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Performance parameters optimization of cascade refrigeration system using ecofriendly refrigerants

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Abstract

The present paper presents optimum thermodynamic performance of three cascade vapour compression refrigeration systems. The numerical thermal model have been developed for two stages cascade refrigeration systems and thermodynamic performances in terms of and first law efficiency, second law efficiency system exergy destruction ratio , first law efficiency of lower temperature and high temperature circuit have been computed. The effect of low temperature evaporator on the system first and second law performances and system exergy destruction ratio it was found that as low temperature evaporator temperature is decreasing , the first law and second law efficiencies are increasing and exergy destruction ratio is decreasing .The optimum performance parameters obtained from thermal model have been presented.

Keywords: Optimal two stages cascade refrigeration systems, HFO Refrigerants, Thermal modelling

1. Introduction

The refrigeration industry has been working for the past few decades to find replacement refrigerants for the ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) being phased out as a result of the Montreal Protocol. The solution for most refrigerant producers has been the commercialization of hydrofluorocarbon (HFC) refrigerants. The new HFC refrigerants, HFC-134a being the most widely used at this time, have zero ozone depletion potential and thus are not affected by the current regulatory phase out as a result of the Montreal Protocol. The refrigeration industry has been working for the past few decades to find replacement refrigerants for the ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) being phased out as a result of the Montreal Protocol.
Global warming potential (GWP) is an index for estimating relative global warming contribution due to atmospheric emission of a kilogram of a particular greenhouse gas compared to emission of a kilogram of carbon dioxide. GWP can be calculated for different time horizons showing the effect of atmospheric lifetime for a given gas. The GWP for the 100 year time horizon is commonly the value referenced.
The new ecofriendly refrigerant (hydrofluoroolefin) HFO-1234ze, has zero ozone-depletion potential and meets EU regulatory requirements for reducing the use of high global-warming-potential (GWP) substances such as R134a etc.. This fourth-generation technology is a direct replacement for hydrofluorocarbon R-134a in the low temperature applications as of today, HFOs found in a number of applications. In refrigeration and heat pump technology HFO-1234yf has been chosen to replace R134a. A number of the refrigerants have been suggested to substitute R134a. R-1234yf, for instance, has very low GWP of 4 and zero ODP. The Thermal performance of R-1234yf in R-134a system have similar coefficient of performance (COP), but R-1234yf provides much lower capacity. Energy conservation and environmental concerns are the main reasons for the development growth of new low GWP refrigerants. While the direct contribution of all the proposed refrigerants to global warming is lower than that of R134a.

2. Literature review

Zubair [1] evaluated the thermal performance of vapour compression system and experimental investigation and theoretical study of a different type of two-stage vapor compression cascade refrigeration system. Bansal P.K [2]

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carried out the thermal analysis of cascade refrigeration system using R717in high temperature circuit and R744 refrigerant in the low temperature circuit. Bhattacharyya et al [3] carried out the thermal performance of a cascade heat pump system and developed thermal model which incorporated both internal and external irreversibility in the system. Agnew et al [4] also computed the first law performance of a cascade refrigeration systems. Mishra [5] studied thermal performances in terms of COP and exergetic efficiency and system exergy destruction ratio (EDR) for very low temperature application using ethane in the low temperature circuits and R1234ze and R1234yf in higher temperature circuit. Kilicarslan [6] carried out the experimental and theoretical studied of two-stage vapor compression cascade refrigeration system. Lee et al [7] studied thermal performances a cascade refrigeration system by using carbon dioxide in low temperature circuit and ammonia (R717) as refrigerant in high temperature circuit. Samant [8] designed & developed of two stage cascade refrigeration system using carbon dioxide (R744) in low temperature circuit and propane as HTC refrigerant. Mishra [5] studied thermal performances in terms of COP and exergetic efficiency and system exergy destruction ratio (EDR) for very low temperature application using R404a , in the low temperature circuits and R1234ze and R1234yf in higher temperature circuit and found that performance using R404a worked in low temperature circuit up to temperature -135°C respectively. S. Fukuda [10] suggested the use of R1234ze (e) for heat pump application to replace R410a.

3. Utility of HFO Refrigerants in Two Stages Cascade Refrigeration Systems

In the two stages vapour compression cascade refrigeration systems 1,3,3,3-Tetrafluoropropene (HFO-1234ze) is known as hydro-fluoro-olefin was used in the high temperature circuit in the condenser temperature range of 40°C to 60°C and evaporator temperature range of -20°C to 20°C . The HFO R1234ze being a stable refrigerant very low global-warming potential (GWP < 7) for high temperature application used as a "fourth generation" refrigerant to replace R-134a.[1] For low temperature applications, ecofriendly refrigerants such as Carbon dioxide, propane, butane, R152a and HFO1234yf has seen as potential candidates to substitute R134a. Finally, HFO1234yf has been chosen due to its properties, which allow replacing R134a ecofriendly. The use of R-134a is being phased out because of its high global-warming potential. HFO-1234yf has zero ozone-depletion potential (ODP=0) and a very low global-warming potential (GWP < 5), are known for low-temperature refrigeration circuit. The refrigerant R152a is more efficient, where it leads to a system with better COP that alternative refrigerants. Similarly hydrocarbons reach similar or better efficiency.

4. Results & Discussions

The following assumptions have been taken for analyzing two stages cascade vapour compression system for low temperature applications. The cooling load is considered to be 35 kW‖ Temperature of condenser is to be 50°C and temperature of R1234yf evaporator to be -50 °C, The temperature of high temperature evaporator to be 0 °C, The temperature overlapping in terms of approach (i.e.) temperature difference between cascade condenser using R1234yf and cascade evaporator using R1234ze is known as approach which is equal to 10°C.

Input Data

Temperature of high temperature circuit condenser ($T_{\_Cond\_HTC}$)=50 °C,
Temperature of high temperature circuit evaporator $T_{\_Eva\_HTC}$=0 °C,
Temperature of low temperature circuit evaporator $T_{\_Eva\_LTC}$= - 50 °C,
Temperature overlapping (Approach) =10°C
Efficiency of Compressor_HTC=0.80,
Efficiency of Compressor_LTC=0.80

Table-1 shows the variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and following refrigerants in low temperature circuitand it was found that R141(b) and R236fa gives better first law efficiency in terms of COP and second law efficiency in terms of exergetic efficiency.

Table-2(a) shows the effect of approaches (differences in temperature between cascade condenser and cascade evaporators in the various intermediate temperature circuits and low temperature circuit) on the first law and second law performances on the four stage cascade refrigeration systems. It was observed that as approach is decreasing the system first and second law efficiency is increasing and exergy destruction ratio is decreases and lowest COP was found by using R407c.

Table-1 Variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and following refrigerants in low temperature circuit for $T_{\_Cond}$=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= 0°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

LTC Refrigerants	COP	System EDR	Exergetic Efficiency	$EDR_{\_Rational}$	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
R-134a	1.219	1.438	0.4101	0.5899	28.84	11.83	3.737	2.294
R-1234yf	1.181	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
R717	1.206	1.466	0.4055	0.5945	29.17	11.83	3.737	2.256

R141b	1.289	1.307	0.4334	0.5666	27.29	11.83	3.737	2.493
R-404a	1.151	1.584	0.3870	0.6130	30.57	11.83	3.737	2.107
R-410a	1.214	1.45	0.4081	0.5919	28.98	11.83	3.737	2.278
R-407c	1.094	1.717	0.3680	0.6320	32.14	11.83	3.737	1.961
R-152a	1.246	1.386	0.4192	0.5808	28.22	11.83	3.737	2.370
R-227ea	1.131	1.629	0.3804	0.6196	31.09	11.83	3.737	2.056
R-236fa	1.188	1.503	0.3995	0.6005	29.6	11.83	3.737	2.207
R-245fa	1.239	1.40	0.4166	0.5834	28.39	11.83	3.737	2.349
R-32	1.203	1.471	0.4047	0.5953	29.22	11.83	3.737	2.250
R-600a	1.215	1.447	0.4087	0.5923	28.94	11.83	3.737	2.282
R-600	1.243	1.392	0.4180	0.5820	28.3	11.83	3.737	2.360
R-290	1.218	1.442	0.4096	0.5904	28.88	11.83	3.737	2.290
R-123	1.259	1.361	0.4235	0.5735	27.93	11.83	3.737	2.408
R-125	1.13	1.632	0.380	0.620	31.13	11.83	3.737	2.052
R-507a	1.168	1.546	0.3928	0.6072	30.11	11.83	3.737	2.153

Table-2(a) shows as the variation of condenser temperature with thermal performance parameters. It was observed that as condenser temperature decreases overall COP of system (First law efficiency of system) increases and System EDR is decreases and also second law efficiency (exergetic efficiency) increases. While First law efficiency of hot fluid circuit is increases. There will not be effect on other circuit first law efficiencies. The exergetic efficiency and Overall COP of system using R1234ze is higher in the high temperature circuit while system EDR increases. As decreasing High temperature evaporator temperature, the first law efficiency (i.e. overall cop of system) and second law efficiency (i.e. exergetic efficiency of whole system) is is increasing up to maximum value at the evaporator temperature of 20°C and then decreases rapidly.

System-1: HFO-1234ze in HTC and HFO-1234yf in low temperature circuit

Table-2(a) Variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit for $T_{\_Cond}$=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

Effect of Temperature Overlapping (Approach)	COP	System EDR	Exergetic Efficiency	$EDR_{\_Rational}$	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
0	1.402	1.121	0.4715	0.5285	25.08	11.83	3.737	2.844
2	1.356	1.193	0.4561	0.5439	25.93	11.83	3.737	2.698
4	1.312	1.267	0.4412	0.5588	26.81	11.83	3.737	2.562
6	1.269	1.344	0.4267	0.5733	27.72	11.83	3.737	2.435
8	1.227	1.423	0.4127	0.5873	28.66	11.83	3.737	2.316
10	1.187	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
12	1.147	1.592	0.3858	0.6142	30.66	11.83	3.737	2.098

Table-2(b) Variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit for $T_{\_Cond}$=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

HTC Refrigerants	COP	System EDR	Exergetic Efficiency	$EDR_{\_Rational}$	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
R1234ze	1.187	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
R717	1.228	1.422	0.4129	0.5871	28.64	11.83	4.030	2.204
R152a	1.217	1.442	0.4095	0.5905	28.89	11.83	3.955	2.204
R290	1.178	1.523	0.3963	0.6037	29.84	11.83	3.682	2.204
R600	1.217	1.442	0.4095	0.5905	28.89	11.83	3.955	2.204
R600a	1.196	1.486	0.4022	0.5978	29.41	11.83	3.801	2.204
R134a	1.190	1.498	0.4003	0.5997	29.55	11.83	3.762	2.204
R1234yf	1.160	1.564	0.390	0.610	30.32	11.83	3.559	2.204

Table-2(d) .shows as the variation of high temperature evaporator with thermal performance parameters As decreasing High temperature evaporator temperature the system EDR first decreasing up to decreasing evaporator temperature and then further constant and then increasing and optimum becomes at evaporator temperature at 20°C in both cases using R1234ze in the high temperature circuit. However COP of hot fluid circuit is decreases and COP of low temperature fluid circuit is increases.

Table-2(c) Variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit for T_Cond=50ºC with subcooling of 5ºC, $T_{\_Eva\_HTC}$= -10ºC, $T_{\_Eva\_LTC}$=-50ºC, $Q_{\_Eva\_LTC}$=35 "kW"

T_Cond (ºC)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
60	1.024	1.905	0.3443	0.6557	34.35	11.83	2.779	2.204
55	1.104	1.694	0.3712	0.6288	31.86	11.83	3.215	2.204
50	1.187	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
45	1.273	1.336	0.4280	0.5720	27.63	11.83	4.379	2.204
40	1.363	1.182	0.4583	0.5417	25.81	11.83	5.192	2.204
35	1.458	1.039	0.4903	0.5097	24.12	11.83	6.264	2.204
30	1.559	0.9070	0.5244	0.4756	22.56	11.83	7.75	2.204
25	1.667	0.7832	0.5608	0.4392	21.09	11.83	9.962	2.204

Table-2(d) shows the variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit and it was observed that first law performance (COP) of system increases as temperature of HTC evaporator is increases and becomes a optimum values at -6ºC and then and then decreases.

Table-2(d) Variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit for $T_{\_Cond}$=50ºC with subcooling of 5ºC, $T_{\_Eva\_HTC}$= -10ºC, $T_{\_Eva\_LTC}$=-50ºC, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (ºC)	COP	EDR	Exergetic Efficiency	EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
20	1.049	1.836	0.3527	0.6473	33.54	11.83	8.032	1.356
15	1.099	1.706	0.3696	0.6304	32.0	11.83	6.415	1.533
10	1.139	1.611	0.383	0.6170	30.88	11.83	5.264	1.729
5	1.168	1.546	0.3928	0.6072	30.11	11.83	4.404	1.951
4	1.173	1.536	0.3944	0.6056	29.99	11.83	4.257	1.998
3	1.177	1.527	0.3958	0.6042	29.89	11.83	4.118	2.048
2	1.180	1.519	0.3970	0.6030	29.79	11.83	3.985	2.098
1	1.184	1.512	0.3981	0.6019	29.71	11.83	3.858	2.15
0	1.187	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
-1	1.189	1.501	0.3999	0.6001	29.58	11.83	3.622	2.259
-2	1.191	1.497	0.4005	0.5995	29.53	11.83	3.511	2.316
-3	1.193	1.493	0.4011	0.5989	29.49	11.83	3.405	2.374
-4	1.193	1.491	0.4015	0.5985	29.46	11.83	3.304	2.435
-5	1.194	1.489	0.4017	0.5983	29.44	11.83	3.206	2.497
-6	1.195	1.489	0.4018	0.5991	29.43	11.83	3.113	2.562
-7	1.195	1.489	0.4018	0.5982	29.44	11.83	3.023	2.629
-8	1.194	1.490	0.4016	0.5984	29.45	11.83	2.937	2.698
-9	1.193	1.492	0.4014	0.5986	29.47	11.83	2.854	2.77
-10	1.192	1.494	0.4009	0.5991	29.5	11.83	2.744	2.844
-15	1.180	1.519	0.3969	0.6031	29.8	11.83	2.416	3.261
-20	1.159	1.585	0.3899	0.6101	30.33	11.83	2.116	3.777

Table-2(e) shows as the variation of low temperature evaporator with thermal performance parameters using R1234yf in thelow temperature circuit It was observed that As evaporator temperature decreases, the first law efficiency (overall COP) and second law efficiency (exergetic efficiency) of the system is increases and maximum efficiency is obtained at evaporator temperature of -50 ºC and also cop of primary intermediate temperature circuit is decreases and secondary intermediate temperature circuit COP is increases.

Table-2(e) Variation of Thermal performance with variation of LTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFO-1234yf in low temperature circuit for $T_{\_Cond}$=50ºC with subcooling of 5ºC, $T_{\_Eva\_HTC}$= -10ºC, $T_{\_Eva\_LTC}$=-50ºC, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (ºC)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_{LTC}
-50	1.187	1.506	0.3991	0.6009	29.64	11.83	3.737	2.204
-45	1.301	1.504	0.3993	0.6007	27.04	11.83	3.737	2.529

-40	1.426	1.515	0.3977	0.6023	24.67	11.83	3.737	2.921
-35	1.563	1.538	0.3939	0.6061	22.51	11.83	3.737	3.404
-30	1.713	1.578	0.3878	0.6122	20.52	11.83	3.737	4.011
-25	1.88	1.638	0.3790	0.6209	18.71	11.83	3.737	4.795
-20	2.064	1.724	0.3672	0.6328	17.04	11.83	3.737	5.845

The performance of two other cascade systems are given below. The system-2 consists of HFO-1234ze in HTC and HFC-134a in low temperature circuit while system-3 consists of HFO-1234yf in HTC and HFC-134a in low temperature circuit and performances are shown in Tables-3 & Tables 4 respectively. It was also shown from table-3(a) & table-4(a) respectively. For system-2 (Table-3 (a)) and system-3(Table-4 (a)) , as low temperature circuit evaporator temperature decreases from -20^{o}C to -50^{o}C, the first law efficiency (COP) of system is decreases and second law efficiency is increases and rational EDR and EDR system is also decreases. Similarly Table-3(b) shows the variation of Thermal performance with variation of HTC condenser temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFC-134a in low temperature circuit and Table-4(b) shows the variation of Thermal performance with variation of HTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234yf in high temperature circuit and HFC-134a in low temperature circuit and it was found that as high temperature circuit condenser is increase, the first law efficiency in terms of COP is and second law efficiency in terms of exergetic efficiency and High temperature circuit first law efficiency (COP_HTC) are also decreases and exergy destruction ratio of system and rational EDR and exergy of fuel I.e. total power required to run both compressors in cascade system are also increases. Table-3(c) shows (system-3) the variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFC-134a in low temperature circuit and Table-4(c) shows the variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234yf in high temperature circuit and HFC-134a in low temperature circuit and it was found that by increasing temperature of high temperature evaporator , the first law efficiency and second law efficiency in terms of exergetic efficiency increases and becomes optimum exergetic efficiency at temperature of -1^{o}C for system-2 and 1^{o}C for system-3 and then decreases.

System-2; HFO-1234ze in HTC and HFC-134a in low temperature circuit

Table-3(a) Variation of Thermal performance with variation of LTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFC-134a in low temperature circuit for T_Cond=50^{o}C with subcooling of 5^{o}C, $T_{\_Eva\_HTC}$= -10^{o}C, $T_{\_Eva\_LTC}$=-50^{o}C, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (^{o}C)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	$COP_{\_LTC}$
-50	1.219	1.438	0.4101	0.5899	28.84	11.83	3.737	2.294
-45	1.331	1.446	0.4088	0.5912	26.41	10.8	3.737	2.622
-40	1.454	1.465	0.4057	0.5943	24.18	9.811	3.737	3.017
-35	1.589	1.497	0.4005	0.5995	24.14	8.866	3.737	3.503
-30	1.737	1.544	0.3931	0.6069	20.25	7.96	3.737	4.112
-25	1.90	1.611	0.383	0.6170	18.51	7.09	3.737	4.899
-20	2.081	1.702	0.3701	0.6699	16.9	6.255	3.737	5.951

Table-3(b) Variation of Thermal performance with variation of LTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFC-134a in low temperature circuit for $T_{\_Cond}$=50^{o}C with subcooling of 5^{o}C, $T_{\_Eva\_HTC}$= -10^{o}C, $T_{\_Eva\_LTC}$=-50^{o}C, $Q_{\_Eva\_LTC}$=35 "kW"

$T_{\_Cond}$ (^{o}C)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	$COP_{\_LTC}$
25	1.724	0.7246	0.5798	0.4202	20.4	11.83	9.962	2.294
30	1.61	0.8470	0.5414	0.4586	21.84	11.83	7.75	2.294
35	1.503	0.9777	0.5056	0.4944	23.39	11.83	6.264	2.294
40	1.404	1.118	0.4721	0.5279	25.05	11.83	5.192	2.294
45	1.309	1.271	0.4403	0.5597	26.86	11.83	4.379	2.294
50	1.219	1.438	0.4101	0.5899	28.84	11.83	3.737	2.294
55	1.133	1.624	0.3811	0.6189	31.03	11.83	3.215	2.294
60	1.05	1.832	0.3531	0.6469	33.50	11.83	2.779	2.294

Table-3(c) Variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234ze in high temperature circuit and HFC-134a in low temperature circuit for T_Cond=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (°C)	COP	EDR	Exergetic Efficiency	EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_LTC
20	1.134	1.621	0.3815	0.6185	31.01	11.83	8.032	1.485
15	1.169	1.544	0.3930	0.6070	30.09	11.83	6.415	1.652
10	1.194	1.489	0.4017	0.5983	29.44	11.83	5.264	1.838
5	1.211	1.455	0.4074	0.5926	29.03	11.83	4.404	2.050
4	1.214	1.45	0.4082	0.5918	28.98	11.83	4.257	2.096
3	1.216	1.446	0.4088	0.5912	28.93	11.83	4.118	2.144
2	1.217	1.443	0.4094	0.5906	28.89	11.83	3.985	2.192
1	1.218	1.44	0.4098	0.5902	28.86	11.83	3.858	2.242
0	1.219	1.438	0.4101	0.5899	28.84	11.83	3.737	2.324
-1 (optimum)	1.22	1.437	0.4103	0.5897	28.83	11.83	3.622	2.347
-2(optimum)	1.22	1.437	0.4103	0.5897	28.82	11.83	3.511	2.402
-3	1.22	1.437	0.4103	0.5897	28.83	11.83	3.405	2.459
-4	1.219	1.438	0.4101	0.5899	28.84	11.83	3.304	2.518
-5	1.219	1.44	0.4098	0.5902	28.86	11.83	3.206	2.579
-6	1.217	1.442	0.4094	0.5906	28.89	11.83	3.113	2.641
-7	1.216	1.445	0.4089	0.5911	28.92	11.83	3.023	2.706
-8	1.214	1.454	0.4083	0.5917	28.97	11.83	2.937	2.774
-9	1.212	1.454	0.4075	0.5925	29.02	11.83	2.854	2.844
-10	1.209	1.459	0.4067	0.5933	29.08	11.83	2.774	2.916
-15	1.192	1.495	0.4009	0.5991	29.51	11.83	2.416	3.325
-20	1.167	1.548	0.3925	0.6075	30.13	11.83	2.116	3.832

System-3; HFO-1234yf in HTC and HFC-134a in low temperature circuit

Table-4(a) Variation of Thermal performance with variation of LTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234yf in high temperature circuit and HFC-134a in low temperature circuit for T_Cond=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (°C)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_H TC	COP_{LTC}
-50	1.191	1.496	0.4007	0.5993	29.52	11.83	3.559	2.294
-45	1.299	1.507	0.3990	0.6010	27.06	10.8	3.559	2.622
-40	1.417	1.529	0.3954	0.6046	24.81	9.811	3.559	3.017
-35	1.546	1.565	0.3898	0.6102	22.74	8.866	3.559	3.503
-30	1.688	1.618	0.3820	0.6170	20.84	7.96	3.559	4.112
-25	1.843	1.691	0.3717	0.6283	19.08	7.09	3.559	4.899
-20	2.015	1.789	0.3584	0.3416	17.45	6.255	3.559	5.951

Table-4(b) Variation of Thermal performance with variation of LTC evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234yf in high temperature circuit and HFC-134a in low temperature circuit for $T_{\_Cond}$=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (°C)	COP	EDR	Exergetic Efficiency	Rational EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_HTC	COP_{LTC}
25	1.716	0.7325	0.5772	0.4338	20.49	11.83	9.783	2.294
30	1.599	0.8592	0.5379	0.4621	21.99	11.83	7.581	2.294
35	1.49	0.9961	0.5010	0.4990	23.61	11.83	6.099	2.294
40	1.386	1.141	0.4661	0.5339	25.38	11.83	5.026	2.294
45	1.287	1.311	0.4328	0.5672	27.33	11.83	4.208	2.294
50	1.191	1.496	0.4007	0.5993	29.52	11.83	3.559	2.294
55	1.099	1.706	0.3695	0.6305	32.01	11.83	3.027	2.294
60	1.007	1.952	0.3388	0.6612	34.91	11.83	2.579	2.294

Table-4(c) Variation of Thermal performance with variation of cascade evaporator temperature of two stage cascade vapour compression refrigeration system using HFO-1234yf in high temperature circuit and HFO-134a in low temperature circuit for T_Cond=50°C with subcooling of 5°C, $T_{\_Eva\_HTC}$= -10°C, $T_{\_Eva\_LTC}$=-50°C, $Q_{\_Eva\_LTC}$=35 "kW"

T_Eva (°C)	COP	EDR	Exergetic Efficiency	EDR	Exergy of Fuel (kW)	Exergy of Product (kW)	COP_ HTC	COP_LTC
20	1.125	1.642	0.3784	0.6216	31.25	11.83	7.768	1.485
15	1.156	1.572	0.3887	0.6113	30.42	11.83	5.264	1.838
10	1.177	1.526	0.3959	0.6041	29.87	11.83	5.054	1.652
5	1.189	1.501	0.3999	0.6001	29.58	11.83	4.211	2.050
4	1.190	1.498	0.4003	0.5997	29.55	11.83	4.068	2.096
3	1.191	1.496	0.4006	0.5994	29.52	11.83	3.931	2.144
2(optimum)	1.192*	1.495	0.4008	0.5992	29.51	11.83	3.801	2.192
1(optimum)	1.192*	1.495	0.4008	0.5992	29.51	11.83	3.677	2.242
0	1.191	1.496	0.4007	0.5993	29.52	11.83	3.559	2.324
-1	1.191	1.497	0.4005	0.5995	29.53	11.83	3.446	2.347
-2	1.190	1.499	0.4001	0.5999	29.56	11.83	3.338	2.402
-3	1.188	1.502	0.3997	0.6003	29.59	11.83	3.235	2.459
-4	1.187	1.506	0.3991	0.6009	29.64	11.83	3.135	2.518
-5	1.184	1.510	0.3984	0.6016	29.69	11.83	3.04	2.579
-6	1.182	1.515	0.3975	0.6025	29.75	11.83	2.949	2.641
-7	1.179	1.521	0.3966	0.6034	29.82	11.83	2.862	2.706
-8	1.176	1.528	0.3955	0.6045	29.90	11.83	2.778	2.774
-9	1.173	1.536	0.3944	0.6056	29.99	11.83	2.697	2.844
-10	1.169	1.544	0.3931	0.6069	30.09	11.83	2.619	2.916
-15	1.145	1.597	0.3850	0.6150	30.72	11.83	2.271	3.325
-20	1.113	1.670	0.3745	0.6255	31.58	11.83	1.979	3.832

Table-5 and Table-6 shows the optimum value of parameters for three systems

Table- 5: Optimum parameters obtained for three systems

Parameters	System-1; using HFO-1234ze in HTC and HFO-1234yf in LTC	System-2: using HFO-1234ze in HTC and HFC-134a in LTC	System-3: using HFO-1234yf in HTC and HFC-134a in LTC
Optimum HTC evaporator temperature	-6 °C	-1 °C	1 °C
First law efficiency (COP_System)	1.195	1.22	1.192
Exergy Destruction Ratio (EDR)	1.489	1.437	1.495
Exergy of Fuel (kW)=	29.43	28.82	29.51
Exergy of Product (kW)=	11.83	11.83	11.83
Total work done by HTC compressor (kW)	15.71	13.85	13.83
Total work done by LTC compressor (kW)	13.73	14.48	15.68
Mass flow rate in HTC compressor (Kg/sec)	0.4181	0.4164	0.4949
Mass flow rate in LTC compressor (Kg/sec)	0.2805	0.2262	0.2303
Heating Load on cascade Condenser (KW)	48.89	50.15	50.15
Cooling Load on LTC Condenser (KW)	35.167	35.167	35.167
Heating Load on HTC Condenser (KW)	64.6	64.0	64.68
Second law efficiency (Exergetic _Efficiency)	0.4018	0.4103	0.4008
First law circuit efficiency (COP_HTC)	3.113	3.622	3.801
First law circuit efficiency (COP_LTC)	2.562,	2.347	2.192

Table 6: Optimum parameters obtained for three systems

Parameters	System-1; using HFO-1234ze in HTC and HFO-1234yf in LTC	System-2: using HFO-1234ze in HTC and HFC-134a in LTC	System-3: using HFO-1234yf in HTC and HFC-134a in LTC
Optimum HTC evaporator temperature	-7 °C	-2 °C	2 °C
First law efficiency (COP_System)	1.195	1.22	1.192
Exergy Destruction Ratio (EDR)	1.489	1.437	1.495
Exergy of Fuel (kW)	29.44	28.82	29.51
Exergy of Product (kW)	11.83,	11.83	11.83
Total work done by HTC compressor (kW)	16.06	13.85	13.83

Total work done by LTC compressor (kW)	13.38,	14.48	15.68
Mass flow rate in HTC compressor (Kg/sec)	0.4176	0.4164	0.4949
Mass flow rate in LTC compressor (Kg/sec)	0.2777	0.2262	0.2303
Heating Load on cascade Condenser (KW)	48.55	50.15	50.15
Cooling Load on LTC Condenser (KW)	35.167	35.167	35.167
Heating Load on HTC Condenser (KW)	64.6	64.0	64.68
Second law efficiency (Exergetic _Efficiency)	0.4018,	0.4103	0.4008
First law circuit efficiency (COP_HTC)	3.113,	3.622	3.801
First law circuit efficiency (COP_LTC)	2.562,	2.347	2.192

5. Conclusions and Recommendation

The following optimum values of parameters were obtained during numerical investigations for system-1.

(i) The optimum temperature of high temperature evaporator for system-1 was found between -6°C to -7°C, for sytem-2: was found between -1°C to -2°C and for system-3: was found between 1°C to 2°C of temperature. The other value of performance parameters for three cascade systems are given in Table-5 & 6 respectively.

(ii) The volumetric refrigerating capacity of HFO R1234ze is below that of R134a and It\s boiling point is also higher than that of R134a in the high temperature circuit of cascade refrigeration system in the range of HTC Circuit from 60°C to -20°C is suitable for replacing R134a.

(iii) HFO R1234yf is suitable for replacing R134a. in the low temperature circuit of cascade refrigeration system in the range of LTC Circuit from -20°C to -50°C.

(iv) Increasing evaporator temperature overall first law efficiency in terms of COP is increases.

References

[1] S. M. Zubair, [1999]Performance evaluation of Vapour Compression System, International Journal of Refrigeration, 22, , 235-243.

[2] P. K. Bansal, [2008] Thermodynamic analysis of an R744–R717 cascade refrigeration system, international journal of refrigeration Vol-31 , page-45-54.

[3] Souvik Bhattacharyya, [2007] Exergy maximization of cascade refrigeration cycles and its numerical verification for a trans critical CO2-C3H8 system, International Journal of Refrigeration, Vol-30, ,page. 624- 632.

[4] B. Agnew, et.a.,[2004] A finite time analysis of a cascade refrigeration system using alternative refrigerants, Applied Thermal Engineering, Vol-24 , page. 2557–2565.

[5] R.S. Mishra[2014] Use of Hydrocarbons in Low Temperature Circuit in Terms of First Law and Second Law Efficiency of Four Stage Cascade Refrigeration of Semen Preservation" International Journal of Advance Research and Innovation, ISSN 2347 - 3258 , Volume 2, Issue 4, page-725-731.

[6] A. Kilicarslan, [2004] An experimental investigation of a different type vapor compression cascade refrigeration system, Applied Thermal Engineering, Vol-24, page. 2611– 2626.

[7] F. Lee. [2002] Monte, Calculation of thermodynamic properties of R407C and R410A by the Martin–Hou equation of state — part II: technical interpretation, International Journal of Refrigeration, 25, , 314–329.

[8] Samant Maji, [2006]Design and Development of two stage cascade refrigeration system, Mechanical Engineering Department, IIT Delhi,

[9] R.S. Mishra[2014] Performance Optimization of Four Stage Cascade Refrigeration Systems using Energy-Exergy Analysis in the R1234ze & R1234yf in High Temperature Circuitand Ecofriendly Refrigerants in Intermediate Ciircuits and Ethane in the Low Temperature Circuit for Food, Pharmaceutical, Chemical Industries" International Journal of Advance Research and Innovation, ISSN 2347 - 3258 , Volume 2, Issue 4 , page- 701-709

[10] DuPont, "DuPont [2012]Fluorochemicals Affirms Confidence that HFO-1234yf Can Be Safely Used as an Automotive Refrigerant," 18 Oct 2012. [Online]. Available: goo.gl/cyyoS.

[11] Honeywell, "Honeywell Solstice[2015]Lower-Global-Warming refrigerants approved by leading global compressor suppliers," 18 June 2015. [Online]. Available: bit.ly/1LedeT.

[12] S. Fukuda, C. Kondou, N. Takata and S. Koyama, [2014] "Low GWP refrigerants R1234ze(E) and R1234ze(Z) for high temperature heat pumps," International Journal of Refrigeration, vol. 40, pp. 161-173.

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