total Exergy Defect
R12	4.723	1.811	0.3558	44.47	15.82	0.3598	0.5286	64.42
R134a	4.676	1.839	0.3523	44.91	15.82	0.3523	0.5235	64.77
R1234yf	4.582	1.897	0.3451	45.83	15.82	0.3451	0.5129	65.49
R1234ze	4.691	1.83	0.3534	44.76	15.82	0.3534	0.5251	64.66
R227ea	4.481	1.963	0.3375	46.87	15.82	0.3375	0.5016	66.25
R236fa	4.668	1.844	0.3516	44.99	15.82	0.3516	0.5225	64.89
R245fa	4.835	1.746	0.3642	43.43	15.82	0.3642	0.5412	63.58

***System-10**:* Vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers

We considered vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-10).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, multiple expansion valves and flash intercoolers are shown in Table-10(a) and Table-10 (b) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table 10-.(a) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) T_{EVA_1}=268"K", T_{EVA_2}=273"K", T_{EVA_3}=278"K", T_R_1=268"K", T_R _2=283"K", T_R_3=288"K", Q_EVA_1=35"kW,Q_EVA_2=70"kW" Q_EVA_3=105"kW"

Refrigerants	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	%Total Exergy Defect	% Exergetic Efficiency_II
R12	5.26	1.892	0.3458	39.93	13.81	0.6625	0.5888
R134a	5.091	1.988	0.3347	41.25	13.81	0.6653	0.5699
R1234yf	5.0	2.042	0.3287	42.0	13.81	0.6713	0.5597
R1234ze	5.112	1.975	0.3361	41.08	13.81	0.6639	0.5722
R227ea	4.902	2.103	0.3223	42.84	13.81	0.6777	0.5488
R236fa	5.093	1.986	0.3348	41.23	13.81	0.6652	0.5701
R245fa	5.134	1.983	0.3375	40.9	13.81	0.6542	0.5747

Table 10-.(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers using alternative refrigerants (for Compressor efficiency_1= Compressor efficiency_2= Compressor efficiency_3=0.80) $T_{\_EVA}\_1$=268"K", $T_{\_EVA}\_2$=273"K", $T_{\_EVA}\_3$=278"K", T_R_1=268"K", T_R _2=283"K", T_R_3=288"K", Q_EVA_1=35"kW,Q_EVA_2=70"kW" Q_EVA_3=105"kW"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% loss sub cooler	%Total Exergy Defect	% Exergetic Efficiency_II
R12	9.960	7.448	27.91	18.875	2.039	0.6625	0.5888
R134a	9.841	8.17	27.35	18.94	2.208	0.6653	0.5699
R1234yf	8.063	8.99	28.21	19.23	2.631	0.6713	0.5597
R1234ze	9.484	8.49	26.91	19.27	2.23	0.6639	0.5722
R227ea	9.22	10.79	25.67	19.29	2.806	0.6777	0.5488
R236fa	9.881	8.617	26.62	19.3	2.095	0.6652	0.5701
R245fa	10.18	6.622	27.8	19.25	1.553	0.6542	0.5747

System-11*:* We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-11) for thermodynamic analysis. 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, multiple expansion valves and flash intercoolers are shown in Table-11(a) and Table-11 (b) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table 11-.(a) 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", Q_EVA_1=105"kW" Q_EVA_2=35"kW ,Q_EVA_3=70"kW"

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Refrigerants	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_ Fuel (KW)	Exergy_Product (KW)	%Total Exergy Defect	Rational Efficiency
R12	4.713	1.813	0.3555	44.56	15.84	64.45	0.3448
R134a	4.666	1.841	0.3520	45.01	15.84	64.8	0.3448
R1234yf	4.57	1.90	0.3448	45.95	15.84	65.52	0.3448
R1234ze	4.68	1.832	0.3531	44.87	15.84	64.69	0.3448
R227ea	4.467	1.967	0.3371	47.01	15.84	66.29	0.3448
R236fa	4.656	1.847	0.3513	45.11	15.84	64.87	0.3448
R245fa	4.824	1.747	0.3640	43.53	15.84	63.60	0.3448

Table 11-.(b) Exergy Destruction of various components based on exergy of product 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", Q_EVA_1=105"kW" Q_EVA_2=35"kW ,Q_EVA_3=70"kW"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% loss sub cooler	%Total Exergy Defect	Rational Efficiency_II	% Exergetic Efficiency_II
R12	9.312	8.156	25.99	19.06	1.899	64.45	0.3555	0.5275
R134a	4.733	8.962	25.44	19.13	2.054	64.8	0.3520	0.5235
R1234yf	7.563	9.921	26.19	19.41	2.444	65.52	0.3448	0.5129
R1234ze	8.816	9.351	25.01	19.44	2.073	64.69	0.3531	0.5251
R227ea	8.571	11.88	23.78	19.46	2.599	66.29	0.3371	0.5016
R236fa	9.21	9.545	24.71	19.47	1.945	64.87	0.3513	0.5225
R245fa	9.494	7.367	25.87	19.2	1.445	63.60	0.364	0.5412

System-12

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-12). To validate computational results from developed thermal model of system-12, the following input values have been taken. The computed results of system-13 for 100% compressors efficiency were compared and shown in Table-12 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, multiple expansion valves and flash intercoolers are shown in Table-12(b) and 12 (c) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table-12(a): Validation of Results of Vapour compression refrigeration system with Multiple evaporators at different temperatures with compound compression, individual expansion valves and flash intercoolers for 100% compressor efficiency using following loads ($Q_{\_EVA\_1}$=35"kW" $Q_{\_EVA\_2}$=70"kW" $Q_{\_EVA\_3}$=105"kW") at following temperatures ($T_{\_EVA\_1}$=263"K", $T_{\_EVA\_2}$=278"K", $T_{\_EVA\_3}$=283"K)

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

Table-12(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	First law Efficiency (System COP)	EDR	Exergetic Efficiency	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-12.(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)	% Total Loss/ Irreversibility
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

We considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-13). To validate computational results from developed thermal model of system-13, the following input values have been taken. The computed results of system-13 for 100% compressors efficiency were compared and shown in Table-13 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, multiple expansion valves and flash intercoolers are shown in Table-13(b) and 13 (c) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances.

Table-13(a):Validation of Results of Vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers 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 [10]
COP	5.794	4.90
Total Work (KW)	36.25	42.64

Table-13(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	First law Efficiency (System COP)	EDR	Exergetic Efficiency	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-13.(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)	% Total Loss /Irreversibility
R12	4.146	4.748	25,27	19.41	1.876	0.08344	57.54
R134a	4.599	5.092	24.91	19.46	2.039	0.06972	56.17
R1234yf	3.686	5.247	26.03	19.68	2.438	0.00255	57.03
R-32	3.66	5.193	26.97	18.84	2.223	0.4131	57.01
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	53.91

System-14: The thermal performances in terms of first law efficiency using energy-exergy analysis is presented in Table-14(a) to Table-14 (d) respectively .Table-14(b)to Table-14(d) represented irreversibility computation using entropy generation principles. The various losses occurred in terms of exergy destruction in components (Exergy defects) in the system components shown in Table-14(b),to Table-14(d) respectively. The considered vapour compressor refrigeration system with multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-14) is used for thermodynamic analysis. To validate computational results from developed thermal model of system-14, the following input values have been taken. The computed results of system-14 for 100% compressors efficiency were compared and shown in Table-14(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, multiple expansion valves and flash intercoolers are shown in Table-14(b) to table-14 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-14(a) : *) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at same temperature with single compressor, individual expansion valves using alternative refrigerants (Validation of Results of VCRS for 100% compressor efficiency) for given data: T_{EVA_1}=268"K", T_{EVA_2}=268"K", T_{EVA_3}=268"K", T_R_1=273"K", T_R_2=273"K", T_R_3=273"K", Q_EVA_1=35 "kW', Q_EVA_2=105"kW', Q_EVA_3=70"kW', T_cond=313"K"*

Parameter	*Program*	*Ref [13]*
COP	*5.232*	*5.07*
Total Work (KW)	*40.14*	*41.4*

Table-14(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at same temperature with single compressor, individual expansion valves *using alternative refrigerants (for Compressor efficiency_1=0.80, T_EVA_1=268"K", T_EVA_2=268"K", T_EVA_3=268"K", T_R_1=273"K", T_R _2=273"K", T_R_3=273"K", Q_EVA_1=35 "kW', Q_EVA_2=105"kW', Q_EVA_3=70"kW', T_cond=313"K"T_subcooled=303"K"*

Refrigerants	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency
R12	4.186	1.585	0.3833	50.17	19.23	0.4685
R134a	4.137	1.591	0.3789	50.76	19.23	0.4632
R1234yf	4.039	1.645	0.3698	52.0	19.23	0.4521
R1234ze	4.144	1.586	0.3795	50.68	19.23	0.4638
R-32	3.959	1.706	0.3626	53.04	19.23	0.4432
R227ea	3.927	1.715	0.3596	53.47	19.23	0.4396
R236fa	4.112	1.609	0.3766	51.07	19.23	0.4603
R245fa	4.281	1.518	0.3920	49.05	19.23	0.4792
R123	4.328	1.493	0.3964	48.52	19.23	0.4845

Table-14.(c)Exergy Destruction of various components based on exergy of fuel of vapour compressor refrigeration system with Multiple evaporators at same temperature with single compressor, individual expansion valves *using alternative refrigerants (for Compressor efficiency_1=0.80, T_EVA_1=268"K", T_EVA_2=268"K", T_EVA_3=268"K", T_R_1=273"K", T_R _2=273"K", T_R_3=273"K", Q_EVA_1=35 "kW', Q_EVA_2=105"kW', Q_EVA_3=70"kW', T_cond=313"K"T_subcooled=303"K"*

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	Total % Losses	Rational Efficiency(%)
R12	8.521	9.039	24.0	18.42	59.98	40.02
R134a	8.394	9.961	23.41	18.52	60.28	39.72
R1234yf	6.966	11.17	23.72	18.96	60.82	39.18
R1234ze	8.0	10.5	22.71	18.98	60.19	39.81
R-32	8.061	8.620	28.31	16.86	61.85	38.15
R227ea	7.78	13.47	21.4	19.02	61.67	38.33
R236fa	8.372	10.83	22.34	19.04	60.59	39.41
R245fa	8.651	8.357	23.54	18.95	59.5	40.5
R123	8.617	7.451	24.42	18.68	61.85	38.15

Table-14.(d) Exergy Destruction of various components based on exergy of product of vapour compressor refrigeration system with Multiple evaporators at same temperature with single compressor, individual expansion valves *using alternative refrigerants (for Compressor efficiency_1=0.80, T_EVA_1=268"K", T_EVA_2=268"K", T_EVA_3=268"K", T_R_1=273"K", T_R _2=273"K", T_R_3=273"K", Q_EVA_1=35 "kW', Q_EVA_2=105"kW', Q_EVA_3=70"kW', T_cond=313"K"T_subcooled=303"K"*

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	Total % Irreversibility	Secnd Law Efficiency
R12	14.21	15.07	40.01	30.17	59.98	0.4685
R134a	13.92	16.52	38.83	30.73	60.28	0.4632
R1234yf	11.45	18.37	38.99	31.18	60.82	0.4521
R1234ze	13.29	17.45	37.72	31.74	60.19	0.4638
R-32	13.03	13.95	45.77	27.26	61.85	0.4432
R227ea	12.61	21.84	34.70	30.84	61.67	0.4396
R236fa	13.82	17.88	36.87	31.43	60.59	0.4603
R245fa	14.54	14.04	39.57	31.85	59.5	0.4792
R123	14.56	12.9	41.27	31.57	58.52	0.4845

***System-15*:** Vapour compressor refrigeration system with Multiple evaporators at different temperatures with single compressor, individual expansion valves and back pressures valves. The considered vapour compressor refrigeration system with Multiple evaporators at different temperatures with compound compression, multiple expansion valves and flash intercoolers (System-15) is used for thermodynamic analysis. To validate computational results from developed thermal model of system-14, the following input values have been taken. The computed results of system-14 for 100% compressors efficiency were compared and shown in Table-15(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, multiple expansion valves and flash intercoolers are shown in Table-15(b) to table-15 (d) respectively. It was found that refrigerant R123 gives highest COP and R-245fa give slightly less performances

Table-15(a) Validation of Results of vapour compressor refrigeration system with Multiple evaporators at different temperatures with single compressor, individual expansion valves and back pressures valves using alternative refrigerants (for Compressor efficiency_1=1.0 T_{EVA}_1=263"K", T_{EVA}_2=273"K", T_{EVA}_3=283"K", T_R_1=268"K", T_R _2=278"K", T_R_3=288"K", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Effect of super heating =5°C, Q_EVA_3=105"kW',T_subcooled=303"K"

Parameter	Program	Ref [10]
COP	4.162	4.38
Total Work (KW)	33.64	31.9

Table-15(b) Thermal Performances (First law efficiency and Second law efficiency, etc.) of vapour compressor refrigeration system with Multiple evaporators at different temperatures with single compressor, individual expansion valves and back pressures valves 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", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Q_EVA_3=105"kW',T_subcooled=303"K"

Refrigerants	First law Efficiency (System COP)	EDR	Exergetic Efficiency	Exergy_Fuel (KW)	Exergy_Product (KW)	Secnd Law Efficiency	Rational efficiency
R12	3.33	2.62	0.2811	42.05	11.82	0.5991	0.3480
R134a	3.243	2.786	0.2738	43.16	11.82	0.5193	0.3390
R1234yf	3.10	3.117	0.2582	45.16	11.66	0.4925	0.3203
R1234ze	3.239	2.97	0.2632	43.22	11.38	0.5075	0.3279
R227ea	2.948	3.692	0.2351	47.5	11.16	0.457	0.2938
R236fa	3.197	3.295	0.2441	43.8	11.69	0.4838	0.3074
R245fa	3.423	2.741	0.2669	40.9	11.92	0.5241	0.3349

Table-15.(c) Exergy Destruction of various components based on Total exergy destruction 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", Q_EVA_1=35 "kW', Q_EVA_2=70"kW', Q_EVA_3=105"kW',T_subcooled=303"K"

Refrigerants	% loss Eva	% loss valve	% loss Condenser	% loss comp	% Irreversibility= Total Exergy Losss/ Exergyof Fuel	Rational Efficiency
R12	2.936	42.06	30.65	24.36	65.20	0.3480
R134a	2.892	44.87	28.75	23.68	66.10	0.3390
R1234yf	1.431	48.48	26.91	23.18	67.97	0.3203
R1234ze	3.421	46.08	26.8	23.70	67.21	o.3279
R227ea	3.15	52.89	22.22	21.94	70.62	0.2938
R236fa	5.455	45.86	25.25	23.45	69.26	0.3074
R245fa	5.868	39.14	29.97	25.20	66.51	0.3349

4. Conclusion

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) By altering evaporator load effects thermal performances considerably.

(iv) The maximum exergy destruction in the system components it is found maximum (i.e. higher) in the condenser and low in the throttle valves.

(v) 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

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