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EXPERIMENTAL EVALUATION OF PERFORMANCE OF AIR-CONDITIONING COMPRESSOR DUE TO AL_2O_3 NANOPARTICLES IN LUBRICATING OIL

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ABSTRACT

Nanoparticles are being widely used in recent years, due to their advantages. Addition of nanoparticles leads to significant change in thermal properties of a fluid. A new engineering medium, called nanofluid attracted a wide range of researchers on many cooling processes in engineering applications, which are prepared by dispersing nanoparticles or nanotubes in a host fluid. Recently, many researchers used nanoparticles in refrigeration and air conditioning systems, because of significant improvement in heat transfer capability to enhance the efficiency of refrigeration and air conditioning systems. In this paper, the thermal conductivities of Al_2O_3 and TiO_2 nanofluids at different volume concentrations were calculated theoretically, and reported that both nanofluids thermal conductivities increases with increase in particle volume concentration, and TiO_2 nanofluids has grater thermal conductivity over Al_2O_3 nanofluids. The performance test of domestic air conditioning rotary compressor was done experimentally, by using Al_2O_3 nanoparticles combined with mineral based lubricating oil (Suniso-4gs oil) and reported that increase in EER is just 0.13% and COP is improved up to 3.8% when Al_2O_3 Nanolubricant is replaced with lubricating oil. So, further experimentation is required with higher concentrations of nanoparticles with smaller sizes of Nano particles, and suitable combinations of nanoparticles are also needed. The refrigerant used in this process is R410a, which is sold under the trademark names of Suva 410a, Forane 410a, Puron, Ecofluor R410, Genetron R410a, AZ-20, which is a zeotropic but near azeotropic mixture of difluoromethane (CH2F2, called R-32) and pentafluoroethane (CHF2CF3, called R-125), also said to be a high pressure compressors refrigerant.

***KEYWORDS:** Air conditioning compressor, Aluminium oxide (Al_2O_3) nanoparticles, Nanorefrigerant, Refrigerant 410a, Energy Efficiency Ratio (EER)*

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NOMENCLATURE

α – Particle volume fraction (m^3)

ASTM – American society for testing and materials

CH2F2 – difluoromethane

CHF2CF3 – pentafluoroethane

COP – Coefficient of performance

EER – Energy Efficiency Ratio

HLB - Hydrophile- Lipophile Balance

K – Thermal conductivity (W/m K)

K_{eff} – Effective thermal conductivity of nanofluid

K_f – Thermal conductivity of fluid

K_p – Thermal conductivity of nanoparticle

ODP – Ozone depleting potential

ppm – parts per million

R410a – Refrigerant 410a

UUT – Unit under Test

V_p – Volume of the nanoparticle

V_f – Volume of the fluid

INTRODUCTION

A compressor is the most important and often the costliest component (typically 30 to 40% of total cost) of any refrigeration system. Compressor is also known as "heart" of any refrigeration system. The function of a compressor is to continuously draw the refrigerant vapor from the evaporator, so that low pressure and low temperature can be maintained in the evaporator. The task of the compressor is to raise the pressure of the refrigerant to a level, at which it can condense by rejecting heat to the cooling medium in the condenser. In today's Indian market, most of the air conditioner brands are employing reciprocating compressor whereas there are some brands, which are using rotary compressors. For continuous operation, rotary compressor would be a good idea. For all small systems meant to be used at house or a small office or a shop, then reciprocating air compressors seem to be a good option. Reciprocating compressors are maintained at low pressures and hence cause little or no maintenance problems. However, rotary air conditioning compressors have certain difficulties with regard to maintenance.

In traditional air conditioning system, there will be certain amount of lubricating oil that is carried away by the refrigerant in the compressor. So, certain amount of lubricating oil circulates along with the refrigerant in the air conditioning circuit. If the solubility of lubricating oil in the refrigerant is low, there is a danger of accumulation of lubricating oil in the condenser. If the solubility of lubricating oil in the refrigerant is high, refrigerant washes away all the lubricating oil in the compressor and there is a danger of increasing high temperature, which could damage the parts of the compressor and functioning. The literature survey reveals that any base fluid combined with nanoparticles (Al_2O_3) will result in better heat transfer performance than any other traditional heat transfer fluids. Then, this nanolubricant (suniso 4gs oil + Al_2O_3) used in the air conditioning rotary compressor will give better performance than ordinary lubricant and helps to improve the efficiency of compressor and air conditioning system. Nanoparticles added to the lubricating oil clog the internal surfaces; thereby decrease the sliding friction between the surfaces. Clogging of the surface also found to decrease the nucleate boiling heat transfer characteristics. Addition of Nanoparticles also found to enhance the critical heat flux of the refrigerant.

Literature studies show that Thermal conductivity of Nanofluid is greater than that of base fluid. Also viscosity of Nanofluid is greater than that of the base fluid. These are the prime uses of Nanoparticles. Nanoparticles also have certain disadvantages. There is a danger of sedimentation of Nanoparticles in compressor, if it is not dispersed properly in the oil. The refrigerant used in the air conditioning setup that is used for testing is R-410a.

The refrigerant 410a, sold under the trademarked names of Suva 410a, Forane 410a, Puron, Ecofluor R410, Genetron R410a and AZ-20 is a zeotropic, but near azeotropic mixture of difluoromethane (CH2F2, called R-32) and pentafluoroethane (CHF2CF3, called R-125), which is used as a refrigerant in air conditioning applications. R-410a cylinders are colored pink. It can operate at higher pressures than traditional refrigerants. Also, the ozone depletion potential (ODP) of R410a is zero, which suggests that it is environmental friendly. Narendra and Narasimha Rao (2018) have recently published a review paper in this area and they reported that Al_2O_3 nanoparticles combined with suniso oils give better performance than ordinary lubricating oils used in refrigeration and air conditioning compressors.

LITERATURE OVERVIEW

China Srinivasa and Srinivas Rao [2016] they have done the experimental investigation and reported that Compressor performance tests indicate that EER is increased 0.1%, when TiO_2 Nanoparticles are mixed with Mineral oil, and 1.5% decreased when Al_2O_3 nanoparticles are used. Spectroscopic analysis of nanoparticles added to lubricant oil shows that sediments start forming on the 7th day indicating that, Nano particles are not fairly well dispersed in the base fluid. Surfactants may be added to enhance the dispersal level. Thermal conductivity of Nanofluids (TiO_2, Al_2O_3 Nanoparticles added to Mineral oil) is greater than that of the base fluid.

Papade and Wale [2015] they have done the experimental study on the performance parameters of an air conditioner system with nanolubricant, and they concluded that R134a refrigerant and POE oil mixture with Al_2O_3 nanoparticles worked normally, and COP of the air conditioning system increased up to 14% when the conventional POE oil is replaced with nanorefrigerant. Also, the power consumption of the compressor reduces nearly by 20%, when the nanolubricant is used instead of conventional POE oil.

Cherng-Yuan Lin *et al.* [2011] prepared the Al_2O_3 nanofluid with a surfactant with a Hydrophile- Lipophile Balance (HLB) value of 12 and found that, it had the lowest nanoparticles precipitation rate. The nanofluids prepared with both a dispersant and a surfactant had the lowest thermal conductivity. The thermal conductivity decreased with storage time for all of the Al_2O_3 nanofluids. An increase in operating temperature leads to an increase in the thermal conductivity of Al_2O_3 nanofluids.

Mahbubul *et al.* [2013] investigated the flow boiling heat transfer coefficient and frictional pressure drop characteristics of Al_2O_3/R141b nanorefrigerants. This study reported that volume fractions have significant effects over heat transfer and pressure drop characteristics of nanorefrigerant. Due to significant enhancement of boiling heat transfer coefficient, nanorefrigerants could be implemented in refrigeration systems, but an optimum particle volume fraction is needed to avoid the high pressure drop as well as pumping power. It is noteworthy that, there could be some unknown effects on the compressor performance of the refrigeration or air conditioning system.

Hatwar and Kripalani [2014] have performed experiments related to the heat transfer enhancement by using oxide form nanofluids such as CuO, Al_2O_3, TiO_2 and ZnO. Amongst these, Al_2O_3 and CuO are frequently used due to the ease of suspension in the base fluid. The use of proper ultrasonic mixer is essential for the uniform mixing of the nanoparticles.

Proper care has to be taken while handling the nanoparticles in order to avoid oxidation. The use of nanofluid with higher concentrations provides considerably higher thermal performance for all the values of Reynolds number. The authors concluded that: (i). the higher the nanoparticles weight fraction, the more will be the rate of heat transfer enhancement, (ii). The heat transfer rate is directly proportional to Nusselt and Peclet numbers of the fluid, (iii). The fine grade of nanoparticles increases the surface area which results in increase in the heat transfer rate, (iv). Nanofluid stability and its production cost are major factors that hinder the commercialization of the nanofluids and (v). There has been considerable pressure drop by the use of nanofluid, but it can be overcome to some extent by using extremely fine powder (less than 20 nm). By solving these challenges, it is expected that nanofluids can make substantial impact as coolant in heat exchanging devices.

Dilip Kumar and Ayyappa [2016] proposed Al_2O_3 nano-oil as a promising lubricant to enhance the performance of vapour compression refrigeration compressor. The stability of Al_2O_3 nanoparticles in the oil is investigated experimentally. It was reported that the nanoparticles steadily suspended in the mineral oil at a stationary condition for long period of time. The application of nano-oil with specific concentrations of 1.5%, 1.7% and 1.9% (by mass fraction) were added in the compressor oil. The vapour compression refrigeration system (VCRS) performance with the nanoparticles was then investigated using energy consumption tests. The results show the COP of system was improved by 19.14%, 21.6% and 11.22% respectively, when the nano-oil was used instead of pure oil.

Yimin Xuan and Qiang Li [1999] concluded that the preparation method of nanofluids has been developed and they are prepared directly by mixing Nano-phase powders and base fluids, which reveals the possibility of practical application of the nanofluid. The nanofluid shows great potential in enhancing the heat transfer process. One reason is that, the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofluid. The volume fraction, shape, dimensions and properties of the nanoparticles affect the thermal conductivity of nanofluids. They also mentioned the alternative expressions for calculating the effective thermal conductivity of solid + liquid mixtures theoretically, which was introduced by Wasp at 1977. They used hot-wire method to measure the thermal conductivity of nanofluids. The measurement results illustrate that, the thermal conductivity of nanofluids remarkably increases with the volume fraction of ultra-fine particles.

For the water + Cu nanoparticles suspension, for example, the ratio of the thermal conductivity of the nanofluid to that of the base liquid varies from 1.24 to 1.78, if the volume fraction of the ultra-fine particles increases from 2.5% to 7.5%.

Saidur *et al.* [2010] they have written a review paper and their survey says that, TiO_2 nanoparticles mixed with mineral oil works normally in refrigerator and improves the performance of the refrigerator and saves the 26.1% energy with 0.1% mass fraction of TiO_2 nanoparticles combined with mineral oil. Also concluded that, the mineral lubricant with Al2O3 nanoparticles (0.05, 0.1, and 0.2 wt %) was used to investigate the lubrication and heat transfer performance. Results indicated that the 60% R134a and 0.1 wt% Al2O3 nanoparticles provided optimal performance. Under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%.

Sendil Kumar *et. al.* [2012] has conducted the performance tests for 150 gm. of pure R134a system, which is treated as the basis for comparison with other test results. Nano Al2O3–R134a with 0.2% concentration was fed to the experimental setup, and the tests were conducted under the same conditions. In order to obtain repeatability, each test was run for 3 to 4 times. A performance test was also conducted with charge mass of the order of 150 gm, 180 gm and 200 gm.

Addition of Nano Al2O3 into the refrigerant shows improvement in the COP of the refrigeration system. Use of Nanorefrigerant reduces the length of capillary tube and is cost effective. His results also indicate that The COP of the system increases with increase in capillary tube length and the Maximum COP of 3.5 are achieved for a capillary length of 10.5 m. The Discharge pressure increases with time and attains a maximum value and then decreases. The Maximum discharge pressure is obtained for charge mass of 150 gm. The suction pressure decreases initially and then increases with time. Suction pressure is found to be less for a charge mass of 150 gm.

Fei Duan (2012) he says that thermal conductivity, viscosity, and surface tension of the Al2O3 water-based nanofluids were measured. It is found the thermal conductivity increases significantly with the nanoparticle volume fraction. With an increase of temperature, the thermal conductivity increases for a certain volume concentration of nanofluids, but the viscosity decreases. The size of nanoparticle also influences the thermal conductivity of nanofluid. He also reported that viscosity increases as the concentration increases at room temperature. At the volume concentrations of 5%, the viscosity has an increment of 60%.

PREPARATION OF NANOLUBRICANT BY TWO-STEP METHOD:

Nanofluids are prepared by using Two-step method, which is the most widely used method. In this method, nanoparticles are first produced as dry powders by chemical or physical methods. Soon after, the Nano-sized powder will be dispersed into lubricating oil in the second processing step with the help of intensive magnetic force agitation and ultrasonic agitation. Figure 1 depicts the schematic of magnetic stirrer and magnetic beads.

Figure 1: Magnetic Stirrer, Lubricating oil with Nanoparticles is Placed in a beaker on the Stirrer With a Magnetic Bead in it

Two-step method is the most economic method to produce Nanofluids in large scale, because Nano-powder synthesis techniques have already been scaled up to industrial production levels.

SPECIFICATIONS OF NANOLUBRICANT USED IN THIS EXPERIMENTAL PROCEDURE:

The Amount of lubricating oil (suniso 4gs oil) used for this experiment is 750 ml and the amount of Al_2O_3 nanoparticles used is 10 grams. Properties of suniso-4gs oil are tabulated below:

Table 1: Properties of Suniso-4gs oil

S. No.	Property	Quantity
1	Density (at 20^0C)	916 kg/m^3
2	Colour (ASTM)	L1.0
3	Viscosity (40^0C)	54.9 mm^2/s
4	Viscosity (100^0C)	54.9 mm^2/s

Table 1: Contd.,		
5	Flash Point	188^0C
6	Pour Point	-35^0C
7	Aniline Point	79.8^0C
8	Water content	20 ppm
9	Floc Point	-46^0C
10	Thermal conductivity (at 20^0C)	0.162 W/m.K

METHODS TO ENHANCE THE STABILITY OF NANOFLUIDS

Surfactants used in the Nanofluids are also called dispersants. The stability of nanofluids can be enhanced by adding dispersants in the two-phase systems. Dispersants can markedly affect the surface characteristics of a system in small quantity. Dispersant consists of a hydrophobic tail portion, usually a long-chain hydrocarbon and a hydrophilic polar head group. Dispersants are employed to increase the contact of two materials, sometimes known as wettability. In a two-phase system, a dispersant tends to locate at the interface of the two phases, where it introduces a degree of continuity between the Nanoparticles and base fluids.

When the base fluid of Nano fluids is polar solvent, water-soluble surfactants should be selected; otherwise, oil soluble ones are to be selected.

THEORETICAL THERMAL CONDUCTIVITY ANALYSIS OF NANOFLUID:

From the literature survey, it is clear that nanofluids exhibit superior heat transfer characteristics than conventional heat transfer fluids. One of the reasons for better performance is that the suspended particles remarkably increase the thermal conductivity of nanofluids. The thermal conductivity of Al_2O_3 based nanofluid is strongly dependent on the nanoparticle volume fraction and volume concentration. So far, it has been an unsolved problem to develop a sophisticated theory to predict thermal conductivity of nanofluids, although there exist some semi-empirical correlations to calculate the apparent conductivity of two-phase mixture. The alternative expression for calculating the effective thermal conductivity of solid + liquid mixtures was introduced by Wasp in 1977 [Fei Duan (2012)].

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f - 2\alpha\left(k_f - k_p\right)}{k_p + 2k_f + \alpha\left(k_f - k_p\right)}$$

Where, K_{eff} is effective thermal conductivity of nanofluid, K_p is thermal conductivity of nanoparticle; K_f is thermal conductivity of fluid and α is particle volume fraction.

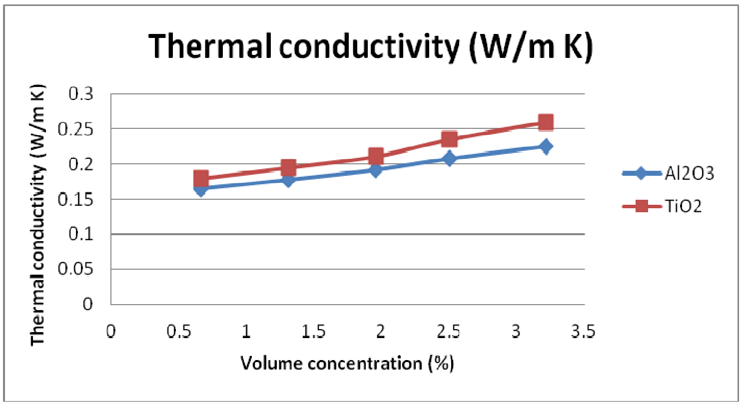
$$\alpha = \frac{v_p}{v_f + v_p}$$

The theoretical calculation for effective thermal conductivity of Al_2O_3 based nanofluid clearly shows the increase in thermal conductivity by increasing the volume fraction and volume concentration of nanoparticles in lubricating oil. Table 2 shows the results of thermal conductivity estimated at different particle volume concentrations.

Table 2: Thermal Conductivities of Nanofluid (Al_2O_3 + Lubricating oil) at different Volume Fractions

Sl. No.	Amount of Nanoparticles in 750 ml of Lubricating oil (gm)	Volume Concentration (%)	Volume Fraction (α) [m^3]	Thermal Conductivity of Al_2O_3 Fluid (W/m K)
1	5	0.66	0.0156	0.16437
2	10	1.31	0.0313	0.17739
3	15	1.96	0.0469	0.19192
4	20	2.5	0.0626	0.20788
5	25	3.22	0.0779	0.22556

The thermal conductivities of TiO_2 nanofluid are also calculated and are compared with Al_2O_3 nanofluid, which shows TiO_2 has greater thermal conductivity than Al_2O_3 nanofluid. Graph 1 depicts the thermal conductivities of nanofluid across different volume concentrations.



Graph 1: Thermal Conductivity Graph where the Values on X-axis Denote the Volume Concentration of Nanoparticles and the Values on Y-Axis Denote Thermal Conductivities in Watt per Meter Kelvin.

PERFORMANCE TEST ON AIR CONDITIONING COMPRESSOR SET-UP

The Nanolubricant prepared above is tested in the compressor of air-conditioning test facility in M/s TECUMSEH, Hyderabad. The equipment is run till steady state is reached or heat balance is attained. The refrigerant used is R-410a. Apparatus are available to maintain the same temperature all over the room. Thermocouples are provided to ensure the required conditions are maintained in the test setup. Experimental set-up is also provided to measure the power input to the compressor, net cooling capacity and temperatures at different places in the conditioned space. Figure 2 shows the circuit diagram of experimental setup of air conditioning system.

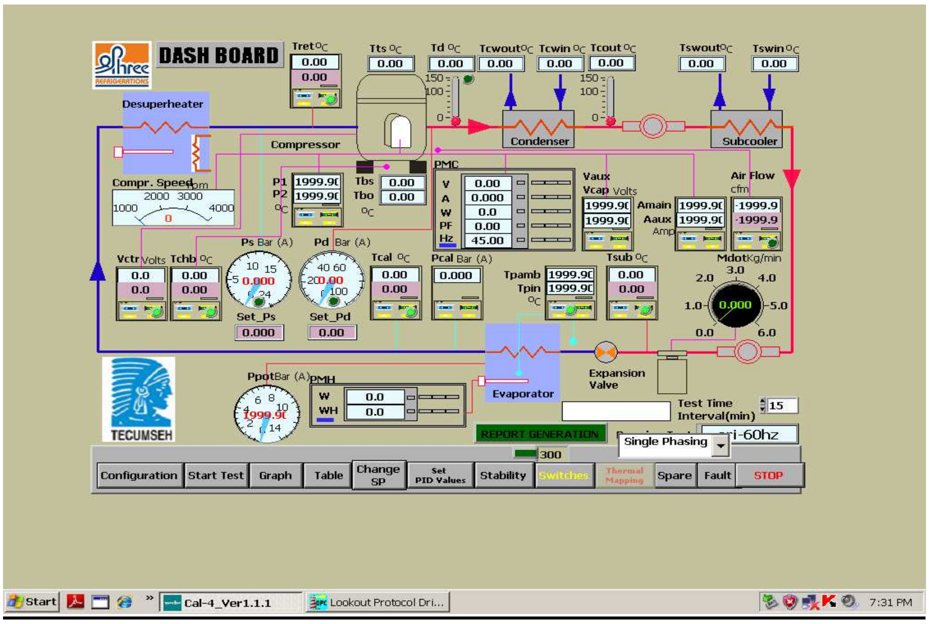


Figure 2: Line Diagram of Experimental Air Conditioning System

Test Procedure

The following guidelines are provided while conducting the experimental work.

- Machine to be tested is selected and inspected according to the sampling, receiving check list.
- If the machine is in satisfactory condition, i. e. without any damage and improper functioning, it is installed in the facility and installation check-list is followed.
- Power supplies of test room, 2 TR chillers and computer software are switched ON.
- Lab view software is initialised on the computer.
- For the test conditions to be followed, TEST REQUEST is to be referred. Following procedure should be followed for conducting cooling capacity test.

Figure 3: Experimental Air Conditioning Compressor Setup

The purpose of the test is to determine the magnitude of following functions:

- Net Cooling capacity,
- Net power input to compressor.

The Energy Efficiency Ratio (EER) is calculated from above determined parameters, and from this EER value, the improvement in coefficient of performance (COP) is determined using.

COP = EER * 0.293

Figure 4: Compressor Test Cabin

- Calorimetric test conditions are selected (27°C/ 19°C, 35°C / 24°C) for the unitary air conditioner (IS – 1391 Part 1) and (27°C/ 19°C, 35°C / ----) for split air conditioner (IS – 1391 Part 2).
- UUT (Unit under Test) is switched ON.
- Fan speed should be highest and the total unit is in cooling mode, temperature is set to minimum set point.
- System is allowed to be stabilized for the above mentioned test conditions.
- Test unit is run for 4 hours under the stabilized condition and the values obtained are recorded.
- Test data is compared with the declared values.
- For the test unit to qualify the cooling capacity test, cooling capacity of the unit should not be less than that of the 90% of the declared value and power consumption of the unit should not be more than 110% of the declared value.

RESULTS AND DISCUSSIONS

- As shown in the results, the Thermal conductivity of lubricating oil mixed with Nanoparticles is found to be greater than that of the base lubricating oil, and also thermal conductivity increases with particle volume fraction and volume concentration. This result agrees with that of the results obtained in the literature.
- The following table shows the experimental results of Compressor performance tests, when Al_2O_3 Nanoparticles are mixed with suniso 4gs-oil and individual suniso oil.

Table 3: Experimental results of Compressor Performance Test

Test Measurements	Suniso 4gs-oil	Suniso oil + Al_2O_3	Set Value
Pressure	**Bar (A)**	**Bar (A)**	**Bar (A)**
Suction pressure	9.9336	9.9382	9.954
Discharge pressure	33.846	33.862	33.86
Cal. Out pressure	9.908	9.912	
Temperatures	**^0C**	**^0C**	**^0C**
Return gas temperature	35	35	35
Compressor chamber ambient	34.9	35	35
Cal. Out temperature	35.1	35	35

Refrigeration Results			
Compressor power (watts)	2329.72	2304.18	2320
Compressor current (Amp)	10.79	10.772	11.5
Cooling capacity (watts)	6721.90	6756.29	6862.17
Energy Efficiency Ratio (EER)	**2.80**	**2.93**	**2.95**

Compressor performance tests indicate that increase in EER is just 0.13%, when Al_2O_3 nanoparticles are mixed with lubricating oil, which is not very significant. So, further experimentation is required with higher concentrations of nanoparticles and suitable combinations of nanoparticles are also needed. Surfactants can also be added to the Nanofluids and EER verified.

CONCLUSIONS

- Thermal conductivity of Nanoparticles mixed in lubricating oil is found to be greater than that of the base lubricating oil, and also thermal conductivity increases with particle volume concentration and TiO_2 nanofluids has better thermal conductivity than Al_2O_3 nanofluids. This result agrees with that of the results available in the literature and there is a need for more experimental investigations on thermal conductivity of nanofluids.
- The reproducibility of the air conditioning test facility was cross-checked by repeating the test results for each case two times. Results show that by using individual suniso 4gs oil, the Energy Efficiency Ratio is 2.8 and by using Al_2O_3 nanoparticles combined with suniso 4gs oil the EER value is 2.93. This amounts to an increase in EER value of 0.13%. The COP improved by 3.8%, which is not very significant, considering the significant additional expenditure for augmenting the lubricating oil with nanoparticles. For better performance, further experimentation is needed with suitable lubricating oils and nanoparticles. The nanoparticles concentration has to be increased and more tests have to be conducted.
- The thermal conductivity of TiO_2 nanofluid is higher than that of Al_2O_3 nanofluid. It can be presumed that the same experiment with TiO_2 nanoparticles gives better performance than Al_2O_3 nanofluid.
- Cost of nanoparticles is very high. This is the major drawback of nanoparticles usage is very low in industrial level.

SCOPE OF FUTURE WORK

- Investigating the same work with different nanoparticles combined with different fluid combinations, and finding out the suitable fluid combination for better compressor performance.
- Finding out the suitable surfactants added to the lubricating oil to reduce the sedimentation problem.
- The enhancement of fundamental properties of nanofluids such as specific heat, density and viscosity is not yet well established experimentally. Hence, experimental researches are needed to determine these properties.

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