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Performance Enhancement of Two-stage Reciprocating Air Compressor by Using Graphene in Lubricating Oil

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Abstract

Air will be cooled between stages in almost all applications of multi-stage compressors, a process known as intercooling. Compressor intercooling is essential for effective operation. The compression is closer to an isothermal compression with intercooling, requiring less power as a result. The compressed air is cooled between stages using an intercooler, which is essentially a heat exchanger. Power loss between the piston and cylinder occurs as a result of the unfavourable effect of friction. Nanoparticles may be added to lubricant to cool the air and increase compressor efficiency. The rolling action, greater cooling, protective coating, and anti-wear capabilities of nano particles in lubricant are the primary contributors increasing compressor efficiency. The objective of the performance enhancement study is to investigate the effects of incorporating graphene nanoparticles (GNP) into lubricating oil in a two-stage reciprocating compressor. Aim is to evaluate the potential improvements in compressor efficiency, reduced wear, and enhanced heat dissipation, leading to overall enhanced performance. High surface area graphene nanoparticles are combined with 500 ml of engine oil in the current study. To have three different samples a mixture of 0.5, 1.0, and 1.5 gram of graphene are added to 500 cc of engine oil. Temperatures before and after the intercooler, viscosity, volumetric efficiency, and the two-stage compressor's isothermal efficiency are all measured. The results show that adding graphene nanoparticles to lubricant enhances compressor performance.

Keywords

Air compressor, Intercooler, Performance enhancement, Isothermal efficiency

Introduction

In a reciprocating air compressor, a kind of positive displacement air compressor, air is drawn into a chamber and compressed with the help of a piston. Similar in basic operation to a crankshaft piston is a reciprocating compressor. The air enters the constricting cylinder after going via an air strainer and a suction valve. The air is compressed by means of a crankshaft and a piston, and then released through a release valve. The compacted air is now kept in a storing tank. Reciprocating compressors are essential in a variety of industries. Gas conduits, chemical factories, natural gas treating plants, and chilling facilities are a few examples of applications.

In a reciprocating air compressor, a considerable fraction of the overall energy loss is initiated by unwelcome rubbing between the surfaces of mechanical parts. Friction losses typically increase as compressor pressure and oil temperature increases. This may be explained by the expanding function of boundary lubrication, which is facilitated by the rising temperature and greater feed oil temperature.

Multi-stage compressors employ intercoolers that are heat exchangers which take away compression heat in between compression stages. Machine efficacy as a whole is impacted by inter cooling [1]. Multi-stage compressor is exemplified by the two-stage compressor being addressed in the presented article.

Lubricating oil is significantly responsible for decreased frictional losses. A thin lubricant coating, on the other hand, will likely result in a higher rate of component wear while reducing fuel consumption. Great viscosity oil in compressor results in lesser friction on the parts however fuel usage may rise. To address these problems, researchers and engineers frequently develop and test new lubricants. Nano-fluids are a new category of fluids that is made by suspending nano-sized elements (1 - 100 nm) in standard base liquids. Numerous studies have demonstrated that surface-modified nanoparticles may enhance features including load bearing capacity, anti-wear, and friction reduction when they are consistently disseminated in lubricants [2]. One of the least energy-efficient utilities is the compressed air system, which also uses a lot of energy. The basic metric employed by all international rules to assess the performance of a compressor is the isentropic efficiency, or the proportion of a compression operation's required power to its theoretical isentropic power. An idealised thermodynamic process called the isentropic process assumes that there is no heat exchange with the surrounding space [3].

In order to boost the effectiveness of a two-stage reciprocating air compressor (RAC) owing to great temperatures, an investigational study was done including the usage of intercooling and a mixed lubricant made of GNPs and other materials. Unusual in the current investigation is the usage of GNPs in motor oil. Graphene offers great thermos-physical characteristics as well as good lubricating properties. The current study aims to improve the compressor's isothermal and heat transfer efficiency by adding GNP as an addition to engine oil. The current study's objective is: (1) to reduce the friction amid piston and cylinder, (2) to lower the compressed air temperature after the intercooler, and (3) to improve isothermal and volumetric efficiency of compressor.

In their work, Gurnule and Banpurkar discuss the value of air compressor intercooling and how essential it is to a productive operation. To improve system efficiency, compression is carried out in stages, with intercoolers positioned between each stage. The intercooler's function is to cool the air both before and after it exits the low-pressure cylinder. By doing this, the compressor works more efficiently and ensures that the air receiver output valves are heated to the appropriate level for the optimal operation of the attached equipment. It is suggested that altering the intercooler's size will prevent heating in high-pressure cylinders over the long term [4].

Gill and others examined the characteristics of two-stage RACs and compressed airflow using a flow arrangement and the air compressor test rig. The intercooler, the air stabilising tank, and the air receivers are all mounted on a raised base in this self-contained, fully instrumented device. An AC motor drives the compressor. The intercooler's role in conjunction with pressure and temperature measurement equipment at the intake and exit is to ensure that the system is properly cooled. Volumetric efficiency has increased by 100% as a result of the intercooler. The air flow needs to be stabilised in order to calculate the airflow rate for this task. The test results revealed that, with a work of 77 N-m, this compressor actually delivers 0.020 m^3 of free air per second [5].

Heating is an unfavourable by-product of compression, at least insofar as compressors are involved, and transfer of heat is how nature directs systems towards stability according to Pipalia et al. Along with challenging designers to develop safe and effective designs while reducing its impact, this has also provided scholars with food for thought as they work to comprehend its influence and quantify its consequences. By utilizing ethylene glycol, radiator coolant, and a water-cooling supply, this study also intends to improve the efficiency of a two-stage RAC. A double cylinder reciprocating compressor system with two stages is used for the tests, along with air, water, and several inter coolants [6].

The usage of compressed air is expanding significantly today. The location, height, length of the pipeline, effectiveness of the intercooler, and even the environment all contribute to the compressor's low efficiency, which raises the power consumption. Inter cooling is the most effective method for reducing coolant. Both Ravur and Subba are expanding the scope of this study's by varying the water's temperature and adding different coolants to it in different proportions. Coolants are chosen based on properties such as miscibility, self-ignition temperature, boiling point, and explosive range. Glycerol and ethylene glycol are used as coolants in this experiment, and a two-stage RAC with a shell and tube heat exchanger is used. This study demonstrates the benefits of using water, glycerol, and ethylene glycol together [7].

According to Terrell's study, intercooling is essential for boosting an air compressor's efficiency. A heat exchanger of the shell and tube type is especially well suited for use as an intercooler between two compression stages of a compressor. Features of a heat exchanger design include the area of heat transfer, pressure drops, and determining whether the assumed design satisfies all requirements. The goal of this study is to present a quick and effective method for building an air compressor intercooler. This document includes a flowchart that illustrates the design process in addition to describing the heat exchanger modelling, which is centered on the reduction of heat transfer area [8].

Wadbudhe et al., the most popular form of compressor is a two-stage RAC, which is utilized in many industrial applications such as petrochemical facilities, refineries, and gas transmission pipelines. In locomotives, a reciprocating air compressor is typically utilized since large pressure ratios are required. Internal components eventually experience unexpected failure for a variety of causes, which has a detrimental effect on how the operating system functions. Establishing the recommended clearances stated for the various compressor components is essential. The decision of which compressor components to repair and which to replace is made based on dimensioning, which simplifies and lowers the cost of maintenance [9].

The study by Gupta et al.'s main goal is to intercool air compressors, which is essential for a successful operation. A rise in pressure results from compression commonly referred to as the decrease of a certain volume. The RAC, which is frequently used to compress air, is the main topic of this paper. Compression occurs in stages, and an intercooler is added between each stage to boost the effectiveness of the system [10].

According to Patil and colleagues, a test rig for experiments has been put up to evaluate RAC of various sizes and capacities. Air was utilized as the operating fluid to test the compressors. The report provides us with crucial information on the effectiveness of the compressors running under identical settings with identical system characteristics. This research also examines the effects of pressure ratio on the indicated power and isothermal efficiency of both compressors. The outcome displays that while the compressor's isothermal efficiency decreases as the pressure ratio increases, the indicated power increases as the discharge pressure rises. General characteristics of both compressor types with regard to system parameters are the same. When the experiment was conducted with the compressor's angular speed constant, there was no difference in volumetric effectiveness. Additionally, a comparison of two compressors was conducted in order to identify their differences. The study seems useful in assessing the accuracy of compressor performance prediction [11].

Materials and Method

Preparation of nano-fluid

Nano lubricating oil is a blend of nanoparticles with base oil (engine oil). Adding of nanoparticles to lubricating oil improves viscosity, anti-friction, anti-wear, and thermosphysical characteristics, according to research. According to the tribological study, the presence of nanoparticles reduces the friction coefficient. The RAC, which is frequently used to compress air, is the main topic of this paper. The physical mechanics of nanoparticles fill the holes and valleys in the liner, creating a hydrodynamic effect; the spherical form of nanoparticles turns sliding contact into an efficient rolling contact mechanism.

Types of nanoparticles and base fluid

By dispersing substances smaller than one nm, such as nanoparticles, nanotubes, nanosheets nanowires, nanofibers, and nanorods in base fluids, a novel kind of fluids known as nano-fluids is produced. Chemically stable metals like copper, gold etc., metal oxides like CuO, Al_2O_3, metal carbides like SiC, and carbon in numerous forms including diamond, carbon nanotubes, and graphite are materials that are frequently utilized to make nanoparticles. Water, organic fluids like ethylene and tri-ethylene-glycols, refrigerants, oils and lubricants, bio-fluids, polymeric solutions, and other typical liquids are examples of base fluids.

According to tribology literature, adding nanoparticles to lubricating oil enhances its tribological characteristics since they function as antifriction and anti-wear materials. As a result, a comparison research based on the literature is made, as shown in table 1.

Nanomaterial used

The specifications of the graphene material employed in this experimental effort are shown in table 2. Materials are obtained from Shimoga Ad-Nano Technologies. Figure 1 shows a SEM (Scanning electron microscope) picture of a GNP.

Nano-fluid synthesis

To create a stable suspension of GNP/engine oil nano-fluid, measured samples of GNPs were introduced to the engine oil and mechanically stirred for 30 min. Engine oil GNP 0.5, 1.0, and 1.5 weight percent concentrations of nano-fluids were created. Table 3 lists the components of the samples that were produced. Figure 2 and figure 3 display samples of pure engine oil and 1.5 wt.% nano oil.

Measurement of viscosity of the lubricating oil

Viscosity is a degree of a liquid's opposition to flow. It is a crucial characteristic of lubricating oil. With the use of a saybolt viscometer, the viscosity of regular oil and nano oil is

Table 1: Impact of nanomaterials in lubricating oil on friction coefficient and wear.

S. No.	Nano lubricant	% reduction in friction coefficient	% reduction in wear
1	APISF + CuO (0.1%)	18.4	16.7
2	API base oil + CuO (0.1%)	5.8	7.8
3	SF oil + diamond (<0.1%)	Not considerable	43.3
4	Base oil + diamond (<0.1%)	Not considerable	62
5	Base oil + TiO_2 (<0.1%)	13	Nil

Table 2: Specifications for the graphene that Ad-nano Technologies in Shimoga (Karnataka, India) provided.

Parameter	Graphene A
Purity	> 99%
Bulk density	0.006 g/cc
Average thickness (z)	0.8 - 1.60
Number of layers	1 - 3
Surface area	200.0 - 700.0 m^2/g
Average lateral dimension X and Y	< 1μm
Physical form	Fluffy, Light black powder
Chemical formula	C
Color	Black powder

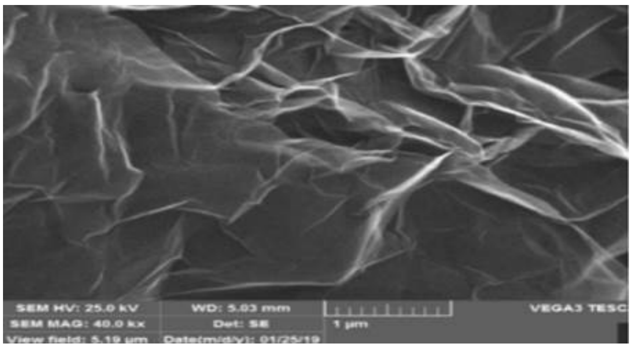

Figure 1: SEM image of GNP.

Table 3: Constituents of prepared samples.

S. No.	Description
Sample 1	SAE 20 W-40 Engine oil (500 ml)
Sample 2	0.5 g graphene in SAE 20 W-40 engine oil (500 ml)
Sample 3	1.0 g graphene in SAE 20 W-40 engine oil (500 ml)
Sample 4	1.5 g graphene in SAE 20 W-40 engine oil (500 ml)

Figure 2: SAE 20 W-40 MG engine oil.

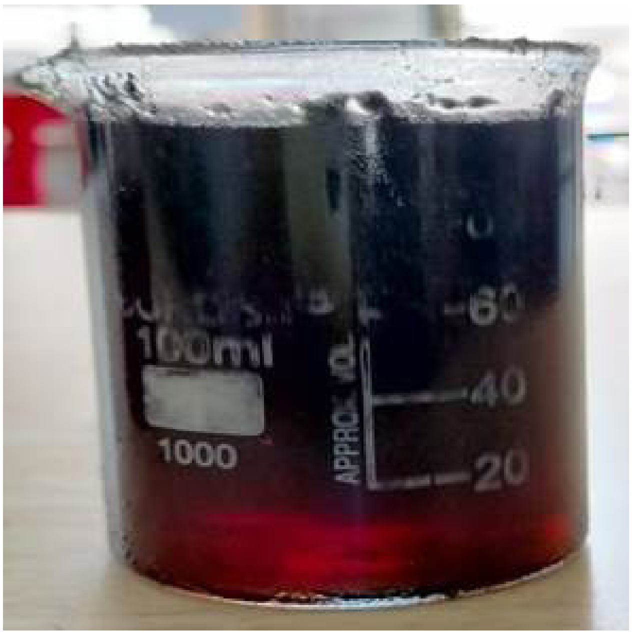

Figure 3: 1.5 wt.% graphene + SAE 20 W-40 MG engine oil (nano oil).

tested. The coaxial cylinder makes up the instrument as it is seen in figure 4. 100 ml of the oil sample are placed in the middle cylinder. Water surrounds the cylinder and fills it. A heater warms the water that surrounds the oil. Oil absorbs heat by conduction and convection. To determine viscosity fluctuation with regard to temperature, the time of flow for 60 cc of oil

Figure 4: Saybolt viscometer apparatus.

and its associated temperature are recorded. Table 4 displays the relationship between viscosity and temperature.

Experimental setup

An induction motor drives a two-stage air compressor with an intercooler as part of the experimental configuration. Through an aperture and an air filter, it draws air from the input air tank. First stage compressed air travels to the finned intercooler to be cooled before entering the second stage cylinder. Here, the air is final compressed before being transferred to the air receiver. Behind the compressor pulley is a fan positioned for the purpose of propelling air over the fins. Table 5 summarizes the technical specifications of the test compressor. Figure 5 displays the picture of the experimental set-up. A Bourdon tube pressure gauge for measuring delivery pressure and intercooler pressure, a multichannel digital K type thermocouple indicator for showing temperatures at various locations, an energy metre for calculating the motor's input power, and a digital tachometer for calculating the crankshaft's speed are also included in the setup.

Engine lubricating oil SAE 20 W-40 MG is used to operate equipment. To determine the compressor's isothermal efficiency and volumetric efficiency, the following information is taken into account: inlet pressure (P1), outlet pressure (P2), air inlet temperature (T1), air temperature after first stage compression (T2), air temperature after inter cooler (T3), air temperature after second stage compression (T4), manometer reading, and energy meter reading. Three samples of graphene nano-oil are used in the experiment again, and the results are compared.

Results and Discussion

Effect of graphene nano-oil on isothermal efficiency

At each pressure ratio isothermal efficiency and volumetric efficiency is calculated for all the samples and presented in the table 6. Variation of isothermal efficiency against pressure ratio is shown in figure 6 and variation of volumetric efficiency

Table 4: Viscosity variation with respect to temperature.

S. No.	Temperature 28 °C	Temperature 34 °C	Temperature 40 °C	Temperature 46 °C
Time for sample 1	1'16"	44"	32"	25"
Dy. viscosity in mPas	1570	679	266.7	Nil
Time for sample 2	1'18"	47"	37"	32"
Dy. viscosity in mPas	1630.8	772	449	266.7
Time for sample 3	1'08"	46"	33"	27"
Dy. viscosity in mPas	2139	862	550.7	414.5
Time for sample 4	1'03"	45"	32"	22"
Dy. viscosity in mPas	2238	979	616	484.7

Table 5: Technical specification of reciprocating compressor.

Make and model	Elgi TS 03 120 HN
Type	Reciprocating, Air cooled, Splash Lubricated
Displacement	18.16 m^3/h
Free air delivery @ 10 bar	15 m^3/h
Working pressure	12 kgf/cm^2
Configuration type	V
No of stages	2
Cylinder size and stroke	70 x 50 x 85
Volumetric efficiency	78
Compressor speed	925
Motor type and rating	Sq. cage, 3HP
Motor speed	1420

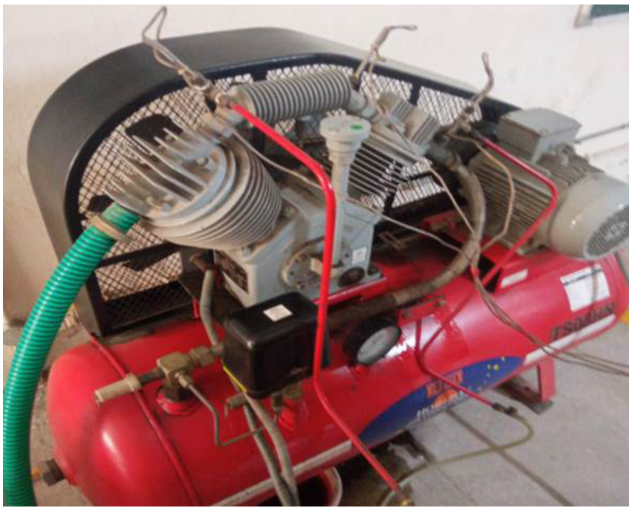

Figure 5: Two-stage reciprocating air-compressor.

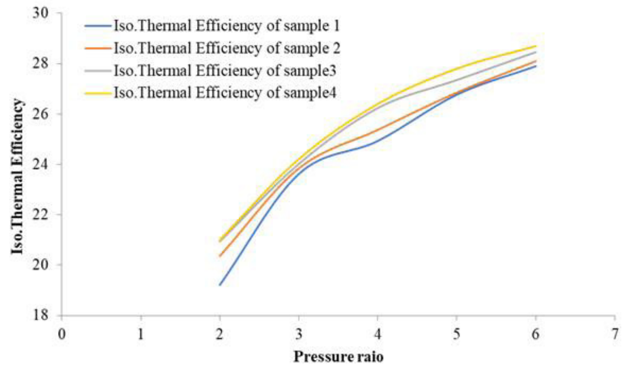

Figure 6: Variation of isothermal efficiency vs pressure ratio for various samples.

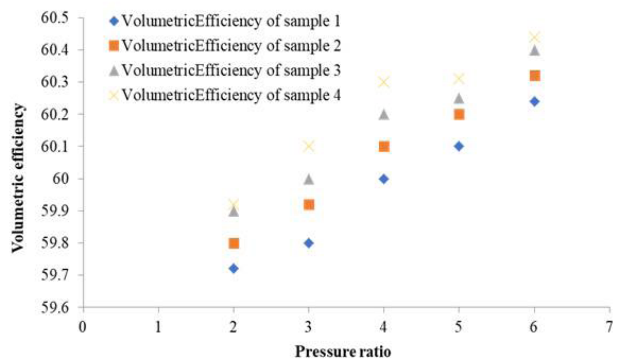

Figure 7: Variation of volumetric efficiency vs pressure ratio for various samples.

against pressure ratio is shown in figure 7. From the figure 6, it can be seen that efficiency rises steadily as delivery pressure rises. The trend for efficiency improvement is the same across all samples. Efficiency rises together with nanoparticle concentration, reaching its peak at 1.5% graphene-oil nano fluid. At 6 kg/cm^2, the percentage increase above ordinary oil is 2.87%.

Effect of graphene nano-oil on volumetric efficiency

The figure 7 shows that, like isothermal efficiency, volumetric efficiency likewise steadily rises for all samples as the delivery pressure rises, although with a little increase. At all pressure ratios, volumetric efficiency is rising along with particle concentration. Sample 4 has a volumetric efficiency improvement of 0.33% as compared to ordinary oil (sample 1).

Table 6: Calculated values of isothermal efficiency and volumetric efficiency against pressure ratio.

Pressure ratio	Isothermal efficiency				Volumetric efficiency			
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
2	19.21	20.36	20.94	21	59.72	59.8	59.9	59.92
3	23.62	23.84	24.02	24.21	59.8	59.92	60	60.1
4	24.93	25.37	26.24	26.4	60	60.1	60.2	60.3
5	26.77	26.85	27.35	27.8	60.1	60.2	60.25	60.31
6	27.9	28.1	28.46	28.7	60.24	60.32	60.4	60.44

Conclusions

The goal of the current experimental investigation is to investigate the reciprocating compressor's performance by incorporating graphene nanoparticles into lubricating oil at various pressure ratios. The conclusions drawn from the experimental findings are listed below.

- When the temperature raises all samples' viscosity decreases. The viscosity of lubricating oil is increased by the addition of nanoparticles. Unlike regular motor oil, nano-oil maintains its viscosity even at greater temperatures.
- The viscosity difference between the base oil and all nano-oil samples is minimal at temperatures higher than 46 °C.
- With regard to pressure ratio and nanoparticle concentration, isothermal efficiency is rising. Sample 4 has a maximum increase of 2.87% at 6 kg/cm^2 pressure. This may be because engine oil containing graphene nanoparticles provides better lubrication or reduces friction between the piston and the cylinder.
- The decrease of the compressor's frictional power loss is caused by the addition of nanoparticles to lubricating fluid.
- Similarly, even yet, there is a little increase in volumetric efficiency when comparing pressure ratios and nanoparticle concentrations. This might be as a result of compressed air losing heat to lubricating oil through a piston. Thus, the volumetric efficiency of compressed air is improving as a result of cooling. The greatest percentage increase in volumetric efficiency is for sample 4, which is 0.33% higher than sample1.

Future Scope

By adding nanoparticles to lubricating oil, compressed air may be cooled. Heat is transferred through the crank case's lubricating fluid, piston, and compressed oil. By installing a nano-fluid circulation tank around the intercooler, direct air cooling can be explored as an alternative. Additionally, greater pressures can be used to assess an air compressor's functioning.

Acknowledgements

None.

Conflict of Interest

The authors declare that there is no conflict of interest.

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