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Performance improvement of vapour compression refrigeration system (VCRS) using ecofriendly refrigerants

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Abstract

The first law thermal performance in term of coefficient of performance (COP) is the ratio of refrigeration effect to the network input given to the system of refrigeration system is evaluated. Therefore the coefficient of performance (COP) of vapour compression refrigeration system can be improved either by increasing evaporator load (i.e. Refrigeration effect) or by reducing high grade energy in terms of exergy of fuel (i.e. work input) given to the system. The constant enthalpy process is also known as throttling process in VCR is an irreversible expansion process causing internal irreversibility computed using entropy changes multiplied by ambient temperature (i.e. reference temperature of 298 K) . In the expansion process, the factors responsible for exergy loss in thermo-symphonic cycle performances. Normally in the throttling process, because of entering the portion of the refrigerant flashing to vapour in evaporator which will not only reduce the cooling capacity but also increases the size of evaporator. This problem can be eliminated by adopting multi-stage expansion where the flash vapors is removed after each stage of expansion by using ecofriendly refrigerants

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1. Introduction

Refrigeration is a technology which absorbs heat at low temperature and provides temperature below the surrounding by rejecting heat to the surrounding at higher temperature. Simple vapour compression system which consists of four major components compressor, expansion valve, condenser and evaporator in which total cooling load is carried at one temperature by single evaporator but in many applications like large hotels, food storage and food processing plants, food items are stored in different compartment and at different temperatures. Therefore there is need of multi evaporator vapour compression refrigeration system. The systems under vapour compression technology consume huge amount of electricity, this problem can be solved by improving performance of system [1-3]. Vapour compression refrigeration system based applications make use of CFC refrigerants which are responsible for greenhouse gases, global warming and ozone layer depletion. Montreal protocol was signed on the issue of substances that are responsible for depleting Ozone layer and discovered how much consumption and production of ozone depletion substances took place during certain time period for both developed and developing countries. Another protocol named as Kyoto aimed to control emission of green house gases in 1997 [4]. The relationship between ozone depletion potential and global warming potential is the major concern in the field of green refrigeration technology (GRT) so Kyoto proposed new refrigerants having lower value of ODP and GWP. Internationally a program being pursued to phase out refrigerants having high chlorine content for the sake of global environmental problems .Due to presence of high chlorine content ,high global warming potential and ozone depletion potential after 90’s CFC and HCFC refrigerants have been restricted. Thus, HFC refrigerants are used nowadays, showing much lower global warming potential value, but still high with respect to non-fluorine refrigerants [5].

2. Methods of performance improvement

Performance of systems based on vapour compression refrigeration technology can be improved by following:
The performance of refrigerator is evaluated in term of COP which is the ratio of refrigeration effect to the net work input given to the system. The COP of vapour compression

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refrigeration system can be improved either by increasing refrigeration effect or by reducing work input given to the system. Normally in the throttling process of vapour compression refrigeration system (VCRS) is an irreversible expansion process. Expansion process is one of the main factors responsible for exergy loss in cycle performance because of entering the portion of the refrigerant flashing to vapour in evaporator which will not only reduce the cooling capacity but also increase the size of evaporator. This problem can be eliminated by adopting multi-stage expansion with flash chamber where the flash vapours is removed after each stage of expansion as a consequence there will be increase in cooling capacity and reduce the size of the evaporator. Work input can also be reduced by replacing multi-stage compression or compound compression with single stage compression. Similarly refrigeration effect can also be increased by passing the refrigerant through subcooler after condenser to evaporator [1-3, 5]. Anand and Tyagi [6] carried out detailed exergy analysis of 2TR window air conditioning test rig with R22 as working fluid and reached to the conclusions that irreversibility in system components will be highest when the system is 100% charged and lowest when 25% charged and irreversibility in compressor is highest among system components.

Arora and Kaushik [7] developed numerical model of actual vapour compression refrigeration system with liquid vapour heat exchanger and did energy and exergy analysis on the same in the specific temperature range of evaporator and condenser and concluded that R502 is the best refrigerant compare to R404A and R507A, compressor is the worst and liquid vapour heat exchanger is best component of the system.

Ahamed et al. [8]emphasized on use of hydrocarbons and mixture of hydrocarbons and R134a in vapour compression refrigeration system and found that compressor shows much higher exergy destruction as compared to rest of components of vapour compression refrigeration system and this exergy destruction can be minimized by using of nanofluid and nano lubricants in compressor. Ahamed et al. [9]performed experimental investigation of domestic refrigerator with hydrocarbons (isobutene and butane) by energy and exergy analysis and found that energy efficiency ratio of hydrocarbons comparable with R134a but exergy efficiency and sustainability index of hydrocarbons much higher than that of R134a at considered evaporator temperature. Also concluded that the compressor shows highest system defect (69%) among components of considered system.

Bolaji et al. [10] carried out experimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator and concluded that the ecofriendly R32refrigerant shows lowest performance whereas R134a and R152a showing nearly same performance but best performance was obtained of system using R152a.

Cabello et al. [11] studied about the effect of operating parameters on COP, work input and cooling capacity of single-stage vapour compression refrigeration system and found that , there is great influence on energetic parameters due change in suction pressure, condensing and evaporating temperatures. Cabello et al. [12] found the effect of condensing pressure, evaporating pressure and degree of superheating was experimentally investigated on single stage vapour compression refrigeration system using R22, R134a and R407C.It was observed that mass flow rate is greatly affected by change in suction conditions of compressor in results on refrigeration capacity because refrigeration capacity depended on mass flow rate through evaporator. Also found that for higher compression ratio R22 gives lower COP than R407C.

Getu and Bansal [13] optimized the design and operating parameters of like condensing temperature, subcooling temperature, evaporating temperature, superheating temperature and temperature difference in cascade heat exchanger R744-R717 cascade refrigeration system using regression analysis and found the optimum thermodynamic parameters of same system. Han et al. [14] performed experimental results under different working conditions revealed that there could be replacement of R407C in vapour compression refrigeration system having rotor compressor with mixture of R32/R125/R161 showing higher COP, less pressure ratio and slightly high discharge compressor temperature without any modification in the same system. Halimic et al. [15] compared performance of R401A, R290 and R134A with R12 by using in vapour compression refrigeration system, which is originally designed for R12. Due to similar performance of R134a in comparison with R12, R134A can be replaced in the same system without any medication in the system components. Kumar et al. [16] did energy and exergy analysis of vapour compression refrigeration system by the use of exergy-enthalpy diagram and calculated, the coefficient of performance and exergy of various losses occurred in different components of vapour compression cycle using R11 and R12 as refrigerants. Mahmood Mastani Joybari et al. [17] performed experimental investigation on a domestic refrigerator originally manufactured to use of 145g of R134a.They concluded that exergetic defect occurred in compressor was highest as compare to other components and found that instead of 145g of R134a if 60g of R600a is used in the considered system gaves same thermodynamic performance which ultimately result into economical advantages and reduce the risk of flammability of hydrocarbon refrigerants. Mohanraj et al. [18] carried out the experimental investigation of domestic refrigerator and concluded that under different environmental temperatures COP of system using mixture of R290 and R600a in the ratio of 45.2: 54.8 by weight showing up to 3.6% greater than same system using R134a, also discharge temperature of compressor with mixture of R290 and R600a is lower in the range of 8.5-13.4K than same compressor with R134a. Nikolaidis and Probert [19] studied analytically that change in evaporator and condenser temperatures of two stage vapour compression refrigeration plant using R22 add considerable effect on plant irreversibility and suggested that there is need for optimizing the conditions imposed upon the condenser and evaporator.

Padilla et al. [20] did exergy analysis of domestic vapour compression refrigeration system with R12 and R413A was done and concluded that performance in terms of power consumption, irreversibility and exergy efficiency of R413A is better than R12, so R12 can be replaced with R413A in domestic vapour compression refrigeration system

Reddy et al. [21] performed numerical analysis of vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A and discussed the effect of evaporator temperature, degree of subcooling at condenser outlet, superheating of evaporator outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature on COP and exergetic efficiency and found that evaporator and condenser temperature have significant effect on both COP and exergetic efficiency and also found that R134a has the better performance while R407C has poor performance in all respect.

Selladurai and Saravanakumar [22] compared the performance between R134a and R290/R600a mixture on a domestic refrigerator which is originally designed to work with R134a and found that R290/R600a hydrocarbon mixture showed higher COP and exergetic efficiency than R134a. Also found the highest irreversibility occurred in the compressor compare to condenser, expansion valve and evaporator.

H.O. Spauschus. et al. [23] did numerical and graphical investigation on one stage vapour compression refrigeration system for studied refrigerants (R22, R134a, R717, R507a, R404a) in terms of COP, compressor work, exergy efficiency and refrigeration effect. Also studied the effect of subcooling, superheating and compression ratio on the same system using considered refrigerants and carried out present system optimization when working with specific refrigerant.

Yumrutas et al. [24] carried out exergy analysis based investigation of effect of condensing and evaporating temperature on vapour compression refrigeration cycle in terms of pressure losses, COP, second law efficiency and exergy losses. Variation in temperature of condenser as well as have negligible effect on exergy losses of compressor and expansion valve, also first law efficiency and exergy efficiency increase but total exergy losses of system decrease with increase in evaporator and condenser temperature. Spatz and Motta [25] mainly focused on replacement of R12 with R410a through experimental investigation of medium temperature vapour compression refrigeration cycles. In terms of thermodynamic analysis, comparison of heat transfer and pressure drop characteristics, R410a gives best performance among R12, R404a and R290a. Yongmei Xuan, Guangming Chen [26] presented in this manuscript about the replacement of R502 by mixture of HFC-161.Through experimental study it was found that mixture of HFC-161 gives same and higher performance than R404A at lower and higher evaporative temperature respectively on the vapour compression refrigeration system designed for R404A.

3. Results and Discussion

The following numerical values have been considered for numerical computation of performance parameters of the vapour compression refrigeration refrigeration system .

- Load on Evaporator = 3.567 “kW”
- Condenser temperature T_{Cond}= 323K,
- Ambient temperature $T\_{ambient}$= 298K,
- Evaporator temperature $T\_{Evaporator}$= 253K

Table-1 & Table-2 show the thermal performances variation with changing eco-friendly refrigerants in the vapour compression refrigeration system. It is clear that the first law efficiency in terms of coefficient of performance of R141b is highest and R125 is lowest . The COP of R245fa is higher than R134a and R236fa. The first law efficiency of HFO-1234yf is 5.6757% lower than HFC-134a and HFO-1234ze has less than 1% lower (around 0.8575%) cop than using R134a. .Similarly second law efficiency of vapour compression refrigeration system using R141b is highest and R407c is lowest. While power consumption by compressor is lowest using R227ea and highest by using M32. Similarly exergy of product is highest using R32 and system exergy destruction ratio based on exergy of product is highest by using R125 and lowest by using R123. It is clear that second law efficiency of vapour compression refrigeration system using HFO-1234ze is nearly approaching to the second law efficiency of vapour compression refrigeration system using R134a. and second law efficiency of vapour compression refrigeration system using HFO-1234yf is slightly lower (around 5.67034%) by replacing R134a.and 0.85668% lower by using HFO-1234ze for replacing R134a.

Table-1: Thermodynamic performances of vapour compression refrigeration system using ecofriendly refrigerants

Parameters	R134a	R1234yf	R1234ze	R245fa	R236fa	M32	R227ea
COP_{Actual}	2.449	2.31	2.428	2.588	2.372	2.369	2.146
System $EDR_{Second\ Law}$	1.296	1.434	1.315	1.172	1.371	1.373	1.62
Second law Efficiency	0.4356	0.4109	0.4319	0.4603	0.4218	0.4214	0.3817
Rational $EDR_{Second\ Law}$	0.5644	0.5891	0.5681	0.5397	0.578	0.5786	0.6183
W_Comp(kW)	55.86	44.69	49.98	55.62	42.68	102.5	32.91
Exergy_Product (kW)	24.33	18.36	21.53	25.6	18.05	43.19	12.56
Exergy_Fuel (kW)	55.86	44.69	49.8	55.82	42.78	102.5	32.91
Exergetic Efficiency	0.1289	0.1232	0.1283	0.1314	0.1261	0.1254	0.1169
System EDR	6.755	7.12	6.795	6.438	6.931	6.974	7.552

Table 2: Thermodynamic performances of vapour compression refrigeration system using ecofriendly refrigerants

Parameters	R143a	R152a	R141b	R410a	R404a	R407c	R125	R123
$COP_{\_Actual}$	2.20	2.577	2.769	2.307	2.121	2.089	1.99	2.668
System $EDR_{Second\ Law}$	1.554	1.181	1.031	1.437	1.651	1.692	1.825	1.107
Second law Efficiency	0.3916	0.4585	0.4925	0.4101	0.3772	0.3715	0.3340	0.4745
Rational$EDR_{Second\ Law}$	0.6084	0.5416	0.5075	0.5896	0.6228	0.6285	0.646	0.5255
W_Comp(kW)	54.41	88.90	66.54	67.86	47.89	69.29	37.58	50.11
Exergy_Product (kW)	21.31	40.15	32.77	27.85	18.07	25.13	13.30	23.78
Exergy_Fuel (kW)	54.41	88.90	66.54	67.86	47.89	69.29	37.58	50.11
Exergetic Efficiency	0.1190	0.1338	0.1441	0.1231	0.1156	0.1137	0.1101	0.1374
System EDR	7.403	6.473	6.088	7.121	7.65	7.794	8.801	6.279

4. Conclusions & Recommendations

Following conclusions were drawn for improving thermal performance of vapour compression refrigeration systems

- First law and second law efficiencies were improved by using HFO-1234ze(Z) and R1233zd(E) in the vapour compression refrigeration systems
- Reduction of system defect in components of system which results into increase in second law efficiency
- Using nano particles in R410a ecofriendly refrigerant of vapour compression refrigeration systems as compared to other ecofriendly refrigerants(i.e. r134a, R407c & R410a) the First law and second law efficiencies are lowest.
- First law and second law efficiencies improved by using multiple evaporators systems with multi-stage expansion and compound compression in vapour compression refrigeration systems because of work input is reduced.
- In the vapour compression refrigeration system (VCRS) by using flash intercooler, flash chamber, water intercooler, liquid sub-cooler and stages in compression of double stage sand triple stages, the thermodynamic performances increased.

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