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Improvements therodynamic performances of variable compressor speed vapour compression refrigeration system using ecofriendly refrigerants

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Abstract

A simple thermal design method for predicting performance of vapour compression refrigeration system using ecofriendly refrigerants have been developed. The numerical computation using EES software for predicting performance of VCR in terms of first law efficiency, second law efficiency in terms of exergetic efficiency and system exergy destruction ratio have been carried out. The developed model predicts experiential well with variation of 5% to 10% accuracy. This models also predicts exergy of fuel in terms of compressor work and exergy of product. The effect of evaporator LMTD, Variation in condenser Liquid LMTD and Condenser vapour LMTED have been predicted along with evaporator and condenser overall heat transfer coefficients. This models takes accounts the variation of volumetric efficiency and isentropic efficiency with condenser water mass flow rates, and also variation of brine water mass flow rates. The developed model is more suitable for predicting irreversibility of the system components and exergy destruction ration the basis of exergy input and also based on exergy output is predicted.

Keywords: Performance improvement, Vapour Compression System, Energy-Exergy Analysis, Reduction in Irreversibility

1. Introduction

Now a day, the harmful effects of ozone depletion and global warming of chlorinated and fluorinated refrigerants i.e. CFCs, HCFCs and HFCs have led the scientist s to look for alternative refrigerants such as HFC 134a is most commonly used refrigerants in recent past were R11,R12, R22, etc either been phase out due to higher ozone depletion potential (ODP). The HFC 134a was found to be most suitable alternative refrigerant for replacing R12 and successfully been used till date for smaller equipment (i.e. domestic refrigerators, water coolers and mobile air conditioning) HFC 134a has very high GWP of 1430 is a matter of` environmental concerned. Therefore utilization of fourth generation refrigerants such as HFOs (R1234yf and R1234ze) is in progress because of their low global warming potentials [1].

2. Literature Review

Brown et.al [2] computed the thermal performance of R1234ze of 6 GWP in the high temperature heat pump system and found excellent first law performance in terms of COP enhancement around 5% for replacing R114 circuit. Similarly Reasor et.al [3] compared thermodynamic properties of three ecofriendly refrigerants and found that R134a and R1234yf have similar thermodynamic properties. And found that HFOs are future refrigerants for replacing R134a. Jarall [4] experimentally found lower refrigerating capacity of R1234yf of 4 GWP the thermodynamic performance in comparison to R134a of 1430 GWP. Sanchez et.al [5] compared R134a (1430 GWP) with low Global Warming potential HFOs as alternate refrigerants (i.e. R1234yf, R1234ze) and HFCs (i.e.R152a) ame operating conditions and found that R1234yf and R152a are two potential drop in alternatives to R134a while R1234ze, and hydrocarbons (R290 and R600a) are ont appropriate drop in in terms of the energy consumptions and the cooling capacity.

3. Result and Discussion

Table-1(a)-(b) shows the variation of performance parameters with increasing brine water mass flow rate in the evaporator of vapour compression system, it was observed that by

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increasing brine water flow rate, the first law efficiency in terms of COP in increasing along with system exergy destruction ratio because predicted condenser temperature is also increasing along with increasing evaporator temperature while second law efficiency in terms of exergetic efficiency is decreasing. Similarly exergy product is decreasing along with increasing brine water mass flow rate with increasing expergy of fuel as shown in table-1(b) respectively. The predicted values of parameters matches well with the experimental results

Table-1(a) shows the effect of brine water flow rate in the evaporator with predicted evaporator refrigerant pressure of vapour compression Refrigeration System it was found that when brine water flow rate in the evaporator is increases with decreasing evaporator refrigerant pressure while pressure of refrigerant in condenser is increasing while volumetric efficiency of compressor and compressor isentropic efficiency is also be increasing. The predicted values of parameters matches well with the experimental results

Table-1(a): Effect of brine water flow rate in the evaporator with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Mbrine_Eva (kg/sec)	Computed COPVCR	Exp. COPVCR	EDR_System	Exergetic Efficiency ETASecond	Computed T_Cond (oC)	Exp T_Cond (oC)	Computed T_Eva(oC)	Exp. T_Eva (oC)
0.006	2.973	2.67	2.447	0.2901	48.22	44.1	-1.497	-1.8
0.007	3.056	2.75	2.494	0.2826	48.72	45.6	-0.5151	-1.7
0.008	3.126	2.84	2.537	0.2827	49.14	48.3	0.2822	1.1
0.009	3.186	2.94	2.576	0.2797	49.49	48.6	0.9464	1.2
0.010	3.237	3.05	2.611	0.2769	49.79	48.9	1.511	1.3

Table-1(b) Effect of brine water flow rate in the evaporator with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25 ^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Mbrine_Eva (kg/sec)	COPVCR	RE Q_EVA (W)	W_Comp (W)	Q_Cond (W)	Exergy of Product (W)	Exergy of Fuel (W)	EDRational_System	Second Law Efficiency
0.006	2.973	303.6	102.10	401.8	29.63	102.10	0.7099	0.2901
0.007	3.056	315.1	103.10	414.0	29.51	103.10	0.7138	0.2826
0.008	3.126	324.7	103.90	424.8	29.37	103.90	0.7173	0.2827
0.009	3.186	332.9	104.50	433.6	29.23	104.50	0.7203	0.2797
0.010	3.237	340.0	105.10	441.3	29.09	105.10	0.7231	0.2769

Table-1(c) Effect of brine water flow rate in the evaporator with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Mbrine_Eva (kg/sec)	COPVCR	ETA_Vol	W_Comp (W)	ETA_isentropic	LMTD_Cond	LMTD_Vapour	LMTD_Eva
0.006	2.973	0.6152	102.10	0.7289	32.64	17.81	18.77
0.007	3.056	0.6178	103.10	0.7389	32.86	17.93	19.06
0.008	3.126	0.620	103.90	0.7472	33.04	18.03	19.34
0.009	3.186	0.6219	104.50	0.7543	33.17	18.11	19.6
0.010	3.237	0.6235	105.10	0.7603	33.27	18.17	19.84

Table-1(d) Effect of brine water flow rate in the evaporator with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Mbrine_Eva (kg/sec)	COPVCR	ETA_Vol	Re_Brine	Re_Cond	Re_Cond	Re_Cap	Re_23
0.006	2.973	0.6152	319.7	136896	8900	17622	176792
0.007	3.056	0.6178	319.2	1378842	9039	17837	182979
0.008	3.126	0.620	318.6	1388853	9176	18049	188953
0.009	3.186	0.6219	318.1	139922	9312	18252	194713
0.010	3.237	0.6235	317.6	200263	9447	18464	200263

Table1 (e) Effect of brine water flow rate in the evaporator with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar

Mbrine_Eva (kg/sec)	COPVCR	Computed P_Eva (Bar)	Exp. P_Eva (Bar)	Computed P_Cond (Bar)	Exp P_Cond (Bar)	Computed T_wo (^{0}C)	Exp T_wo (^{0}C)	Computed T_Brine (^{0}C)	Exp T_Brine (^{0}C)	U_Cond (W/m^{2}K)	U_Eva (W/m^{2}K)
0.006	2.973	2.774	2.7	12.61	12.9	37.01	34.7	12.9	13.1	646.35	639.73
0.007	3.056	2.805	2.7	12.77	13.0	37.38	36.1	14.24	13.3	657.41	670.43
0.008	3.126	2.96	2.8	12.90	13.1	37.69	37.2	15.3	14.2	666.54	697.28
0.009	3.186	3.032	2.9	12.92	13.2	37.96	37.4	16.16	15.4	674.24	721.11
0.010	3.237	3.094	3.0	13.12	13.3	38.19	37.6	16.87	16.5	680.84	742.52

Table-2(a) shows the variation of performance parameters with increasing condenser water mass flow rate of vapour compression system, it was observed that by increasing condenser water flow rate, the first law efficiency in terms of COP in increasing along with decreasing system exergy destruction ratio because predicted condenser temperature is also increasing along with increasing evaporator temperature while second law efficiency in terms of exergetic efficiency is decreasing. Similarly exergy product is decreasing along with increasing brine water mass flow rate with increasing expergy of fuel as shown in table-1(b) respectively.

Table-2(b-c) show the effect of condenser water flow rate with predicted volumetric efficiency of compressor of vapour compression Refrigeration System it was found that when condenser water flow rate is increases with decreasing volumetric efficiency while isentropic efficiency of compressor is increasing. The variation of Reynold numbers also shown in Table-2(c). The capillary Reynold number is increasing as condenser water mass flow rate is increasing along with increasing condenser Reynold number while Reynold number of brine water flowing in evaporator is also decreasing with compressor speed.

Table-2(a) Effect of Water flow rate in the condenser with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

MWater_Cond (kg/sec)	COPVCR	EDR_System	ETASecond	T_Cond (oC)	T_Eva (^{0}C)	EDRational_System
0.006	2.823	2.74	0.2674	51.22	-0.7889	0.7326
0.007	2.906	2.570	0.2801	49.53	-1.199	0.7199
0.008	2.973	2.447	0.2901	48.22	-1.497	0.7099
0.009	3.027	2.354	0.2982	47.2	1.722	0.7018
0.010	3.072	2.281	0.3048	46.38	1.897	0.6952

Table-2(b) Effect of Water flow rate in the condenser with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25oC, Condenser water temperature inlet=25oC, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

MWater_Cond (kg/sec)	COPVCR	RE Q_EVA (W)	W_Comp (W)	Q_Cond (W)	Exergy of Product (W)	Exergy of Fuel (W)
0.006	2.823	296.4	105.0	397.1	28.08	105.0
0.007	2.906	300.5	103.40	399.8	28.97	103.40
0.008	2.973	303.6	102.10	401.8	29.63	102.10
0.009	3.027	306.1	101.10	403.4	30.15	101.10
0.010	3.072	308.0	100.30	404.6	30.56	100.30

Table-2(c) Effect of Water flow rate in the condenser with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

MWater_Cond (kg/sec)	COPVCR	ETA_Vol	W_Comp (W)	ETA_isentropic	LMTD_Cond	LMTD_Vapour	LMTD_Eva
0.006	2.823	0.6061	105.0	0.7399	32.64	17.81	18.77
0.007	2.906	0.6113	103.40	0.7335	32.86	17.93	19.06
0.008	2.973	0.6152	102.10	0.7289	33.04	18.03	19.34
0.009	3.027	0.6182	101.10	0.7254	33.17	18.11	19.6
0.010	3.072	0.6205	100.30	0.7227	33.27	18.17	19.84

Table-2(d) Effect of Water flow rate in the condenser with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

MWater_Cond (kg/sec)	COPVCR	ETA_Vol	Re_Brine	Re_Cond	Re_Cond	Re_Cap	Re_23
0.006	2.823	0.6061	319.7	136896	8900	17622	176792
0.007	2.906	0.6113	319.2	1378842	9039	17837	182979
0.008	2.973	0.6152	318.6	1388853	9176	18049	188953
0.009	3.027	0.6182	318.1	139922	9312	18252	194713
0.010	3.072	0.6205	317.6	200263	9447	18464	200263

Table-2(e) Effect of Water flow rate in the condenser with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

MWater_Cond (kg/sec)	COPVCR	P_Eva (Bar)	P_Cond (Bar)	T_wo (^{0}C)	T_Brine (^{0}C)	U_Eva (W/m^{2o}C)	U_Cond (W/m^{2o}C)
0.006	2.823	2.847	13.61	40.82	13.19	646.7	642.33
0.007	2.906	2.805	13.03	38.66	13.03	644.04	640.61
0.008	2.973	2.774	12.61	37.01	12.9	642.06	646.35
0.009	3.027	2.752	12.28	35.72	12.81	640.65	659.77
0.010	3.072	2.734	12.03	34.67	12.73	639.73	670.94

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Table-2(d)-(e) shows the effect of water flow rate in the condenser with predicted evaporator refrigerant pressure of vapour compression Refrigeration System it was found that when condenser water flow rate is increases with decreasing evaporator refrigerant pressure while pressure of refrigerant in condenser is increasing . Similarly by increasing condenser water flow rate, the brine water outlet temperature of evaporator is decreasing. The evaporator overall heat transfer coefficient is decreasing while condenser water flow temperature outlet is increasing and condenser overall heat transfer coefficient is increasing with decreasing first law thermal performance in terms of coefficient of performance with increasing condenser water flow rate .

Table-3(b-c) show the effect of compressor speed with predicted volumetric efficiency of compressor of vapour compression Refrigeration System it was found that when compressor speed is increases with decreasing volumetric efficiency while isentropic efficiency of compressor is increasing. The variation of Reynold numbers also shown in Table-3(c). The capillary Reynold number is increasing as compressor speed in increasing along with increasing condenser Reynold number while Reynold number of brine water flowing in evaporator is also decreasing with compressor speed.

Table-3(d) shows the effect of compressor speed with predicted evaporator refrigerant pressure of vapour compression refrigeration system it was found that when compressor speed is increases with decreasing evaporator refrigerant pressure while pressure of refrigerant in condenser is increasing . Similarly by increasing compressor speed, the brine water outlet temperature of evaporator is decreasing while condenser water flow temperature outlet is increasing. With increasing compressor speed, the evaporator overall heat transfer coefficient is decreasing while condenser overall heat transfer coefficient is increasing with decreasing first law thermal performance in terms of coefficient of performance.

Table-3: Effect of Compressor speed with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Compressor Speed (rpm)	COPVCR	EDR_System	ETASecond	T_Cond (^{0}C)	T_Eva (^{0}C)	EDRational_System
2500	3.087	2.516	0.2844	47.10	- 0.1408	0.7156
2600	3.051	2.501	0.2857	47.4	- 0.5101	0.7143
2700	3.021	2.484	0.2870	47.69	-0.8578	0.7130
2800	2.995	2.446	0.2885	47.96	-1.186	0.7115
2900	2.973	2.437	0.2901	48.22	-1.497	0.7099
3000	2.954	2.426	0.2919	48.46	-1.791	0.7081

Table-3(a) Effect of Compressor speed with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Compressor Speed (rpm)	COPVCR	RE Q_EVA (W)	W_Comp (W)	Q_Cond (W)	Exergy of Product (W)	Exergy of Fuel (W)
2500	3.087	290.4	94.07	380.6	26.75	94.07
2600	3.051	293.8	96.27	386.2	27.5	96.27
2700	3.021	297.1	98.35	391.6	28.23	98.35
2800	2.995	300.4	100.30	396.8	28.94	100.30
2900	2.973	303.6	102.10	401.8	29.63	102.10
3000	2.954	306.8	103.90	406.8	30.31	103.90

Table-3(b) Effect of Compressor speed with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Compressor Speed (rpm)	COPVCR	ETA_Vol	W_Comp (W)	ETA_isentropic	LMTD_Cond	LMTD_Vapour	LMTD_Eva
2500	3.087	0.6383	94.07	0.7038	32.64	17.81	18.77
2600	3.051	0.6323	96.27	0.7098	32.86	17.93	19.06
2700	3.021	0.6264	98.35	0.716	33.04	18.03	19.34
2800	2.995	0.6207	100.30	0.7224	33.17	18.11	19.6
2900	2.973	0.6152	102.10	0.7289	33.27	18.17	19.84
3000	2.954	0.6098	103.90	0.7356	33.34	18.9	20.06

Table-3(c) Effect of Compressor speed with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C, Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Compressor Speed (rpm)	COPVCR	ETA_Vol	Re_Brine	Re_Cond	Re_Cond	Re_Cap	Re_23
2500	3.087	0.6383	319.7	136896	8900	17622	176792
2600	3.051	0.6323	319.2	1378842	9039	17837	182979
2700	3.021	0.6264	318.6	1388853	9176	18049	188953
2800	2.995	0.6207	318.1	139922	9312	18252	194713
2900	2.973	0.6152	317.6	140263	9447	18464	200263
3000	2.954	0.6098	317.1	142217	9579	18666	205605

Table-3(d) Effect of Compressor speed with performance parameters of vapour compression Refrigeration System (L_Eva=0.80 m, L_Cond=1.20 m, Mbrine_Eva=0.006(kg/sec), Brine temperature inlet=25^{0}C, Condenser water temperature inlet=25^{0}C Flowing Brine water Pressure=2 "Bar" Flowing water condenser Pressure=2 "Bar"

Compressor Speed (rpm)	COPVCR	P_Eva (Bar)	P_Cond (Bar)	T_wo (^{0}C)	T_Brine (^{0}C)	U_Eva (W/m^{2o}C)	U_Cond (W/m^2 ^{0}C)
2500	3.087	2.915	12.25	36.37	13.43	646.7	640.01
2600	3.051	2.875	12.35	36.54	13.30	644.04	641.10
2700	3.021	2.84	12.44	36.7	13.16	642.06	642.54
2800	2.995	2.806	12.52	36.86	13.03	640.65	644.3
2900	2.973	2.774	12.61	37.0	12.9	639.73	646.35
3000	2.954	2.745	12.68	37.16	12.78	639.21	646.67

The thermodynamic performance of vapour compression refrigeration using Al_2O_3 for different ecofriendly refrigerants are shown in Table-4.

Table-4: Performance improvement using Nano particles of Al_2O_3 size 0.00001 m mixed in Brine water in secondary evaporator circuit and following ecofriendly refrigerants in the primary circuit of evaporator

S.No.	Refrigerant	Computed COP from Model	%COP improvement
1	R-290	3.54	20
2	R134a	3.41	18
3	R1234yf	3.36	17.4
4	R404a	3.06	16
5	R-407c	3.1	17%
6	R152a	3.41	18%
7	R-600	3.34	17%
8	R600a	3.466	20%
9	R125	3.0	15%

4. Conclusions and Recommendations

Following conclusions have been made.

1. As compressor speed increases the first law efficiency (COP) decreases while second law efficiency in increases with reduced system exergy destruction ratio.
2. As compressor speed increases the evaporator temperature and pressure and brine water temperature out is decreases while condenser pressure and temperature is increases. Similarly exergy of fuel and exerg y of product are increases.
3. As brine mass flow rate in the evaporator increases the first law efficiency (COP) increases while second law efficiency in decreases with increased system exergy destruction ratio (EDR).
4. As brine mass flow rate in the increases the evaporator temperature and pressure and brine water temperature out is increases along with increases compressor work, refrigerating effect and condenser heat rejection while condenser pressure and temperature is also increases. Similarly exergy of fuel and exergy of product are increases.
5. As water mass flow rate in the condenser increases the first law efficiency (COP) increases while second law efficiency in decreases with increased system exergy destruction ratio (EDR).
6. Water mass flow rate in the condenser increases the evaporator temperature and pressure and brine water temperature out is increases along with increases compressor work, refrigerating effect and condenser heat rejection while condenser pressure and temperature is also decreases. Similarly exergy of fuel decreases while exergy of product is increases.
7. The use of Nano particles enhances thermodynamic performances of vapour compressions refrigeration systems from 8% to 22% and maximum performance is achieved using copper Nano particles and lowest & 8% is found using TiO_2

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