Performance Analysis of VCRS with Nano-Refrigerant

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Abstract - *Nano refrigerant is nothing but the combination of nano-particle with the refrigerant for the sake of better refrigeration process. It has been observed that, as compared to alternative refrigerant, there is better improvement in heat transfer capacity of the refrigerant after addition of nanoparticles. The use of nano-particles along with the conventional refrigerant with vapour compression cycle is relatively a new idea, where nano-refrigerants, so obtained are found to have their improved thermo-physical properties over the conventional refrigerants. Nano-particles can be used along with refrigerant in order to improve the performance of vapour compression refrigeration system. In this paper, alumina (Al_2O_3) nanoparticles of 50 nm diameter are dispersed in refrigerant R134a to improve its heat transfer performance to have their improved thermal & physical properties over the conventional refrigerants.*

Keywords: Refrigeration test rig, Refrigeration Cycle, Refrigeration performance, Nanoparticles, Nanorefrigerant.

1.INTRODUCTION:

In past time only refrigerants were used in refrigeration process and they were having a global warming coefficient at high level. Now, as time change the modern techniques are coming into existence with the help of them the refrigeration process become more efficient and safe as compare to previous in atmospheric prospective. [14]

Nanofluid is an advanced kind of fluid, which contain nanometer sized (10^{-9} m) solid particles known as nanoparticles. Nanoparticles enhance the property of normal fluid. In past five years, nano- refrigerant has become more popular for large number of experimental vapour compression systems because of shortage in availability of energy and environmental considerations. [5]

Recent advancements in nanotechnology have originated the new emerging heat transfer fluids called nano-fluids. Nano-fluids are prepared by dispersing and stable suspending nanometer sized solid particles in conventional heat transfer fluids. Past researches have shown that a very small amount of suspending nanoparticles have the potential to enhance the thermo physical, transport and radiative properties of the base fluid. Due to improved properties, better heat transfer performance is obtained in many energy and heat transfer devices as compared to traditional fluids which open the door for a new field of scientific research and innovative applications. [16]

The addition of nanoparticles to the refrigerant results in improvements in the thermophysical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. [5]

Nanoparticles directed the innovative world into a new direction by its ability to influence working properties of fluid. Nanofluids are advanced class of fluids with particles of nano size (1-100 nm). The concept is based on the fact that solids have high heat capacity as compared to fluid. So nano sized particles or nanoparticles are dispersed into a base fluid in order to enhance physical properties of base fluid. The nanoparticle materials are usually of metal, non-metal and their oxides, which enhance the heat transfer performance of base fluids. Hence, there is huge scope of its application in heat transfer area. Recently, some investigations revealed the application of nanoparticles in refrigeration systems and significant improvement in performance has been observed. In refrigeration systems the nanoparticles can be either added to compressor lubricating oil or to refrigerant. Dispersion of nanoparticles into lubricating oil (Nano lubricant) improves the lubrication of compressor or decrease friction of moving parts. Additionally, the in case hermetically sealed compressor fractional amount of lubrication oil is carried away by refrigerant in compressor dome. So, by this means the heat transfer characteristics can be improved and hence performance of the refrigeration system. On other hand when nanoparticles are dispersed in refrigerant (termed as nano-refrigerant), then it directly enhance the refrigerant thermal properties and thereby performance of refrigeration system is found to be improved. [1]

The conventional refrigerants have major role in global warming and depletion of the ozone layer. Therefore, there is need to improve the performance of vapour compression refrigeration system with the help of suitable refrigerant.

2. LITERATURE REVIEW:

Air conditioners and refrigerator-freezers are major energy users in a household environment and hence efficiency improvement of these appliances can be considered as an important step to reduce their energy consumption along with the environmental pollution prevention. As per the Montreal Protocol, CFC12 is being phased out following a stipulated time frame. The developed countries have already phased out these substances and the developing countries are to totally phase out the CFCs by 2030 as per the Montreal Protocol. Most of the developing countries are drastically reducing their CFC production and consumption. This demand for a suitable substitute for CFC12 for possible retrofitting of existing systems as well as for new systems. **S. Joseph Sekhar *et al.* (2004)** presented two potential substitutes, namely, HFC134a and HC blends are available as drop in substitutes for CFC12. HC (hydrocarbon) refrigerants do have inherent problems in respect flammability. HFC134a is neither flammable nor toxic. But HFCs (hydro fluorocarbons) are not 15 compatible with mineral oil and the oil change is a major issue while retrofitting. They carried out an experimental analysis in a 165 liters CFC12 household refrigerator retrofitted with eco-friendly refrigerant mixture HFC134a/HC290/HC600a without changing the mineral oil. Its performance, as well as energy consumption, is compared with the conventional one. As the system has been running successfully for more than 12 months consumption by 4 to 11% and improve the actual COP by 3 to 8% from that of CFC12. The new mixture also showed 3 to 12% improvement in theoretical COP. The overall performance has proved that the new mixture could be an eco-friendly substitute to phase out CFC12.

Satnam Singh et al. represented a review on behavior of Nano- refrigerant in vapour compression cycle with different concentration of Nano-particles. The experimental studies revealed that the performance of such systems gets improved by using Nano refrigerants. It is observed that using a Nano-refrigerant with higher concentration is not always true. **T. Coumaressin et al.** studied performance of a refrigeration system using nano fluid and concluded CuO nanoparticle with R134a refrigerant can be used as an excellent refrigerant to improve the heat transfer characteristics of a refrigerant. Heat transfer coefficients were evaluated using FLUENT for heat flux ranged from 10 to 40 kW/m^2, using nano CuO concentrations ranged from 0.05 to 1% and particle size from 10 to 70 nm. The results indicate that evaporator heat transfer coefficient increases with the usage of nano CuO. **Kuljeet Singh et al.** carried out an investigation into the performance of a Nano refrigerant (R134a+Al_2O_3) based refrigeration system. It has been found out that the improvement in coefficient of performance (COP) is maximum (7.2 to 8.5%) with 0.5% Al2O3 (% wt.) nanoparticles. When the mass fraction of nanoparticles increased to 1% in refrigerant COP is found to be lower than even from pure R134a. Further, increased mass fraction of Al2O3 (1%), lowers down the pressure and temperature after expansion of the Nano refrigerant in the expansion valve. In addition to this the specific heat of refrigerant gets decreased. So these both factor will results in decrease in the refrigeration effect, hence COP. Improvement is found to be maximum by using Nano-refrigerant R134a+0.5% Al_2O_3 keeping refrigerant flow rate as 6.5 LPH. **N. Subramani et al.** done experimental studies on a vapour compression system using nano-refrigerants. It was found that, the R134a refrigerant and mineral oil mixture with nanoparticles worked normally (ii) Freezing capacity of the refrigeration system is higher with SUNISO 3GS + alumina nanoparticles oil mixture compared the system with POE oil (iii) The power consumption of the compressor reduces by 25% when the nano-lubricant is used instead of conventional POE oil (iv) The coefficient of performance of the refrigeration system also increases by 33% when the conventional POE oil is replaced with nano-refrigerant (v) the energy enhancement factor in the evaporator is 1.53. **D. Sendil Kumar et al.** Nano Al_2O_3-PAG oil was used as nano refrigerant in R134a vapour compression refrigeration system and it was found that addition of nano Al_2O_3 in to the refrigerant shows improvement in the COP of the refrigeration system. Usage for Nano refrigerant reduces the length of capillary tube and cost effective. The system performance was investigated using energy consumption test and freeze capacity test. The refrigeration system performance was better than pure lubricant with R134a working fluid with 10.32% less energy used with 0.2%V of the concentration used.

Omer A. Alawi et al. presented a comprehensive review of fundamentals, preparation and applications of nanorefrigerants. Physical properties of nanorefrigerants such as density and viscosity, surface tension and specific heat have a significant effect on nucleate pool boiling, convective flow boiling and condensation. He concluded that adding nanoparticles to the refrigerant enhanced the heat transfer and that the heat transfer coefficient increased with increased nanoparticle mass fraction. From the literatures, it has been found that the thermal conductivities of Nano refrigerants are higher than pure refrigerants. The power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%. The refrigerator's performance was found 26.1% better with 0.1% mass fraction of TiO_2 nanoparticles compared to a refrigerator's performance with the HFC134a and POE oil system. **R. S. Mishra et al. studied** thermo physical properties by addition of different nanoparticle mixed with ecofriendly refrigerant are analyzed and their effects on the coefficient of performance (C.O.P.). The experimental results are indicating the thermal conductivity, dynamic viscosity and density of Nano-refrigerant (different nanoparticle i.e. Cu, Al_2O_3,CuO and TiO_2 with ecofriendly refrigerant R134a,R407c and R404A) increased about 15 to 94 %, 20% and 12 to 34 % respectively compared to base refrigerant on the other hand specific heat of Nano refrigerant is slightly lower that the base refrigerant. Moreover Al_2O_3/R134a Nano refrigerant shows highest C.O.P. of 35%. R404A and R407 with different nanoparticle show enhancement in C.O.P. about 3 to 14 % and 3 to 12 % respectively. **A. Senthilkumar et al.** studied the method that uses natural gas to enhance the energy efficiency of refrigeration retorting method employing CuO - R600a as alternate refrigerants. A new nano refrigerant is employed in the domestic refrigerator. The performances of the nano refrigerant, such as the cooling capacity, energy efficiency ratio were determined. The results indicate that the mixture of R600a with nano particles (CuO) works normally in the domestic refrigerator. The cooling capacity of the domestic refrigerator is increased by 10 - 20% by using nano – refrigerant. The results indicated that CuO - R600a can work normally and efficiently in refrigerator. Combined with refrigerator using pure R600a as working fluids. 0.1 & 0.5g/L concentrations of CuO - R600a can save 11.83% and 17.88% energy consumption respectively and the freezing velocity of CuO - R600a was more quickly than the pure R600a system

Several investigations have been carried out to tackle the problem of Global Warming and Ozone layer depletion with the usage of alternative refrigerants in the refrigeration system. Hence it is felt that a detailed investigation on the possibility of exploring new alternative refrigerant and addition of nano additives to the refrigerant. Accordingly the specific objectives of the present research work are as follows:

1. Nano additives Al_2O_3 were blended with R134a refrigerant and their corresponding performance on the same system was investigated. Nano additives of Al_2O_3 with particle size of 40- 50 nm. The compressor discharge temperature, discharge pressure and evaporator temperature, Coefficient of performance (COP), vapour pressure, volumetric cooling capacity (VCC) were measured. An experimental test rig is designed and fabricated indigenously in the lab to carry out the investigations. Nanoparticles with refrigerant mixture were used in HFC R134a refrigeration system. The system performance with nanoparticles was then investigated.

The scope of this work is limited based on the following:

1. Al_2O_3 nanoparticles were selected for study.
2. The concentration of nano additives were chosen as 0.5% and 1% by mass in this investigation.

3. TEST SETUP & METHODOLOGY

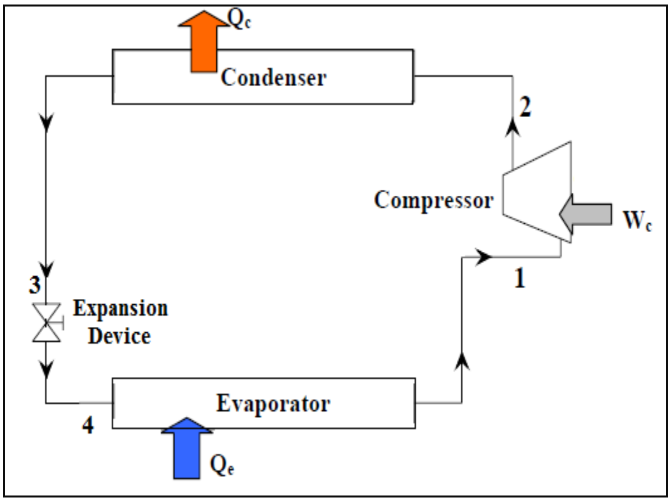


Figure 3.1: Simple Vapour Compression

3.1 Components of Vapour Compression Refrigeration System [12, 17]

1. Compressor

The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve and it is compressed isentropically to a high pressure and temperature and discharged into the condenser through the delivery or discharge valve.

2. Condenser

The condenser consists of coils of thin copper pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed by the process of forced convection. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water.

3. Receiver

The function of the receiver vessel is to store the condensed vapour-liquid mixture at high temperature and pressure and supply pure liquid refrigerant to the expansion valve so as to get better throttling and controlling effect.

4. Expansion Valve

It is also called throttle valve and the function of this valve is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature.

5. Evaporator

An evaporator usually consists of coils of copper pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

3.2 Actual Test Setup

Figure 3.2: Actual Test Setup of VCRS with Nano Refrigerant

Table 3.1 Technical specifications of Setup

Capacity	165 Litre Domestic Refrigerator
Refrigerant	R-134a and Al_2O_3 Nano Fluid
Compressor	Hermetically Sealed
Condenser	Natural Convection Air Cooled
Drier / Filter	Dryall Make
Expansion Device	Capillary Tube
Refigureerant Flow	Rotameter

Measurment	
Pressure Indication	Pressure Gauges, 2nos Provided
Energy Meter	Jaipur Make
Evaporator For Refrigeration Test Rig	Shell And Coil Type, Direct Expansion Coil.
Tempe. Indicator	Digital Led
Insulation For Water Tank	Thermocol
Supply	230 VOLTS, 50HZ, 1 PHASE, AC.

3.3 Nano-Refrigerant Preparation:

3.3.1 Using single step method [8, 15]

The single-step method is a process of combining the preparation of nanoparticles with the synthesis of nanofluids, for which the nanoparticles are directly prepared by physical vapour deposition (PVD) technique or liquid chemical method. In this method the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized and the stability of fluids is increased. But a disadvantage of this method is that only low vapour pressure fluids are compatible with the process. This limits the application of the method.

A suitable power source is required to produce an electric arc between 6000-120000C which melts and vaporizes a metal rod in the region where arc is created. The vaporized metal is condensed and then dispersed by deionized water to produce nanofluids.

3.3.2 Using Two step method [8, 15]

The two-step method for preparing nanofluids is a process by dispersing nanoparticles into base liquids. This step-by step method isolates the preparation of the nanofluids from the preparation of nanoparticles. As a result, agglomeration of nanoparticles may take place in both steps, especially in the process of drying, storage, and transportation of nanoparticles. The agglomeration will not only result in the settlement and clogging of micro channels, but also decrease the thermal conductivity. Simple techniques such as ultrasonic agitation or the addition of surfactants to the fluids are often used to minimize particle aggregation and improve dispersion behavior. Since nanopowder synthesis techniques have already been scaled up to industrial production levels by several companies, there are potential economic advantages in using two-step synthesis methods that rely on the use of such powders. But an important problem that needs to be solved is the stabilization of the suspension prepared. Two-step preparation process is extensively used in the synthesis of nanofluids by mixing base fluids with commercially available nanopowders obtained from different mechanical, physical and chemical routes such as milling, grinding, and sol-gel and vapor phase methods. An ultrasonic vibrator or higher shear mixing device is generally used to stir nanopowders with host fluids. Frequent use of ultrasonication or stirring is required to reduce particle agglomeration. Stability is a big issue that inherently related to this operation as the powders easily aggregate due to strong van der Walls force among nanoparticles. In spite of such disadvantages this process is still popular as the most economic process for nanofluids production. The most common two-step method is shown in Figure below

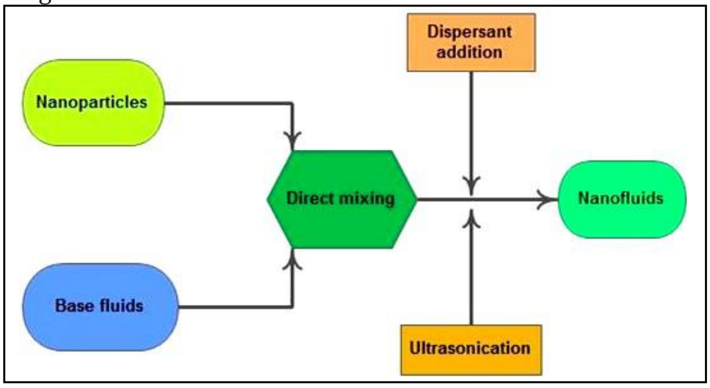


Figure 3.3: Two step preparation process of nanofluids

The Nano refrigerant for this work is prepared in National Chemical Laboratory, Pashan, Pune

National Chemical Laboratory (CSIR-NCL), Pune, established in 1950, is a constituent laboratory of Council of Scientific and Industrial Research (CSIR). CSIR-NCL is a science and knowledge based research, development and consulting organization. It is internationally known for its excellence in scientific research in chemistry and chemical engineering as well as for its outstanding track record of industrial research involving partnerships with industry from concept to commercialization.

Al_2O_3 Nanoparticles with concentration of 0.5wt%, and 0.1wt% were measured by digital weight balance. Each mass fraction of nanoparticles is mixed with R134a Resultant nano refrigerant was homogenized for 15 minutes followed by sonication for up to 4 hours using ultrasonicator.

The test were conducted on simple VCRS first without Nano refrigerant (R134a) and then with Al_2O_3 Nano-Refrigerant and results are compared at these two conditions and same discussed below.

4. RESULT & DISCUSSION

4.1 Effect on Coefficient of Performance

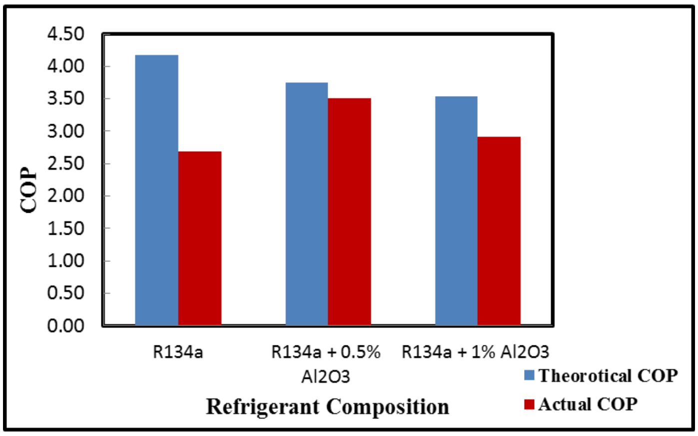


Figure 4.1: Effect on COP with and without Nano Refrigerant

COP is ratio of refrigerating effect and work input. In this study, COP has been calculated with help of experimental data. Refrigeration effect is estimated by means of energy meter connected to heater. Ultimately the heater is supplying heat to evaporator by means of heating water and same amount of heat is removed by refrigerant after achieving steady state. Theoretical COP is evaluated as 4.17 for pure R134a. On the other hand, with R134a+0.5% Al_2O_3 and for R134a+1% Al_2O_3 theoretical COP is found to be 3.75 and 3.54 respectively. R134a+0.5% Al_2O_3 shows the decline in theoretical COP by 10.07% and R134a+1% Al_2O_3 shows the decline in theoretical COP by around 15.10%. Actual COP is evaluated as 2.69 for pure R134a. On the other hand, with R134a+0.5% Al_2O_3 and for R134a+1% Al_2O_3 actual COP is found to be 3.52 and 2.92 respectively. R134a+0.5% Al_2O_3 shows the improvement in actual COP by 30.85% and R134a+1% Al_2O_3 shows the decline in actual COP by around 8.55%

4.2 Effect on suction and Discharge Temperatures of compressor

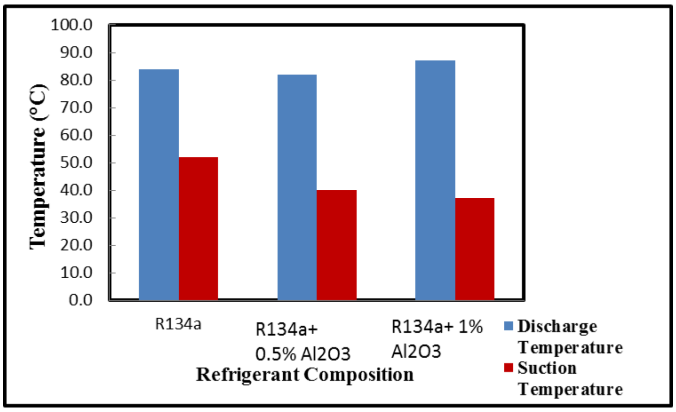
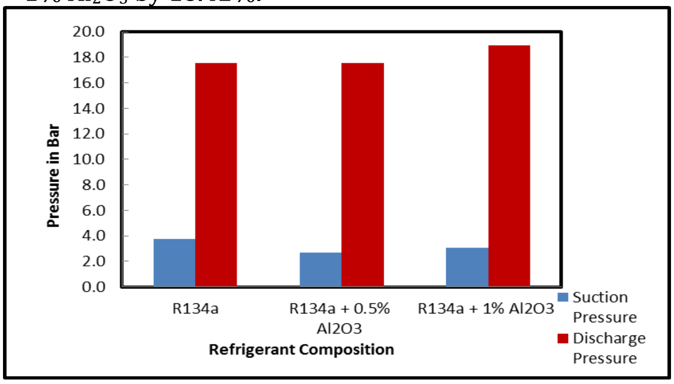


Figure 4.2: Effect on suction & discharge Temperature of compressor with and without Nano Refrigerant

The discharge temperature for pure R134a is 84^0 C. It is decreased by 2.8% in R134a + 0.5% Al_2O_3. And for R134a+1 % Al_2O_3 it is increased by 3.557. The suction temperature for pure R134a is 52^0 C. It is decreased by 23.07% in R134a + 0.5% Al_2O_3. And for R134a+1 % Al_2O_3 it is decreased by 28.84%. Higher discharge temperature results in high condensing temperature and low evaporating temperatures.

4.3 Effect on suction & Discharge pressure

For the above experiments the Pressures at suction and discharge have been recorded and are discussed in following section. P_1 and P_2 refer the Pressure at compressor suction and compressor discharge. Suction pressure shows decrement for R134a + 0.5% Al_2O_3 by 28.94% and for R134a + 1% Al_2O_3 by 18.42%.



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4.4 Effect on Subcool & Superheat

Superheating of the suction vapour is advisable in practice because it ensures complete vaporization of the liquid in the evaporator before it enters the compressor. Also, in most refrigeration and air-conditioning systems, the degree of superheat serves as a means of actuating and modulating the capacity of the expansion valve. Superheat is improved in R134a + 0.5% Al_2O_3 by 200% and in R134a + 1% Al_2O_3 it is improved by 114%.

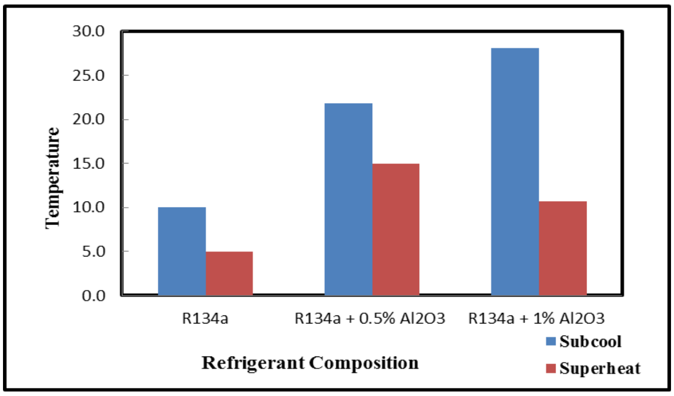

Figure 4.4: Effect on degree of subcool and superheat of system with and without Nano Refrigerant

It will be seen that sub-cooling reduces flashing of the liquid during expansion and increases the refrigerating effect. Consequently, the piston displacement and horsepower per ton are reduced for all refrigerants. The advantage of subcooling is offset by the increased work of compression. For pure R134a the subcooling is 10. It is improved by 118% for R134a + 0.5% Al_2O_3 and for R134a + 1% Al_2O_3 it is improved by 181%.

4.5 Effect on Compression Ratio

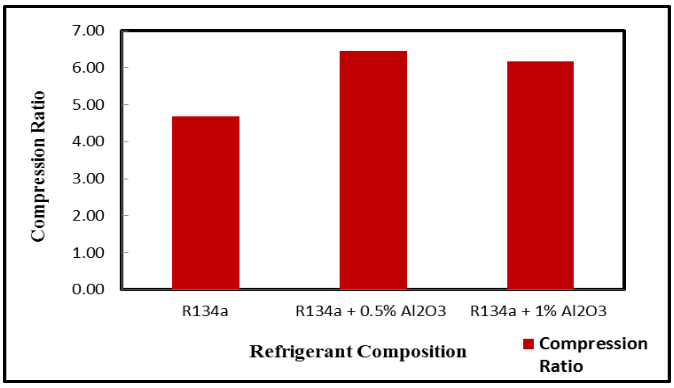

Figure 4.5: Effect on Compression Ratio of system with and without Nano Refrigerant

High compression ratios are a result of high condensing pressures or low evaporator pressures, or both. So, any time there are high condensing pressures or low evaporator pressures, or both, there will be high compression ratios. This will cause the heat of compression to increase and the compressor will have a higher discharge temperature. The compression ratio for pure 134a is 4.68. For R134a + 0.5% Al_2O_3 it is increased by 37.82% and for R134a + 1% Al_2O_3 it increased by 31.83%. Thus the For R134a + 0.5% Al_2O_3 have higher discharge temperature then pure R134a and R134a + 1% Al_2O_3.

4.6 Effect on Isentropic efficiency and volumetric efficiency

The volumetric efficiency for pure R134a is 88.27. It is decreased by 12.20% for R134a + 0.5% Al_2O_3 and for R134a + 1% Al_2O_3 it is decreased by 9.3%.

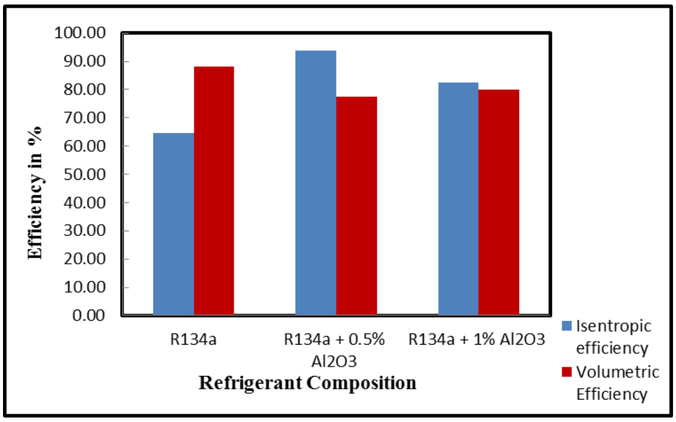

Figure 4.6: Effect on Compression Ratio of system with and without Nano Refrigerant

A high volumetric efficiency means that more of the piston's cylinder volume is being filled with new refrigerant from the suction line and not re-expanded clearance volume gases. The higher the volumetric efficiency, the greater the amount of new refrigerant that will be introduced into the cylinder with each down stroke of the piston, and thus more refrigerant will be circulated with each revolution of the crankshaft.

5. CONCLUSION

From the above result and discussion it is concluded that, addition of 0.5% of Al2O3 Nanoparticles in the base refrigerant will leads to improvement in the overall performance of the VCRS than that of pure base Refrigerant. However, increase in the percentage of nanoparticles in the base refrigerant will result in decreased system performance.

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