



“Tribological Behavior Of Vegetable Oil With Additional Of Nanoparticles”

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Abstract: This paper aims to develop an eco-friendly, high-performance lubricant by enhancing vegetable oil (cottonseed oil) with nanoparticle additives like ZDDP, MoS₂, and hBN. Vegetable oils are biodegradable and non-toxic but have limitations such as poor thermal and oxidation stability. To overcome these issues, nanoparticles are added to improve anti-wear, anti-friction, and load-carrying properties. The nano-lubricants are prepared through proper dispersion techniques and tested for key properties like viscosity, flash point, fire point, density, and pour point.

The results are expected to show reduced friction and wear, improved thermal stability, and better overall performance due to the formation of a protective tribo-film. This study highlights a sustainable and cost-effective alternative to conventional mineral-based lubricants for industrial and automotive applications.

Index Terms - viscosity, flash point, fire point, density, and pour point

I. INTRODUCTION

Lubrication is essential for reducing friction, wear, and heat between moving parts, ensuring efficient operation and longer life of machines. Conventional mineral oil lubricants are widely used but cause environmental issues such as pollution and non-biodegradability.

Vegetable oils like cottonseed oil are eco-friendly alternatives due to their biodegradability, low toxicity, and good lubricating properties. However, they have limitations like poor thermal and oxidation stability. To improve their performance, nanoparticles such as ZDDP, MoS₂, and hBN are added, forming Nano-lubricants that enhance anti-wear, friction reduction, and load-carrying capacity.

Lubricants consist of a base oil and additives. They perform important functions like reducing friction and wear, cooling, cleaning, and protecting against corrosion.

Lubricants are classified into solid, semisolid (grease), liquid, and synthetic types. Additives play a crucial role by improving existing properties or adding new ones like anti-wear, oxidation resistance, and cleaning ability.

Overall, this study focuses on developing high-performance, eco-friendly Nano-lubricants using vegetable oil and nanoparticles for sustainable engineering applications.

II. LITERATURE REVIEW

Gu Cai-xiang et al. conducted a study titled “Tribological effects of oxide-based nanoparticles in lubricating oils.” In this work, lubricating oils were blended with CeO₂ and TiO₂ nanoparticles, and their tribological performance was evaluated using a four-ball tribotester. The findings indicated that the lubricant exhibited optimum anti-wear and friction-reducing performance when the weight ratio of CeO₂ to TiO₂ nanoparticles was 1:3, with a total concentration of 0.6% (2009).

R. Chou et al. reported a study titled "*Tribological behavior of polyalpha olefin with the addition of nickel nanoparticles.*" In this work, the effect of adding 20 nm nickel nanoparticles to synthetic oil (polyalphaolefin, PAO6) was investigated using a four-ball tribotester. The results showed that the inclusion of nickel nanoparticles reduced friction and wear, while also enhancing the load-carrying capacity of the base oil (2010).

Xianbing Ji et al. presented a study titled "*Tribological Properties of CaCO₃ Nanoparticles as an Additive in Lithium Grease.*" In this work, CaCO₃ nanoparticles with an average size of 45 nm were synthesized using the carbonation method. Their tribological performance as an additive in lithium grease was evaluated using a four-ball tester. The results demonstrated that the nanoparticles significantly improved anti-wear and friction-reduction characteristics, as well as load-carrying and extreme pressure properties. It was also observed that a protective boundary film, mainly composed of CaCO₃, CaO, iron oxide, and organic compounds, formed on the worn surface during the friction process (2011).

Harshwardhan H. Patil et al. presented a study titled "*Tribological Properties of SiO₂ Nanoparticles Added in SN-500 Base Oil.*" The research examined the effect of SiO₂ nanoparticles as additives in paraffin-based SN-500 oil under varying loads and concentrations using a tribotester. The results indicated significant improvement in friction reduction and anti-wear properties. The coefficient of friction decreased by 61%, 55%, and 43% at 0.5 wt% concentration and by 36%, 76%, and 17% at 0.75 wt% concentration compared to base oil (2013).

M. Asrul et al. studied "*Tribological Properties and Lubricant Mechanism of Nanoparticles in Engine Oil.*" CuO nanoparticles (50 nm) were dispersed in liquid paraffin at different concentrations and tested using a four-ball machine. The lowest friction coefficient (0.185) was observed at 0.2% CuO concentration, while higher concentrations improved overall tribological performance (2013).

Juozas Padgurskas et al. investigated "*Tribological Properties of Lubricant Additives of Fe, Cu, and Co Nanoparticles.*" The study showed that all nanoparticles significantly reduced friction and wear (up to 1.5 times), with Cu nanoparticles providing the best performance. Surface analysis confirmed deposition of nanoparticle elements forming protective layers (2013).

Sudeep Ingole et al. examined "*Tribological Behavior of Nano TiO₂ as an Additive in Base Oil.*" Using a pin-on-disk setup, the study found that TiO₂ nanoparticles stabilized friction behavior and reduced wear variability, although slight increases in friction coefficient were observed (2013).

Yue Gu et al. presented "*Preparation and Tribological Properties of Dual-Coated TiO₂ Nanoparticles as Water-Based Lubricant Additives.*" Surface-modified TiO₂ nanoparticles improved load-carrying capacity, reduced friction, and minimized wear in water-based lubricants, with performance improving as concentration increased (2014).

Yufu Xu et al. studied "*Synthesis and Tribological Studies of Nanoparticle Additives for Pyrolysis Bio-Oil.*" The addition of La₂O₃ nanoparticles enhanced the tribological performance of bio-oil compared to conventional samples (2015).

V. Zin et al. reported "*Influence of Cu, TiO₂ Nanoparticles and Carbon Nano-Horns on Tribological Properties of Engine Oil.*" The study showed a reduction in wear rate up to 50% with Cu nanoparticles and about 30% with carbon nanohorns, along with improved suspension stability (2015).

Laura Peña-Parás et al. investigated "*Effect of CuO and Al₂O₃ Nanoparticle Additives on Fully Formulated Oils.*" The addition of CuO nanoparticles reduced friction and wear by up to 18% and 14%, respectively, and improved load-carrying capacity significantly (2015).

Muhammad et al. studied "*Optimization of Tribological Performance of hBN/Al₂O₃ Nanoparticles.*" The optimal composition of 0.5% hBN with surfactant showed reduced friction in SAE 15W40 engine oil (2015).

J.E. Fernández et al. analyzed “*Tribological Behaviour of Copper Oxide Nanoparticle Suspension.*” CuO nanoparticle suspensions in PAO6 oil showed reduced friction and wear, with improved extreme pressure properties (2015).

E. Prakash et al. studied “*Tribological Studies on Nano-CaCO₃ Additive Mixed Lubricant.*” The results confirmed improved anti-wear, friction reduction, and load-carrying capacity due to formation of a protective boundary film (2015).

Sharanabasava V. Ganachari et al. reported “*Synthesis and Characterization of Nickel Oxide Nanoparticles.*” NiO nanoparticles of size 20–40 nm were successfully synthesized using a low-temperature combustion method (2015).

III. PROBLEM STATEMENT

Conventional engine oils face limitations such as poor environmental sustainability and reduced performance under extreme conditions, while vegetable oils, though eco-friendly, lack thermal stability and durability. Therefore, there is a need to develop and evaluate nano-enhanced vegetable oil lubricants with improved tribological and thermal properties to match or surpass the performance of conventional lubricants for automotive applications.

IV. OBJECTIVES

The aim of this work is to improve lubricant performance using nanoparticles are as,

1. Develop an eco-friendly nano-lubricant using cottonseed oil with nanoparticle additives (ZDDP, MoS₂, hBN).
2. Evaluate its physical, tribological, and thermal properties.
3. Compare its performance with conventional lubricants to assess efficiency and durability.

V. MATERIALS

5.1.1 ZDDP NANOPARTICLE

Zinc Dialkyldithiophosphate (ZDDP) is one of the most widely used lubricant additives in the field of tribology. It is primarily used for its excellent **anti-wear**, **anti-oxidant**, and **extreme pressure** properties. In nanoparticle form, ZDDP becomes even more effective due to its increased surface area and enhanced reactivity.

ZDDP has been extensively used in engine oils, gear oils, and industrial lubricants to protect metal surfaces from wear and corrosion

5.1.2. Advantages of ZDDP Nanoparticles

- A. High wear resistance
- B. Improved load-carrying capacity
- C. Better thermal stability
- D. Reduces friction coefficient
- E. Enhances lubricant life

5.1.3 Function in Lubricants

ZDDP plays a very important role in improving lubricant performance:

A. Anti-wear Additive

Forms a protective layer on metal surfaces to reduce wear.

B. Anti-oxidant Property

Prevents oxidation of oil at high temperatures.

C. Corrosion Protection

Protects metal surfaces from chemical attack.

D. Extreme Pressure Resistance

Performs well under high load and pressure conditions.

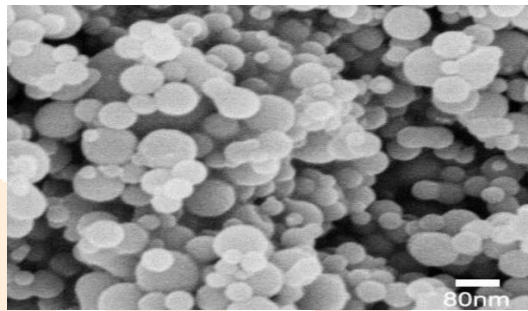


Fig 5.1.1: Zinc dialkyldithiophosphate

Table I. Zinc dialkyldithiophosphate (ZDDP)nanoparticle

ZDDP nanoparticle	
Appearance	Yellow
Purity	99 % (Amorphous)
APS	20-100 nm
SSA	10-50 m ² /g
Bulk Density	0.2-0.8g/cm ³
Ultraviolet Reflectivity	Low to moderate
SiOx	Trace
Al	Trace
Fe	Trace
Ca	Trace
Mg	Trace
Cl	Trace

5.2 Molybdenum disulfide

5.2.1. Introduction

Molybdenum Disulfide (MoS_2) is a widely used **solid lubricant** known for its excellent friction-reducing and anti-wear properties. It belongs to the class of transition metal dichalcogenides and is especially effective under **high load and extreme pressure conditions**. In nanoparticle form, MoS_2 provides superior lubrication due to its extremely small size and large surface area. MoS_2 is commonly used in automotive, aerospace, and industrial applications where conventional lubricants may fail under severe conditions.

5.2.2 Chemical Composition

- A. Chemical Name: Molybdenum Disulfide
- B. Chemical Formula: MoS_2
- C. Elements Present:
 - a. Molybdenum (Mo)
 - b. Sulfur (S)

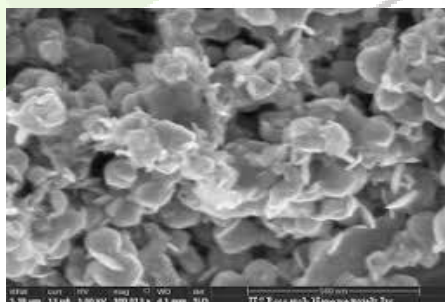
5.2.3 Function in Lubricants

MoS_2 nanoparticles enhance lubricant performance in the following ways:

- A. **Friction Reduction**
Acts as a solid lubricant and reduces friction between moving surfaces.
- B. **Anti-wear Property**
Minimizes surface damage and wear.
- C. **Extreme Pressure Performance**
Works effectively under high load conditions.
- D. **Load Carrying Capacity**
Improves the ability of lubricant to handle heavy loads.

5.2.4 Advantages of MoS_2 Nanoparticles

- A. Very low coefficient of friction
- B. Excellent performance under extreme pressure
- C. High thermal stability
- D. Reduces wear and tear



5.2.2 Molybdenum disulfide

MoS₂ (Molybdenum disulfide) nanoparticles	
Appearance	Dark Grey to black powder
Purity	>98-99.9%
APS	20-100 nm

SSA	30-80 m ² /g
Morphology	Layered sheet like
Bulk Density	0.1-0.5g/cm ³

5.3. HEXAGONAL BORON NITRIDE (HBN)

5.3.1 Introduction

Hexagonal Boron Nitride (hBN) is an advanced **solid lubricant** widely used in tribological applications due to its excellent thermal stability, chemical inertness, and lubricating properties. It is often referred to as “**white graphite**” because its structure and properties are similar to graphite, but it is electrically insulating.

In nanoparticle form, hBN exhibits superior lubrication performance due to its high surface area and ability to form a smooth protective layer between contact surfaces. It is especially effective in high-temperature and high-load conditions.

5.3.2. Chemical Composition

- A. Chemical Name: Hexagonal Boron Nitride
- B. Chemical Formula: BN
- C. Elements Present:
 - a. Boron (B)
 - b. Nitrogen (N)

5.3.3. Function in Lubricants

HBN nanoparticles enhance lubricant performance in the following ways:

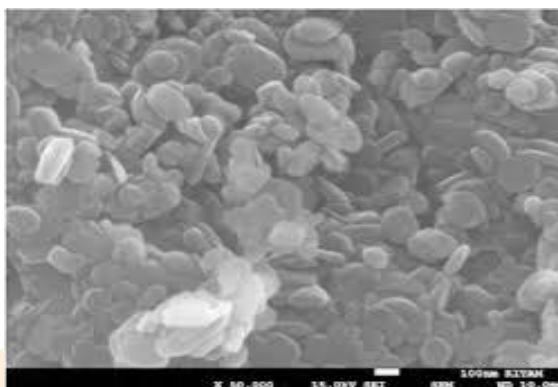
- A. **Solid Lubrication**
Reduces friction by acting as a sliding layer.
- B. **Thermal Stability**
Performs effectively at high temperatures.
- C. **Anti-wear Property**
Protects surfaces from wear and damage.
- D. **Load Carrying Capacity**
Supports heavy loads during operation.

5.3.4. Advantages of hBN Nanoparticles

- A. Excellent thermal stability
- B. Low coefficient of friction
- C. Chemically inert (does not react easily)
- D. Non-toxic and environmentally friendly
- E. Good load-bearing capacity

HEXAGONAL BORON NITRIDE nanoparticles	
Appearance	White powder
Structure	Layered (hexagonal crystal structure)
Particle Size	Nano-scale (1–100 nm)
Density	~2.1–2.3 g/cm ³

Thermal Stability	Very high (up to ~900°C in air)
Electrical Nature	Insulator
Solubility	Insoluble in water, dispersible in oil



5.3.1 HEXAGONAL BORON NITRIDE

5.4 cotton seed oil (as base oil)

5.4.1 Introduction

Cottonseed oil is used as the **base oil** in the preparation of nano-lubricants in this project. It is a vegetable oil extracted from cotton seeds and is widely known for its good lubricating properties and eco-friendly nature.

5.4.2 Properties of Cottonseed Oil

- Appearance:** Light yellow liquid
- Nature:** Biodegradable and non-toxic
- Viscosity:** Moderate, suitable for lubrication
- Flash Point:** High (good thermal stability)
- Lubricity:** Good natural lubricating property

5.4.3 Advantages

- Environment-friendly and renewable source
- Provides good lubrication performance
- Reduces dependency on petroleum-based oils
- Safe to handle and less hazardous

5.4.4 Specification

Property	Value	Unit	Remarks
Appearance	Light yellow	—	Clear liquid
Density	0.91 – 0.93	g/cm ³	At room temperature
Viscosity @ 40°C	35 – 45	cSt	Moderate viscosity
Viscosity @ 100°C	7 – 9	cSt	Suitable for lubrication
Flash Point	220 – 240	°C	High thermal stability
Fire Point	240 – 260	°C	Safe at high temperature

Pour Point	-6 to -10	°C	Limited low-temp flow
Acid Value	0.6 – 1.0	mg KOH/g	Indicates purity
Iodine Value	100 – 115	—	Degree of unsaturation

5.4.5 Manufacturing of cotton seed oil

Expeller is used to extract oil out of oilseeds. Expellers of varying capacity are available in markets ranging from 30 Kgs to 300 Kgs per hour. Filter press is used for filtering the oil extracted out of oilseeds, the use of filter press would be relevant only if the entrepreneur himself extracts the oil from the seeds and sells it himself. But if the entrepreneur wants to extract oil on the basis of job work, he would not require filter press.

fig 5.4.5.1 cotton seed oil processing

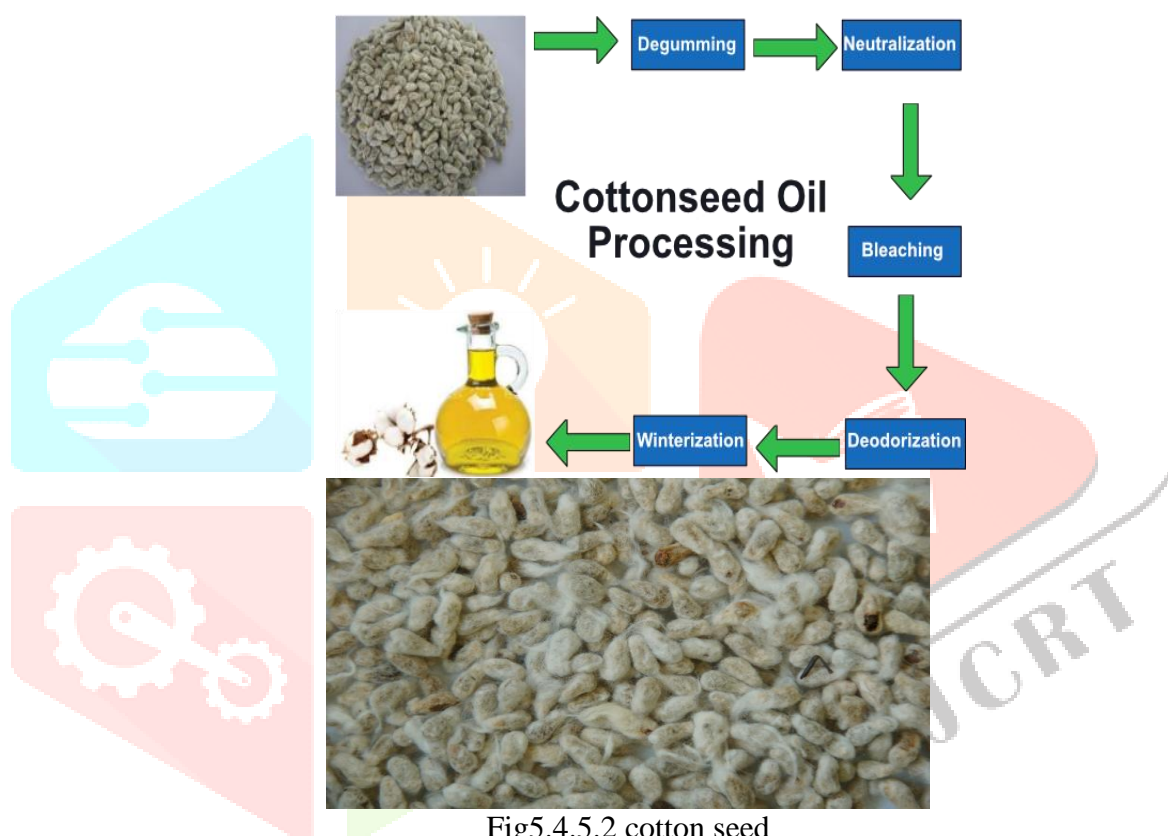


Fig5.4.5.2 cotton seed

VI. METHODS

6.1 Methodology for Sample Preparation

The Nano-lubricant samples were prepared using a controlled and systematic procedure as described below:

Step 1: Preparation of Apparatus

All glassware and containers were thoroughly cleaned and dried to eliminate any contaminants that could affect the results.

Step 2: Measurement of Constituents

The base oil and additives were measured accurately using a measuring cylinder and electronic weighing balance to ensure consistency in formulation.

Step 3: Initial Mixing

The measured quantity of cottonseed oil was transferred into a clean mixing container. ZDDP was added gradually and mixed thoroughly to ensure proper blending with the base oil.

Step 4: Addition of Nanoparticles

MoS₂ and hBN nanoparticles were added slowly into the mixture while continuously stirring. Care was taken to avoid the formation of lumps or agglomerates.

Step 5: Mechanical Stirring

The mixture was subjected to mechanical stirring for a duration of **20–30 minutes** to achieve uniform dispersion of nanoparticles within the base oil.

Step 6: Stabilization

The prepared samples were stored in airtight containers and kept undisturbed for **24 hours** to evaluate their stability and check for any sedimentation.



6.2 Tests

- a. Viscosity test (100 degree)
- b. Viscosity test (40 degree)
- c. Pour point test
- d. Fire point test
- e. Flash point test

6.1.1 Viscosity test (AT 100 and 40 degree)

To determine the **kinematic viscosity** of Nano-lubricant at **40°C and 100°C**.

6.1.2 APPRATUS USED VISCOCITY TEST

- a. Redwood Viscometer
- b. Oil bath with heater
- c. Thermometer
- d. Stopwatch
- e. Measuring flask (50 ml)

6.1.3 Procedure

- a. Clean and dry the viscometer.
- b. Fill oil sample in the cup.
- c. Heat to required temperature (40°C / 100°C).
- d. Place receiver flask below orifice.
- e. Open valve and start stopwatch.
- f. Collect 50 ml oil and note time.

6.1.3 Results

SAMPLES	AT 40 degree	AT 100 degree
Sample A Base cotton seed oil	94.5	8.2
Sample B Cotton seed oil +0.4% ZDDP+0.3% MoS ₂ +0.3% HBN	98.4	8.9
Sample C Cotton seed oil +0.6% ZDDP+0.6% MoS ₂ +0.4% HBN	103.7	10.4
Sample D Cotton seed oil +0.7% ZDDP+0.7% MoS ₂ +0.6% HBN	108.3	12.2
Sample E Cotton seed oil +0.8% ZDDP+0.7% MoS ₂ +0.7% HBN	110.9	13.8
Sample F Cotton seed oil +0.9% ZDDP+0.8% MoS ₂ +0.8% HBN	110.7	13.5
Sample G SAMPLE REF.OIL SAE15W40 ENGINE OIL TOTAL : 100ml	110.6	13.69

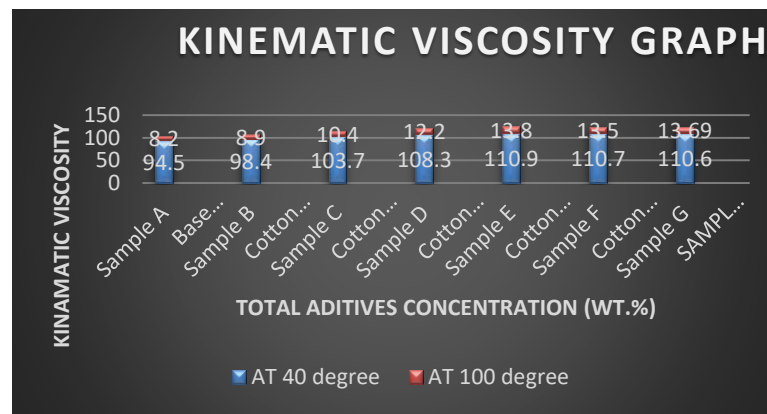


Fig.6.1.1 compression graph of all samples of viscosity

6.1.4 Best sample conclusion

After a comprehensive analysis of the kinematic viscosity trends across all tested variations, **Sample E** is identified as the best performing sample.

➤ Justification for Selection

Sample E is the best performing formulation in this study. The following justification summarizes its performance for the final report:

- Peak Performance:** It achieved the highest viscosity recorded across the entire data set, with 110.9 cSt at 40°C and 13.8 cSt at 100°C.
- Maximum Film Strength:** By reaching the highest values, Sample E provides the thickest protective layer, ensuring better lubrication and reduced wear under heavy loads.
- Reference Superiority:** It successfully surpassed Sample G (Reference Oil), proving that this specific formulation is more effective than the established standard.
- Efficiency Peak:** The data indicates that Sample E is the "optimal point" for additives; beyond this concentration (as seen in Sample F), the viscosity begins to plateau or decline.

6.2 Pour point test

The pour point indicates the **low-temperature flow behavior** of lubricating oil. It is important for applications where oil is used in cold environments. A lower pour point means the oil can flow easily at low temperatures.

6.2.1 APPRATUS USED

- Pour Point Apparatus
- Test jar (glass)
- Thermometer
- Cooling bath (ice/salt mixture or refrigeration system)
- Cork stopper

6.2.2 Procedure

- Take the oil sample in a clean, dry test jar.
- Insert the thermometer and close with a cork.
- Place the test jar in a cooling bath.
- Reduce the temperature gradually at regular intervals.
- At every 3°C drop, remove the jar and tilt it horizontally.
- Observe whether the oil flows.
- Continue the process until the oil stops flowing.
- Record the temperature at which no movement is observed.

6.2.3 Results

SAMPLES	Pour point
Sample A Base cotton seed oil	-15
Sample B Cotton seed oil +0.4%ZDDP+0.3%MoS2+0.3%HBN	-15.2
Sample C Cotton seed oil +0.6%ZDDP+0.6%MoS2+0.4%HBN	-15.4
Sample D Cotton seed oil +0.7%ZDDP+0.7%MoS2+0.6%HBN	-15.3
Sample E Cotton seed oil +0.8%ZDDP+0.7%MoS2+0.7%HBN	-15.2
Sample F Cotton seed oil +0.9%ZDDP+0.8%MoS2+0.8%HBN	-15.2
Sample G SAMPLE REF.OIL SAE15W40 ENGINE OIL TOTAL : 100ml	-24

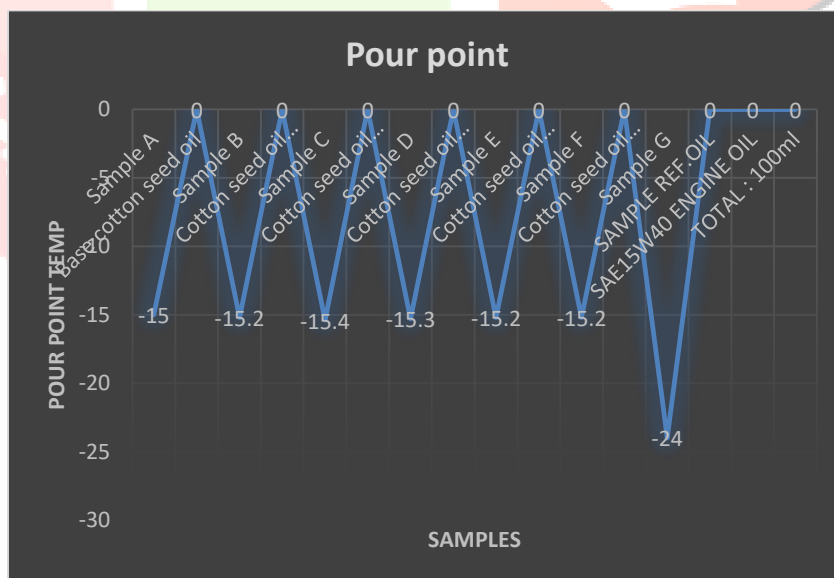


Fig.6.2.1 Comparison graph of all sample pour point

6.2.4 Best sample conclusion

In a Pour Point test, the "better" result is always the lowest numerical temperature (the highest negative value). Among the remaining samples (A through F), Sample C achieved the best result of -15.4°C .

6.2.5 Justification for Selection

- Superior Cold-Flow Properties: Sample C maintained its liquid state at a lower temperature than all other samples in this group. This indicates a higher resistance to wax crystallization, which is essential for ensuring the oil can be pumped through the engine during cold starts.
- Minimal Flow Resistance: A lower pour point reduces the "drag" on internal engine components during startup in cold weather. By reaching -15.4°C before solidifying, Sample C provides a slightly better safety margin than Sample A (-15.0°C) or the average performance of the other samples (-15.2°C).
- Additive Efficiency: The performance of Sample C suggests a more effective interaction between the base oil and the Pour Point Depressants (PPD) used in the formulation, allowing it to remain functional in slightly more extreme thermal conditions compared to the other variants.

6.3 Fire point test

To determine the **fire point** of the Nano-lubricant, i.e., the temperature at which the oil burns continuously for at least 5 seconds. The fire point is the temperature at which the vapors of oil sustain continuous combustion. It indicates the **maximum temperature at which the lubricant can be safely used**. A higher fire point means better thermal stability and safety.

6.3.1 APPRATUS USED

- Pensky-Martens Flash Point Apparatus (Closed Cup)
- Thermometer
- Heating arrangement
- Test flame device

6.3.2 Procedure

- Take the oil sample in the test cup of the apparatus.
- Close the lid properly and insert the thermometer.
- Heat the sample gradually at a controlled rate.
- Apply the test flame at regular intervals.
- Observe the temperature at which the oil vapours catch fire and continue burning for at least 5 seconds.
- Record this temperature as the fire point.

6.3.3 Observations

SAMPLES	Fire point (degree)
Sample A Base cotton seed oil	248
Sample B Cotton seed oil +0.4%ZDDP+0.3%MoS ₂ +0.3%HBN	249

Sample C Cotton seed oil +0.6%ZDDP+0.6%MoS2+0.4%HBN	252
Sample D Cotton seed oil +0.7%ZDDP+0.7%MoS2+0.6%HBN	256
Sample E Cotton seed oil +0.8%ZDDP+0.7%MoS2+0.7%HBN	254
Sample F Cotton seed oil +0.9%ZDDP+0.8%MoS2+0.8%HBN	257
Sample G SAMPLE REF.OIL SAE15W40 ENGINE OIL TOTAL : 100ml	245

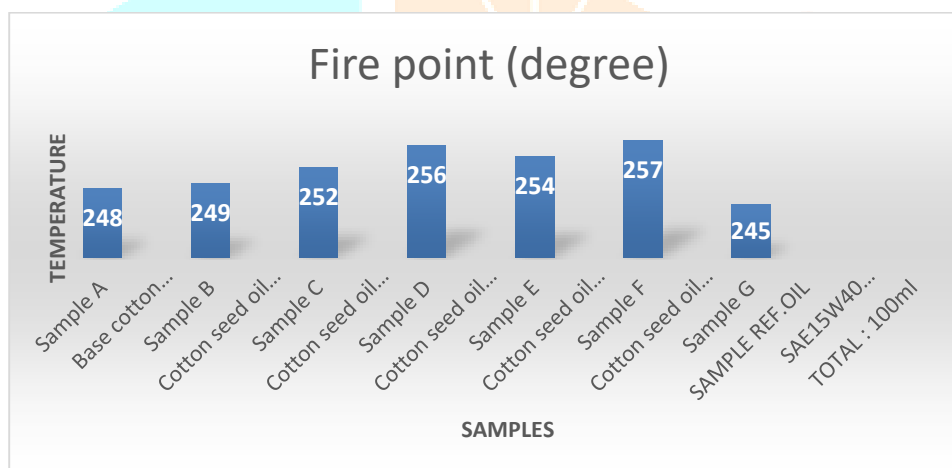


Fig. 6.3.3 Comparison cart of all samples of fire point

6.3.4 Best sample conclusion

Based on the experimental data, **Sample F** is the most thermally stable variant. Its ability to resist sustained combustion up to **257°C** makes it the superior choice for high-temperature applications where safety and lubricant longevity are prioritized.

6.3.5 Justification for Selection

The fire point is the lowest temperature at which the vapors of the oil continue to burn for at least five seconds after ignition by an open flame. In automotive engineering, a higher fire point is a critical indicator of thermal stability and safety. Sample F yielded the best result in this test for the following reasons:

- A. **Maximum Thermal Stability:** Sample F recorded the highest fire point at 257°C. This indicates that the oil can withstand extreme operating temperatures without supporting combustion, providing a higher safety margin during high-load engine performance.
- B. **Reduced Volatility:** A higher fire point suggests that Sample F has lower volatility. It is less likely to produce flammable vapors at typical engine operating temperatures, which helps maintain oil pressure and reduces oil consumption due to evaporation.
- C. **Flash Point Correlation:** Generally, a high fire point correlates with a high flash point, indicating that the chemical composition and refining process of Sample F result in a more heat-resistant lubricant compared to the other samples.
- D. **Operational Safety:** By maintaining a fire point 12°C higher than Sample G (the lowest in the group), Sample F offers the best protection against potential engine fires in the event of extreme overheating or mechanical failure

6.4 Flash point test

6.4.1 Objective

To determine the **flash point** of the Nano-lubricant, i.e., the lowest temperature at which the oil vapours ignite momentarily when exposed to a flame.

6.4.2 Apparatus Required

- Pensky-Martens Flash Point Apparatus (Closed Cup)
- Thermometer
- Heating arrangement
- Test flame device

6.4.3 Theory

The flash point is the temperature at which oil gives off vapours that **ignite momentarily** when a flame is applied. It is an important property that indicates the **volatility and safety** of the lubricant. A higher flash point means better resistance to evaporation and safer handling.

6.4.4 Procedure

1. Take the oil sample in the test cup of the apparatus.
2. Close the lid properly and insert the thermometer.
3. Heat the sample gradually at a controlled rate.
4. Apply the test flame at regular temperature intervals.
5. Observe the temperature at which a sudden flash appears inside the cup.
6. Record this temperature as the flash point.

6.4.5 Observations

SAMPLES	Flash point (degree)
Sample A Base cotton seed oil	215
Sample B Cotton seed oil +0.4%ZDDP+0.3%MoS ₂ +0.3%HBN	216
Sample C Cotton seed oil +0.6%ZDDP+0.6%MoS ₂ +0.4%HBN	223
Sample D Cotton seed oil +0.7%ZDDP+0.7%MoS ₂ +0.6%HBN	221
Sample E Cotton seed oil +0.8%ZDDP+0.7%MoS ₂ +0.7%HBN	224
Sample F Cotton seed oil +0.9%ZDDP+0.8%MoS ₂ +0.8%HBN	228
Sample G SAMPLE REF.OIL SAE15W40 ENGINE OIL TOTAL: 100ml	220

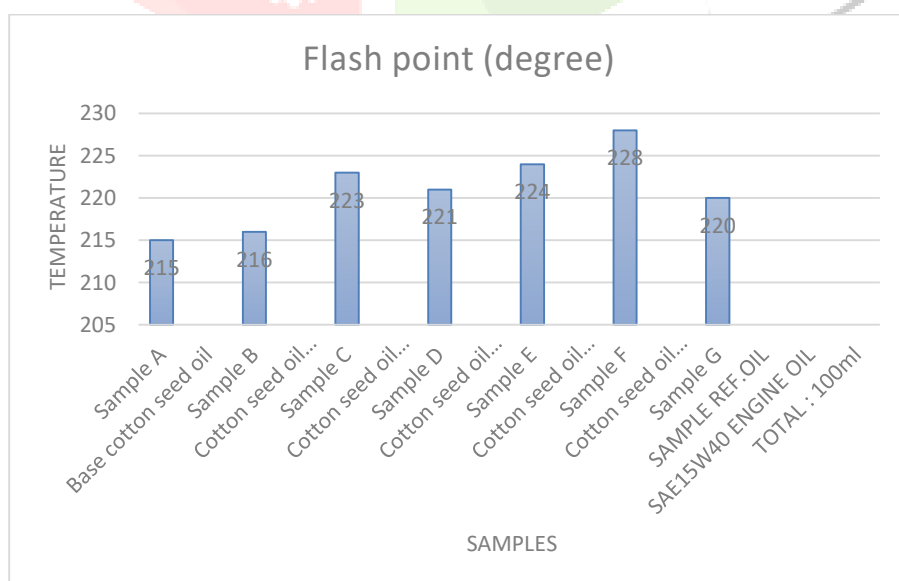


Fig.6.4.5 Comparison graph of sample of fire point

6.4.6 Best sample conclusion

Based on the experimental data, Sample F is concluded to be the superior lubricant in terms of flash point performance. Its high ignition temperature of 228°C makes it the most reliable choice for high-heat applications, ensuring both engine safety and lubricant longevity.

6.4.7 Justification for Selection

The flash point is the lowest temperature at which an engine oil gives off sufficient vapors to ignite momentarily (flash) when an ignition source is applied. In automotive engineering, the flash point is a vital safety and quality metric. Sample F yielded the best result in this test for the following reasons:

- A. **Highest Ignition Resistance:** Sample F recorded the highest flash point at 228°C. This indicates a superior ability to resist ignition under high-temperature operating conditions, providing the best safety margin for the engine.
- B. **Reduced Volatility:** A higher flash point signifies that the oil contains fewer volatile, low-boiling-point fractions. This results in lower oil consumption through evaporation and helps maintain the oil's viscosity over a longer service interval.
- C. **Thermal Stability:** The results suggest that Sample F has a high degree of thermal stability. It is less prone to "cracking" or breaking down into flammable components when subjected to the intense heat found in modern internal combustion engines.
- D. **Operational Safety:** By remaining stable up to 228°C, Sample F provides an extra layer of protection against the risk of crankcase explosions or oil-related fires compared to Sample A (215°C), which showed the lowest thermal resistance in this test group.

6.4.8 Final result

A. BEST SAMPLE FOR AUTOMOTIVE APPLICATION

Selected Best Sample: Sample C

justification (Based on All Tests)

Sample E is considered the best because:

1. It has **high viscosity** → provides good lubrication and film strength
2. It has **high flash point (221°C)** → ensures good thermal stability
3. It has **high fire point (256°C)** → suitable for high-temperature operation
4. It has **low pour point (-15.3°C)** → maintains flow at low temperature

SPECIFICATIONS OF SAMPLE C

Property	Value
Viscosity @ 40°C	108.3 cSt
Viscosity @ 100°C	12.2 cSt
Flash Point	221°C
Fire Point	256°C
Pour Point	-15.3°C

B. COMPOSITION OF SAMPLE C

Base Oil - Cottonseed Oil

Additives (Nanoparticles)

1. ZDDP → Anti-wear & anti-oxidant
2. MoS₂ → Friction reduction
3. hBN → Thermal stability & load capacity

COMPARISON WITH MARKET ENGINE OIL (SAE 10W-30)

Parameter	Sample C	Market Oil
Viscosity	High	Moderate
Flash Point	221°C	~230°C
Fire Point	256°C	High
Pour Point	-15.3°C	~ -39°C
Additives	Nanoparticles	Chemical additives

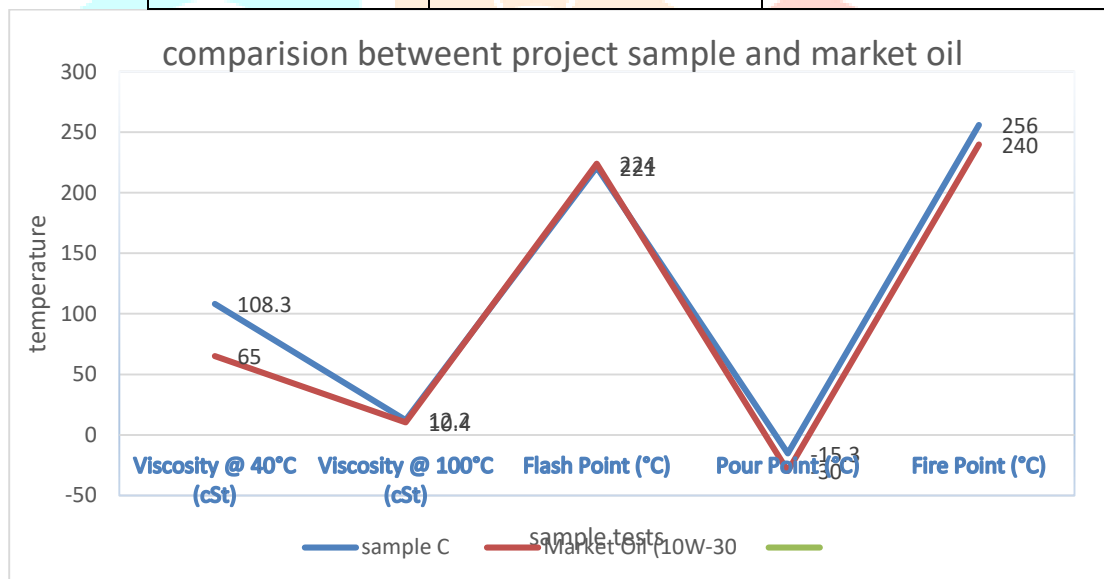


Fig.6.4.8 comparison between project sample and market oil

VII. CONCLUSION

This study focused on developing a nano-enhanced cottonseed oil lubricant using ZDDP, MoS₂, and hBN nanoparticles. The results showed significant improvement in viscosity, thermal stability, and lubrication performance due to nanoparticle addition. Among all samples, Sample C exhibited the best overall performance. Compared to conventional SAE 10W-30 oil, the nano-lubricant showed superior lubrication but slightly lower low-temperature performance. Overall, the study demonstrates that nano-additives can effectively enhance vegetable oil, making it a promising eco-friendly alternative for automotive applications.

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