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Experimental Investigation of a Domestic Refrigerator using Nano Lubricants

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ABSTRACT: *Nanoparticles have attracted great attention in different fields as they show unique properties which can't be attained by conventional macroscopic materials. Low cost additives like nanoparticles play a vital role in modern lubricants. It improves the performance and life of machines by reducing frictional work, wear and prevents failure of its components. In the situations of high thermal loading and high heat flux nanofluids with stabilized nanoparticles emerge as a key for efficient heat transfer. Here a performance analysis was conducted on a hermetically sealed compressor in a domestic refrigeration system working with conventional POE oil lubricant. the POE oil is replaced by SUNISO3GS mineral oil. Nano lubricant samples of POE+ silver nanoparticles oil mixture, POE +tin nanoparticles oil mixture, POE +nickel nanoparticles oil mixtures SUNISO3GS+ silver nanoparticles oil mixture, SUNISO3GS +tin nanoparticles oil mixture, SUNISO3GS +nickel nanoparticles oil mixtures are made. The COP, freezing capacity, power consumption, dome temperature, flash and fire point are measured in all cases and studied. Compressor working with nanofluid as lubricant shows lower power consumption. Heat transfer rate was also found to be higher by the use of nanofluids. The viscosity of mineral oil and nanofluid were measured and are compared. From this study, it was found that use of nanoparticles as additives is economical and aids in better performance compared to mineral oil lubricant.*

***Keywords**: Compressor, Dome, Nanolubricant, Refrigerator, Thermometer, Ultrasonic Agitator*

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I. INTRODUCTION

Refrigeration is the technology which makes a major contribution to humanity in many ways including food preservation, control of indoor air quality, gas liquefaction, industrial process control, storage and transport of food and drinks and computer cooling. Without refrigeration, modern life is impossible. IIR (Indian Institute for Refrigeration) has estimated that about 15% of all electricity produced worldwide is used for refrigeration and air-conditioning processes of various kinds. Inefficient use of energy is waste of valuable resource and it leads to global warming. So, to protect the environment and to find the solution for the energy crisis it is essential to develop techno economical viable systems. The aim of this work is to experimentally investigate the performance of a domestic refrigerator using nano lubricants. The experiment is done using R134a as the refrigerant.

Experimental study on the system is done at various load conditions. The objective is to compare the performance of a nano lubricant at various load conditions.

The household refrigerator is converted to the experimental setup with suitable modifications and is properly instrumented with various measuring instruments to note down the various system variables.

II. EXPERIMENTAL SETUP

Following are some of the important requirements and parameters taken for the system design:

Refrigerant inlet temperature = 380K
Refrigerant exit temperature = 310K
Condenser load (QC) = 700W
Outer diameter of water tube = $1.47e^{-2}$ m
Inner diameter of water tube = $1.27e^{-2}$ m
Outer diameter of refrigerant tube =$0.835e^{-2}$ m
Inner diameter of refrigerant tube = $0.635e^{-2}$ m
Density of refrigerant = 1154.90 kg/m^3

Viscosity of refrigerant = 182.50e-6 Ns/m^2
Specific heat of refrigerant = 1104 J/kg
Thermal conductivity of refrigerant = 0.0759 W/mK
Density of water = 993.38 kg/m^3
Viscosity of water = $693.54e^{-6}$ Ns/m^2
Specific heat of water = 4179.2 J/kg
Thermal conductivity of water = 0.62609 W/mK
Inside area of the refrigerant tube = $3.17e^{-5}$ m^2

III. SPECIFICATION OF THE SYSTEM

Model - Godrej
Capacity - 165litres
Power - 500W
Refrigerant - R134a
Maximum Current - 1A
Maximum Voltage - 220V
Refrigerant mass - 140g
Condenser type - Air Cooled
Compressor type - Hermetic
Expansion device - Capillary tube
Length of air-cooled condenser - 12m
Length of the WHRS - 7m
Diameter of water tube - ½ inch
Diameter of refrigerant tube - ¼ inch
Material - Copper

IV. MEASURING INSTRUMENTS

As the measurement of variables affect the test results, care is taken to choose the best instrument at our premises.

1. **Pressure Gauge**

Fig.1 Pressure Gauges

The pressure gauges used in this rig is of Bourdon tube type pressure gauges. Using copper tubes, tapings are taken from various points and the gauges are fixed on the panel board. For the high-pressure side, gauge with maximum pressure of 35Kg/cm2is used and at low-pressure side, gauge with maximum pressure of 17.5Kg/ cm^2 is used.

Number of gauges - 2
Number of high pressure gauge - 1
Number of low pressure gauge - 1
Range of high pressure gauge - 0 to 35 kg/cm^2
Range of low pressure gauge - 0 to 17.5 kg/cm^2

2. **Digital Energy meter**

Fig.2 Energy Meter

In the experimental setup single phase digital energy meter is used for measuring the power input to the compressor.

Energy meter constant - 3200 Imp/kWh
Maximum current - 5-20 A
Maximum voltage - 240 V ±25%
Frequency - 50Hz± 10%

3. **Stop Watch**

A stopwatch is a handheld timepiece designed to measure the amount of time elapsed from a particular time when activated to when the piece is deactivated. Two buttons on the case traditionally control the timing functions. Pressing the top button starts the timer running, and pressing the button a second time stops it, leaving the elapsed time displayed. A press of the second button then resets the stopwatch to zero. The second button is also used to record split times or lap times. When the split time button is pressed while the watch is running, the display freezes, allowing the elapsed time to that point to be read, but the watch mechanism continues running to record total elapsed time. Pressing the split button a second time allows the watch to resume display of total time.

Fig.3 Stop Watch

4. **Digital Thermometer**

Fig.4 Digital Thermometer

Digital thermometers are the most commonly used temperature measuring instruments. They are easier to read than glass thermometers, generally more accurate than the older dial-type thermometers based on bimetal coils, have a great range of specialized uses and applications and tend to have a much quicker response-time.

Temperature measuring range	: 10oC ~ +100oC
Accuracy	: ±1oC (10oC ~ +100oC)
Resolution	: 0.1 ^{o}C
Product size	: 55.5mm x 42.5 mm x 16 mm
Sensors	: NTC sensors
Temperature	: 0 ^{o}C ~ 60^{o} C
Relative humidity	: 20% ~ 85% RH
Power	: one button battery (LR44, 1.5V)

5. **Measuring Jar**

Measuring jar is used to measure the volume flow rate. It is usually made of glass or plastic. Measuring jar are graduated ones that help us to measure the volume flow rate accurately and precisely.

6. **Measuring Tank**

A graduated tank or measuring tank is a piece of laboratory equipment used to measure the volume of a liquid with respect to time. Graduated tanks are generally more accurate and precise than laboratory flasks and beakers. However, they are less accurate and precise than volumetric glassware, such as a volumetric flask or volumetric pipette. For these reasons, graduated tanks should not be used to perform volumetric analysis. Graduated tanks are sometimes used to indirectly measure the volume of a solid by measuring the displacement of a liquid.

V. FABRICATION

Few types of fabrication methods are done on the machine. They are: Bending, Flaring and Brazing. Also, further operations are cleaning and assembling

Bending is the operation used to make the waste heat recovery system. Bending of the copper tube is done using spring bender. Flaring is the process which is used to increase the diameter of the copper tube in order to fix the valves properly using flaring tool. Brazing is a metal joining process whereby a filler material is heated above melting point and distributed between two or more closely fitting parts by capillary action. This is done in order to prevent leakage. Gas filling is the operation of filling required amount of R134a refrigerant into the system. Cleaning is the operation to clean the all machined parts without dust and chip formals. By meaning, the parts they are brightened and good looking. Assembling is the operation, it deals with the assembling of various parts produced by above operations. Charging of refrigerant in the system includes: Before charging the refrigerant, pressure test is conducted to make it leak-proof. Nitrogen gas is charged into the system and pressure is build up to 200 psi and the system is checked for leaks at the joints using soap solution.

If there is no leak, the system is then evacuated using a vacuum pump. The system can be charged with refrigerant through the high or low sides.

When the charging is done through the high side, the refrigerant is introduced in liquid form and when the charging is done through the low side, the refrigerant should be added in vapour form in order to prevent the possible damage to the compressor. Normally it is convenient to add the refrigerant through the low side on small units.

In this experiment setup R134a is charged into the system through the suction valve of the compressor until (i) electrical current taken by the compressor during the compression process will not exceed the rated current of the compressor (measured by using multimeter connected to the current supply wires of compressor) (ii) Suction and discharge pressure never exceed over the rated compressor pressure. It is advisable to weigh the container before and after charging so that the amount of refrigerant added to the system can be noted down. This information is often helpful during further charging. The system is fully evacuated and charged as follows:

>Connect the charging line to the suction valve gauge port.

>Connect the other end of the charging line to the refrigerant cylinder.

>Open the cylinder slightly and loosen the flare nut at the compressor end. Air will be removed by this operation. Tighten the nut when sound of escaping gas is heard.

>Turn the suction valve, thus drawing the gas directly from the cylinder by the compressor.

>Start the compressor to draw the required amount of refrigerant. Make sure that the suction pressure should not exceed the rated value.

>Close the cylinder valve and allow the compressor to run for sufficient time.

>Stop the compressor and back seat the suction valve.

VI. EXPERIMENTAL SETUP

The experimental test rig connected with suction and delivery pressure gauges and energy meter.

Fig.5 Refrigerator connected with pressure gauges and energy meter

VII. NANOPARTICLES

1. **Silver Nanoparticle**

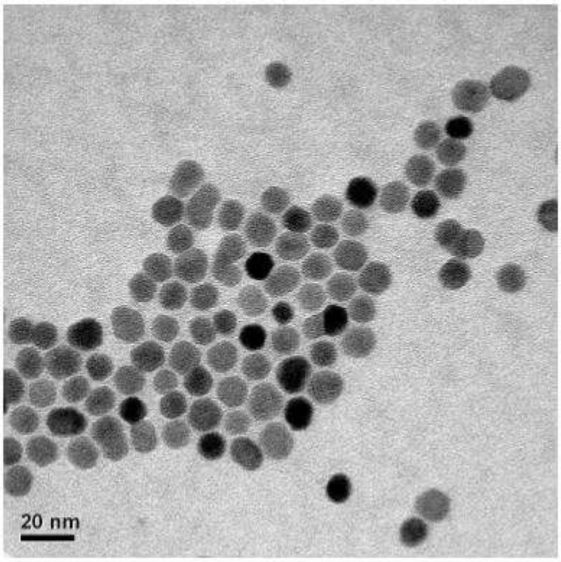

Fig.6 Silver Nanoparticle

Silver nanoparticles have unique optical, electrical, and thermal properties and are being incorporated into products that range from photovoltaics to biological and chemical sensors. Examples include conductive inks, pastes and fillers which utilize silver nanoparticles for their high electrical conductivity, stability, and low sintering temperatures. Additional applications include molecular diagnostics and photonic devices, which take advantage of the novel optical properties of these nanomaterials. An increasingly common application is the use of silver nanoparticles for antimicrobial coatings, and many textiles, keyboards, wound dressings, and biomedical devices now contain silver nanoparticles that continuously release a low level of silver ions to provide protection against bacteria.

2. **Nickel Nanoparticle**

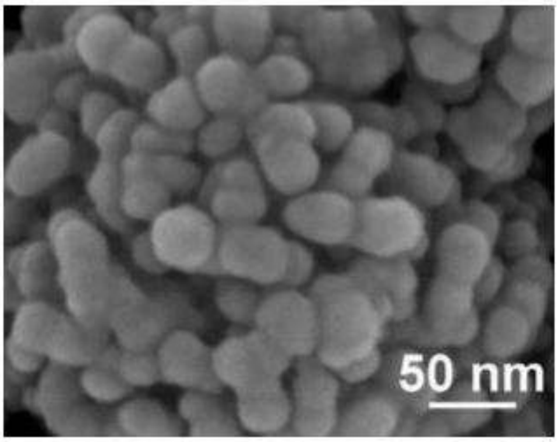

Fig.7 Nickel Nanoparticle

Nickel (Ni) Nanoparticles, nanodots or nanopowder are black spherical high surface area particles. Nanoscale Nickel Particles are typically 10 -40 nanometers (nm) with specific surface area (SSA) in the 30 - 50 m2/g range and also available in with an average particle size of 50 - 100 nm range with a specific surface area of approximately 5 - 10 m2/g. Nano Nickel Particles are also available in passivated and Ultra high purity and high purity and coated and dispersed forms. They are also available as a dispersion through the AE Nano fluid production group. Nano fluids are generally defined as suspended nanoparticles in solution either using surfactant or surface charge technology. Nano fluid dispersion and coating selection technical guidance is also available.

Other nanostructures include nano rods, nano whiskers, nano horns, nano pyramids and other nano composites. Surface functionalized nanoparticles allow for the particles to be preferentially adsorbed at the surface interface using chemically bound polymers.

3. **Tin Nanoparticle**

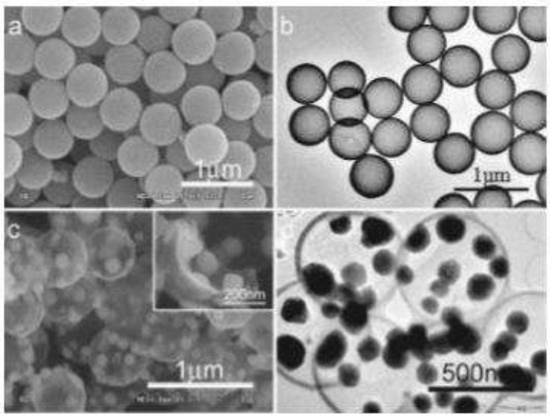

Fig.8 Tin Nanoparticle

Nanoparticles research is rapidly growing into an extensive research area. This is due to the fact that nanoparticles can be easily altered by varying their chemical environment, shape and size. One of the key benefits of nanoparticles is that their properties differ from bulk material of the same composition. Tin is a malleable post-transition metal that is not easily oxidized in air. It can be coated onto other metals to prevent corrosion. Tin nanoparticles have high surface activity, large specific surface area, good dispersion performance and uniform particle size. Tin nanoparticles dispersed in lubricating oil can be used as multi-purpose oil additives, which have the potential to reduce friction and wear in automobile engines.

VIII. COMPRESSOR OILS

1. **Sunizo 3GS Oil**

SUNISO GS Oils are miscible well with HCFC and CFC refrigerants such as R-22, R-502 and R-12 while featuring excellent stability and giving long trouble-free service life in the refrigeration systems using above refrigerants.

In addition, SUNISO GS Oils also perform excellently with natural refrigerants such as R-717, R-600a and R-290.

Fig.9 Sunizo 3GS Oil

SUNISO GS Oils are refined from specially selected naphthenic crude oils by special method assuring excellent lubricity and other properties. SUNISO GS Oils are approved by all major air-conditioner, refrigerator, freezer, car air-conditioner manufacturers in the world. Chemical name: Refined Petroleum Oil.

2. **Polyolester Oil**

POE oils are a family of synthetic lubricants. Unlike natural mineral oils, POE oils are completely wax-free and are the best choice of lubricants for use with the new generation of chlorine-free HFC refrigerants, such as R-410A. This is because they provide superior lubrication, offer better thermal stability, and are more miscible in HFC refrigerants than mineral oils. POE oils are also highly biodegradable.

IX. PREPARATION OF NANOLUBRICANTS

- Mass concentration of nanoparticles in nanolubricants is 0.06 percentage, calculations shows that the silver nanoparticles to be taken is 0.6845 g, nickel nanoparticle is 0.5885 g, and tin nanoparticle is 0.4865 g.
- Beakers used are thoroughly cleaned with hexane.
- Measured 1000 g of suniso mineral oil and taken into the beakers and added measured quantity of nanoparticles.
- Beakers were then placed in digital ultrasonic agitator and kept for 3 hours in there so that the oil and nanoparticle will be mixed thoroughly.
- The oil is then taken away into storage cans.
- Continued the above steps for 3 different types of nanoparticles and repeated the process with changing the suniso mineral oil with POE oil.

X. ANALYSIS AND RESULTS

1. **COP Analysis**

The coefficient of performance (COP) of a domestic refrigerator can be found out calculating the rate of heat removal from the refrigerated space and the work done by the compressor.

Rate of heat removal:

$$\mathbf{Q = m \times C_p \times (t_1\text{-}t_2) / t_m}$$

m = Mass of water in the reservoir
C_p = Specific heat of water in J/kgK
t_1 and t_2 =Initial and final temperature of water
t_m = Total time the system runs

Power input:

$$\mathbf{W = N \times 3600/ T_m \times K}$$

N= Number of blinks of energy meter
T_m=Time for blinks of energy meter
K=Impedence constant

$$\mathbf{COP=Q/W}$$

Procedure:

1. Run the refrigerator for some time
2. Fill water in a steel vessel of known volume, place the vessel inside the refrigerator.
3. Note down initial temperature and time at which experiment is started

4. Run the unit for an hour and note down the total time, temperature and the pressure readings.
5. Perform the suitable calculations for finding the actual COP
6. Determine the specific enthalpy, h at each of the four states using the R134 a refrigerant tables. 7. Determine the theoretical coefficient of performance of the refrigerator
8. Compare the actual and theoretical COP.

Sample calculations:

$$\mathbf{Q = m \times C_p \times (t_1\text{-}t_2) / t_m}$$

Q = 4.77836 x 4187 x (30.2-28.2) /3600 Q = 38.9025 watt

$$\mathbf{W = N \times 3600/ T_m \times K}$$

Tm =11.2 seconds
W = 1 x 3600 / 11.2 x 312000
W = 100.466 watt

$$\mathbf{COP = Q/W}$$

COP = 38.9025/100.446 = *0.3872*

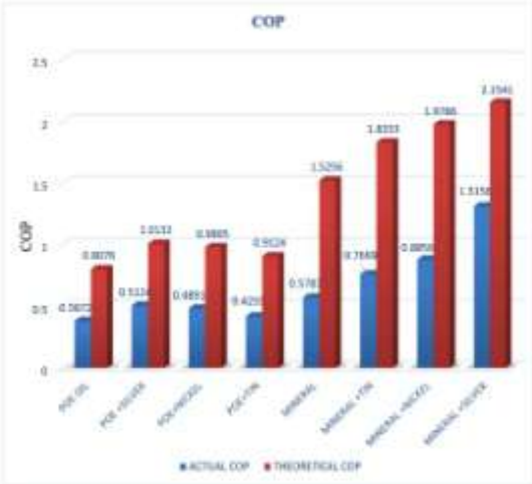

Fig.10 Experimental Readings

OIL NAME	Time	$P_{suction}$	$P_{delivery}$	$T_{water\ initial}$	$T_{water\ final}$	Q	W	COP_{act}
	(m)	bar	bar	(^{0}C)	(^{0}C)	(J/kg)	(kJ/kg)	
POE	60	.068	13.78	30.2	23.2	38.9	0.229	0.3872
POE+SILVER	60	.020	11.85	31.9	14.3	97.8	0.156	0.5124
POE+NICKEL	60	.027	12.95	32.1	15.9	90.02	0.184	0.4891
POE+TIN	60	.020	13.36	31.6	15.7	88.35	0.2083	0.4231
MINERAL OIL	45	.013	11.98	31.1	20	61.68	0.142	0.5787
MINERAL+TIN	45	.068	11.57	32.2	18	105.22	0.138	0.7669
MINERAL+NICKEL	45	.027	10.47	30.6	15.5	111.88	0.126	0.8856
MINERAL+SILVER	45	.020	10.05	32.4	11.8	152.63	0.115	1.3156

Fig.11 COP Graph

2. **Viscosity Analysis**

Viscosity is the property of a fluid that determines its resistance to flow. It is an indicator of flow ability of a lubricating oil; the lowest the viscosity, greater the flow ability. It is mainly due to the forces of cohesion between the molecules of lubricating oil.

Procedure:

1. Select the appropriate viscometer depending up on the nature of lubricating oil
2. Clean the viscometer cup properly with the help of suitable solvent e.g. CCl4, ether, petroleum spirit or benzene and dry it to remove any traces of solvent.
3. Level the viscometer with the help of leveling screws.
4. Fill the outer bath with water for determining the viscosity at 80 o c and below.
5. Place the ball valve on the jet to close it and pour the test oil into the cup up to the tip of indicator.

6. Place a clean dry Kohlrausch flask immediately below and directly in line with discharging jet.
7. Insert a clean thermometer and a stirrer in the cup and cover it with a lid.
8. Heat the water filled in the bath slowly with constant stirring. When the oil in the cup attains a desired temperature, stop the heating.
9. Lift the ball valve and start the stop watch. Oil from the jet flows into the flask.
10. Stop the stop watch when lower meniscus of the oil reaches the 50 ml mark on the neck of receiving flask.
11. Record the time taken for 50 ml of the oil to collect in the flask.
12. Repeat the experiment to get more readings.

Viscosity = 0.226 T – 195/T , for 34<T<100

Where, T is time taken for 10cc rise of oil.

TEMP	POE OIL	POE +Ag	POE +Ni	POE +Tin	MINERAL	MINERAL +TIN	MINERAL +NI	MINERAL +Ag
35	98.58	107.25	100.63	98.61	100.59	106.79	114.59	117.394
40	93.57	97.9	97.33	93.32	96.77	97.41	98.89	99.39
45	72.52	81.38	74.54	71.91	76.38	80.94	86.97	90.23
50	65.85	70.35	66.83	64.34	65.57	71.12	74.11	80.12
55	58.38	63.51	61.95	58.16	62.33	63.15	68.55	70.41
60	51.21	53.92	53.68	48.73	52.71	55.98	60.58	70.41
65	45.26	49.16	48.65	45.83	47.37	49.74	52.27	55.24
70	37.72	42.07	41.16	39.88	40.68	45.47	49.62	51.44

Fig.12 Time taken for 10 cc of rise of oil for different temperatures

TEMP	POE OIL	POE +Ag	POE +Ni	POE +Tin	MINERAL	MINERAL +TIN	MINERAL +NI	MINERAL +Ag
35	20.3012	22.981	21.402	20.9185	21.3936	22.872	24.721	25.394
40	19.0631	20.1348	19.995	19.0012	19.856	20.0143	20.9863	21.106
45	13.701	15.9961	14.2319	13.5412	14.7114	15.8848	17.4136	18.2321
50	11.9219	13.1273	12.1872	11.5123	12.9219	13.3316	14.1193	15.6736
55	9.8422	11.2387	10.8541	9.7934	10.9587	11.1856	12.6495	13.1451
60	7.769	8.5715	7.9541	7.0123	8.2149	9.1696	10.4734	13.1451
65	5.9211	7.1445	6.9876	6.1029	6.5899	7.3209	8.0839	8.9547
70	3.3565	4.876	4.5678	4.1256	4.4025	5.9886	7.2868	7.8353

Fig.13 Viscosity of different oils in different temperatures (viscosity in stokes)

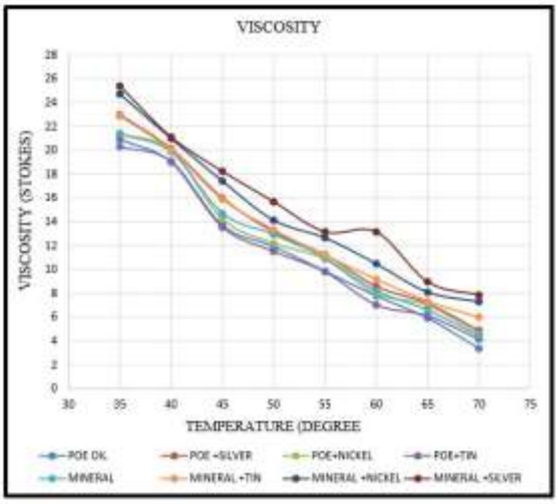

Fig.14 Graph showing viscosity of oils at different temperature

3. **Flash Point and Fire Point Analysis**

Flash point is the lowest temperature at which the lubricating oil gives off enough vapors that ignite for a moment when tiny flame is brought near it.

COMRESSOR OILS	FLASH POINT	FIRE POINT
MINRAL	179	192
MINERAL+SILVER	194	208
MINERAL+TIN	183	195
MINERAL+NICKEL	190	202
POE	256	271
POE OIL+SILVER	268	282
POE +TIN	260	275
POE +NICKEL	262	278

Fig.15 Flash and fire point of different oils

Fire point is the lowest temperature at which the vapors of the oil burn continuously for at least five seconds when a tiny flame is brought near it.

Fig.16 Graph showing the Flash and fire point of different oils

4. **Dome Temperature**

The graph shows the compressor dome temperature for all the 8 oils. The refrigerator is run for 15 hours under constant evaporator load. The decrease in dome temperature may be due to decrease of friction with nanolubricant. Lower the compressor dome temperature, more stable will be the compressor oil and hence increase the life and performance of the refrigeration system.

OIL NAME	TEMPERATURE
POE OIL	78.24
POE +SILVER	68.25
POE+NICKEL	70.67
POE+TIN	73.51
MINERAL	64.87
MINERAL +TIN	63.13
MINERAL +NICKEL	61.67
MINERAL +SILVER	58.23

Fig.17 Dome temperatures for different oils

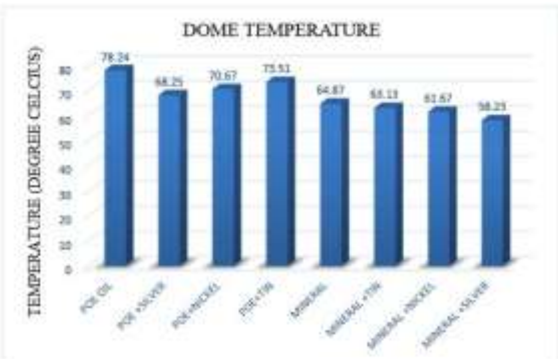

Fig.18 Graph showing dome temperature while using different oils

5. **Freezing Capacity**

The graph shows the time required for reducing the cooling load temperature from 30ºC to 18ºC for all the 8 oils. With SUNISO 3GS oil + silver nano particle, the time required to bring the cooling load is least.

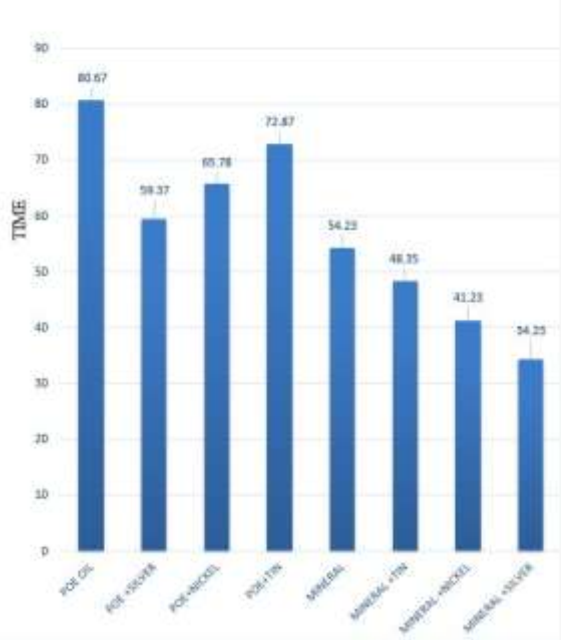

Fig.19 Graph showing freezing capacity of different oils

6. **Power Consumption**

The histogram shows power consumption of the compressor. From the histogram, it is clear that there is considerable reduction in power consumption when nano lubricants are used.

The reduction in power consumption is highest for SUNISO 3GS + silver nano oil. The decrease in compressor work input may be attributed to better lubricity of the nano lubricants.

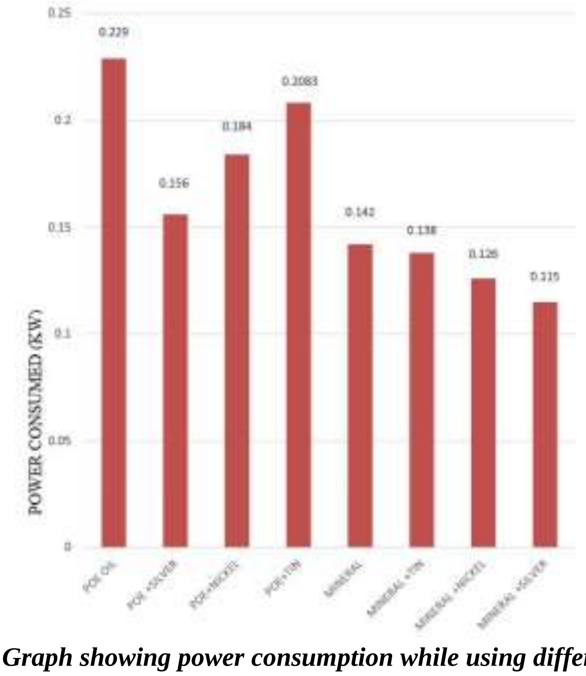

Fig.20 Graph showing power consumption while using different oils

XI. CONCLUSION

Extensive experimental and theoretical studies have been carried out to evaluate the performance parameters of a vapor compression refrigeration system with POE oil, SUNISO 3GS oil and with different nanolubricants. The dispersion of nanoparticles in the lubricant resulted in overall performance enhancement of compressor. The conclusions derived from the present study are:

1. The coefficient of performance of the refrigeration system also increases by 16.6 % when the conventional POE oil is replaced with SUNISO3GS + silver nanoparticles oil mixture. This is because of the lower power

consumption of the compressor that facilitates the increase in COP of the system.
2. Freezing capacity of the refrigeration system is higher with SUNISO 3GS + silver nanoparticles oil mixture compared the system with POE oil.
3. The power consumption of the compressor reduced when the nano lubricant is used instead of conventional POE oil. The reductions in power consumption is because of the reduced friction due to the better performance of the nano lubricant due to the conversion of the sliding friction to rolling friction.
4. The compressor dome temperature is more for POE oil and least with SUNISO 3GS + silver nanoparticles oil mixture. The reduction in compressor dome temperature may be due to decrease of friction with nanolubricant. Lower the compressor dome temperature, more stable will be the compressor oil and hence increase the life and performance of the refrigeration system.
5. There is an increase in flash and fire points because of the improvement in thermal conductivity of the nanolubricants.

The cost of nanoparticles is Rs. 500/g but each charging requires only a very low quantity of nanoparticles .Hence the use of nano fluids is economically feasible and paves a new path for use as an effective lubricant.

ACKNOWLEDGEMENTS

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