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Experimental investigation on performance of reciprocating air compressor by using nanoparticle in lubricating oil

Omkar Chandrakant Nikam
omkar.nikam77@gmail.com
Government College of Engineering, Karad, Maharashtra

Anil R. Acharya
tpogcekarad@gmail.com
Government College of Engineering, Karad, Maharashtra

ABSTRACT

Reciprocating compressors are positive displacement machines in which the compressing and displacing element is a piston having a reciprocating motion within a cylinder. The reciprocating compressor plays an important role in various fields such Applications include oil refineries, gas pipelines, chemical plants, natural gas processing plants and refrigeration plants. One specialty application is the blowing of plastic bottles made of polyethylene terephthalate (PET) is widely used in these fields. Good performance is very crucial for the use in these fields because it is related to the energy-saving benefit. A remarkable part of entire power loss in a reciprocating air compressor is due to the undesirable friction between rubbing surfaces of mechanical components. The development of low friction compressor is necessary for the limitations of fossil fuels. The colloidal effect, rolling effect, protective film, and the third body may be the main mechanisms of friction-reduction and antiwear of nanoparticles in lubricant. So in the present dissertation work the two nanoparticles i.e. CuO and TiO2 are used as lubricating oil additives and its effect on the performance and characteristics of compressor were studied.

Keywords— *Nanoparticle, Compressor, Lubrication, Friction, Nano-oil*

1. INTRODUCTION

A remarkable part of entire power loss in a reciprocating air compressor is due to the undesirable friction between rubbing surfaces of mechanical components. The development of low friction compressor is necessary for the limitations of fossil fuels. Friction losses increase with increasing pressure and increase power input, and that these losses have greater significance in the large capacity compressor. The various friction losses in a compressor are shown in Figure 1 Since there are many sliding and rolling parts operating under various conditions in a compressor, different lubrication regimes may be expected including hydrodynamic, elastohydrodynamic and boundary lubrication; even metal to metal contact is possible. A substantial part of the friction losses, however, can be considered as those of hydrodynamically lubricated contacts under normal running conditions. It is evident here that the friction losses increase with compressor pressure, and generally increase with increasing oil temperature. This may be attributed to the increasing part played by boundary lubrication higher feed oil temperature plus increased temperature. Rise at the contacts reduces the viscosity of the oil such that sufficient hydrodynamic film thickness can no longer be maintained.

The component contributions to friction losses listed in Figure 1 for a reciprocating compressor. It is seen that losses in the piston systems account for the largest part, the proportion contribution increasing with pressure. Losses in the crankshaft and connecting rod systems combined, almost compare with those in the piston systems. Valve system losses seem to become important at lower speeds.

Lubricating oil plays a critical role in reducing the frictional losses. Using high viscosity oil in the compressor will reduce the components wear and friction but may increase fuel consumption, otherwise, the thin lubricant film will decrease fuel consumption but there is a danger of higher component wear rate. Engineers and scholars are working constantly to develop and test new lubricants to meet these challenges. Nanofluids are an innovative new class of fluids which can be engineered by suspended nanosized particles (1–100 nm) in conventional base fluids. A large number of papers have reported that surface modified nanoparticles stably dispersed in lubricants are effective in enhancing load-carrying capacity, antiwear, and friction reduction properties.

According to theories in the literature, colloidal effect, rolling effect, protective film, and the third body may be the main mechanisms of friction-reduction and antiwear of nanoparticles in lubricant. The rolling friction is a dominant mechanism under low-load condition. In addition, under high-load conditions, due to the adhesion of nanoparticles, the lubricating film at the asperity crests can decrease the straight asperity contact, and thus increase wear resistance. With load continuously increasing, the nanoparticles penetrate into the contact surface, preventing the rubbing surfaces from contact directly and increase the load-carrying capacity. So in the present dissertation work the two nanoparticles i.e. CuO and TiO_2 are used as lubricating oil additives and its effect on the performance and characteristics of compressor were studied.

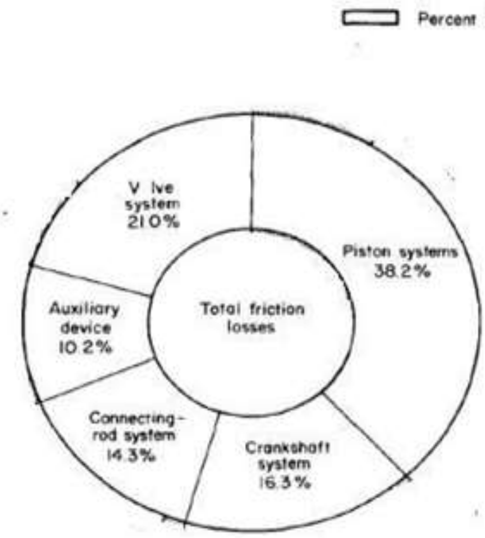

Fig. 1: Frictional contributions of the components to the total friction losses

2. THEORY AND PREPARATION OF NANOFLUID

A mixture of nanoparticles in a base oil (engine oil) is known as nano-lubricating oil. Researcher finds out that the addition of nanoparticles in lubricating oil enhances its viscosity, anti-frictional, anti-wear as well as thermophysical properties. So attains ion has to be made in this tribological study so that it can be effectively utilized for Engine lubricating system.

From the Tribological study, it is found that the addition of nanoparticles results in a reduction in coefficient of friction which may be one or more of the following reasons. The spherical shape of nano-particles converts sliding contact into effective rolling contact mechanism; Physical mechanisms of nanoparticles filling out the liner voids and valleys, thus providing a hydrodynamic effect, Increase in viscosity at elevated temperature, Third body material transfer. The tribochemical film produced at a higher temperature.

2.1 Types of nanoparticle and base fluid

Nanofluids are a new class of fluids engineered by dispersing nanometre-sized materials i.e. nanoparticles, nano fibers, nanotubes, nanowires, Nano rods, nanosheets, or droplets in base fluids. Materials commonly used as nanoparticles include chemically stable metals e.g. gold, copper etc., metal oxides e.g.. Al2O3, CuO, metal carbides e.g. SiC, carbon in various form e.g. diamond, graphite and carbon nanotubes. Common base fluids are water, organic liquids e.g. ethylene, tri-ethylene-glycols, refrigerants, oils and lubricant, bio-fluids, polymeric solutions and other common liquids.

From the literature of tribology is found that the addition of nanoparticles in lubricating oil improves the tribological properties of lubricating oil as they act like antifriction and antiwear materials. So from the literature comparative study is made as shown in Table 1.

Also one of the researchers carried out an experiment on a hermetically sealed compressor by using TiO2 (0.2 % by wt) as additives in the base oil. His results reduction of 9.33% of average compressor power consumption was observed.

So from the above, it is clear that the CuO and TiO_2 give best results towards the reduction of the coefficient of friction and wear as well.

Table -1: Effect of nano-materials in lubricating oil on COF and wear

Sr. No	Nano- lubricant	% Reduction in friction coefficient	% Reduction in worn & scar
1	API SF +CuO (0.1 %)	18.4	16.7
2	API Base Oil + CuO (0.1 %)	5.8	78.8
3	SF Oil + Diamond (< 0.1 %)	Not Considerable	43.3
4	Base Oil + Diamond (< 0.1 %)	Not Considerable	62.1
5	Base oil + TiO_2 (1%)	13	Nil
6	PAO 10 + MoS_2 (3% wt)	38	Not mentioned
7	PAO 10 + BN (3%wt)	No improvement	No improvement

2.2 Nanomaterial

Table 2 and 3 show the specification of the TiO_2 and CuO Nanoparticles used for this dissertation work which purchased from the USA based Nanoshell Chemicals Private Ltd. Company.

Table 2: Specification of TiO_2 nanoparticle

Chemical Formula	$Ti0_2$
Colour	White
Morphological	Spherical
Density, g/cc	3.9
Average particle size, nm	10-25

Table 3: Specification of CuO nanoparticle

Chemical Formula	CuO
Colour	Black
Morphological	Spherical
Density, g/cc	6.315
Average particle size, nm	25-55

2.3 Measurement of viscosity of the lubricating oil

Viscosity represents resistance to the flow of liquid. It is one of the important tribological properties of the lubricating oil. It can be measured by methods

A. Couette viscometer

Couette, or rotational, viscometers comprise two members, a central bob or cylinder, and a coaxial or concentric cup. One or both are free to rotate in relation to each other. Between these is the test substance, in the annulus. Three basic configurations have been utilized. These are a rotating cup with strain measurement on the central bob, a rotating central bob with strain measurement on the cup, and a fixed cup with both rotation and strain measured on the bob. The first of these configurations originally provided the cup rotation by the force of weights hanging on a pan that was suspended from a cord wound around the cup. The central bob displacement was restrained by an appropriate spring of known modulus so that angular displacement could be equated to angular torque on the bob. The second type of Couette viscometer is merely a mechanical inversion of the first. The third classification represents the majority of modern mass-produced instruments. The rotation, usually of the inner member, is provided by a synchronous electric motor, usually with variable ratio drives that provide a series of discrete speeds, with another member rigid. The classic instrument of this category is Brookfield viscometers, whose use in a wide range of pharmaceutical and cosmetic literature testifies to its general versatility.

B. Effect on the viscosity of the oil

The results are presented in Figure 2 and 3 Figure shows the viscosity variation with the temperature ranged from 30 ºC to 80ºC. Both nano-oil and base oil, the viscosity has the same trend, decrease with the increase in temperature, and increase with the increase in the concentration of nanoparticles. Compared with the base oil, the maximum increase in viscosity value of TiO_2 nano-oil lubricant is 16.12% with 0.3 % concentration. Similarly, maximum 17.8% increase in viscosity of CuO nano-oil lubricant with 0.3 % concentration is observed at 30 ºC.

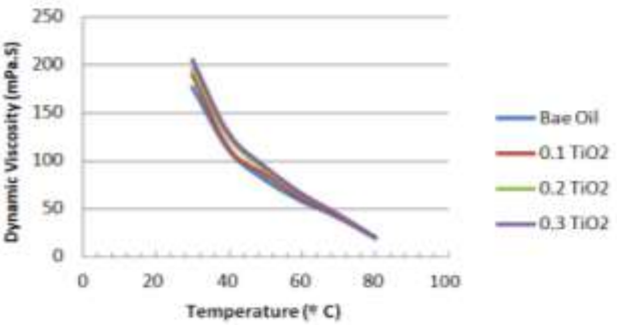

Fig. 2: Viscosity –Temperature Curve of TiO_2 Lubricants

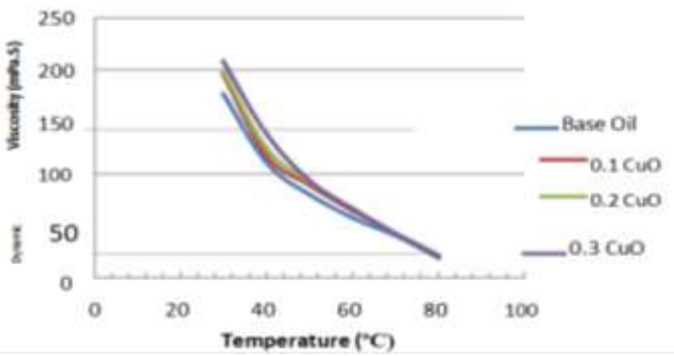

Fig. 3: Viscosity–Temperature Curve of CuO Lubricants

3. EXPERIMENTAL SETUP

These consist of a two-stage air compressor with intercooler driven by an induction motor. It sucks air from inlet air tank through an orifice and air filter. Compressed air from the first stage goes to the finned intercooler, where its temperature is lowered and it enters second stage cylinder. Final compression is completed here and the air is then sending to the air receiver. For forcing the air over the fins, a fan is mounted over compressor pulley.

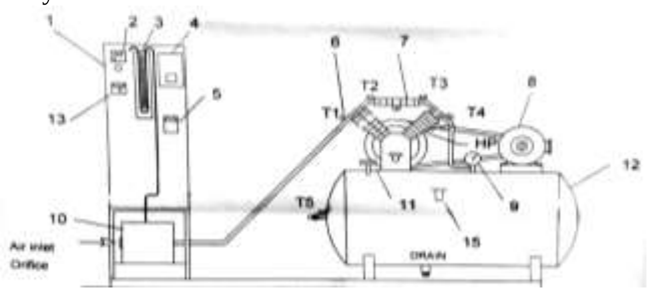

Fig. 4: Schematic Diagram of Experimental Setup

Technical specification of test compressor is summarized in Table 4 and Figure 4 shows the schematic diagram of the experimental set-up. Compressor -Two cylinders, two-stage compressor with finned intercooler, mounted over air receiver, Constant speed, L. P. cylinder bore 70 mm, stroke length 66 mm. Max. Working pressure 12 Kg/cm^2 Air receiver capacity 160 liters. Air Displacement 220 lpm provided with pressure relief valve, pressure switch and receiver drain cock. The motor of 2 HP, 3-Phase, induction motor. Air inlet tank with an orifice, water as manometer for inlet air volume measurement. Orifice diameter 10mm. Multichannel digital K type thermocouple indicator for indicating temperatures at various points. An energy meter for measurement of input power of the motor. Bourdon tube pressure gauge for delivery pressure and intercooler pressure. The digital tachometer is used to measure the speed of the crank shaft. Ensure the presence of sufficient oil in the crankcase of the compressor, Up to red mark of oil indicator glass. Fill up water in the manometer up to about half of the height of manometer. The close delivery valve of the compressor and start the compressor. Let the receiver pressure rise up to around 2.5 Kg/ cm 2. Now open the delivery valve so that constant delivery pressure of 2 Kg/cm^2 is achieved. Wait for some time and see that delivery pressure remains constant.

Table 4*: Specifications of Reciprocating Compressor*

Make	Supersonic Electronics
Motor Output	2 HP
Receiver capacity	160lpm
Type	Tow cylinder, Tow stage
Max Working pressure	12kg/cm2
Bore	70 mm
Stroke	66 mm

0.3 %TiO_2 0.2% TiO_2 0.1%TiO_2 BASE OIL

Fig. 5 : Photographic Image of TiO_2 Nano-Oil after Preparation

0.3% CuO 0.2% CuO 0.1%CuO BASE OIL

Fig. 6: Photographic Image of CuO Nano-Oil after Preparation

4. RESULT AND DISCUSSION

4.1 Effect of TiO_2 Nano-oil on Polytrophic Efficiency

From the graph, it is observed that efficiency is continuously increased as the delivery pressure increases and it is maximum in between pressure 6-8 (kg/cm^2) and then drops as pressure is increased. Both all type of concentration nano-oil and base oil, the efficiency has the same trend. And also observed that the as the concentration of nano particle is increased efficiency also increase and it is maximum for 0.3% TiO_2 is 9.54% at 2kg/cm2 pressure.

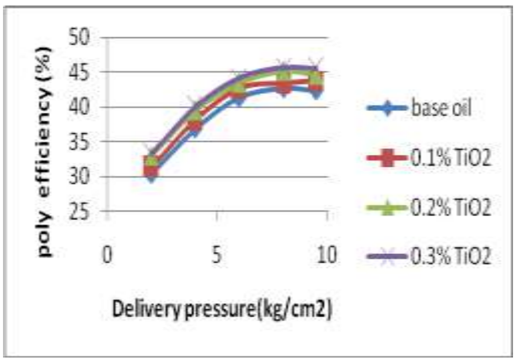

Fig. 7: Variation of polytrophic efficiency for the Different concentration of TiO_2 Nano-oil at Different pressure ratio

4.2 Effect of CuO Nano-oil on Polytrophic Efficiency

From the graph, it is observed that efficiency is continuously increased as the delivery pressure increases and it is maximum in between pressure 6-8(kg/cm^2) and then drops as pressure is increased. Both all type of concentration nano-oil and base oil, the efficiency has the same trend. And also observed that the as the concentration of the nano particle is increased efficiency also increase only at 0.2%CuO and then start decreases efficiency as nano particle concentration increases. It is maximum for 0.2% TiO_2 is 11.53% at 2kg/cm^2 pressure.

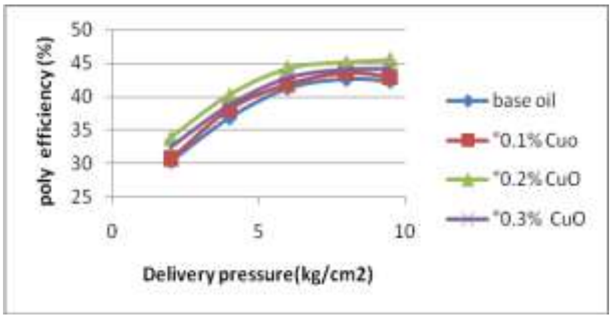

Fig. 8: Variation of polytrophic efficiency for the Different concentration of CuO Nano-oil at a Different pressure ratio

4.3 Effect of TiO_2 Nano-oil on Power loss

So the graphs below show the effect of Nano-oil on friction power of the compressor at different pressure ratio. From the graphs, it is observed that the highest reduction of 8.5% in frictional power was attained with 0.3% TiO_2 nano-oil at 2kg/cm^2.

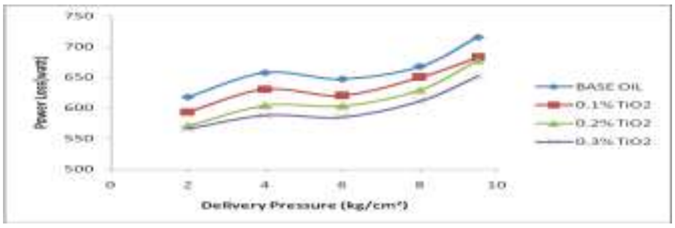

Fig. 9: Variation of power loss for the Different concentration of TiO_2 Nano-oil at Different pressure ratio

4.4 Effect of CuO Nano-oil on Power loss

So the graphs below show the effect of Nano-oil on friction power of the compressor at different pressure ratio. From the graphs, it is observed that as the pressure ratio increases power losses increases for all concentration of CuO. Highest reduction of 9.5% in frictional power was attained with 0.2%CuO nano-oil at 2kg/cm^2. If we increase concentration above 0.2%CuO power loss increase.

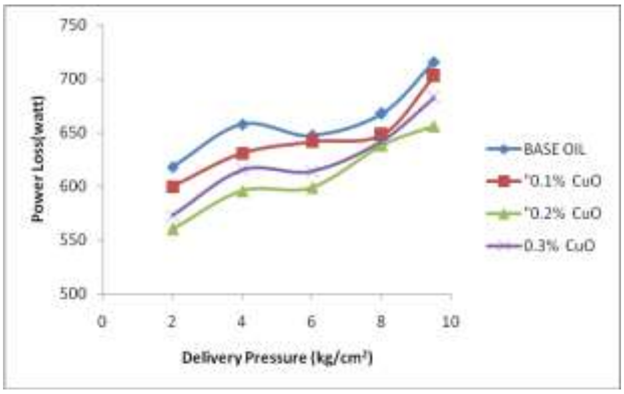

Fig. 10: Variation of power loss for the Different concentration of CuO_2 Nano-oil at Different pressure ratio

5. CONCLUSIONS

A conclusion The objective of this dissertation work is to study the performance of the Reciprocating air compressor by adding nanoparticles in lubricating oil. The TiO_2 and CuO are the two nano-materials used as oil additives with 0.1 %, 0.2% and 0.3% by weight in base oil. Performance of Reciprocating air compressor carried out different pressure ratios. Results and discussion explain the effect of Nano-oil on the performance and characteristics compressor. So the following are the conclusions made from the experimental results.

a. Addition of nano-particles in lubricating oil increases its viscosity. The increase in viscosity is more in case of CuO as compared with TiO_2 as additives for all the concentrations.
b. At a higher temperature greater than 50°C the difference between the viscosity of the base oil and that of all nano-oil is very small.
c. Addition of nano-particles in lubricating oil has both good and bad effect on the performance parameters of the engine.
d. Except at all the concentrations of TiO_2 reduces the power loss of compressor.
e. Maximum 9.33% reduction in friction power occurs with 0.2%CuO nano-oil at pressure ratio 2kg/cm^2.
f. For the concentrations, 0.1% and 0.2% f CuO nano-oil reduce the friction power at all the pressure ratio except 0.3%CuO. This is may be due to higher particle size as compared with TiO_2 nanoparticles.
g. CuO nano-oil have maximum friction power reduction of 9.33% at 2(kg/cm^2) and 0.2% CuO concentration.
h. In case of polytropic efficiency, the maximum rise of 11.53% occurs with 0.2%CuO at CR18. This is because there is a maximum friction reduction occurred as discussed earlier. At the same time, 9.54% increase in polytropic efficiency occurred with 0.2%CuO at 2kg/cm^2.
i. Because of friction power reduction and polytropic efficiency, the power consumption is minimum at and with 0.3%TiO_2. Whereas brake specific fuel consumption is maximum with 0.2%CuO and at CR20.
j. There is not much change in exhaust Air temperature is observed for all the concentration nano-oil.
k. The effect of Nano-oil on volumetric efficiency is increased for all concentration of nano oil. And maximum increase at 2kg/cm^2 is 8.8% for 0.2% CuO.
l. So from above all the discussion it is clear that CuO nanoparticles in lubricating oil have a greater reduction in friction power as compared with TiO_2 at all the pressure ratio.

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