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Modelling of vapour compression refrigeration system (VCRS) by using alternative refrigerants with CuO and without Nano materials

R.S. Mishra

Department of Mechanical & Production Engineering, Delhi Technological University Delhi, India

Abstract

Application of Nano particles in refrigerants has been identified as a better way of enhancing the thermal performance of the vapour compression refrigeration system (VCRS) without modification the system design. When nano particles are dispersed in a refrigerant, they are regarded as Nano refrigerants. The improvement in evaporator and condenser heat transfer coefficient are responsible for the enhancement of VCRS performance.
In this paper, the effect of CuO (Nano particles) on the first law efficiency in terms of coefficient of performance (COP), exergetic efficiency (second law efficiency0 and system exergy destruction ratio (EDR) based on exergy of fuel / exergy of product) using alternative refrigerants are discussed. It is shown that the application of Nano particles as additives in refrigerant and lubricant in VCRS is favourable and promising. Therefore, Nano refrigerants are expected to be the future refrigerants for improving thermal performances of vapour compression refrigeration systems

Keywords: Thermodynamic performance improvements, Mixing Nano materials, Vapour Compression Refrigeration System.

1. Introduction

Refrigeration systems have become one of the most important utilities for people's daily lives. Vapour compression refrigeration system worked on vapour compression cycle. Vapour compression refrigeration systems are commonly used in domestic, industrial & commercial applications. i.e. large-scale warehouses for chilled or frozen storage of foods , refrigerated trucks and railroad cars, Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants. With the advancement and technological developments in the field of refrigeration new methods are developed to increase the COP of the systems. Traditional methods for exchanging heat from the system involves increment in the surface area but this leads to the increase in the size of the system, so there was need of some efficient way that can enhance the heat transfer [1]. Therefore improvement of thermal performances of vapour compression refrigeration systems are also important for higher refrigerating effect or reduced power consumption for same refrigerating effect. Many efforts have to be done to improve the performance of vapour compression refrigeration systems. In the various environmental convention, more environmentally friendly refrigerants have been investigated in recent years [2-3]. Two aspects are of particular concern, namely the use of ecological (environmentally friendly) refrigerants and the energy consumption issue. Because the thermodynamic and thermo-physical proprieties of refrigerants influence the energetically performances of the system and while exerting an environmental impact, they must be carefully analyzed and taken into account during the conception and design of the cooling systems [2-7]. Recently, HFO refrigerants (i.e.R1234yf and R1234ze) were proposed as an alternative of R134a in Refrigeration and automotive air conditioning systems [8]. R1234yf has an ODP of 0, and its GWP is only 4 while R1234ze has an ODP of 0, and its GWP is only 6 [9-10]. Hence, R1234yf and R1234ze satisfied the recent environmental requirements and polices quite well. These refrigerants have been classified as a very low flammable working fluid (A2L safety group). In addition, the thermo-physical properties of R1234yf and R1234ze are quite similar to those of R134a. The working pressure of the R1234yf and R1234ze in the vapour compression refrigeration systems is very close to that of the R134a system under the similar

Corresponding author: R. S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in

working conditions [10]. HFO1234yf has excellent potential as a new low global warming refrigerant for automotive air conditioning and potentially for stationary applications. It has excellent environmental properties which can have a long term favourable impact on climate change and meet current and future climate regulations. Significant toxicity tests have been completed with encouraging results. It is compatible with existing R134a technology which can allow for a smooth and cost effective transition. The mild flammability properties of HFO-1234yf have shown its high potential for use in direct expansion applications [11]. Performance improvement potentials of R1234yf in the mobile air conditioning system, and concluded that R1234yf system COP and cooling capacity were lower than that of R134a system. By increasing subcooling temperature from 1K to 10K could improve system COP and cooling capacity by 15%. The effect of superheat on COP and cooling capacity was adverse for larger refrigerant mass flow rate. Improving compressor efficiency would be better options in the future R1234yf mobile air conditioning system enhancement [12-13]. Exergy analysis in the vapour compression refrigeration systems using R1234yf and R1234ze as R134a replacements in a two evaporator vapour compression refrigeration system and concluded that the exergy efficiency was greatly affected by changes in the evaporator and condenser temperature and found that the values of performance parameters for HFO-1234yf are smaller than that of HFC-134a, because of its environmentally friendly properties. They also found that the greater portion of exergy destruction takes place in the compressor. Mixing chamber has lower exergy destruction compared to other components and observed highest exergy efficiencies using R1234ze and R134a as compared to R1234yf [14]. R-1234yf is more suitable than R-1234ze to replace R-134A and conducted experiments on two refrigeration systems. In Refrigeration system-1 and 2, R-1234yf had 2.7% and 1.3% higher energy consumption than R-134a which indicates that R-1234yf is a suitable for replace R134a. In refrigeration system-1 and refrigeration system-2, R-1234ze had 16% and 5.4% lower energy consumption than R-134a. Therefore R-1234ze may not be suitable for drop-in replacement [15]. A possible solution for environmental protection is the use of The HFO mixtures represent a very active research and development area today and may hold a solution for selection of alternative refrigerants in the future. The inorganic refrigerants (NH_3, CO_2) and hydrocarbon refrigerants (propane, isobutene, ethylene, and propylene) are also used for industrial applications, household cooling and in air-conditioning or food storage. The drawback of hydrocarbon refrigerant is a high risk of flammability and explosion. Therefore these substances will not be often used as refrigerants compared with R744 (i.e.CO_2) and R717 (i.e.NH_3). The refrigerant mixtures having lower environmental impacts with higher energy efficiency are considered to be fourth generation refrigerants [16].

To evaluate energy performance of low GWP alternatives to R134a and concluded that the propane as the hydrocarbon (R290) obtained the best results in terms of COP & cooling capacity and found the increment in power consumption around 45%. The R290 hydro-fluorocarbon and R152a presents an average reduction in cooling capacity and power consumed by the compressor and concluded that it can be considered a suitable direct drop-in alternative to R134a by taking into account the corresponding safety requirements. When HFO refrigerant (R1234yf) introduced in the vapour compression refrigeration system and found a decrease in small cooling capacity, therefore HFO-1234yf can be considered as direct drop-in alternative to R134a with a considerable COP reduction [17]. The hydro-fluoroolefin R1234ze (E) yields a outstanding reduction in cooling capacity and power consumption, and therefore R1234ze (E) is not suitable for use as a direct drop-in alternative to R134a. Similarly R600a hydrocarbon is also not suitable for use as a direct drop-in alternative to R134a and also concluded that the two refrigerants such as R1234yf and R152a are finally potential drop-in alternatives to R134a by considering the energy consumption and the cooling capacity of the refrigerating systems. Nano fluid containing metallic or non-metallic particles. The inventive idea of using nanofluids, fluids which consist of suspended nanoparticles are used to remove such kind of barriers. The nano refrigerant is used to improve vapour compression refrigeration system thermodynamic performances (i.e. decreased energy consumption of the system (viz. enhance heat transfer rate in cooling coil). Nano particles of Al_2O_3, TiO_2 and CuO are used due to their higher thermal conductivity to achieve better efficiency [18]. Mishra The performance of a vapour compression refrigeration system by using Cu, Al_2O_3 CuO and TiO_2 based nano refrigerants in the primary circuit. The experimental results showed that the C.O.P of the system using Al_2O_3/R134a nano refrigerant was enhanced by 35% which was highest among all other Nano refrigerant [1, 38, 39]. 17% increase in COP by using 0.01% experimentally by volume concentration of TiO2 nano fluid as a lubricant additive in the vapour compression refrigeration system [20]. Nano fluids and found that there is the significant increase in the thermal conductivity of Nano fluid when compared to the base fluid and also found that addition of nanoparticles results in significant increase in the critical heat flux [21]. R134a was used the refrigerant with a mixture of mineral oil TiO_2 used as the lubricant and found that the refrigeration system with the Nano refrigerant worked normally and efficiently and the energy consumption reduces by 21.2% [22].

The R134a/TiO_2 Nano-refrigerant combines the Rl34a refrigerant with TiO_2 nanoparticles. A refrigerant test system was built to study the refrigeration reliability and performance with R134a/TiO_2 Nano-refrigerants with various fractions of TiO_2 particles without any change of the original refrigeration system. The experimental results indicate that the R134a/TiO2 Nano-refrigerant works normally and safely in the refrigerator with lower electricity consumption and faster refrigeration speed than the pure R134a system with an optimal TiO_2 Nano-particle concentration of 10 mg/L which reduces the energy consumption by 7.43%-Therefore, Nano-refrigerants can be used without any system change with energy savings.

Reduction in the power consumption and significant improvement in freezing capacity and also observed improvement in the system performance due to better thermo-physical properties of mineral oil in the presence of nanoparticles in the refrigerant [23]. Experimental investigation on the thermal performance of a domestic refrigeration system using working fluid as TiO_2-R600a Nano-refrigerant and found that that the TiO_2-R600a system worked competently in the refrigeration system in terms of performance improvement with 9.6% of energy saving and also reduction in power consumption upto 25% by mixed mineral oil TiO_2 as the lubricant with refrigerant R600a [24]. An experimental study on the performance of a domestic refrigerator using Al_2O_3-R134a Nano refrigerant as working fluid and found that the Al_2O_3-R134a system performance was better than pure lubricant with R134a working fluid with 10.30% less energy used with 0.2%V of the concentration used and also increase in heat transfer coefficient by using nano Al_2O_3 particles [25-26]. Conducted an experimental study on the performance of a domestic refrigerator using TiO_2 - R12 nano refrigerant as working fluid and found that the freezing capacity increased and heat transfer coefficient increases by 3.6 %, compression work reduced by 11% and also coefficient of performance increases by 17% due to the addition of nanoparticles in the lubricating oil [27]. Conducted an experimental study on the performance of a domestic refrigeration system using TiO_2-R600a nano refrigerant as working fluid and found that the energy consumption reduced by 11% and coefficient of performance increases by 19.6 [28]. The performed analysis on vapour compression refrigeration system using R152a nano-refrigerants with ZnO particles for energy conservation and green environment, and concluded that the system works safely with replacing of R152a with the conventionally used R134aand also found that the no modification in the vapour compression refrigeration system was required for the retrofitting process and also concluded that the COP increases with the increase in nano concentration of ZnO. Maximum COP of 3.56 was obtained with 0.5%v of ZnO. The suction temperature decreases with the increase in nano concentration. The input power decreases with increases in nano concentration. The pull-down temperature of the evaporator decreases with time. The usage of R152a with very low GWP ensures safe and clean environment with low power consumption. The pressure ratio decreases with the increase of nano ZnO concentration [29-33]. Performance analysis of a domestic refrigeration system using working fluid as CuO-R600a nano refrigerant and concluded that nano refrigerant using CuO R600a can work usually and efficiently in domestic refrigeration system due to more quickly freezing velocity of CuO - R600a as compared to the pure R600a system and also found that the CuO - R600a can improve thermodynamic performance of the domestic refrigeration system [34]. Performed analysis on the thermal Performance Improvements of VCRS using ecofriendly based nano-refrigerants in primary circuit and concluded that use of nanoparticles enhances thermal performance of vapour compression refrigeration system from 8% to 35 % using nano-refrigerant in primary circuit. With use of nanoparticles increase in the thermal performance of vapour compression refrigeration system from 7 to 21 % using nano fluid in secondary circuit was observed. Maximum enhancement in the performance was observed using R134a/ Cu nano-refrigerant in primary circuit and water in secondary circuit of VCRS. Lowest enhancement in performance was observed using R404A/TiO_2 nano refrigerant in primary circuit and water in secondary circuit of VCRS [35]. Investigated first law efficiency improvement of vapour compression refrigeration system using nano particles mixed with R-404a as ecofriendly refrigerant and concluded that the use of nano-refrigerant instead of pure refrigerant in vapour compression refrigeration cycle increase the thermal performance of nano-refrigerant enhances significantly and also the performance of refrigeration system and also nano particle suspended in pure refrigerant enhance the thermal conductivity from 10 to 95 %, convective heat transfer coefficient from 10 to 80 % and heat transfer enhancement factor ranges from 1.4 to 2.5. The performance enhancement of vapour compression refrigeration system in terms of C.O.P from 3% to 15 %, along with exergetic efficiency of 2% to 5 % and concluded that the exergy destruction ratio of the system reduced by adding nano particle in the pure refrigerant [36, 40, 41]. Improvement found in COP by 19.6% and reduction in power consumption by 11.5%. Due to enhancement in heat transfer coefficient using Nano fluid Al_2O_3 & R600a/mineral oil as working fluid in a domestic refrigerator [34]. The conventional refrigeration system performance improved with nano-refrigerant. Compressor work decreases by about 13.3% and system C.O.P. increases by about 12%. Nano-refrigerants are going to have a promising future but there are few challenges. Because of their improved heat transfer attributes and improvement in COP and energy saving, it is safe to assume that nano-refrigerants will be utilized as a part of numerous modern refrigeration system and gadgets sooner rather than later [38]. The analysis of an air conditioning system by using a concentration of 0.01-0.1wt% of CNT Polyester oil with refrigerant R134a and found 4.2% enhancement in the COP was enhanced by using CNT particles concentration of 0.1% by weight [39]. On a vapour compression refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. The mineral lubricant included added Al_2O_3 nanoparticles to improve the lubrication and heat-transfer performance and found optimal that the 60% R-134a and 0.1 wt % Al_2O_3 nanoparticles and also reduced 2.4% power consumption along with 4.4% increased COP (coefficient of performance) [40]. The refrigeration system with nano refrigerant works normally. It was found that the freezing capacity was higher and the power consumption reduces by 25 % when POE oil was replaced by a mixture of mineral oil and alumina nanoparticles. Calculations show that the enhancement factor in the evaporator was 1.53 when nano refrigerants are used instead of pure refrigerant [41-42]. The effect of using CuO-R134a in the vapour compression refrigeration system on the evaporating heat transfer coefficient, and concluded that evaporating heat transfer coefficient increases with the usage of nano CuO [43].

2. Results and Discussion

The numerical computation was carried out for finding thermal performance of vapour compression refrigeration from developed model, the following input data have been assumed. Condenser temperature=48^{0}C, Evaporator temperature -5^{0}C, mixing of nano particles =5% by volume

The performance of environments friendly refrigerants HFC-134a, R407c, R404a and HFO1234yf, HFO1234ze with variation of phi is shown in the table-1 to 5 respectively. It was found that first law performance in terms of COP using R134a mixed with nano particles of 10 microns particle size gives best performance and lowest performance was observed by using R4074a. It was observed that first law efficiency in terms of COP increases with increasing evaporator temperature and decreases with increasing condenser temperature. Similarly the second law efficiency i.e. exergetic efficiency decreases with increasing evaporator. The system defect in terms of exergy destruction ratio is increases. The increases in superheating in evaporator at condenser inlet, the first law efficiency (i.e. COP) and second law efficiency is increases. Similarly by increasing condenser temperature the first law efficiency (COP) and exergetic efficiency of system is decreases.

Table-1 shows the % improvement in first law efficiency in terms of cop improvement by using Nano particles mixed with R718 in the secondary evaporator circuit it was observed that first law efficiency without Nano particles using R152a is maximum while by using R410a is minimum however second highest is found to be by using R290 as hydrocarbon in the primary evaporator circuit. The use of R407C as ecofriendly refrigerants is quite adequate while first law performance improvement is around 12.1% by using nano particles. The % improvement in first law efficiency is found to be 14.8% by using nano particles as compared to without nano particles. While by using R134a 32.90% improvement was observed. Due to 1360 global warming potential of R134a, the next alternate refrigerant R1234yf (GWP=4, and ODP=0) is suitable which can replace R134a as shown in Table-2 in the coming future. It was also observed that without using nano particles, the first law performance by using R1234ze is better than R1234yf as shown in Table-3. It was also observed that second law performance is better due to 39.13% improvement by using R1234yf as compared to 16.52% improvement by using R1234ze in the primary evaporator circuit. It was found that the reduction in the irreversibility in terms of exergy destruction ratio in the system and maximum exergy destruction ratio around 25.3% was observed by using R134a and exergy destruction ratio is 27.79% by using R407c hydrocarbon and 29.4% by using R404a as ecofriendly refrigerant. The Reduction in EDR is 26.09% by using R1234ze and 26.3% by using R1234yf. The R1234ze and R1234yf have slightly less reduction in EDR as compared by using R134a.

Table-1: Variation of thermal performances (First law efficiency (COP) with R134a ecofriendly refrigerants using CuO Nano material mixing

R-134a	First law COP	% improvement
0.01	3.464	22.8
0.02	3.616	28.2
0.03	3.681	30.5
0.04	3.725	32.1
0.05	3.748	32.9

Table-2: Variation of thermal performances (First law efficiency (COP) with R1234yf ecofriendly refrigerants using CuO Nano material mixing

R-1234yf	First law COP	% improvement
0.01	3.421	21.3
0.02	3.604	27.8
0.03	3.707	30.2
0.04	3.717	31.8
0.05	3.737	32.4

Table-3: Variation of thermal performances (First law efficiency (COP) with R1234ze ecofriendly refrigerants using CuO Nano material mixing

R-1234yf	First law COP	% improvement
0.01	3.454	21.8
0.02	3.606	28.0
0.03	3.675	30.7
0.04	3.720	31.9
0.05	3.742	32.6

Table-4: Variation of thermal performances (First law efficiency (COP)) with R404aecofriendly refrigerants using CuO nanomaterial mixing

R-404a	First law COP	% improvement
0.01	2.502	5.2
0.02	2.572	8.1
0.03	2.630	10.6
0.04	2.683	12.8
0.05	2.73	14.8

Table-5: Variation of thermal performances (First law efficiency (COP) and Exergetic efficiency) with ecofriendly refrigerants using CuO Nano material mixing

R-407c	First law COP	% improvement
0.01	2.669	4.4
0.02	2.747	7.5
0.03	2.806	9.8
0.04	2.842	11.2
0.05	2.864	12.1

The variation of evaporator temperature with variation of first law thermal performances in terms of COP and second law efficiency (exergetic efficiency) for different ecofriendly refrigerants with CuO Nano particles and without Nano by using R134a It was found that by increasing evaporator temperature the first law performance (COP) increases. And best first law performance (COP) was found by using R134a Since, therefore R1234ze gives slightly lower first law performance (COP) than R134a and also slightly higher than R1234ze . Similarly by increasing condenser temperature, the first law thermal performance (COP) decreases as shown in table-2(b) and table-3((b) respectively.

3. Conclusion

In this paper, first law and second law analysis of vapour compression refrigeration system with and without Nano particles using ecofriendly refrigerants (R134a, R407c, R404a, R1234yf, and R1234ze) have been presented. In response to various environmental conventions, more environmentally friendly refrigeration systems have been investigated in recent years. Two aspects are of particular concern, namely the use of ecological (environmentally friendly) refrigerants and the energy consumption issue. This study contains a good amount of information regarding ecological refrigerant trend and Nano-refrigerant. The blend of nanoparticles with ecological refrigerant has a promising future and R1234yf and R1234ze Nano refrigerants have potential to replace R134a. Following conclusions were drawn from present investigation.

(i) By using Nano in the R410a gives worst thermal performance in terms of first law efficiency, second law efficiency and exergetic efficiency.
(ii) The best thermal performance in terms of first law efficiency is found by using R134a.
(iii) By increasing evaporator temperature the first law performance (COP) increases.
(iv) By increasing condenser temperature, the first law thermal performance (COP) decreases.
(v) First law and second law efficiency for vapour compression refrigeration system without CuO nano particles mixed in R718 in the secondary evaporator circuit and ecofriendly refrigerants in the primary circuit (i.e. R134a and R1234ze) are matching the same values although R1234ze has slightly less performances than R134a.
(vi) HFO-1234ze ecofriendly refrigerant is better than that for R123yf which has low GWP (i.e. GWP =4) is showing 2–6% higher value of first law efficiency (i.e. COP).
(vii) Both energetic and exergetic increases with increase in degree of sub cooling
(viii) Energetic and exergetic efficiency greatly affected by changes in evaporator and condenser temperature.
(ix) R1234ze is the best among considered refrigerant since it has 218 times lower GWP values than R134a and R1234ze is ecofriendly has both ODP and GWP are lowest. The R1234yf and R1234ze can replace R-134a after 2030 due to low global warming potential.

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