Reducing Energy Consumption of Refrigerator Compressor using Aluminum Oxide Nanoparticles

Reducción del Consumo de Energía del Compresor de Refrigerador mediante Nanopartículas de Óxido de Aluminio

Reduzindo o Consumo de Energia do Compressor de Refrigeradores usando Nanopartículas de Óxido de Alumínio

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Summary. - Refrigeration has become an integral part of our daily lives and can be regarded as a process whose replacement is nearly impossible. Therefore, the only way of making this process efficient is by reducing the energy consumed by the components of refrigerators. One way of doing this is to reduce the power consumption of compressor by the addition of nanoparticles either in a refrigerant or in a lubricant. This study focusses on producing nanolubricant (Al2O3/Synthetic lubricant) and dispersing the nanolubricant into R-134a compressor. This study investigates that how much power can be reduced when Aluminum oxide (Al2O3) nanoparticles dispersed in SL-32 lubricant (base fluid). A comparison between SL-32 lubricant with and without the addition of Aluminum oxide nanoparticles was done and it showed a reduction of 0.913% in current consumption and 2.74% in power at the same initial temperature of 31°C in both cases. Hence it can be concluded that Alumina nanoparticles can be utilized to reduce the energy utilized by compressors by creating a nanolubricant with SL-32 lubricant.

Keywords: Refrigeration, Nanoparticles, Lubricant, Compressor, Energy.

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Resumen. - *La refrigeración se ha convertido en una parte integral de nuestra vida diaria y puede considerarse como un proceso cuya sustitución es casi imposible. Por tanto, la única forma de hacer eficiente este proceso es reduciendo el consumo energético de los componentes de los frigoríficos. Una forma de hacerlo es reducir el consumo de energía del compresor mediante la adición de nanopartículas en un refrigerante o en un lubricante. Este estudio se centra en la producción de nanolubricante (Al2O3/lubricante sintético) y la dispersión del nanolubricante en el compresor R-134a. Este estudio investiga cuánta energía se puede reducir cuando las nanopartículas de óxido de aluminio (Al2O3) se dispersan en el lubricante SL-32 (líquido base). Se realizó una comparación entre el lubricante SL-32 con y sin la adición de nanopartículas de óxido de aluminio y mostró una reducción del 0,913% en el consumo de corriente y del 2,74% en la potencia a la misma temperatura inicial de 31°C en ambos casos. Por lo tanto, se puede concluir que las nanopartículas de alúmina se pueden utilizar para reducir la energía utilizada por los compresores mediante la creación de un nanolubricante con lubricante SL-32.*

Palabras clave: *Refrigeración, Nanopartículas, Lubricante, Compresor, Energía*.

***Resumo*. -** *A refrigeração tornou-se parte integrante do nosso dia a dia e pode ser considerada um processo quase impossível de substituir. Portanto, a única forma de tornar esse processo eficiente é reduzir o consumo de energia dos componentes do refrigerador. Uma maneira de fazer isso é reduzir o consumo de energia do compressor adicionando nanopartículas a um refrigerante ou lubrificante. Este estudo tem como foco a produção de nanolubrificante (Al2O3/lubrificante sintético) e a dispersão do nanolubrificante no compressor R-134a. Este estudo investiga quanta energia pode ser reduzida quando nanopartículas de óxido de alumínio (Al2O3) são dispersas em lubrificante SL-32 (líquido base). Foi feita uma comparação entre o lubrificante SL-32 com e sem adição de nanopartículas de óxido de alumínio e mostrou uma redução de 0,913% no consumo de corrente e 2,74% na potência na mesma temperatura inicial de 31° C em ambos os casos. Portanto, pode-se concluir que nanopartículas de alumina podem ser utilizadas para reduzir a energia utilizada pelos compressores, criando um nanolubrificante com lubrificante SL-32.*

Palavras-chave: *Refrigeração, Nanopartículas, Lubrificante, Compressor, Energia*.

1. Introduction. - Thermal systems like air conditioners and refrigerators use a lot of electricity; therefore, research into producing energy-efficient refrigeration with environmentally benign refrigerants is necessary. The characteristics of a preferable refrigeration system include system efficiency [1]. Due to increasing demands for energy, innovative approaches are being adopted by engineers to improve the efficiency of refrigeration systems [2]. Improving system efficiency is a key to save energy and make the system more energy efficient. It conserves available energy resource and has environmental benefits such as reduced greenhouse gas emission and other pollutants. Improving insulation and upgrading to energy efficient system are the two main traditional methods of improving energy efficiency. As opposed to the traditional methods, addition of nanoparticles provides a new means to improve system efficiency and hence the energy conservation. A refrigeration system usually comprises a condenser, evaporator, expansion device and compressor. Without these components, heat cannot flow from a colder region to a warmer region [3].
The thermal conductivities of fluids that contain suspended solid metallic particles are expected to be significantly more enhanced when compared with conventional heat transfer fluids. Nano fluids are engineered by suspending ultrafine metallic or nonmetallic particles of nanometer dimensions in traditional heat transfer fluids such as water, engine oil, and ethylene glycol. [4]

One way of using nanoparticles is by adding them to the lubricant utilized in the compressor [5]. By dispersion of metal or metallic oxide nanoparticles into a chosen base fluid, such as water, oils, or ethylene glycol, nanofluids can be created. After adding nanoparticles, the base fluid's density, viscosity, specific heat, and thermal conductivity can be altered, this results in improved compressor performance. [6]. The primary purpose of oil is to improve the lubrication of the compressor along with cooling. The main characteristic of a good lubricant is that it should be chemically stable, produces no wax deposits, has excellent performance at low temperatures and is compatible with the material used in the compressor [7]. Nanofluids can be prepared in two steps: Firstly, nanoparticles are produced in the form of dry powder then they are dispersed in the base fluid using a magnetic force agitation. In two step method Nanoparticles, Nanofibers, Nanotubes or any other nanomaterial are produced in a form of dry powder using chemical or any physical method. In the second step, they are dispersed in the fluid by the use of magnetic force agitation, ultrasonic agitation, high shear mixing, homogenizing, and ball milling. On the large scale, this method is more economical because they have been scaled up to the industrial level. In one step method, the making and dispersing of nanoparticles in the fluid are done simultaneously. The processes such as drying, transportation, storage and dispersion are eliminated. The nanoparticle's agglomeration is reduced as the nanoparticles are uniformly dispersed in the fluid and stably suspended in it. This method cannot be used for large-scale synthesis, and it is more expensive than the two-step method [8].

Several studies have shown that nanofluids help in reducing the energy consumed by the compressor. A study conducted in 2019 used an R-12 household refrigerator tested under certain ambient temperature conditions with a 40g R-600a charge enhanced with different TiO_2 nano-lubricant concentrations (0 g/L and 0.2 g/L nano-lubricants) which shows that reduction in energy consumption was in the range of 3.42 to 4.52% when compared to the base fluid [9]. In 2011, a comparison was done between three lubricants POE oil, SUNISO 3GS and SUNISO 3GS mixed with nanoparticles while the refrigerant was R-134a. Compared to POE oil, the power consumption was reduced up to 18% when SUNISO 3GS was used and this reduction in energy consumption increased to 25% when nanoparticles were mixed in SUNISO 3GS [10].

An experimental investigation was done with R-134a refrigerant and a nano-oil mixture of Polyalkylene glycol in which Al_2O_3 nanoparticles were dispersed. The comparison was done between PAG oil and nano-oil mixture. It was found that the COP of the systems improved up to 6.5% and sub-cooling was also improved at the exit of the condenser [11]. In a study conducted in 2009, 0.1 % by weight of Al_2O_3 nanoparticles were added to mineral refrigeration oil and the power consumption was reduced by an amount of 2.4% while the COP increased by 4.4%. The primary refrigerant used was R-134a [12]. R-600a refrigerant with TiO_2 nanolubricant and LPG refrigerant were compared in a study. Titanium dioxide was dissolved in mineral oil to create a nanolubricant. There were three different concentrations: 0.2 g/l, 0.4 g/l, and 0.6 g/l. In comparison to baseline LPG refrigerant, the power used by the system for all charges of R-600a refrigerant and 0.2 g/L of TiO_2 nano-lubricant was 1.94-33.33% lower [13]. In 2008, a study was done to compare how much energy is reduced if HFC134a/nano-oil mixture is used instead of HFC134a/Polyester oil. Nano-oil was a mixture of mineral oil in which Titanium oxide was dispersed with a 0.1% mass fraction. The results showed a 26.1% decrease in energy consumption and also nanoparticles helped in improving the solubility of HFC134a and mineral oil which was shown clearly by the higher oil return ratio [14].

In 2009, a study was conducted in which 1% mass fraction of Copper Oxide nanoparticles of 50nm size was utilized in POE oil to reduce the compressor work by 21.37% [15]. A reduction was showed in compressor work of 11% when a combination of TiO_2 nanolubricant and R134a refrigerant was tested and a boost in COP of 24% was observed when SiO_2/PAG nanolubricant was used instead of TiO_2 with R134a refrigerant. The influence of nano refrigerants and nano lubricants on heat transfer, refrigerant-oil combination, and tribology improved the overall performance of Vapor

Compression Refrigeration Systems [16]. It is anticipated that nano refrigerants and nano lubricants will be the greatest candidates for increasing the effectiveness of the Vapor Compression Refrigeration System. A test was done using Polyalkaline glycol (PAG) compressor oil and modifying it with a 1.0% volume fraction of Titanium dioxide nanoparticles with R134a refrigerant and the COP improved by 21.42% [17]. CuO/SiO_2 nano-lubricants was used in vapour compression refrigeration systems in place of pure mineral oil. In this study, experiments are conducted with hybrid nano-lubricants made by dispersing two distinct nanoparticles, namely CuO and SiO_2, at concentrations of 0.2 g/L and 0.4 g/L and 40 and 60 g of R-600a refrigerant, respectively. CuO and SiO_2 hybrid nano-lubricants result in a 35% increase in performance efficiency, an 18% increase in cooling capacity, and a 75W reduction in compressor power consumption [18]. When employing R-290 with TiO_2 nanoparticle in the lubricants, the air conditioner's input power falls by about 3.1%, while the cooling capacity and the coefficient of performance (COP) rise by about 5.1% and 8.4%, respectively, in comparison to the system without nanoparticle in the lubricant [19]. When SiO_2 nano-oil was added to compressor oil at particular concentrations of 1%, 2%, and 2.5% (by a mass fraction), it enhanced the system's coefficient of performance (COP) by 7.61%, 14.05%, and 11.90% when used in place of pure oil, respectively [20]. In an experimental investigation, the performance of an R-134a refrigerant vapour compression refrigeration system was examined utilizing nanolubricant with various volume percentages of Al_2O_3 to mineral oil (MO) (0.05%, 0.075%, 0.1%, and 0.2%). The outcome indicates a maximum improvement in COP of almost 85% for a volume percentage of 0.075%. Comparing nanolubricant to base fluid, the use of nanolubricant reduces compressor power usage by about 27% [21].

This research is focused on a method that can help in decreasing the overall energy consumed by a refrigerating system by utilizing an approach that is environment-friendly and cost-effective. The presence of a nanolayer at the solid-liquid interface is the primary cause of the thermal conductivity enhancement, however particle clustering may also play a significant role. The liquid or oil molecules that are closer to the particle are referred to as forming layered structures because they behave like solid surfaces and serve as a thermal bridge between the oil molecules and the particle. Additionally, compared to oil, particles have a higher heat conductivity and hence higher heat transfer [22]. Most of the research on improving heat transfer of thermal fluid is done on either water or ethyl glycol. In this research a novel thermal fluid is investigated which is made by adding aluminum oxide nanoparticles to lubricant compressor oil. Keeping all the factors in mind SL-32 lubricant was considered as a base fluid (See Table I. Properties of Suniso SL-32 lubricant). It is a synthetic ester lubricant. This research utilizes a test rig and compares a synthetic lubricant i.e., SL-32 with and without any addition of Alumina Nanoparticles. The solvent SL-32 is being utilized as it is already an effective lubricant, and the addition of nanoparticles will reveal how much improvement can further be made in its properties.

In this study we will investigate how much power can Aluminum oxide nanoparticles reduce when dispersed in SL-32 lubricant (base fluid).

2. Methodology. -

2.1 Preparation of Nanofluid. - One way to create nanofluids is to mix metal or metallic oxide nanoparticles with a chosen base fluid, like ethylene glycol, water, or oil. By adding nanoparticles, the base fluid's density, viscosity, specific heat, and thermal conductivity can all be altered, improving compressor performance. Using nanoparticles in lubricants or thermal fluids has three key benefits presently. By increasing the solubility of the refrigerant in the lubricant and decreasing wear and friction coefficient through dispersion, nanoparticles can improve the lubricant's thermal conductivity and heat transfer properties. Increased heat transfer rate from nano-lubricant may result in refrigeration systems using less electricity and smaller compressors.

SL-32 lubricant properties are mentioned in **¡Error! No se encuentra el origen de la referencia..** Al_2O_3 nanoparticles were used to prepare the nanofluid by dispersing it in SL-32 lubricant. Al_2O_3 nanoparticle had an average class size of 100nm. Nanofluid is not just a simple mixture of solid (powder) and liquid. It requires some special guidelines which include stable and durable suspension, negligible agglomeration of particles, and no chemical change of the fluid. For the preparation of Nanolubricant, we first take a sample of 100ml Suniso SL-32 in the beaker and measure its weight on a digital scale and put a 0.06% mass fraction of Aluminum Oxide (Al_2O_3) in the beaker as it is the only mass fraction of Al_2O_3 that passed the sedimentation test (See Section 0). Then a magnetic stir bar was added to the beaker and the mixture was stirred. The beaker is then placed on the hot plate stirrer and a mixture of nanoparticles and lubricant is allowed to heat and stirred for 30 minutes at 70 ºC and 400 rpm (See figure I). After that Nano lubricant is allowed to cool. Then the nano lubricant is shifted from the beaker to the glass bottle. Then Ultrasonication is performed to ensure the proper mixing of lubricant with nanoparticles for 30 minutes in and kept under observation for the sedimentation process.

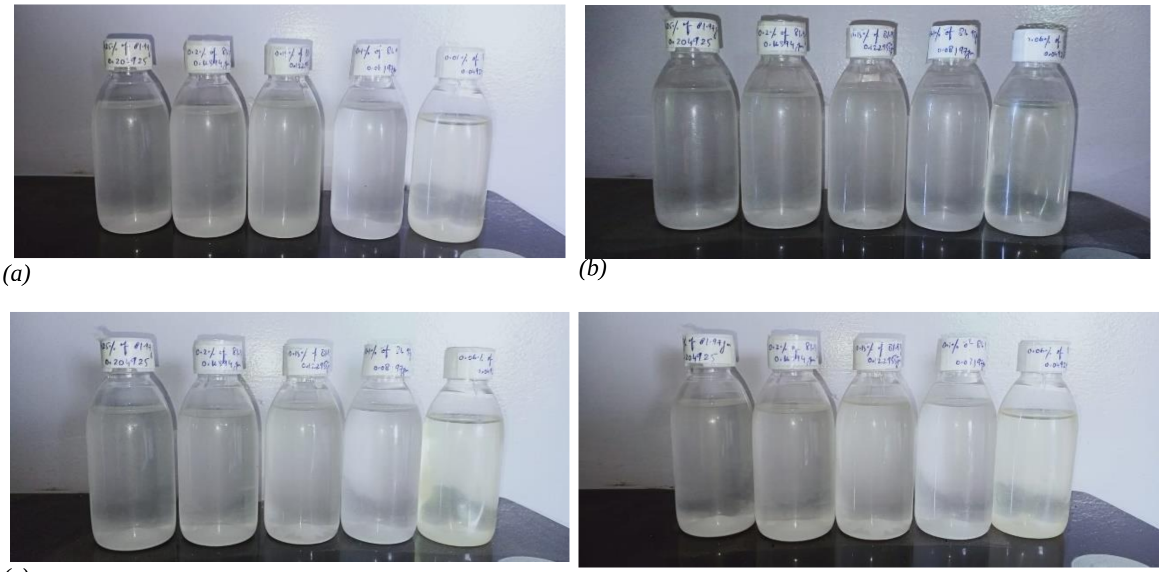
Density at 15 ºC	0.980

Viscosity at 40 ºC	32.0 cSt
Viscosity at 100 ºC	5.8 cSt
Viscosity index	125
Flash Point ºC	235 ºC
Pour Point ºC	-48 ºC
Color	L0.5
Cu Corrosion at 100 ºC x 3hrs	1a

Table I. *Properties of Suniso SL-32 lubricant*

Figure I.*- Beaker with magnetic stirrer placed on Hot plate*

2.2 Sedimentation Test. - The sedimentation test is done to check the settling down of suspended particles after a period of time. Images displayed were taken on the 4th day, 8th day, 12th day and 16th day respectively. The complete time period of observation was 16 days. After 12 days, 0.06% was the only sample which did not settle while all the other samples did not pass the test.



(a) *(b)* *(c)* *(d)*

Figure II.*- Samples on 4th, 8th, 12th and 16th day*

In order to find out the number of nanoparticles that would pass the sedimentation test trial and error method was adopted. The volume is converted into kilograms by weighing with electronic balance. 0.06% was the number of nanoparticles that was added in the lubricant.

2.3 Test Rig. - The refrigerator we used for this experiment is a defrost, double-door refrigerator from the Haier brand as shown in Figure III. The specifications of the refrigerator were shown in Table II.

Model	HRF-368J
Storage Volume	329L
Freezer Volume	68L
Power	180W
Voltage	200-240V (50 Hz)
Refrigerant	R-134A(190g)
Freezing Power	4Kg/24h
Overall Dimensions	620x600x1700(mm)

***Table II**. Refrigerator specifications*

***Figure III**.- Refrigerator with Data logger Sensors*

The test rig was modified by placing the compressor outside the refrigerator as shown in **¡Error! No se encuentra el origen de la referencia.**V for easily changing the lubricant and refrigerant. The refrigerant circuit was rebuilt with the proper facilitation to measure pressure and temperature. A leak check was carried out to make sure that there is no leakage of refrigerant and pressure drop because of that.

***Figure IV**.- Modified location of Compressor*

2.4 Changing Lubricant in Hermetic Compressor. - First, we have to evacuate the mineral oil present in the system. For this operate the charging nozzle to drain out the entire refrigerant and shut off the suction and discharge line of compressor by untighten the copper coupling. Dismantle the compressor out of the body and unplug the charging nozzle and then place the compressor upside down to drain out the lubricant in the pot. Leave the compressor for 24 hours to drain out every single drop of lubricant. Install the compressor in the refrigerator body. The amount of oil added to the compressor is 250 ml. Measure the correct quantity of lubricant in a beaker. Fix the rubber pipe to the charging nozzle and immerse the other side of the pipe in the lubricant. Switch on the compressor to displace the lubricant. Screw the Non-Return Valve to charging nozzle and plug the charging cap. Couple the suction and discharge line of refrigerant.

***Figure V**.- Draining out lubricant*

Figure VI.- *Charging Lubricant*

2.5 System Evacuation. - The evacuation procedure is used to get rid of incondensable materials like air, water, moisture, and inert gases from the refrigeration system. The most popular pieces of equipment for evacuation are a charging manifold and a vacuum pump. A tst-215 model 2-stages vacuum pump (see figure VII) and a three-hose charging manifold with low-side and high- side pressure gauges are used in this experiment to evacuate the system. Check the pressure gauge manifold make sure that both suction and discharge valves are closed. Connect the low-pressure hose pipe of pressure gauge manifold to Vacuum Pump. Attach the other hose pipe to compressor charging point. Switch on the vacuum pump and observe the suction pressure gauge and make sure it reaches to -30 psi for complete air removal. Switch off the vacuum pump and close the suction pressure valve of pressure Gauge manifold and disconnect the low-pressure hose pipe.

Figure VII.- *Vacuum Pump for system evacuation*

2.6 Charging R-134a Refrigerant in Hermetic Compressor. - The refrigerator (Figure III) can be fully charged with 190 g of refrigerant. R-134a. Connect the low-pressure hose pipe with Refrigerant R-134a cylinder. Open the valve of Refrigerant cylinder and open the pressure gauge valve and then Switch on the Refrigerator. Close the valve of refrigerant cylinder and check the discharge pressure if it decreases then again opens the valve of refrigerant cylinder until discharge pressure is not decreasing. Disconnect the hose pipe from compressor charging point and plug the Charging cap. Refrigerator is ready to operate.

Figure VIII.- *Charging R-134a Refrigerant*

As safety precaution personal protective equipment (PPE) such as gloves, safety goggles, and respirator masks made especially for working with refrigerants has been used. This guards against coming into direct touch with the refrigerant and keeps dangerous fumes from entering the lungs. To disperse any possible refrigerant leaks or vapors that may emerge during installation made sure the workspace has enough ventilation. It's important to follow fire safety procedures since refrigerants have the potential to catch fire, therefore, smoking and open fires in locations where refrigerant handling takes place should be avoided.

2.7 Experimental Procedure. - The compressor was charged with lubricant and then readings of current, voltage, temperature and time were obtained using data logger. The temperature sensors were installed in the refrigerator and freezer compartment (see figure IX) and connected to data logger. The voltage and current sensors were connected with compressor. The temperature sensors which we utilized are DS18B20 in our analysis. They have a measuring range -55°C to 125°C.Then, power (P) was calculated using the relation P= IV, where current (I) is in amperes and voltage (V) is in volts. Graphs were plotted between Power versus Time and Current versus Time. Comparison between the reduction in power and compressor was done by calculating the amount of percentage reduced by replacing nanolubricant instead of SL-32 lubricant. The data was collected for several days.

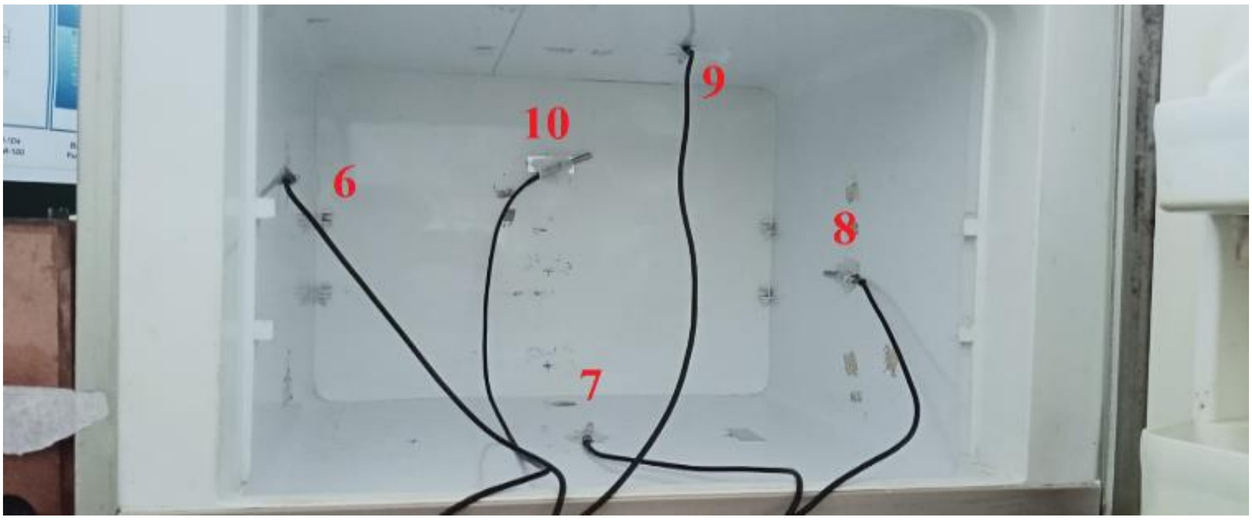


Figure IX.- Sensors in Freezer compartment

3. Results & Discussions. - The power consumption with and without nanofluid versus time graph plotted in figure X. As shown in figure X power consumption decreases with addition of Al_2O_3 nanoparticles. The power dropped down to approximately zero at the 270-minute mark due to the thermostat shutting off the current supply when lubricant SL-32 is used without nano particles. The maximum power in the whole process is 447.635 Watts. As shown in figure X with the addition of nano particles in SL-32 lubricant the power dropped down to approximately zero at the 260-minute mark that means the compressor is shutting down 10 minutes early with the addition of nanolubricant which is saving power. The actual difference in the power consumption with and without nanoparticles is magnified in figure XI which clearly shows that power consumption is less with nanoparticles. The average power consumed without nanoparticles is 407.98 Watts and with nano particles it is reduced to 396.809 Watts as shown if figure XII. The maximum power consumed by the compressor throughout the operation is 434.99 Watts while the average power consumed is 396.809 Watts.

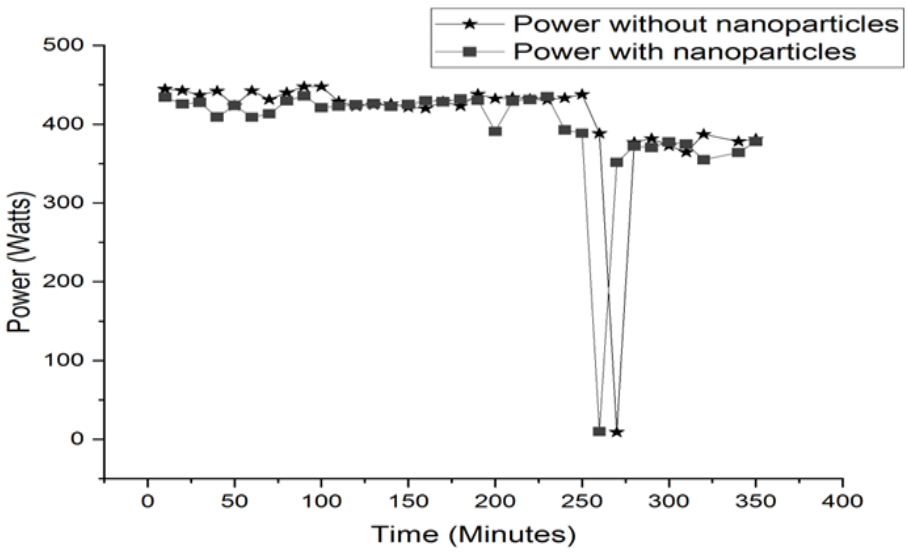


Figure X.*- Power versus Time graph*

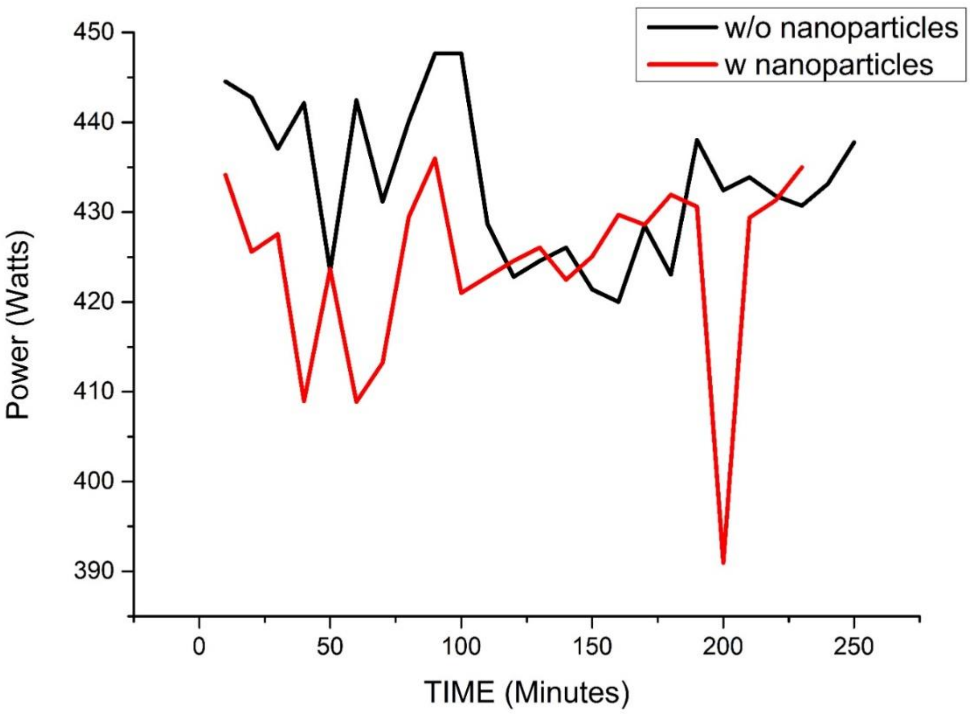


Figure XI.- *Magnified Power versus Time graph*

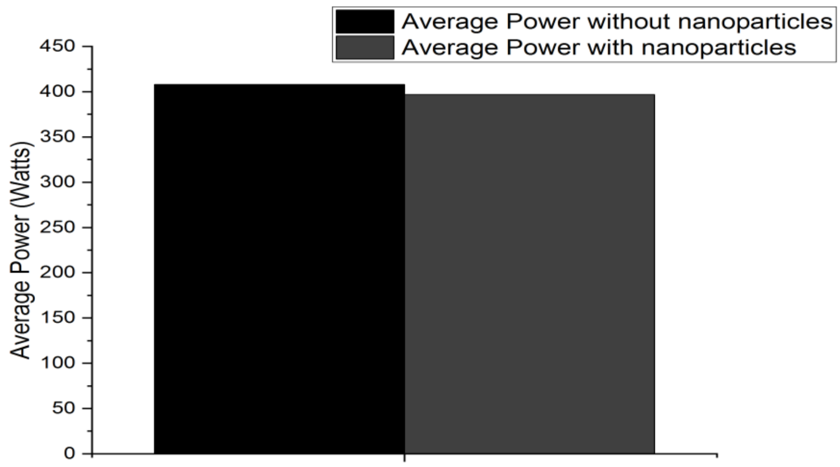


Figure XII.- *Reduction in power due to nanoparticles*

The current consumption with and without addition of Al_2O_3 nanoparticles versus time graph plotted in Figure XIII. As shown in figure current consumption decreases with addition of Al_2O_3 nanoparticles. The actual difference in the current consumption with and without nanoparticles is magnified in figure XIV which clearly shows that current consumption is less with nanoparticles. The average current consumed by the compressor without nanoparticles is 1.643 amperes while it is 1.628 amperes with nanoparticles as shown if figure XV.

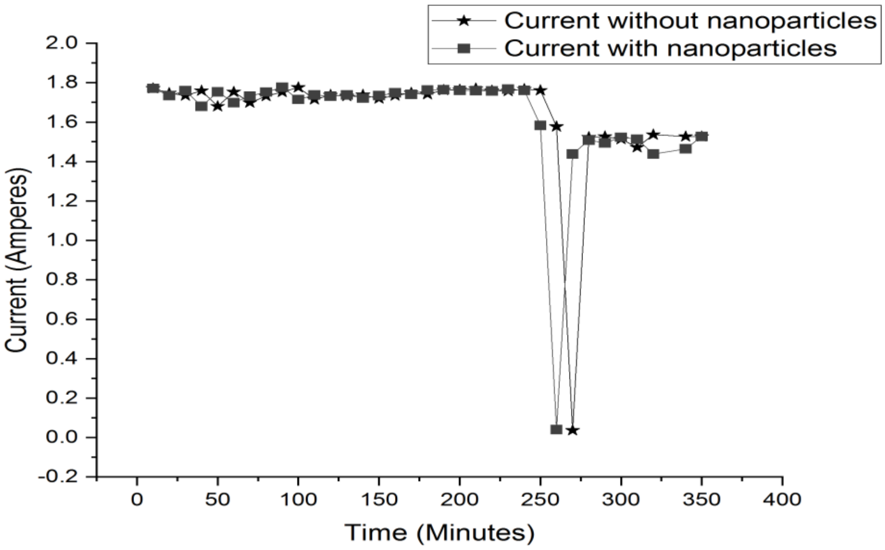


Figure XIII.- *Magnifed Current versus Time comparison Graph*

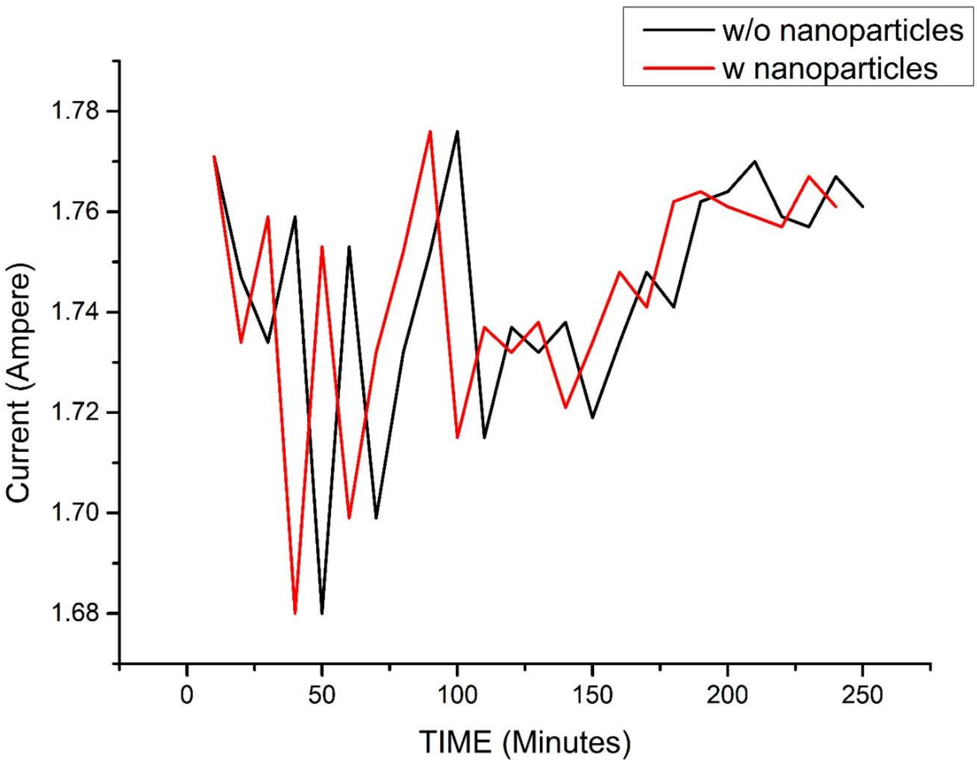


Figure XIV.- *Magnifed Current versus Time comparison Graph*

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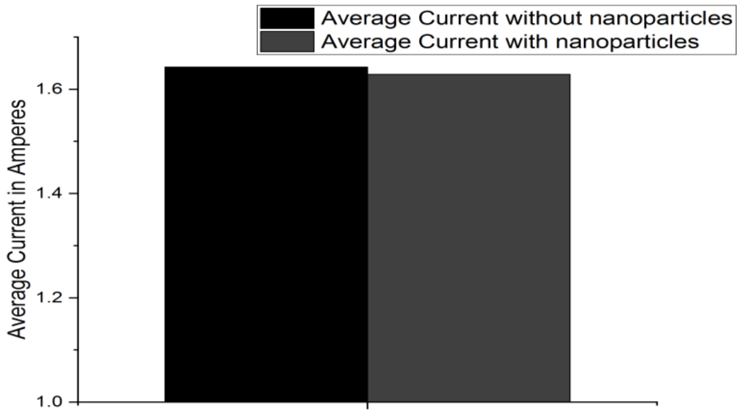

Figure XV.- *Reduction in current due to nanoparticles*

The Average values of power and current with and without nanolubricant is shown in Table III.

Parameters	Power	Current
Average value without nanoparticles	407.98 Watts	1.643 amperes
Average value with Nanoparticles	396.809 Watts	1.628 amperes
Percentage reduction in average consumption	2.74	0.913
Maximum value without nanoparticles	447.635 Watts	1.776 amperes
Maximum value with nanoparticles	434.99 Watts	1.776 amperes
Percentage reduction in maximum value	2.82	0

Table III. *Reduction in Current and Power because of nanoparticles*

4. Conclusions. - The compressor was charged with lubricant and then readings of current, voltage, temperature and time were obtained. Then, power (P) was calculated using the relation P= IV, where current (I) is in amperes and voltage (V) is in volts. Graphs were plotted between Power versus Time and Current versus Time. Comparison between the reduction in power and compressor was done by calculating the amount of percentage reduced by replacing nanolubricant instead of SL-32 lubricant. The data was collected for several days with the same initial temperature of 31°C. The average current consumption was reduced by 0.913% while the power consumption was effectively reduced by 2.74% while keeping the operating time of the refrigerator same. These results conclude that Al_2O_3 nanoparticles can be utilized to reduce the energy utilized by compressors by creating a nanolubricant with SL-32 lubricant. This could be because the lubricant's friction and heat transfer properties are both improved by the nanoparticles. The decrease in friction power loss is explained by the fact that while an increase in nanoparticle concentration is shown to enhance viscosity, it also decreases the friction coefficient.

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Nota contribución de los autores:

1. Concepción y diseño del estudio
2. Adquisición de datos
3. Análisis de datos
4. Discusión de los resultados
5. Redacción del manuscrito
6. Aprobación de la versión final del manuscrito

AAK ha contribuido en: 1, 2, 3, 4, 5 y 6.
MEUH ha contribuido en: 1, 2, 3, 4, 5 y 6.
FS ha contribuido en: 1, 2, 3, 4, 5 y 6.
SMTN ha contribuido en: 1, 2, 3, 4, 5 y 6.
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