TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING INSTITUTE MECHANICAL DIVISION DEPARTMENT OF AUTOMOTIVE

Thesis on:

Investigation The Effect Of Alternative Additive Mixed Castor And Cottonseed Oil On The Lubricity Of Diesel Fuels.

A thesis submitted in partial fulfillment of the requirements for the Award of degree of Masters of Science in Automotive Management Technology

Prepared by

By: Yohannes Degife

ETU/MR/310/14

Major Advisor: Prof. Ing. Pedro Dionisio Remedios Castañeiras, PhD

Co- Advisor: Hailegrebiel Zewude

Addis Ababa, Ethiopia

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CANDIDATE'S DECLARATION

I am Yohannes Degife, a registration number /I.D. Number/ETU/MR/310/14, do hereby declare that, this thesis work which is entitled **"Investigation the effect of alternative additive mixed castor and cottonseed oil on the Lubricity of Diesel Fuels"**

Using Alternative Additive Cottonseed and castor seed Vegetable Oil" in partial fulfillment of the requirements for the award of the Degree Of Master Of Science In Automotive Technology is my original work and it has not been submitted partially; or in full, by any other person for an award of a degree in any other university/institution. All relevant resources of information used in this paper have been duly acknowledged.

Student Name	Signature	Date
1. Yohannes Degife Sahile	______________	______________

CERTIFICATE

I certify that this thesis work which is entitled as **"Investigation the effect of alternative additive mixed castor and cottonseed oil on the Lubricity of Diesel Fuels"** has been undertaken independently by Yohannes Degife under my guidance and supervision and it has not been previously worked for the award of any degree.

Main Advisor Name	Signature	Date
Prof. Ing. Pedro Dionisio Remedio Castañeiras	____________	02-08-2023
Co. Advisor	Signature	Date
Hailegrebiel Zewude	____________	____________

APPROVAL

The under signed certify that they have read and hereby recommend to Ethiopian Technical University Faculty of Mechanical Technology, to accept this work submitted by **Yohannes Degife**. Which is entitled as "**Investigation the effect of alternative additive mixed castor and cottonseed oil on the Lubricity of Diesel Fuel**" in partial fulfillment of the requirements for the Degree of Master of Science in Automotive Technology, Department of Automotive Technology. This thesis has been submitted for examination with our approval.

Approved by Board of Examiners	Signature	Date
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Name of Head of Department	Signature	Date
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ASTM	American Society of Testing and Materials	**FAMS**	Fatty acid methyl esters
SLBOCLE	Scuffing Load Ball on cylinder lubricity evaluator	**FIP**	Fuel injection pump
CFPP	Cold Filter Plugging Point	**GDP**	Gross domestic product
°C	Degree Celsius	**HDS**	Hydrodesulphurization
CSO	Cotton seed oil	**HFRR**	High Frequency Reciprocating Rig
CBS	Castor bean oil	**HMN**	Heta methyl nonanal
CI	Compression ignition	**IC**	Internal combustion
DI	Direct injection	**KM**	Kilo meter
DO	Diesel oil	**LA**	Lubricating additives Test
DOE	Design of experiment	**LTFT**	Low Temperature Flow
EPE	Ethiopian Petroleum Enterprise	**MAX**	Maximum
ETU	Ethiopian technical university	**MIN**	Minute
°F	Degree far	**MIN**	Minimum
PRA	Piston ring assembly	**NOC**	National Oil Company
RPM	Revolution per minute	**NOx**	Nitrogen oxide
Scr	selective catalytic reduction	**PPM**	Part per million

Sox	Sulphur dioxide	**ULSD**	Ultra Low Sulfur Diesel
SVO	Straight vegetable oil	**USA**	united States of America
VI	Viscosity index	**WT**	Waits

ABSTRACT

Fuel additives are used worldwide for a variety of applications including fuel efficiency increase, emission reduction, and modifying storage/handling properties among others. Because of the high percentage of global diesel fuel consumption and its impacts on internal combustion engines, various investigations are being conducted around fuel additives that increase the efficiency of diesel fuel-powered internal combustion engines in terms of diesel fuel consumption, wear, lubricity, and greenhouse gas emissions. In this research, the effect of castor bean and cotton seed oil (CBO/CSO) as an additive to diesel fuel and its tribological behavior in terms of engine performance and efficiency and greenhouse emissions has been experimentally investigated, and ANOVA and Pareto chart is used to support the research and optimize the acquired data in spell out the level of influence of castor bean and cotton seed oil from other parameters. To this effect as starting point characterization of diesel fuel used in Ethiopia and the castor bean and cotton seed oil has been conducted separately. At the same time, an extensive literature survey has been conducted in search of the optimum percentage of castor bean and cotton seed oil to be added to the diesel fuel that does not affect the essential characteristics of normal diesel oil. Consequently, using the diesel oil tribological behavior as benchmark samples of blends with 0.5% (5ml Castor bean and cotton seed oil 995ml Diesel fuel), 0.75% (7.5ml castor bean and cotton seed oil 992.5ml Diesel fuel) and 1% (10ml castor bean and cotton seed oil 990ml Diesel fuel) As the result, a cotton seed and caster bean oil additive of 1% has shown enhanced tribological properties over normal diesel fuel. Moreover, experimental evaluations on performance, combustion, and emissions characteristics have been conducted using a computer-aided performance test and finally, the blend of 1% cotton seed and caster bean oil has shown superior characteristics in terms of wear, lubricity, and reduction of carbon monoxide and hydrocarbon emissions as compared with normal diesel oil.

Keywords: - castor bean oil, cotton seed oil diesel fuel, additive, Tribology, performance, emission

CHAPTER ONE

1. Introduction

1.1.Background of the thesis

The definition of tribology, which emerged in the 1960s, is "the science of rubbing." The Greek word "tribos" is translated to indicate rubbing, wearing, friction, etc. The engineering science of moving, interacting surfaces is known as tribology. The science deals with lubrication, wear, and friction for moving machine parts.[1, 2]

A machine or prototype used to conduct simulations and tests of the wear and friction of lubricants, which are goals pursued by tribology, is known as a 'tribometer'. The engineering and science of interacting surfaces in motion is known as tribology. Utilizing a tribometer tool or machine, it comprises the study and application of the principles of wear, lubrication, and friction. Figure 1 illustrates how tribology is regarded as an interdisciplinary science due to the application of interdisciplinary knowledge from the fields of mechanics, projecting, lubrication technology, ergonomics, business economy, management, industrial methods, etc. Tribologists are individuals who work in the field of tribology.[3, 4]

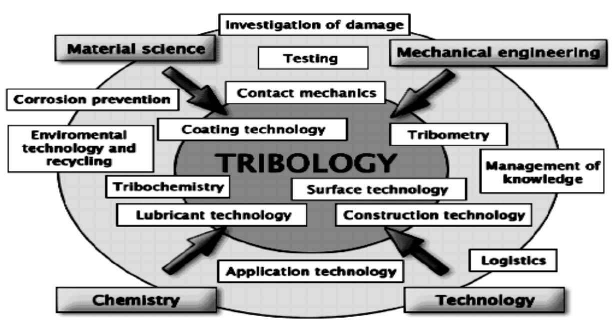


Figure 1.1 Graphic description of tribology interacting with other sciences [5]

A machine or prototype used to conduct tests and simulations of lubricant wear and friction—objectives that follow tribology—is known as a tribometer. A tribometer is a device that measures the tribological properties of surfaces in contact, such as the coefficient of friction, friction force, and wear volume. A Tribometer may measure friction on a surface using a variety of techniques, one of which involves sliding a ball across the reference surface to determine the friction's relative value (called ball on disc). The original apparatus for measuring friction consists of a constant mass suspended from a mass at rest by a rope running through a pulley. To quantify friction at the contacting surfaces of various shapes and sizes of test specimens, a variety of test apparatus and procedures are used. Four-Ball, Pin on Disc, Ring on Block, Block on Ring, Disk on Disk, and Ball on Disk Testers are among the apparatus's features.[6]

Vegetable oils, often known as vegetable fats, are derived from fruit seeds or, less frequently, other sections of the fruit. Vegetable fats are triglyceride combinations, just like animal fats. Among the fats from seeds are soy oil, grape seed oil, and cocoa butter. Fats from different portions of fruits include rice bran oil, olive oil, and palm oil. Vegetable fats that are liquid at room temperature are the only types of vegetable oils that are commonly used to describe them. The majority of vegetable oils are edible, while mineral oils are non-edible oils made primarily from petroleum.[7]

Friction and wear are the obvious requirement when one substance is moving over another substance. In engine fuel system, the relevant components experience the friction with the fuel flow activities. The useful work is obtained from the engines only when the produced energy can overcome the friction of these moving parts. Reportedly, more than 30% of the mechanical energy (i.e., ~38% of total thermal energy produced by the engine) is lost due to friction in the engine and other moving parts to move the vehicle. On the other hand, lubricity of a fluid is the indication of how much it can protect two mating surfaces from wear or scarring due to motion between that two mating bodies.

Fuel lubrication is necessary to the engine components to reduce the friction between the mating components. If the fuel does not contain enough lubricating ingredients, it is considered as a “dry fuel” for its incapacity of lubricating the components like fuel delivery and injection system, cylinder liners, etc... Low sulfur diesel fuel is essential requirement as per the emission regulation and Sulphur has several undesirable properties when combined with the internal combustion engine. It is acidic in nature, which can result in the corrosion of the constituent metal parts, and is known to poison catalytic converters, i.e., to reduce catalytic activity, thereby reducing the effectiveness of exhaust systems. So, content of Sulphur extract through hydro treatment involves treating the Sulphur with hydrogen. Hydrogen is highly reactive and can reduce the lubrication properties of diesel, a significant problem for rotary injector pumps which use the diesel for lubrication. Varying levels of hydro treatment result in the lubrication properties of diesel varying, depending on the location of the refinery or the source of their crude oil [8]

1.2.Rational of the thesis

Diesel fuel is one of the major contributing factors to the national economy. As petroleum is a non-renewable resource and its demand is increasing year after year, the prices for raw materials used in the production of spare parts also tend to increase. On the other hand, additives are introduced in tribological systems to control or reduce friction as a direct way of saving energy. Additionally, additives control and reduce wear-saving materials and spare parts from damage. Diesel fuel, therefore, is expected to meet the minimum tribological requirements (lubricity, wear, and friction) for the protection of components such as pumps and fuel injectors. When processing fuel to remove sulfur or reduce aromatic levels, a typical side effect is a drop in fuel lubricity. To improve this situation, lubricity improvers provide boundary lubrication between moving fuel system components. Therefore, from an extensive literature survey, castor bean oil and cotton seed oil could be considered as an additive for enhancing tribological behaviors of normal diesel fuel. While caster bean oil and cotton seed oil could easily be extracted in Ethiopia, using it as an additive requires characterization and investigations to determine it's tribological, performance efficiency, and greenhouse gas emission effects when added to normal diesel fuel. To mitigate this problem, lubricity additives are used; there are previous research where are the use of environmentally friendly lubricity additives is addressed, such as vegetable oils; due to their different composition of fatty acids and composition; their effect on lubrication varies as well as other factors (viscosity effect, antioxidants, corrosives, etc). According to that this research tries to study the effect on the lubricity of diesel fuel with the use of the mixture of cottonseed oil and castor, because these two vegetable oils show good lubricating properties in previous works; but with different effects on other fuel properties, which could be improved using mixtures with the aim of compensating the levels of fatty acids and their physicochemical properties.

1.3.Statement of the problem

With the adoption of hydro desulfurization (HDS) process, the diesel fuel loses its inherent lubricity, however certain amount of lubricity of diesel fuel is needed to save several engine components from wear and failure. That's why most injection pumps and high-pressure pumps are frequently wear and needs servicing. Injection pump comparatively needs a good lubrication than another parts of fuel system because of its sensitive plunger and other parts. There are in the last time vegetable oils as additives to improve the lubricity of low-Sulphur fuel [9]that the vegetable oils could be a suitable raw material improving the lubricating properties of low-Sulphur diesel oils. Considering that in

Ethiopia there are available different raw material to produce vegetable oils; and some recent research regarding to produce lubricant and biodiesel from cotton seed oil[10] and use as additive in oil lubricant to increase the tribological properties, Cottonseed oil it's better oil to compare with other vegetable oil by Antioxidants, Corrosion inhibitor, Good anti-wear capability[11] Castor bean oil its good oil compare to other vegetable oil by High lubricity Corrosion inhibitor Greater viscosity index High thermal stability[12] due to in this thesis research tried to investigate by mixing of cotton seed oil and castor bean oil as an alternative additive Because this vegetable oil are High lubricity, Corrosion inhibitor, Greater viscosity index, High thermal stability, Antioxidants, Good anti-wear capability then its enhance or increase the lubricity of diesel fuel.

1.4.Objective of the thesis

1.4.1. General objective

The general objective of the study is to investigate The Effect of Alternative Additive Mixed Castor bean and Cottonseed Oil on the Lubricity of Diesel Fuels.

1.4.2. Specific objective

- ✓ To modify the tribometer block on a ring (ASTM G77) to a ball on cylinder (ASTM D6078).
- ✓ To characterize diesel fuel properties, use in Ethiopia.
- ✓ To characterize mixed caster seed and cotton seed oil.
- ✓ To determine the tribological property (wear and friction) of diesel fuel and samples of diesel fuel with mixed cottonseed and castor bean vegetable oils as an alternative additive.
- ✓ To characterize diesel fuel with mixed cottonseed and castor bean vegetable oils as an alternative additive
- ✓ Evaluate performance and emission.

1.5.Scope of the thesis / Delimitation of the thesis

This research tried to address to only tribological behavior of Diesel Fuel Using Alternative Additive Cottonseed and Castor bean Vegetable Oil. As it involves wide and complex issue, one should require detail analysis and evaluation and also the experience of other. This research is based on the result of few experimental process and literature review on the area. As a result, the outcome of this research shall not be considered as a comprehensive study on the tribological behavior of Diesel

Fuel. And Modification of Block on Ring tribometer to ball on cylinder and tribological investigation of diesel fuel lubricity Therefore, the scope of this study are;

- Modify block on ring tribometer to ball on cylinder according to ASTM standard.
- Test wear rate and friction coefficients use modify diesel fuel lubricity cotton seed oil and castor bean oil as an additives by applying different loads, with that of standard test D 6078
- Evaluate the tribometer.

1.6.Limitation of the thesis

During the development of this thesis, the researcher was face some limitations which affected the process and outcomes of the study, those are Lack of sufficient and relevant literature that relates to the title and the result may be affected by the absence of an accurate and precise laboratory tester, electric utility on off all this are affect the overall process of the thesis.

1.7.Significance of the thesis

It was investigated that the findings from this study would contribute to the body of knowledge on Tribological behavior of Diesel Fuel Using Alternative Additive Cottonseed and castor seed Vegetable Oil. The findings generated by this research would be used to make recommendations to the government and other policy makers on the appropriate steps to be taken while using alternative additive cottonseed and castor seed vegetable Oil in Ethiopia. The research outcome helps to reduce frequently wearing of injection pump and high-pressure pump. Furthermore, it was also hoped that the findings would add the existing documents on Tribological behavior of Diesel Fuel while using alternative additive Cottonseed and castor seed Vegetable Oil in Ethiopia. Lastly, the research could open the door for other researchers who are going to undertake further study in the area

- To reduce frequently wearing of injection pump and high-pressure pump
- To reduce foreign currency for the concept of import setup lab.
- To allow in the automotive workshop make tribology research.
- To use the tribometer for course lab and training.

1.8.Organization Of the thesis

This research study was organized into five chapters. **Chapter 1-Introduction**: In this chapter, a brief introduction and background of the thesis are discussed. Aspects such as problem identification, thesis objectives, scopes, thesis limitations, thesis significance, and thesis hypothesis are discussed. **Chapter 2-Literature review**: This chapter presents an overview of the relevant literature concerning tribometer, tribology testing and investigation, lubricating type and highlights the importance as well as their applications. The chapter also deals with the chemical composition of lubricants. The chapter highlights various possible methods for fabricating tribometers for tribology testing and investigation. **Chapter 3-Methodology**: Materials, designs, and experimental procedures for the thesis are described. **Chapter 4** is results and discussions, includes the results that were obtained and discuss with those result and compare the results obtained by different dual fuel ethanol ratio. **Chapter 5** compiles conclusion and findings made from the result and point out recommendation for future work that is possibly researchable in this area.

CHAPTER TWO

2.LITERATURE REVIEW

2.1.Introduction

A literature review was conducted from journals reports, conferences, books with several research papers were studied to formulate the problem and the research topic is related to additive fuels. In this chapter section lot of research papers were studied that are interrelated to synthesis the effect of vegetable oil addition of diesel blends properties, effect on wear and friction (tribological) test and combustion performance test and emission on fuel properties, characteristics test. Some papers were reviewed related to additive production engine performance tests and emission characteristics tests. The literature was categorized as follows.

2.2.Related to Literature Reviews of the Thesis Work

The results of HFRR testing on mixtures of diesel fuel with castor, *Lesquerella*, rapeseed and soybean oil esters. The esters were mixed with reference diesel fuel at the following concentrations: 0.10%, 0.25%, and 0.50%, on a mass basis. The properties of this reference fuel to examine the effects of additive concentrations beyond 1.00%, the analysis was repeated with higher mass concentrations of methyl esters; 0.5%, 3.0% and 5.0%[13].

The literature analysis emphasis mainly the procedure of different diesel additives on the appearances of the fuel tribology test, engine performance, and engine emissions. Investigators have accepted their results which show improvement in the fuel characteristics of the different additives with diesel by using caster bean oil additives in the blend. The additive blend fuel and additive blend fuel within the additive caster bean oil additive produce lower wear and coefficient of friction as compared to pure diesel [14]. Currently, oil is practically a unique source of motor fuels production which consumes more than 70% of extracted petroleum. An application of biofuels reduces the issue of practically all harmful substances in comparison with the use of oil diesel fuels. For pure biofuels, the content of unburned hydrocarbons is reduced down to 56% of firm particles - to 55%, carbon oxide - to 43% In connection with the above-stated the current article considers the issue of castor oil receiving research of its physical and chemical properties and an opportunity of its application as the additive to diesel fuel with the ultimate purpose of getting additive fuel with the improved characteristics [15] Castor oil is representative of the group of completely non-drying liquid oils. The bean contains up to 55% of the oil when released from a peel it contains up to 69% of the oil is manufactured mainly using pressing technology.

2.3.Definition and History of Tribology

The term "tribology" was first used by Just in a seminal report from 1966. The direct translation would be "the science of rubbing" because the name is derived from the Greek word tribos, which means to rub. According to dictionaries, tribology is the study of interacting surfaces that are moving relative to one another, as well as associated concepts and procedures. Tribology is the practice of applying operational analysis to issues that have significant economic ramifications, such as the dependability, upkeep, and wear of technical equipment, which can range from home appliances to spacecraft. Surface interactions in a tribological interface are extremely complex, and comprehending them takes expertise in a number of fields, including materials science, rheology, lubrication, solid mechanics, fluid mechanics, thermodynamics, heat transfer, and machine performance and dependability. A machine or instrument used to conduct tests and simulations of wear, friction, and lubrication, (figure 2.1) which are the topic of the study of tribology, is known as a tribometer (tribotester). Tribometers are frequently built by manufacturers who want to test and evaluate the long-term functioning of their products, and they frequently have incredibly precise functions.[2]

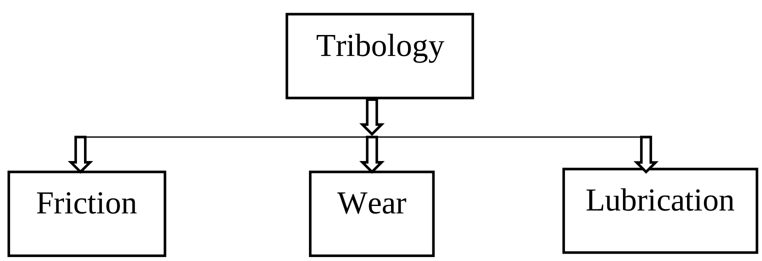


Figure 2. 1: Different aspects of tribology [2, 16]

2.4.Tribometer

For any tribological experiment, it is a crucial piece of equipment. A method for measuring the friction force produced in relative motion between the surfaces is known as a tribometer. Additionally, it has been applied to gauging or assessing material wear**.**[17] The 1989 edition of the Oxford English Dictionary described a tribometer as a means for measuring sliding friction.

Tribometers for a variety of purposes are developed, but not limited to:

- Simulate a specific machine's tribocontact condition.

- Evaluation for friction critical use of candidate-bearing material.
- Application measurement of the lubricants.
- Surface pollution testing for a commodity.
- Examine the basic core of solid or lubricated solids friction.

Classification of tribometer: Some basic classifications of tribometer are[3]:

- Four-Ball Tester
- Block on ring
- Pin on Disc
- Ball on Disc
- Ball on cylinder

2.4.1.Four-Ball Tester

The properties of lubricating oil and grease are calculated using this type of measuring system in sliding applications. It consists of spinning a loading ball in lubricated conditions alongside three stationary balls (figure 2.2). The extent of the scar that characterizes the lubricant in avoiding wear is assessed after the testing. The load applied during wear testing cause's circular wear on any ball which is calculated for comparison with the normal wear scar diameter. Usage of image acquisition device to calculate wear ball diameter steel ball[3]. Four-ball tests are applied in ASTM standard D 4172 for tribological testing[18]. The four-ball tribometer is intended to evaluate the tendency of lubricative oil and grease anti-wear (AW) and extreme pressure (EP). For lubricating oil and grease, severe pressure tests ASTM D 2783 and ASTM D 2596 are standard-based[19].

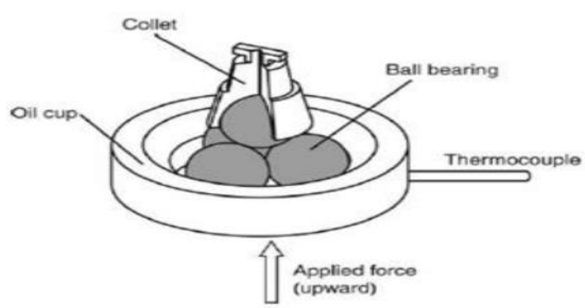


Figure 2. 2: Main part of the four-ball tester [20]

2.4.2.Block on ring

The block-on-ring approach uses laboratory methods to assess the resistance of the material to sliding wear. According to their slipping wear properties, pairs of materials are categorized in the research using Block on Ring friction and wears test equipment [17]. Determine the stiffness, wear, friction, wear rate, wear volume, and EP/extended play coefficients with the use of the Block on

Ring tribometer. Fats, rollers, rings, and shafts all have a high wear resistance. The load, sliding speed, and rotating speed under which the test can be carried out can all be altered. A rotating shaft or a block that has been loaded in a circle often make up the test setup [3, 18]. Block on Ring tribometer, which uses a block and a ring of sample-related components. During load blocks, the ring rotates, pressing the ring (figure 2.3). A lubricant can be provided to quantify the importance of the properties of the lubricating oils to be measured in the Block on Ring tribometer form, on the plane surface.

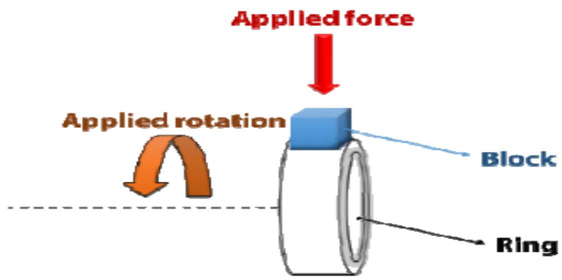


Figure 2. 3: Schematic drawings of a Block on Ring tribometer [3]

2.4.3. Block on Ring standards

In any test of slipping and rolling wear behavior, BOR is used, for example, tires, bearings, camshafts, pulleys. The potential requirements for BOR are: ASTM G77, ASTM D2509, ASTM D2782, ASTM D2981, ASTM G137-97, ASTM D2714, ASTM D3704 and ASTM G176 [3]. ASTM G77 is targeted at the metal on the metal block on ring testing and describes using the width of the wear scar to calculate the wear rate of the block. The ring is massed to assess its mass loss throughout the test to calculate its wear rate. The Block on Ring case study included later most closely resembles this ASTM standard[21]. This standard test is a widely used technique that evaluates the sliding wear behaviors of materials in different simulated conditions, allows reliable ranking of material couples for specific tribological applications[22].

Table 2. 1 ASTM Block on Ring standards summary [21]

Specification	G176	G137	G77	D2714
Ring Outer Diameter(mm)	34.99 0.025	100-0, +0.05	34.99 0.025	35
Ring Eccentricity(mm)	0.00125	0.06	0.00125	0.013
Block Width(mm)	6.35-0.025, +0	6.35-0.025, +0	6.35-0.025, +0	6.35
Type of Motion	Unidirectional	Unidirectional	Unidirectional	Unidirectional

2.4.4. Pin on Disc

It comprises of a pin that stays in place and a disc that spins (figure 2.4). A dead weight or actively operated mechanism loads the pin. The pin might be flat, triangular, or spherical, among other shapes. It has been questioned if a streamlined setup could replicate the greases' characteristics and behavior with regard to friction and wear.[3, 23].

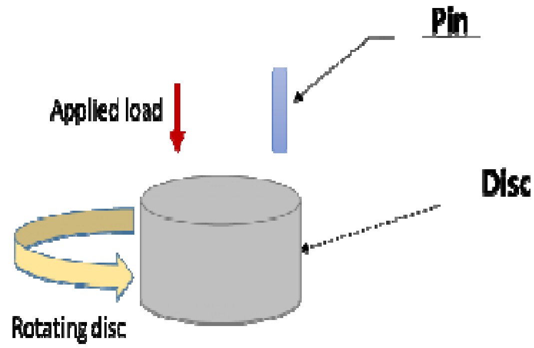


Figure 2. 4: Schematic drawings of a POD[3]

2.4.5. Ball on Disc

This BOD consists of a rotating or slipping disk and a ball that is supported by an AC servo motor (figure 2.5). BOD is an alternate method for measuring twin disks; it has the same advantages as a twin disco tribometer, but is easier to use for tribology monitoring than a two-disk tribometer.[3].

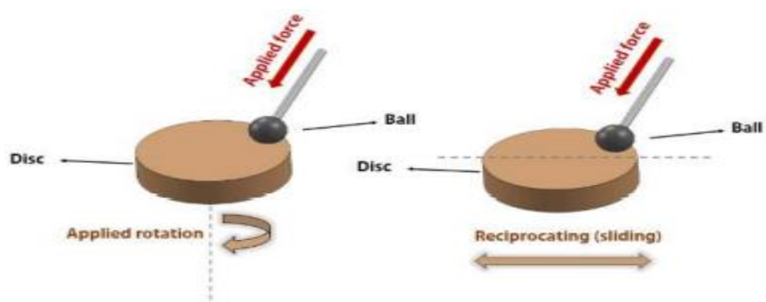


Figure 2. 5: Schematic drawings of a Ball on Disc (BOD) [3]

2.4.6. Ball on cylinder tribometer (BOCLE)

Testing important oil and gasoline lubricant qualities can be done in a variety of methods. The scuffing load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE), which is standardized as ASTM D6078, is one of the test procedures that is frequently used to evaluate the lubricating qualities of jet fuel. A fixed steel ball and a rotating metal cylinder are used in the test, both of which are immersed in a sample of oil or diesel fuel. The test ball has a diameter of 12.7 mm and is made of AISI standard steel No. E-52100, a chrome alloy steel. The steel used in the metal cylinder is SAE 8720. The steel ball is forced against a metal cylinder during the test with a constant applied stress of 1000 g [24]. The metal cylinder is attached to a motor, which rotates it for 1 minutes at a fixed speed of 525 revolutions per minute (RPM). In order to evaluate the impact of the sample oil lubricant or diesel fuel, the equipment effectively duplicates the metal-metal contact. Researchers and industry professionals can assess lubricating characteristics at the control speeds and contacting loads thanks to wear scars on the ball.

In conclusion, the longevity of the engine can be impacted by understanding the lubricating qualities of oil or fuel. There are many different fuel types available on the market today that can be utilized for lubrication. Researchers and industry professionals can better grasp the characteristics of the oils that are being investigated for usage in particular applications with the aid of testing techniques like SLBOCLE. The test can reveal whether the oil performs poorly under controlled conditions, in which case it is extremely likely to perform similarly—if not worse—in industrial conditions, when there are many additional uncontrollable variables. By ensuring that the engine or other moving parts last as long as possible, knowing this information in advance could help you save money on maintenance and repair expenses.

In Figure 2.6: it show Schematic of ball-on-cylinder tribometer test method evaluates the lubricity (load carrying ability) of diesel fuels using a scuffing load ball-on-cylinder lubricity evaluator (SLBOCLE). This test method is applicable to middle distillate fuels, such as Grades Low Sulfur No. 1 D, Low Sulfur No. 2 D, No.1 D, and No. 2 D diesel fuels, in similar petroleum-based fuels which can be used in diesel engines. [25]

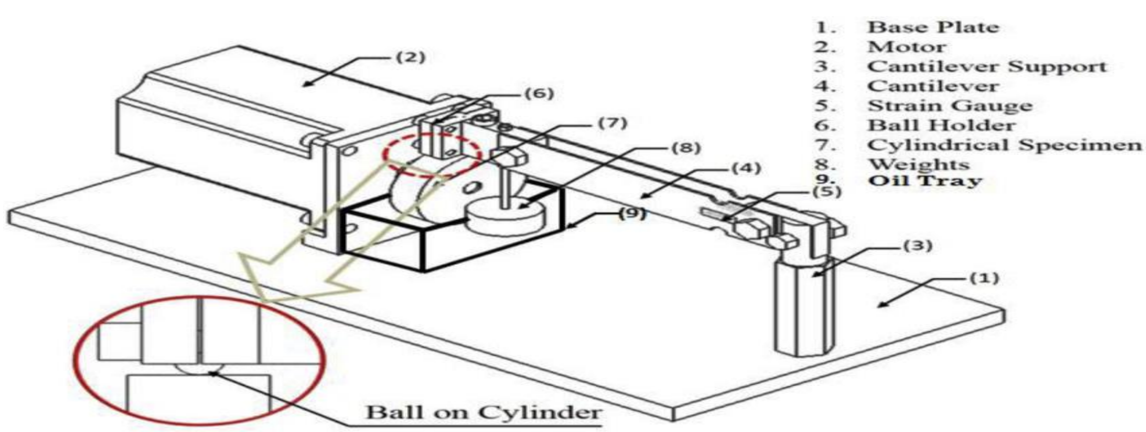


Figure 2. 6: Schematic of ball-on-cylinder tribometer[25]

2.5. Diesel Fuel Additive Descriptions and their Uses

This section reviews published papers and national laboratory tests to provide a technical understanding of fuel additives. Each additive type is defined, motivations for and risks of using a particular type of additive are given, as are the basic mechanisms that allow the additives to function. Understanding how the additives affect fuel properties and the mechanisms through which they act will help utilities recognize which additives they can use productively [26].

2.5.1. Pour Point Depressants

Diesel No. 2 is the standard diesel fuel in most climates. However, as distilled, No. 2 diesel begins to produce wax crystals that clog fuel filters at around 10°F, much too warm for most Alaska utilities. There are two basic solutions to this problem: the first is burning No. 1, rather than No. 2 diesel, or blending the two fuel grades together. Diesel No. 1 fuel sold in Alaska can be used at temperatures as low as -60°F, so it naturally satisfies utilities' requirements. The essential component of pour point depressants is a chemical that reacts with wax crystals and prevents them from growing. This reaction is most effective when the polymers in the pour point depressant are similar to the polymers in the diesel fuel. However, the chemical structure of the hydrocarbons in diesel fuel is not regulated and varies dramatically between different crude oil sources. As a result, the efficacy of a particular pour point depressant depends on the fuel it is blended with. It is not possible to specify how well any particular pour point depressant will work with all fuels.

2.5.2. Alternative Cold Flow Improvers

Several measurements besides pour point are also used to characterize low temperature fuel properties. These include the Cloud Point, Cold Filter Plugging Point (CFPP), and Low Temperature Flow Test (LTFT). Each fuel property provides some indication of how the fuel will perform in engines at low temperatures, but none fully describe cold weather performance. Each measurement consists of one temperature characteristic of the fuel. The cloud point is the highest of these temperatures. It is the temperature at which the first visible wax crystals begin to form in the fuel as it is cooled. Fuel at temperatures just below the cloud point may clog the fine one micron fuel filters used immediately before the fuel enters the engine, but can pass through coarse filters.

2.5.3.Conductivity Improvers

Due to new EPA regulations, the U.S. is in the process of switching to Ultra Low Sulfur Diesel (ULSD) for off-road diesel engines. ULSD contains less than 15 ppm sulfur (unregulated diesel fuel is often near 5,000 ppm sulfur). ULSD greatly improves exhaust emissions, but removing the sulfur from Petro-diesel also results in a loss of lubricity and conductivity of the fuel. Therefore, conductivity and lubricity additives are necessary in ULSD, and unnecessary in diesel that has higher sulfur content. Refiners and suppliers (who are concerned with static discharge during fuel handling) blend these additives into the fuel, and preclude any need for utilities to be concerned with conductivity improvers. However, since they are present in ULSD fuel, they warrant a brief description. Conductivity describes how easily electric charge can flow through the fuel. If fuel conductivity is too low, electric charge can accumulate while the fuel is transported, increasing the risk of a spark igniting the fuel. ASTM provides a minimum conductivity specification of 25 PS/m (Pico Siemens per meter). Satisfying the ASTM requirement requires a very small amount of additive, typically one or two parts per million of additive in ULSD.

2.5.4. Lubricity Additives

Lubricating additive (LA) are organic or inorganic compounds that can significantly improve the anti-wear performance. Since the 1990s, when the low sulfur diesel was massively promoted and applied, the further research and development of LA of diesel has received more and more attention.14 At present, LA is mainly produced by the transesterification of renewable biological triglyceride sources (vegetable oils and animal fats) with alcohols using homogeneous catalysts.15-19 However, the homogeneous process has brought problems of pollution and corrosion. The process of synthesizing FAMEs by using the prepared catalyst was able to minimize environmental pollution, and prevent the device from corrosion. Meanwhile, studies found that unsaturated FAMEs as a multifunctional additive could remarkably improve lubricity and the low temperature flow property of fuel[27].

The service life of fuel system components is the most important characteristic of vehicle engines that is evaluated by fuel lubricity capacity indicator. Operational tests show that when the concentration of sulfur in diesel fuel less than 0.05%. is required the use anti-wear doping’s [28]

As the name implies, lubricity measures a fuel’s ability to lubricate components in the fuel system. This property is particularly important for fuel injectors and pumps, which wear out quickly if fuel lubricity is too low. Fuels with high sulfur content generally have sufficient natural lubricity to reduce wear in the engine. However, ULSD does not have adequate lubricity (sometimes referred to as "dry fuel"), necessitating the use of lubricity additives.

ASTM International standardized diesel lubricity measurement in 2005 with the High Frequency Reciprocating Rig (HFRR) Test. In this test, a steel ball is rubbed against a disk while submerged in fuel for 75 minutes. At the end of the test, the size of the resulting wear scar on the disk is measured, and fuel lubricity is recorded as the size of the scar.

The ASTM lubricity standard for both No. 1 and No. 2 diesel fuels is a wear scar of 520 microns, as measured using the HFRR test. John Deere, Detroit Diesel, Cummins and Caterpillar have their own lubricity specifications that range from 450 to 520 microns (note—scuff ball tests are like golf—a smaller wear scar is a more stringent criteria). It is important to be aware that the HFRR test is only accurate to within 80 microns. Therefore, all of the engine manufacturers' lubricity standards are consistent with the ASTM standard to within the margin of error associated with the HFRR test.

All engine manufacturers suggest using a lubricity additive if the available fuel does not meet the lubricity standard (although they encourage consulting with your fuel supplier to make sure that the fuel is treated effectively). Most major engine manufacturers produce their own additives that include a lubricity component, and these are the only additives that engine manufacturers guarantee will not harm the engine. Using other additives generally will not void the warranty, but any damage that they cause will not be covered.

ASTM International only recently included a lubricity standard in their diesel fuel specifications to address problems with low lubricity ULSD. Untreated ULSD fuel does not meet the ASTM lubricity standard (let alone the more demanding engine manufacturers' standards). Therefore, most fuel suppliers blend a lubricity additive into the fuel after the sulfur has been removed but before the fuel is distributed.

If a lubricity additive is needed, products exist that are well understood and have been thoroughly tested (see Southwest Research Laboratory, for example). Unlike engine oil, diesel fuel and diesel fuel additives are primarily boundary lubricants: molecules in the fuel with polar 'heads and nonpolar hydrocarbon 'tails' bond to the surface of the surrounding metal and create a protective layer on the surface of the metal. The types of molecules that can be adsorbed by metal and do not degrade fuel quality are useful for many applications, including cold flow improvers and corrosion inhibitors. As a result, many additives that are intended for a different purpose improve lubricity as well. Typically, additives in adequate concentration can achieve wear scars near 350 microns in the HFRR test (Figure 2). At that point, the additive concentration is sufficient to completely maintain a protective film on metal surfaces, and increasing the additive concentration does not improve the fuel lubricity further.

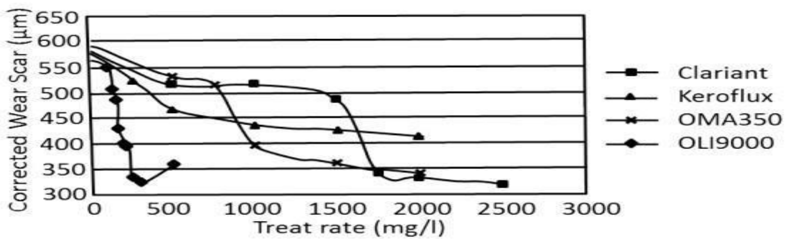


Figure 2.7 Documentation of the effect of various additives on fuel lubricity.

The lubricity agents used in ULSD fuels are "hygroscopic" meaning that they are especially prone to capturing water from the air, so tanks that contain ULSD fuels treated with these compounds tend to accumulate more water than tanks that contain jet fuel (which does not need a lubricity additive). A tank used to move treated ULSD can be used for transporting jet fuel only after being subjected to a rigorous and expensive cleaning process. Barge transporters typically deal with this issue by transporting ULSD without the lubricity additive, and mix the additive in at the dock when fuel is delivered to the customer, metering it into the fuel while it is being transferred.

Utilities need to be aware that if a barge operator offers to blend a lubricity additive to their fuel during offloading, they should verify that the ULSD on the barge has not been treated with the lubricity additive, and accept this additive. There should not be an additional charge for this additive, as it is required to bring the fuel into ASTM D975 specifications.

2.5.5. Fuel Stabilizers

Fuel stability measures a fuel's tendency to form resins, gums, or other insoluble products before it is combusted. The processes that form insoluble are highly temperature dependent, which creates two distinct stability challenges. Many modern engines cool fuel injectors with fuel, exposing fuel to high temperatures before 10 it is burnt in the engine. Fuel with good "thermal stability" must not degrade when exposed to elevated temperatures for hours before combustion. At outdoor air temperatures, fuel stability typically does not become an issue for many months or years. Fuel with good "storage stability" is essential for many military applications that require storing fuel for years before use.

Stabilizer additives can be used to improve the stability of diesel fuel for long-term storage (over one year). There are several types of additives that address different mechanisms of instability. The most common stabilizers contain antioxidants that bond with free radicals in the fuel to prevent them from initiating unwanted reactions.

Other additives known as metal deactivators prevent reactions between fuel and metals that may be present in fuel lines or tanks. The military requires fuels that may be stored over six months to include a stability additive. The thermal stability of diesel fuel generally is not regulated, and can vary significantly between fuels. This makes it difficult to determine whether a stability additive is necessary. However, ASTM does provide a “Standard Test Method for High Temperature Stability of Middle Distillate Fuels”. According to the National Conference of Weights and Measure, fuel labeled “premium diesel” must meet a minimum thermal stability requirement, as measured by the ASTM test.

2.5.6. Cetane Enhancers

Cetane number describes the ignition quality of diesel fuel. It is measured by comparing the ignition delay of a fuel to the ignition delay of two reference chemicals (cetane and heptamethyl nonane or HMN). Ignition delay is the length of time between when fuel is injected into the combustion chamber and when the fuel ignites. Cetane ignites very quickly and is given a cetane number of 100, while HMN has a longer ignition delay and is given a value of 15. In the U.S., diesel fuel typically has a cetane number a little greater than 40, as required by ASTM D975. The cetane number of fuels can be raised by 5 to 10 points with the addition of an additive.

Ethylhexyl nitrate is perhaps the most well-known cetane-improving chemical, but numerous other chemicals can be used as well. Cetane number is primarily important in cold start applications. There is also some interest in using cetane enhancers to improve engine performance, but there is little evidence to support this. In fact, using diesel with too high a cetane number can adversely affect engine performance. In diesel power plants, there is little need for cetane boosters since the engines are kept indoors and rarely cold started.

2.5.7. Injector Cleaners

It is well known that deposits can form within the fuel system of diesel engines. Deposits on the fuel injectors are of particular importance. These deposits can restrict fuel flow, decreasing the atomization of the fuel stream and also reducing the homogeneity of the fuel air mix in the combustion chamber. This leads to an increase in hazardous emissions as well as a decrease in fuel efficiency.

2.6.Lubricating Aspects of Automotive Fuels

Lubricity is a very important issue for diesel fuel injectors and pumps (of an engine) that are lubricated by the fuel itself. Biodiesel as an alternative fuel has a number of technical advantages compared to conventional diesel. It is required to perform more research about the tribological behavior of biodiesel blends under run-in period conditions at different rotational speeds. Friction characteristics of biodiesel (mixture of sunflower and soybean methyl ester) were studied by using a four-ball wear testing machine. Results indicated that the friction was reduced with the increase in rotational speed under the run-in period conditions. Moreover, the results showed that the friction coefficient decreases at rotational speeds of 600 and 900 RPM as the proportion of biodiesel increases in the fuel blend. This is due to higher viscosity of biodiesel and the presence of free fatty acids and monoglyceride and diglyceride components in this fuel, which improve the lubricity properties of the fuel blends. However, the coefficient of friction of the fuel blends that contained more biodiesel (B50 and B100) increased at rotational speeds of 1200 and 1500 RPM as a result of reduced fuel viscosity, oxidation, and moisture absorption in a higher temperature condition. So, it was concluded that the better tribology performance belongs to B20 at higher rotational speeds[29].

Back in the 1960s, the term “lubricity” was defined by Appeldorn and Dukek as: “If two liquids have the same viscosity, and one gives lower friction, wear or scuffing, it is said to have better lubricity”. It should be noted, however, that this definition was not strictly applied and many researchers carried out lubricity experiments on fuels based on their own understanding of the concept. The lubricating ability of fuels, because of their very low viscosity, depends mostly on their boundary film-forming properties. Some moving parts of diesel fuel pumps and injectors are protected from wear by the fuel. To avoid excessive wear, the fuel must have some minimum level of lubricity. Lubricity is the ability to reduce friction between solid surfaces in relative motion[30].

Analytical and numerical simulation of engine component lubrication characteristics has prime importance that can be applied by designers and companies to understand the contribution of each engine component in overall tribological performance and how and where they must consider the modifications. Piston ring pack and piston skirt which are known as piston ring assembly (PRA) and connecting rod big eye bearing have largest contribution in engine power losses. The devoted analytical studies to engine friction losses can be grouped into two distinct categories; first, empirical models which are based on correlations between influential parameters that are realized by experimental investigation and second one, instantaneous friction models based on lubrication theory and solving Reynold's equation to define pressure field developed by lubricant and consequently calculation of friction losses[31].

Fuel composition is a key factor in determining the lubricity of fuels, since it depends not only on the crude oil the fuel is prepared from, but also on the refinery process, finishing process, and blending method. The gradual increase in severity of refinement in recent years to meet tightening environmental regulations has simultaneously reduced the concentration of many potential lubricity agents and thus made fuel lubricity poorer. Gasoline is the lightest liquid fraction of petroleum, boiling between about 30°C and 200°C, i.e., containing mainly C5 to C12 hydrocarbons. It is reasonable to infer that the inherent lubricity of gasoline will be poorer than that of aviation fuel and diesel fuel due to the lighter distillation cut, in which natural anti wear impurity concentration will be lower. Fortunately, and till now, the lubricity requirements of gasoline are generally much lower than for diesel since gasoline fuel injection systems inject fuel upstream of the inlet valves and thus operate at much lower pressures than diesel fuel pumps. In 1990s, the amount of Sulphur, nitrogen and aromatics in diesel fuels was reduced by severe hydrotreating to minimize SOX emissions from diesel powered vehicles[30].

2.7.Low Sulphur diesel fuels

When low sulfur diesel fuels were introduced to the automotive market, lubricity was likewise little understood and field issues rapidly followed, involving excessive and rapid fuel pump wear [32]

Sulfur content of diesel fuel has been cut down to ultra-low levels by environmental regulation in many countries with the aim of reducing diesel engine's harmful emissions and improving air quality. As a result, research on the production of ultra-low sulfur diesel (ULSD) has gained enormous interest in the scientific community worldwide. The renewed interest in ULSD research is driven by the need, to have a comprehensive understanding of the various factors influencing deep desulfurization of diesel to the ultra-low level as well as to find cost-effective ways for ULSD production[33].

Lower Sulphur content has two environmental benefits, resulting in both directly reducing levels of particulate matter and acid rain components and making possible the full exploitation of in vehicle oxidation catalyst technology. The refining processes necessary to meet this specification can result in diesel fuels with viscosities somewhat lower than conventional fuels, and with reduced levels of polar compounds and polycyclic aromatics[34].

The use of low Sulphur diesel fuels led to numerous pump failures. To combat the loss of this lubrication, packages of additives that increase lubricity could be blended with the fuel prior to distribution. The lubricity characteristics of diesel fuel are similar to aviation turbine fuels, up to the middle of the 1980s, but the lubricity of diesel fuels was not considered a significant factor that could lead to serious problems and little work concerning diesel lubricity had been carried out. There was not widely accepted test method existed to determine the lubricity of diesel fuels. In the 1990s, Sweden and United States introduced low Sulphur, low aromatic diesel fuels and this was followed by other countries, including Canada, Switzerland, Austria, and Germany. Soon after the introduction of these environmental diesel fuels in the Scandinavian and Californian markets in the early 1990s, a number of injector equipment failures were reported from all manufacturers. These failures took place in passenger cars working with Bosch rotary pumps after only 3000 to 10,000 km. In Europe and the USA, such fuels have been shown to reduce the life of distributor type pumps by up to 95%. Field trials and pump rig durability testing of both Swedish Class 1 and 2 showed that their inherent lubricity was unacceptable. Diesel fuel work has revealed that humidity, which reflects environmental water vapor pressure, can have an important influence on the friction and wear, although this was not taken into account in test work until recently.

Low sulfur fuels have been produced and marketed in Southern California since 1985 with no apparent evidence of any field problem. Nevertheless, concern outside of this area exists. Therefore, one such fuel with a sulfur content well below 0.05% was used to conduct a vehicle test to evaluate its effect on the fuel injection pump. This fuel and a low aromatics diesel fuel were used to investigate the effect of various levels of two different sulfur compounds on the lubricity characteristics of the fuels. The standard Ball-on-Cylinder Lubricity Evaluator (BOCLE) test method as well as a modified version of this test were used[35].

The automotive industry has historically recommended diesel below 50 ppm for standards that require SCR systems, such as Euro IV. In countries where diesel fuel with different levels of sulfur is available at gas pumps, if misfuelling occurs, it poses a challenge for some emission control technologies. This is because some after treatment technologies are sensitive to fuel sulfur levels; they may experience pollutant conversion inefficiencies and, in some extreme cases, even catalyst poisoning[36].

2.8. Lubricant, additives, vegetable oil, and cottonseed oils

2.8.1. Lubricants

Lubricants are those substances that intervene between rubbing surfaces, thereby preventing any negative influences upon moving. The three major functions of lubricants are below[4]. Controlling friction—this is the primary role of lubricants. Reducing friction and preventing wear and seizure (or failure) are necessary in most applications. Well-controlled, high friction is required for clutches, breaks, etc. Since this is the central objective of the lubricant, we discuss the phenomena with a lubrication model. Optimized performances with minimized side effects could be achieved by proper selection of lubricants for specific machine elements. As modern machines are required to work in a more energy efficient way, the roles of lubricants are increasing.

- Cooling the contact—Heat generated by rubbing motion can have many negative influences on surface materials, such as transformation of microstructure or thermal failure. Ageing of lubricants is accelerated at higher temperatures. Heat accumulation could be prevented by circulating a liquid lubricant. The heat capacity of a lubricant is the controlling factor for this function. This function is mainly supported by the properties of base fluids.
- Cleaning the contact—Wear particles, external dusts, or deposits by aged lubricants could appear during machine operation. These contaminants negatively influence lubrication performances. Circulating a lubricant can wash out these nuisances physically. Advanced lubricants contain some substances to help the cleaning process

A lubricant performs a variety of functions in engines and machines, such as it protects metal surfaces against corrosion, it acts as a heat transfer agent, it flushes out contaminants and it absorbs shocks and seal's foam. High performance engines and machines demand lubricating oils, which contain tailored additive packages. Additives increase useful life and provide additional performance characteristics to the lubricant, such as improved flow, modified friction, and resistance to oxidation, extended pressure or temperature stability. Lubricant and additives may be petroleum, synthetic, or biological in origin[11].

Furthermore, vegetable oil–diesel blends present significant interest for all developing countries which lack energy sources and have agriculture-based economies. So far, several types of vegetable oils have been investigated for direct application as diesel engine fuel such as rapeseed oil, jatropha oil[37] ,coconut oil, rubber oil[38], cottonseed oil[39], cooked vegetable oils[40] These studies reveal the potential vegetable oils have as fuels either directly or through transesterification. However, they are usually limited to the analysis of the physical properties of the oils and fuels.[41] It was reported that pure biodiesel inherently possesses excellent lubricity and can improve the lubricity of low-sulfur fossil diesel even at low blend levels[42]

Cottonseed contains averagely 18-25% of oil and 20-25 % high quality protein but presently cottonseed is not used in food preparations. It is used in animal feed in regulated manner due to the presence of gossypol. Cottonseed oil contains different fatty acids, such as saturated fatty acids (1.2% of myristic acid, 18–25% of palmitic acid, 1–25% of stearic acid, 1– 2% of palmitoleic acid), monounsaturated fatty acids (17–38% of oleic acid) and di unsaturated linoleic acid (45– 55% of linoleic acid)[43]

2.8.2. Effect of lubricity additives on diesel fuel lubricants

The lubricity issue is significant, because the advent of low-sulfur Petro diesel fuels and, more recently, ultralow-sulfur diesel (ULSD) fuels, as required by regulations in the United States, Europe, and elsewhere, has led to the failure of engine parts such as fuel injectors and pumps, because they are lubricated by the fuel itself. The poor lubricity of low-sulfur Petro diesel requires additives or blending with another fuel of sufficient lubricity to regain lubricity. The reason for the poor lubricity of low-sulfur Petro diesel is not the removal of the sulfur-containing compounds but rather that polar compounds with other heteroatoms such as oxygen and nitrogen are also reduced in low-sulfur Petro diesel[44].

Table 2.2 Vegetable oil characteristics of CSO[11]

Characteristics	**Values**
Density, 20◦C (kg/m3)	914.8
Refractive index, 20◦C	1.4720
Acid value (mg KOH/g)	0.24
Saponification value (mg KOH/g)	195.3
Iodine value (gl/g) 65.48	65.48
Fatty acid composition (wt.%	
Miristic acid	0.70
Palmitic acid	21.79

Palmitoleic acid	0.56
Stearic acid	2.48
Oleic acid	12.02
Linoleic acid	61.62
Arachidic acid	0.36
Other acids	0.47
Calculated mean molecular weight (kg/kmol)	861.1

Table 2.3 Lubricating oil properties of CSO[11]

Properties	Method	Values
Color	ASTM D 1500	L 2.0
Density at 15◦C (kg/m3)	ASTM D 1298	925.1
Flash point (◦C)	ASTM D 92-93	242
Pour point (◦C)	ASTM D 97	−10.2
Cloud point (◦C)	ASTM D	−8.7
Cold filtered plugging point (◦C)	ASTM D	−12.0
Sulfur content (wt. %) IP 336	IP 336	0.002
Ash content (wt. %)	ASTM D 482	0.002
Water and sediment content (wt. %)	ASTM D 1796	Absent
Sediment content by the extraction method (wt. %)	ASTM D 473	Absent
Copper corrosion at 50◦C for 3 hours	ASTM D 130	No. 1a
Viscosity @ 40◦C (cSt)	ASTM D 445-97	35.8
Viscosity @ 100◦C (cSt)	ASTM D 445-97	8.1
Viscosity index	ASTM D 2270-93	202.8

2.9. Implications for vegetable oil fuels

Important environmental, social and economic benefits can be obtained by using biodiesel from agro-alimentary wastes (such as used vegetable oil, fish oil and animal fats) as a lubrication additive in diesel fuels[45]. In this paper the possibility to obtain good results using cotton seed oil as a lubrication additive in fuels with low Sulphur content is proved. Numerous vegetable oils are derived from various sources. These include the popular vegetable oils: the foremost oilseed oils – soybean, cottonseed, peanuts, and sunflower oils; and others such as palm oil, palm kernel oil, coconut oil, castor oil, rapeseed oil, and others[46].Some researchers showed that vegetable oils showed better lubricity than mineral and synthetic lubricants because they have polar ester groups along with long-chain fatty acids. The polar carboxyl group of fatty acids adhere to the metallic surface and forms an effective thin lubricating film to decrease friction and wear by minimizing metal to metal contact. Reeves et al used vegetable oils as lubricants and found that long-chain fatty acids (with C18 and above Catoms) show good lubricity and anti-wear properties. Ertugrul and Filiz's research showed that a very small amount of cottonseed oil can be used as additives in commercial lubricants to decrease friction[47].

The mechanisms governing the ignition and combustion of fuels in a compression-ignition (CI) engine differ from those operating in an SI engine and it has been suggested that the molecular structural characteristics of an effective fuel in the CI case are the reverse of those required for the SI counterpart? In view of this suggestion, it is of interest to examine the structures of vegetable oils and their components in the light of the above structure-performance data and to test any conclusions against the known CI engine performances of such vegetable oil fuels[48].

Vegetable oils have been evaluated in compression ignition engines as alternatives to substitute petroleum fuels. However, they cause potential problems without engine modification and have several disadvantages. Some of these disadvantages include poor atomization due to high viscosity, incomplete combustion, and carbon deposit build-up on several engine parts such as injectors, piston rings, cylinder walls, and valve seats. However, the problem of high viscosity can be solved by preheating the vegetable oils. It has been reported that a diesel engine can operate without any engine modification if the fuel mixture contains 20% vegetable oil and 80% diesel[49].

Increasingly strict regulations on the sulfur content of commercial petroleum diesel fuels result in a decrease in the lubricity of these fuels. This reduced lubricity can be damaging to the engine and fuel injection systems that use these fuels. Vegetable oil-based diesel fuel additives may be a possible solution to this emerging problem. (Daniel P. Geller, Effects of specific fatty acid methyl esters on diesel fuel lubricity, 2004) Previous studies have shown that acid esters of triglycerides derived from vegetable oils have increased diesel fuel lubricity at concentrations of less than 1%. These mixtures of fatty acid methyl esters (FAMEs), commonly known as biodiesel, provide a clean, effective fuel for diesel engines. This makes them attractive for use as additives in petroleum-based diesel fuels.

This study sought to examine the effects of individual cottonseed oil on diesel fuel lubricity. The lubricity of varying concentrations of individual CSO in diesel fuel was studied using the tribometer analysis method. This method uses a ball on block. The entire system is immersed in the studied fuel and lubricity is measured relative to the diameter of the wear scar.

2.10. Caster bean oil

Figure 2.8.Castor plant cultivation phase

Castor is original to the southeastern Mediterranean Basin Eastern Africa and India. The Castor plant which is the source of castor bean is shown in fig2.1. Castor plant has a short growing period (4 to 5 months) compared to other oil-producing plants and farmers have greater experience and awareness about its farming. Castor bean also contains 30% up to 55% oil by weight[50]

Chemically castor bean oil is comprised of different acid components such as ricinoleic acid linoleic acid and oleic acid. The presence of high ricinoleic acid makes the castor bean oil unique and. highly soluble in alcohol. Castor oil is a colorless to very pale-yellow liquid. The oil also has improved lubricity compared to other oils with similar carbon chain fatty acids[51]. Additive derived from castor bean oil has several promising advantages. Most of its fuel properties are close to conventional fuel properties[52] It has a high cetane number (high ignition quality), high oxygen content (complete combustion), high flash point (safe for handling and storage) It has also low emission of carbon monoxide (CO) sulfur dioxide ($SO2$), nitrogen dioxide ($NO2$) compared to conventional diesel It also needs minimum production cost[53]

2.10.1. Caster bean oil properties

Castor beans are cultivated for their beans yielding a viscous. Pale yellow nonvolatile and nondrying castor oil. The physical properties of castor oil have been studied (Table 2.1). Comparative analysis shows that the values of viscosity, density, thermal conductivity, and pour point for castor oil were higher than the values of a standard lubricant

Table 2.4.Physical properties of Caster bean oil[54].

Physical properties	
Viscosity (centistokes)	**889.3**
Density (g/ml)	**0.959**
Thermal conductivity(w/m°C)	**4.727**
Specific heat (kj/kg/k)	**0.089**
Flash point (°C)	**145**
Pour point (°C)	**2.7**
Melting point (°C)	**-2to-5**
Refractive index	**1.480**

2.11. Lubricity test for diesel fuel

Numerous laboratory tests address the lubricity of diesel fuel. The high-frequency reciprocating rig (HFRR) test was selected as the reference assessment to control the lubricity of the diesel fuel, and it has proven to be very useful to guarantee this property in the market, giving an optimal compromise between the cost of testing, effectiveness, and uncertainty of the test. The scuffing load ball on cylinder essay (SL-BOCLE) test was also considered to be a reference test for lubricity determination, and consequently, there is extensive research on both the HFRR and SL-BOCLE testing methods. (Jesus Delgado, 2020) The HFRR test is more robust than the SL-BOCLE test with conventional fuels and shows lower uncertainty. With respect to paraffinic samples, Sasol also observed the higher severity of the HFRR test in mixtures of diesel gas to liquid (GTL) and fatty acid methyl esters (FAME) 0.5−7% v/v[55].

The HFRR method is characterized by the low sensitivity of lubricity results in cases of low concentrations of some fuel additives. This may be due to the nature of the wear mechanism that occurs in the test friction node of this method[56]. The predominant wear in the HFRR method is plasticity-dominated – i.e., adhesive wear and delamination wear. Under such conditions, some polar compounds, due to their low concentrations, may not produce a sufficiently stable lubrication film that can subsequently degrade within the tribological node[57] the HFRR method may not be sensitive to the presence of fuel additives at low concentrations, in accordance with the standard requirements, the lubricity of diesel fuel should be determined by this method[58].

The SLBOCLE (Scuffing Load Ball-on-Cylinder Lubricity Evaluator) method, where the loaded ball cooperates with a rotating ring partially submerged in the tested fuel, and the diameter of the wear scar formed on the ball is used as a measure of the lubricity of the fuel. Other, less frequently used methods for assessing fuel lubricity include BOTS (Ball-on-Three Seats), its modified version BOTD (Ballon-Three Discs)

2.12. Physical and chemical properties of additive

Density The fuel injection system of diesel engine measures fuel by capacity so the difference in the density of fuel will affect the brake power of the engine due to different mass elements of fuel injected into the chamber of a diesel engine Also the difference in density besides influences the fuel atomization through fuel injection and burning in the cylinder So that they affect the burning characteristic and exhaust gas emissions.

Kinematic viscosity is a conflict with the movement of a liquid under gravity. These properties influence fuel movement the size of fuel drops fuel atomization and jet penetration overall affect the quality of burning for use in diesel engines. The viscosity of fuel must be within the limit of the ASTM D-6751 standard. The viscosity available of this limit affects the fuel injection system like an injector, fuel pump lubrication fuel leakage, poor atomization, incomplete combustion. Etc[59].

Cloud Point (CP): The cloud point is the temperature at which a cloud of polish minerals first appears in a fluid when it is cooled down below specific conditions. The cloud point is a critical influence in cold weather performance for all diesel fuels. Aimed at additive the cloud point is normally higher than the cloud point of conventional diesel. To reduce this importance combination feedstock that has comparatively high in saturated fatty acids with a feedstock that has lower saturated fatty acid contented or blend additive with nanoparticles that delay the formation of solid crystals in the additive by various mechanisms[60].

Flashpoint (FP): Flash point (closed) device. The sample full test cup was heated with the help of a heater by air bath. It was heated in such a way that the rate of temperature rise was around 5 per min which was agitated at a slow constant rate. At every 1 temperature rise flame was introduced for a moment with the help of a shutter. The temperature at which a flash appeared in the form of a sound was recorded as a flash point. The fire point was recorded as the temperature at which test oil sample vapors catch fire and stay for a minimum of five seconds[61].

The calorific value or heat of ignition is the amount of energy available from a sample of fuel. It is a measure of heat obtained through the combustion of a unit mass of fuel that produces the maximum promising output limit of power or heat that can be obtained from a fuel. Fuel is defined as a substance that experiences a physical and chemical change in return releasing large amounts of heat energy to do work. The calorific value is measured in a bomb calorimeter using the standard ASTM D2015 method[62].

Cetane number the cetane number reflects the ability of a fuel to self-ignite at the conditions in the engine cylinder. In general adequate cetane value is required for better engine performance. The cetane number of additives from different feed stocks was from 48 to 60. This is much higher than the typical 43 to 47 observed for petroleum diesel fuel. The cetane number is typically estimated for petroleum diesel fuel using the cetane index. However, a cetane index is not an accurate predictor of the cetane number for additive because it provides faulty information for additive. A cetane engine must be used to determine the cetane number for additive[63].

Copper Strip Corrosion – Analysis of diesel for copper strip corrosion indicates issues that may arise with copper components in the fuel system and generally provides a relative degree of the corrosiveness of the fuel. The analysis encompasses immersing a polished copper strip in the fuel for three hours at 50°C. The copper strip is then washed and the tarnish level is determined by comparing the copper strip to the ASTM Copper Strip Corrosion Standard[64].

2.13. Specification of diesel standards

The American Society for Testing and Materials (ASTM) Ethiopian fuel supply enterprise set standard specifications for diesel fuels by ASTM-D976 respectively. It determines the quality of fuel to be used in diesel engines. Some of the test methods' standard limits and characteristics of fuel are listed in Table 2.2 shows the fuel properties of additive blends.[65] Test Method

Table 2.5. Specifications of diesel fuel properties (Ethiopian .P,S.E,)

Test Method	Parameter	Limits (MAX/MIN)
Density @15 ℃	**D 4052/1298**	**0.820-0.806**
Kinematic Viscosity @40℃ (mm2/sec)	**D445**	**2.0-4.5**
Total sulfur %wt	**D 4294**	**Max 0.05**
Cetane index	**D 976**	**Min 48**
Cloud point (℃)	**D2500**	**Max +5**
Flash point, PMCC, ℃	**D93**	**Min.66**
Copper strip corrosion 3hrs@100	**D130**	**Max no.1**
CCR,%Wt	**D189**	**Max 0.2**

2.14. Research Gaps

Comprising this much of the literature reviewed on additive has been used in diesel fuel for low combination ratios (greater than 0.75%) application. Hence there is a research gap in this research study: -

- ❖ In previous work the researcher uses different additives separately then there is some effect on the lubricity and other parameters example performance emissions then based on this in this thesis to use different vegetable oil to enhance the lubricity of the diesel fuel and it does not affect other parameters.
- ❖ The literature reviewed terminologies that the study on diesel fuel additive with caster bean oil blends with the addition of diesel fuel as an additive on different tribology tests with different loads is very much limited.
- ❖ The literature is almost low about the high mixing ratio of fuel additive systems to improve the behavior of fuel characteristics of caster bean oil-cotton seed oil diesel blended fuel problems.
- ❖ In most existing studies the effect of caster bean oil and cotton seed oil additives on tribological test parameters (friction. wear) and lubricity for a lower percentage caster bean oil-diesel blends fuel is not studied deeply under varying load at rates.

Table 2.6 gap analysis:

No.	Vegetable oil type	Viscosity @40°C (cSt)	Author	Viscosity Index	Pour Point (°C)	Flash point	Coefficient of friction	Wear scar diameter (mm)	Friction
1	Jatropha oil	34/16	{Yakubu Woma, 2019}	-	9	45–60	0.0646	-	- High friction
2	Palm oil	34.6	{ S.K. Gupta, 2012}	188	-		0.078	0.777	- High friction and wear
3	Soybean oil	28.86	{ S.K. Gupta, 2012}	170	-9	240	0.112	-	- High friction
4	Sesame oil	31.86	(Yakubu woma 2019)	213.5	-15	315	0.0832	0.65	- High friction
5	Coconut oil	27.7	(Yakubu woma 2019)	176	22	320	0.0901	0.83	-high friction
6	Sunflower oil	29	(Yakubu woma 2019)	159	-18	332	0.0742	0.685	--High friction and wear
7	Castor oil	220.6	(Yakubu woma 2019)	220	-33	250	0.0607	0.68	High lubricity Corrosion inhibitor Greater viscosity index High thermal stability
8	Cottonseed oil	35.8	{ERTUGRUL Durak, 2004}	211	-15.0		0.0636	0.65	Antioxidants Corrosion inhibitor Goodanti-wear capability

2.15. Literature summary

Because of the above categories of literature limited researcher studies have been approved out on the effect of caster bean oil and cotton seed oil as an additive in the tribological behavior of diesel fuel. It improves the blend fuel properties leads better mixture formation and improves wear and friction even low blend ratio of caster bean and cotton seed oil separately . Thus there is a reduction in the wear and coefficient of friction with the percentage of diesel and however, the formation of lubricity slightly increases because of the increased wear and friction. One set of approaches focuses on implementing additives for lower caster bean and cotton seed oil-diesel blend ratios (above 0.1% of caster bean and cotton seed oil) procedures in diesel fuel to reduce wear and friction and increase lubricity. Caster bean cotton seed oil for a substitution mineral diesel fuel is also easily available and relatively cheap simplicity of handling and implementing in a diesel fuel application for improving wear and friction characteristics which leads better fuel efficiency especially for developing countries like Ethiopia. In previous work the researcher uses different vegetable oil as additive separately then there is some effect on the lubricity and other parameters example performance emissions then based on this in this thesis to use different vegetable oil that are cotton seed and castor bean oil to enhance the lubricity of the diesel fuel and it does not affect other parameters. in this thesis research tried to investigate by mixing of cotton seed oil and castor bean oil as an alternative additive Because this vegetable oil are High lubricity, Corrosion inhibitor, Greater viscosity index, High thermal stability, Antioxidants, Good anti-wear capability then its enhance or increase the lubricity of diesel fuel.

CHAPTER THREE

3. DESIGN, METHODS, AND MATERIALS

3.1.Introduction

This chapter has presented the explanation of research experiments and design of experiments (DOE), the materials and samples preparation to experiment according to the DOE; to formulation of Diesel Fuel Using Alternative Additive Cottonseed and castor bean Vegetable Oil**.** Explains conceptual study, laboratory experimental work, analysis, and completion of the research. In general, the experiment parts are considered on two main parts: the first one collected &characterized diesel fuel and cottonseed oil and castor bean oil and the second blended diesel fuel with cottonseed and castor bean oil, data analysis, and characterization.

3.2.Methodology

Basically, the research is conducted in the certain automotive workshop for some specialized testing some of the characteristics, according to the treatments observed on the design of experiment. It is mostly experimental based which includes the following stages. The procedure of each stage is given bellow.

Preparing tribological test of diesel fuel using alternative additive cottonseed and castor bean vegetable oil.

- ✓ **Step 1** To modify the tribometer block on a ring (ASTM G77) to a ball on cylinder (ASTM D6078).
- ✓ **Step 2** To characterize diesel fuel properties, use in Ethiopia.
- ✓ **Step 3** To characterize mixed caster seed and cotton seed oil.
- ✓ **Step 4** To determine the tribological property (wear and friction) of diesel fuel and samples of diesel fuel with mixed cottonseed and castor bean vegetable oils as an alternative additive.
- ✓ **Step 5** To characterize the best sample diesel fuel with mixed cottonseed and castor bean vegetable oils as an alternative additive
- ✓ **Step 6** To Evaluate performance and emission

Based on the literature review and related researches that is given the data analysis the laboratory and tested results that it going to be from each characterization instrument that is mentioned below, to conclude. First, the entire necessary sample will be prepared for the test, characterization of the samples, by mixing the sample producing the samples diesel and using the standard procedures to conduct the research. According to the DOE, to consider the main factor to mixed diesel fuel with cottonseed and castor bean oil and the response that is important too, that is possible to get on the correct condition and lab setup available.

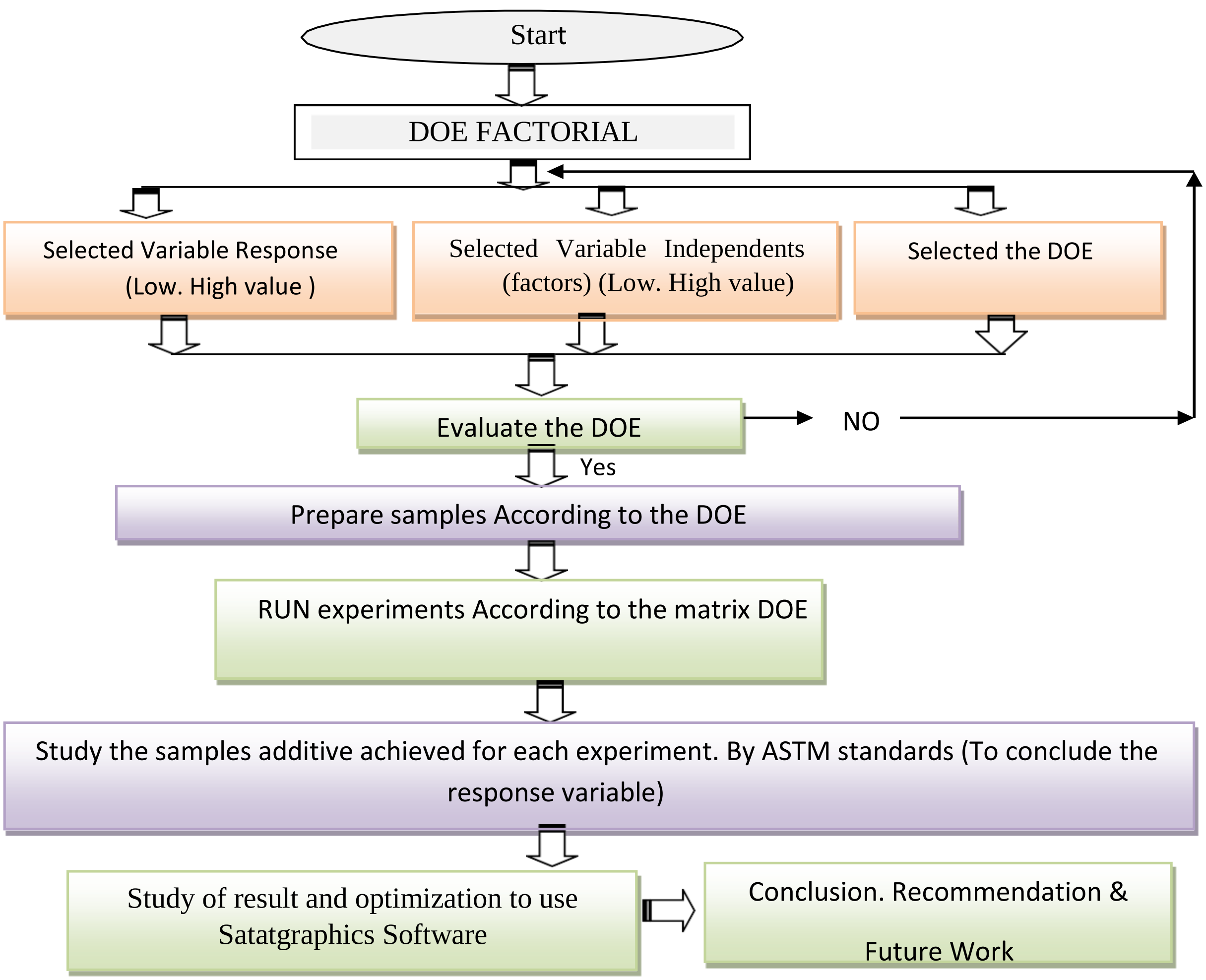


Figure 3.1 General procedure

The main objectives of the experiments are evaluated: to determine which variables are most influential on the responses; where to set the influential factors (for blend diesel fuel with cotton seed oil and castor bean oil) to optimize the responses near the desired nominal value (in comparison with previous low sulfur diesel fuel one); where to set the influential of factors, so that variability in the responses is small.

3.3. Design of experiment for tribological test of diesel fuel using alternative additive cottonseed and castor bean vegetable oil.

The main objectives of the experiments are evaluated: to determine which variables are most influential on the responses; where to set the influential factors (for diesel fuel with cotton seed oil and castor bean oil as lubricity additive) to optimize the responses near the desired nominal value (in comparison with low Sulphur diesel fuel one); where to set the influential of factors, so that variability in the responses is small. According to (Douglas C. Montgomery, 2000) said in his book DOE. To use the statistical approach in designing and analyzing an experiment, it is necessary for everyone involved in the experiment to have a clear idea in advance of exactly what is to be studied, how the data are to be collected, and at least a qualitative understanding of how these data is to be analyzed. It gives the following Guidelines for Designing an Experiment: Recognition of and statement of the problem. Choice of factors, levels, and ranges. Select the response variable. Select of experimental design. Experiment. Statistical analysis of the data. Conclusions and recommendations.

This research, it is following the methodology given by (Douglas C. Montgomery, 2000) with the use of Statgrapichs software to make the DOE and analysis. The design of the experiment to conducting lubrication of diesel, in the beginning, there are two inputs (factors) that will be considered to evaluate the research, and other variables will be controlled in the investigation. Those factors or independent variables are Load (X1); and Part per million (PPM) of CSO and CBO (X2). Those factors take levels high and low, as experience takes from the literature review for this purpose in other reviews produced to allow make some comparison. The response variable is wanted to determine, the relative influence (importance) of each of these factors on the dependent variables (Friction (Y1), Wear (Y2).

With the minimum number of experiments (runs), what means: to determine the combinations of these settings to establish the best way to increase the tribological properties.

Independent variables & Dependent variables

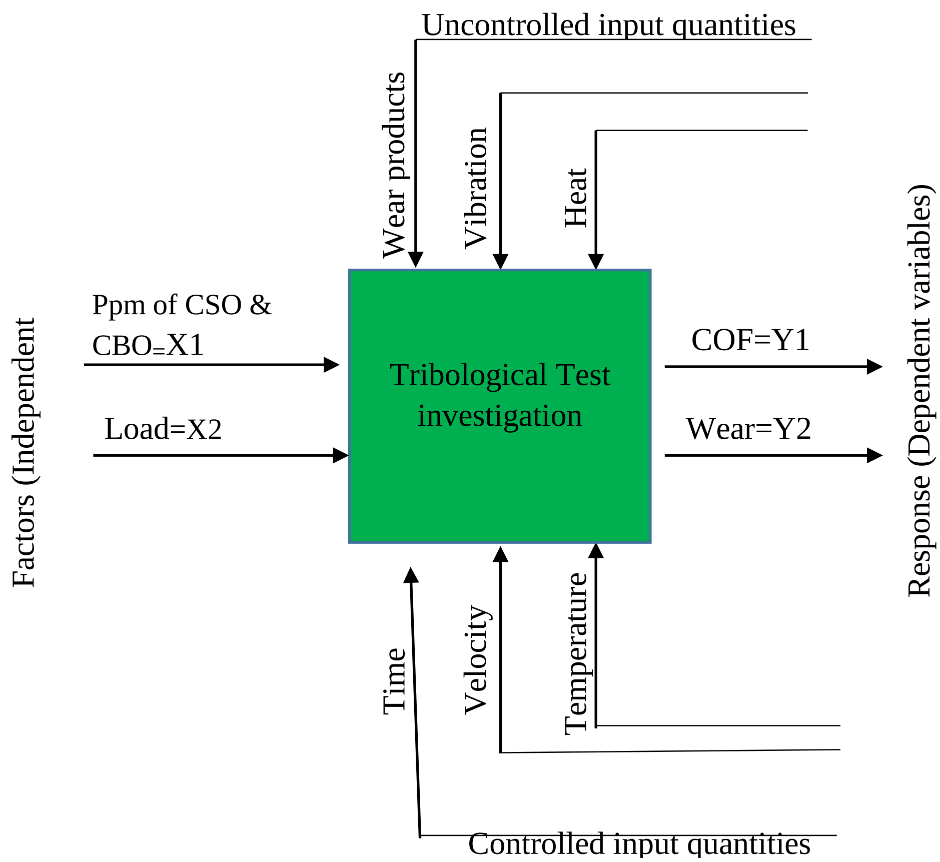


Figure 3.2 Dependency: input-output in the tribological test

3.4. Definition of variables (independent and dependent)

Table 3.1 independent variables

No.	Factorials	Min	Max	Unit
1	Load	10	100	Newton
2	% Of CSO and CBO	0.5	1	%

Table 3.2 dependent variables

No	Response	Min	Max	Unit
1	Friction coefficient	0.3	0.8	
2	Wear	0.01	0.5	gram

3.5.Factorial experimental design (2k)

Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response most important of these special cases is that of k factors, each at only two levels. These levels may be quantitative, the "high" and "low" levels of a factor, or perhaps the presence and absence of a factor. A complete replicate of such a design requires 2 × 2 × ⋯ × 2 = 2k observations and is called a **2**-k factorial design. Factorial design of experimental, in the present case, the total amount of factors (independent variables) to be investigated is k = 3. So, by using the Stat graphics software is selected and obtained runs of experiments (all possible factor combinations) to selected 10 factorial center point design; and by selected execution, the following experimental matrix is obtained. Full Model Running the full complement of all possible factor combinations means that we can estimate all the main and interaction effects.

Table 3.3 Factorial Experiment Design Table or Design Matrix

No	DIESLE FUEL (ml)	CSO/CBO (%)	F_N load (N)	COF	Wear, (g)
1.	999.25	0.75	10		
2.	999.5	0.5	100		
3.	999.5	0.5	40		
4.	999	1	40		
5.	999.25	0.75	100		
6.	999.5	0.5	10		
7.	999	1	100		
8.	999.25	0.75	40		
9.	999	1	10		
10	999.25	0.75	70		

The above Stat graphics establish the value of the independent variables of factors of the matrix for each main 10 runs selected. But the dependent variable (Response) will be found after the experiment conducts.

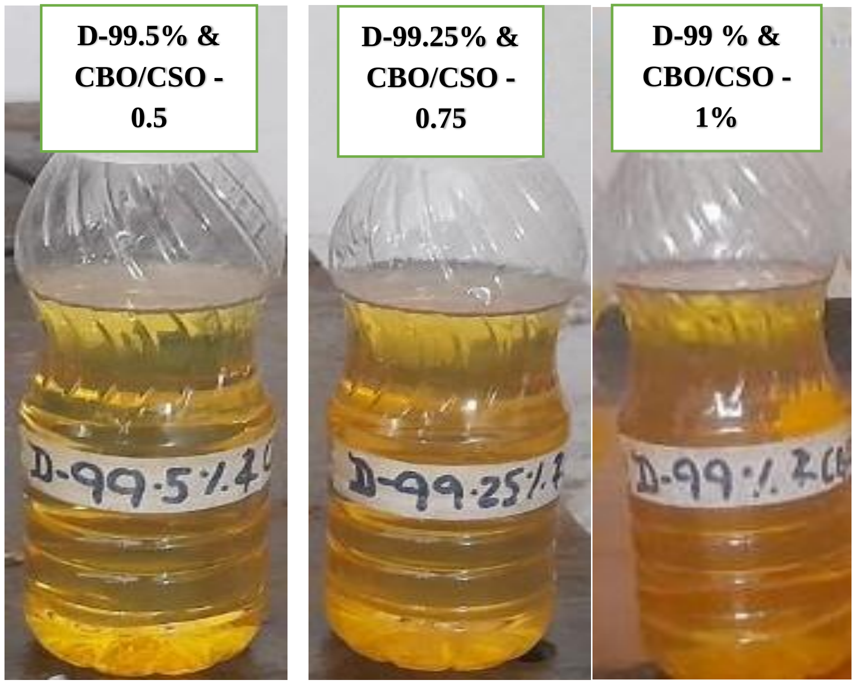


Figure 3.3 Experimental fuels

3.6.Material and method for mixing of diesel fuel using alternative additive cottonseed And castor bean vegetable oil.

3.6.1. Raw Material

Table 3.3 materials used for mixing of diesel fuel using cottonseed and castor bean vegetable oil.

NO	List of material	Application
1	Cottonseed oil and castor seed oil	Additive
2	Diesel fuel	Raw material

The cottonseed seed and castor bean oil is collected from Addis Ababa

A. Cotton seed Oil and castor seed oil Selection

• The selected vegetable oil, cottonseed oil, is available in the country and has not competition with edible oil.

B. Diesel fuel

• Different diesel fuel firstly selected from the different stations at different time and then after sulfur content test the lowest Sulphur diesel is ready to experiment.

3.6.2. Equipment

Table 3.4 equipment used for mixing of diesel fuel using cottonseed and castor bean vegetable oil.

S.NO	List of Equipment	Application
1	tribometer	Measure the lubricity of the mixed solution
2	digital balance	Measuring the mass of diesel fuel, cotton seed oil and the scares.
3	filter paper	Filter unwanted materials from the diesel.
4	Thermo meter	Measure the temperature of fuel during testing
5	Measuring cylinder	Measure the volume of diesel fuel and cotton seed oil.
6	Visco meter	Measuring the viscosity(resistance to (internal flow) of the fuel
7	Dynamo meter	Determining the brake power of the engine involves the measurement of its torque and angular speed of its output shaft.
8	Exhaust gas analyzer	measure the various gasses present and provide the Operator with an end reading.

3.7 Tribological test to evaluate tribological behavior of diesel fuel for the purpose of using cottonseed and castor bean vegetable oils as an alternative additive oil

The tribological properties of different samples, like wear and friction testing, determined on tribometer available in the Automotive Work Shop of ETU Institute, Addis Ababa.

Wear and Friction Evaluation

The machine uses to perform a Tribological test of wear and friction is called “Tribometer” it can be available only in specialized lab facilities to study the diesel fuel. It is very useful for developing new antifriction materials. A Tribometer can measure friction on a surface based on a large number of methods, one of which is performed with Testing important oil and diesel lubricant qualities can be done in a variety of methods. The scuffing load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE), which is standardized as ASTM D6078, is one of the test procedures that is frequently used to evaluate the lubricating qualities of jet fuel. A fixed steel ball and a rotating metal cylinder are used in the test, both of which are immersed in a sample of oil lubricant or diesel fuel. The test ball has a diameter of 12.7 mm and is made of AISI standard steel No. E-52100, a chrome alloy steel. The steel used in the metal cylinder is SAE 8720. The steel ball is forced against a metal cylinder during the test with a constant applied stress of 1000 g [24]. The metal cylinder is attached to a motor, which rotates it for 1 minutes at a fixed speed of 525 revolutions per minute (RPM). In order to evaluate the impact of the sample oil lubricant or diesel fuel, the equipment effectively duplicates the metal-metal contact. Researchers and industry professionals can assess lubricating characteristics at the control speeds and contacting loads thanks to wear scars on the ball.

Steps we use for friction test

1. Measure the weight of the scare (ball) before tightening it into the wear tester (tribometer) by using a digital weight.
2. Switch on the motor plug and control the time, temperature and load of operation
3. Uninstall the scare and measure the weight of the scare after the experiment.
4. Repeat steps 1 – 3 with the same material of scare and different samples.
5. The data was recorded.

Figure 3.4 ball on cylinder tribometer

3.7.1 Experimental Setup for engine performance test

After the selected samples were tested tribological test engine performance and emission test by Asynchronous motor dynamometer. In doing the experimental work all the necessary electrical connections to the panel and lubricating oil level in the engine were checked, the test engine was driven by the Buying fuels used for the experiment: mixed diesel and cottonseed oil determining the quality.

The selected and best on tribological test ratio of cottonseed oil and castor bean oil with diesel fuel were prepared and tested on the engine and compared with pure diesel fuel. The selected ratio consists of D100% and D99%CSO and CBO1% on the performance, combustion, and emission parameters of an engine. The experimental test rig consists of TBMC-3, a single-cylinder, four strokes, direct injection (DI), naturally aspirated diesel engine rated at 7.5 kW. The schematic layout diagram representation of the experimental setup is shown in Figure 3.5, respectively. The technical specification of the test engine is shown in Table 3.5). The experimental setup is equipped with all the necessary instrumentation, devices, and controllers to acquire various data during experimentation. It also contains the fuel supply system, water cooling system, lubrication system, and various speed sensors and instruments. Auto puls flue gas analyzer was used to measure the emissions, HC, CO, CO2, and NOx emissions, and also oxygen from the engine exhaust. The measurement is performed by letting the flue gas samples surge through a probe in the steady operation of the engine. The samples are investigated inside the flue gas analyzer and return the values of CO, CO2, O2, NOx, and HC emissions on the display of the control unit.

Table 3.5 Test engine technical specifications

Item	Description
Engine model	TBMC-8
Engine type	4-stroke, single-cylinder, air-cooled
Bore diameter	69 x 60mm
Stroke	127cc
Compression ratio, CR	21: 1
Fuel injection pressure and timing, IP and IT	25° TDC
Engine power@ rated speed	7.5 kW
Cooling type	10.4 Nm/3600rpm

Dynamometer	Computer controlled test bench
Fuel capacity	3 L
Recommended battery	12/36

3.7.2Test Procedures

All the tests were conducted under steady-state conditions after the exhaust gas temperature and the cooling water temperature were stabilized. Experiments were carried out at constant ambient temperature to improve the reliability of the recordings. In each test, a fixed load was applied during which included the stabilization period followed. The engine was run with diesel fuel the baseline data was recorded. The engine was always run before starting recording at each load condition to allow for stabilization. Each test was repeated three times to ensure repeatability.

Initially, baseline experiments were carried out to study the effect of engine load on the performance and emission parameters of diesel engines fueled with diesel fuel at rated engine speed under varying engine loads. To achieve the performance and emissions test, the engine was performed at various loads such as at on load 0%, 20%, 40%, 60%, and 80% loads. For this experimental work two percentage ratios by volume diesel fuel (100%), and one blends of (D99%CSO and CBO1%), and for comparative analyses neat diesel fuel were considered for the whole experimental study.

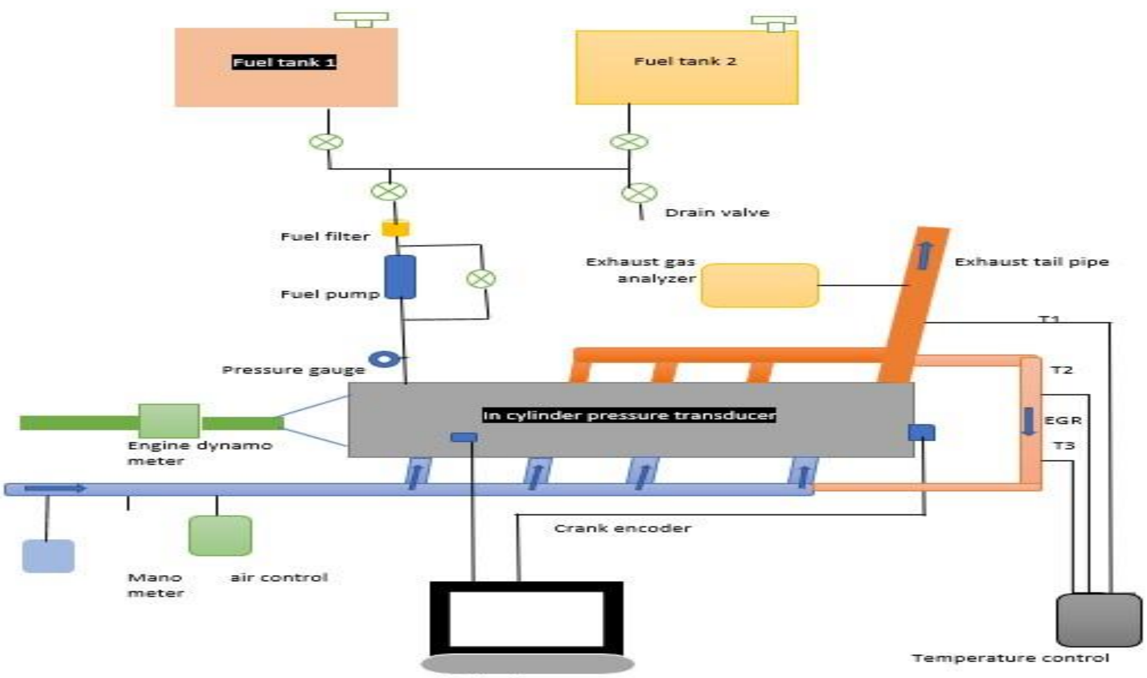


Figure 3.5 schematic diagram test engine experimental setup[66]

3.7.3 Procedure and sampling method used in this research

The sample is prepared, for comparison, by varying independent variables of the experiment additives, cotton seed oil and castor seed oil at constant levels of diesel fuel to evaluate the effect of load of reaction on the dependent variables according to the DOE

Controllable factor that affects the property of diesel blending period

- Mixing, adding, and cooling temperature,
- Time duration (except time of reaction) in each procedure starts from the addition of base to final cooling …etc. The following figures show the procedure step-by-step to blend diesel fuel for each runs it should be following to complete the experimental matrix

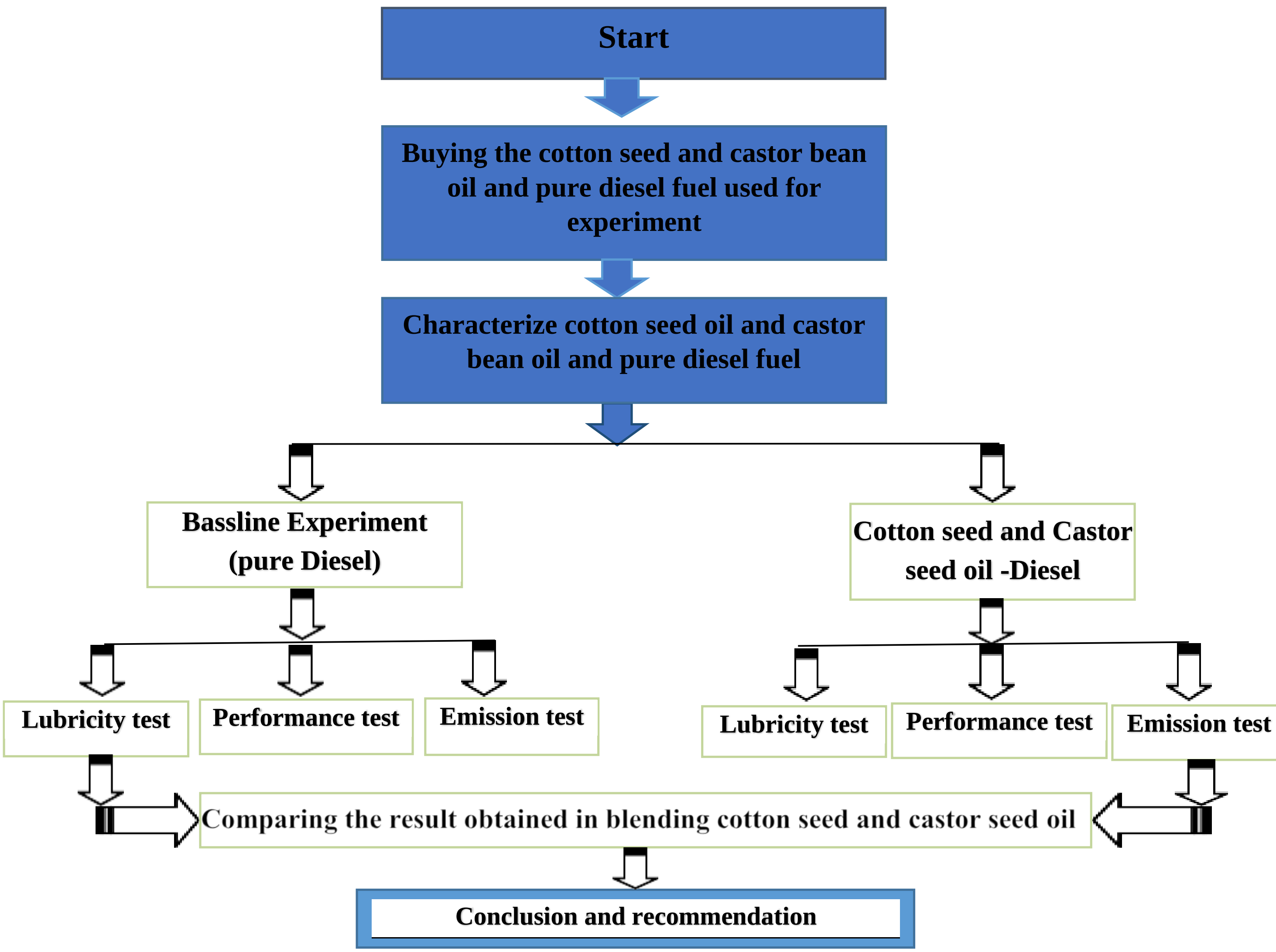


Figure 3.6 schematic diagram test engine experimental setup

3.8 Method of processing and analysis of data

The tribology test was conducted using pure diesel and mixed diesel with cottonseed and castor bean oil at different load condition and constant time. In this investigation the tribometer was tested in two setup conditions; pure diesel condition and mixed diesel with cottonseed and castor bean oil at different load condition and constant time condition. Additionally, the engine performance and emission test were conducted using diesel and mixed diesel with cottonseed and castor bean oil at different load condition and constant time given.

CHAPTER FOUR

4 Result and Discussion

4.1 Result

Introduction

By the experimentation and testing carried out for the different samples of diesel fuel obtained and using the Stat graphics Software to make the statistical analysis and some optimization view of the influence of factors on responses.

The experimental investigation has been carried out to study the tribological behavior of diesel fuel at different tribometer speed and at rated load for four test fuels to find the best diesel blend fuel which offered better lubricity and a new diesel fuel with additive which not affect engine power. The important findings are as follows:

4.1.1 To modify the tribometer block on a ring (ASTM G77) to a ball on cylinder (ASTM D6078).

Element composition test

Chemical composition analysis can require the application of a combination of analytical methods to achieve a full picture of the chemical structures and concentrations of the components in a sample. To aid product development, the concentration of specific components, such as an active ingredient that imparts a unique function to the product, should be determined to understand the product's performance or quality. Accurate analysis of the chemical composition of a material will provide invaluable information, and ensure the quality of a chemical formulation or product. As shown in tables 4.1, 4.2, the element composition of the material was tested by using an Optical Emission Spectrometer (figure 4.1) from the Federal Tvet Institute department of manufacturing technology.

Table 4.1: Chemical Composition of Ring

Elements	Fe	C	Si	Mn	Cr	Mo	Ni
Percentage	98.2	0.0447	0.005	0.777	0.859	0.005	0.005
Elements	Al	Co	Cu	Nb	Ti	V	W
Percentage	0.086	0.004	0.0074	0.004	0.004	0.005	0.05

Table 4.2: Chemical Composition of specimen (ball)

Elements	Fe	C	Si	Mn	Zr	Cr	Mo	Ni
Percentage	96.7	1.00	0.490	0.246	0.0050	1.75	0.0050	0.0050
Elements	Al	Co	Cu	Nb	Mg	Ti	V	Pb
Percentage	0.125	0.0040	0.0038	0.0050	0.0290	0.0698	0.0040	0.0150

Hardness test

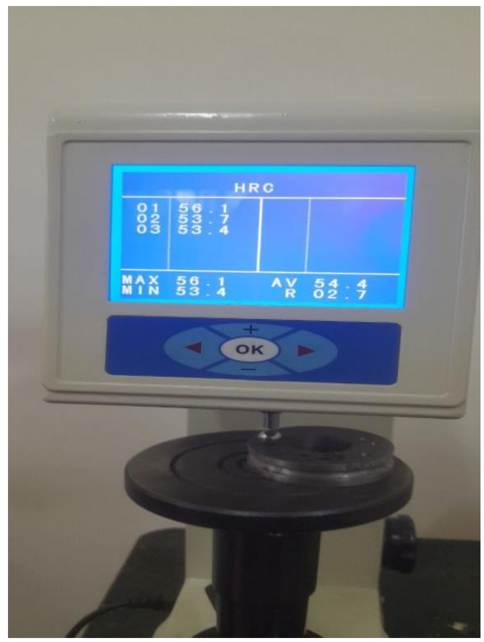
Hardness test results can be extremely useful when selecting materials, because the reported hardness value indicates how easily the material can be machined and how well it will wear, and evaluate the materials property such as strength, ductility, and wear resistance, and so helps you determine whether a material or material treatment is suitable for the purpose you require. The material's property enables it to resist deformation, bending, scratching, abrasion, or cutting. Tables 4.3, and 4.4 show the hardness of the ring and the specimen that tests were performed using Rockwell (figure 4.1) in the Federal Tvet Institute manufacturing technology department.

Table 4.3: Hardness value of Ring (HRC)

Test round			
1	2	3	Average
58.8	52.9	68.9	60.2

Table 4.4: Hardness value of ball (HRC)

Test round			
1	2	3	Average
56.1	53.7	53.4	54.4



Optical Emission Spectrometer Rockwell

Figure 4.1: Experimental setups used to test material element composition and hardness (ETU)

4.1.2 Characterization of diesel Fuels, use in Ethiopia

The diesel fuel used in Ethiopia is imported from different countries by means of Ethiopian petroleum supplier enterprise. After imported, the diesel fuel in various volume distributed to different company. The pure diesel fuel used in this study buying from a company called Total and, the characteristics of pure diesel were tested in Ethiopian petroleum supplier enterprise and the following results are given in Table 4.5.

Table 4.5 Characterization of diesel Fuels, use in Ethiopia (from Ethiopian petroleum supplier enterprise)

no	parameter	Teste method	Limits (Maximum)
1.	Density @15℃	D4052/1298	0.820 – 0.860
2.	Color	D1500	MAX. 2
3.	Total sulfur, %WT	D4294	MAX. 0.05
4.	Flash point, PMCC, ℃	D93	MIN. 66
5.	Calorific value, but/lb	ISO8217	19,624.4
6.	Kinematic viscosity @ 40℃	D445	2.0-4.5
7.	Cetane index	D976	MIN 48
8.	Copper strip corrosion 3HRS @100℃	D130	MAX. NO. 1
9.	Ash, 5WT	D482	MAX. 0.01
10.	Water and sediment, V/V %	D2709	MAX. 0.05

4.1.3 Characterization of mixed cotton seed oil and castor bean oil

The product of cottonseed and castor bean oil viscosity, density 15, 20,40,100℃, and flash point and compare each additives were tested in Addis Ababa university institute Of technology School of chemical and bio engineering And the following results are given in Table 4.6.

Table 4.6 Characterization of cotton seed and castor bean oil (from Addis Ababa university institute of technology)

NO	Tests	Test method	Additive No 1 CSO 50% to CBO 50%	Additive NO 2 CSO 75% to CBO 25%
1	Density @15℃	D4052/1298	0.9896g/m^3	0.9607g/m^3
2	Viscosity @20℃(cSt)	D445	45.3	21.2
3	Viscosity @ 40℃(cSt)	D445	35.8	16.8
4	Viscosity @ 100℃ (cSt)	D445	20.3	10.6
5	Flash point (◦C)	D93	275	260

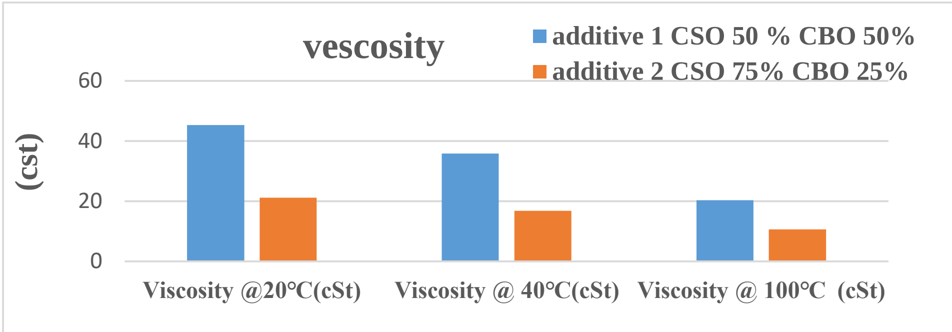


Figure 4.2 kinematic viscosity

In figure 4.2 the graph show as the viscosity of the the two different ratio oil that are additive 1 CSO 50% and CBO 50% and the other is additive 2 CSO 75% and CBO 25%then based on this data additive one is higher viscosity then additive two.

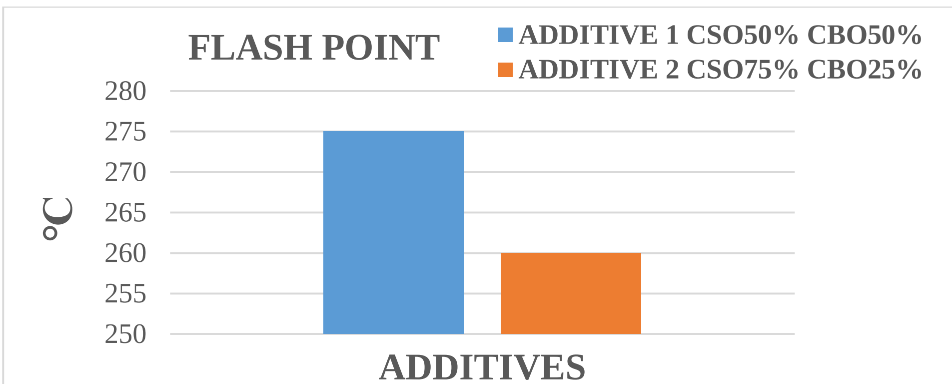


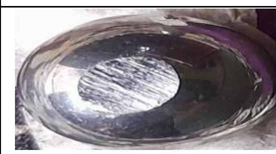
Figure 4.3 flash point

In figure 4.3 the graph show as the flash point of two different ratio oil that are additive 1 CSO 50% /CBO 50% and the other is additive 2 CSO 75%/CBO 25% then based on this data additive one is higher flash point then additive two.

4.1.4 Tribological test

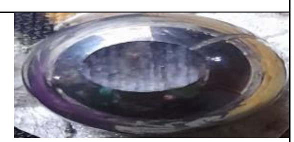
The testing results including the independent variable and dependent (response) variable are shown in the following table. Table 4.7 Expressing the independent (load, % of CSO/CBO) Variables and dependent or respond (coefficient of friction and wear) variable testing result of produced new diesel fuel value. And the photo of wear ball is show as the wear scar its captured by phone camera because there is no electro microscopic scar diameter analysis setup in Ethiopia. Table 4.7 Results obtained by carrying out the experimental matrix for the response variable were analyzed.

Table 4.7 Results obtained by carrying out the experimental matrix for the response variable were analyzed

No	Diesel Fuel (ml)	CSO/CBO (%)	FN, load (Newton)	COF	Wear, (gram)	Photo of Wear Ball
1.	999.25	0.75	10	0.459	0.052	
2.	999.5	0.5	100	0.624	0.092	
3.	999.5	0.5	40	0.602	0.077	
4.	999	1	40	0.371	0.026	
5.	999.25	0.75	100	0.605	0.074	
6.	999.5	0.5	10	0.551	0.054	
7.	999	1	100	0.482	0.038	
8.	999.25	0.75	40	0.510	0.057	

9.	999	1	10	0.367	0.023	
10	999.25	0.75	70	0.599	0.072	

Table 4.8.Experiment data in pure diesel 100%

No	Diesel fuel (ml)	Load (Newton)	Friction	Wear (gram)	Photo of Wear Ball
11	1000	100	0.728	0.109	
12	1000	40	0.649	0.094	
13	1000	10	0.643	0.075	

4.1.5 Characterization of Experimental Fuels

The new diesel fuel used in this study is obtained from cottonseed oil and diesel fuel by mixed each other in different ratios. a new diesel fuel in various volume concentrations study the effects of blending on the fuel properties blends fuel in comparisons of diesel international standard specifications (ASTM D4052, ASTM D445, ASTM D4294, ASTM D93 and IS8217)). The level of diesel and cottonseed oil, castor bean oil mixing for convenience is referred to as D and CSO/ CBO, where D indicates the percentage of diesel and CSO/CBO indicates the percentage of cottonseed oil castor bean oil present in the mixture.

After application on the tribology test, various physio-chemical properties and engine performance of the best new diesel fuel (D99 and CSO /CBO 1%) were determined and compared to diesel fuel (D100).

Table 4.9 diesel characterization and properties testing results (from Ethiopian petroleum enterprise)

NO	Properties	Unit	Test method	Test Result (D99CSO/CBO1)	Measurement uncertainty
1	Density@15°C	g/ml	D0452	0.8448	0.0002
	Density@20°C	g/ml	D4052	0.8406	0.0002
2	Kinematic viscosity 40°C	CST	D445	3.2692	
3	Calorific value	btu/1b	ISO8217	19,566.80	

4.1.6 Performance Parameters

In this study, after tribology test by selected one of the best a new diesel fuel from the sample's engine performance was evaluated in terms of BP, BSFC, and BTE. In this regard, tests were conducted using pure fuel and a new mixed fuels D99CSO/CBO1 and D100.

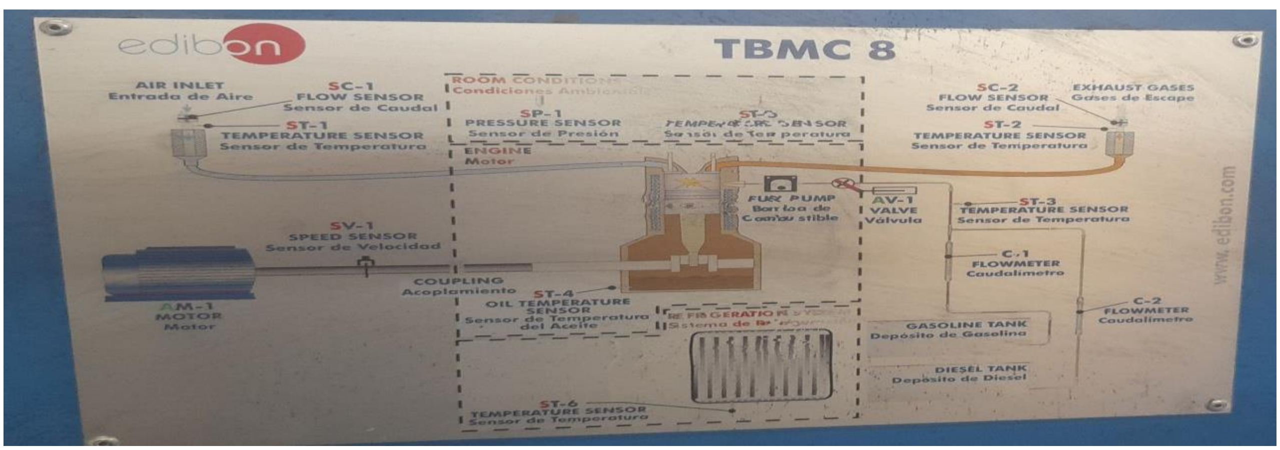


Figure 4.4.The performance testing of a Computer-controlled test bench for a single-cylinder engine 7.5 kW (pictured by the author).

Brake power

The results of the engine brake power tests for the different engine loads the engine brake power dropped as the additive ratio in the blended fuel increased in comparison to the brake power achieved on diesel fuel ADD1% at various operating conditions respectively. This discrepancy is due to the

ADD1% blend fuel's higher viscosity and higher heating value when compared to plain diesel fuel.

Figure 4.10: Brake Power Variation with Engine Load

Table 4.10 Brake power of various fuels at different engine load

Engine load %	**Brake power in (kW)**	
	D100%	D99CSO/CBO1%
0	0.42	0.4
20	0.7	0.72
40	1.14	1.16
60	1.7	1.74
80	2.51	2.5

Table 4.11 Brake Torque of various fuels at different engine load

Engine load %	**Brake torque in (Nm)**	
	D100%	D99CSO/CBO1%
0	5.9	5.95
20	5.3	5.35
40	5.6	5.7
60	6.9	6.7
80	6.7	6.8

Table 4.12 Brake specific fuel consumption of various fuels

Engine load %	**Brake specific fuel consumption (Kg/kW hr.)**	
	D100%	D99CSO/CBO1%
0	0.888	0.809
20	0.79	0.77
40	0.48	0.47
60	0.39	0.37
80	0.36	0.36

Table 4.13 Brake thermal efficiency of various fuels at different engine load

Engine load %	Brake thermal efficiency (%)	
	D100%	D99CSO/CBO1%
0	8.936	8.277
20	10.046	10.2698
40	16.534	16.721
60	20.35	20.701
80	21.535	21.318

4.2 Discussion

4.2.1 Modification of the tribometer

The modification of tribometer block on a ring (ASTM G77) to a ball on cylinder (ASTM D6078).

The scuffing load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE), which is standardized as ASTM D6078, is one of the test procedures that is frequently used to evaluate the lubricating qualities of jet fuel. A fixed steel ball and a rotating metal cylinder are used in the test, both of which are immersed in a sample of oil or diesel fuel. The test ball has a diameter of 12.7 mm and is made of AISI standard steel No. E-52100, a chrome alloy steel. The steel used in the metal cylinder is SAE 8720. The steel ball is forced against a metal cylinder during the test with a constant applied stress of 1000 g [24]. The metal cylinder is attached to a motor, which rotates it for 1 minutes at a fixed speed of 525 revolutions per minute (RPM). In order to evaluate the impact of the sample oil lubricant or diesel fuel, the equipment effectively duplicates the metal-metal contact. Researchers and industry professionals can assess lubricating characteristics at the control speeds and contacting loads thanks to wear scars on the ball. Then based on this to modify the arm ball hold or specimen and change the cylinder based on the standard diameter.

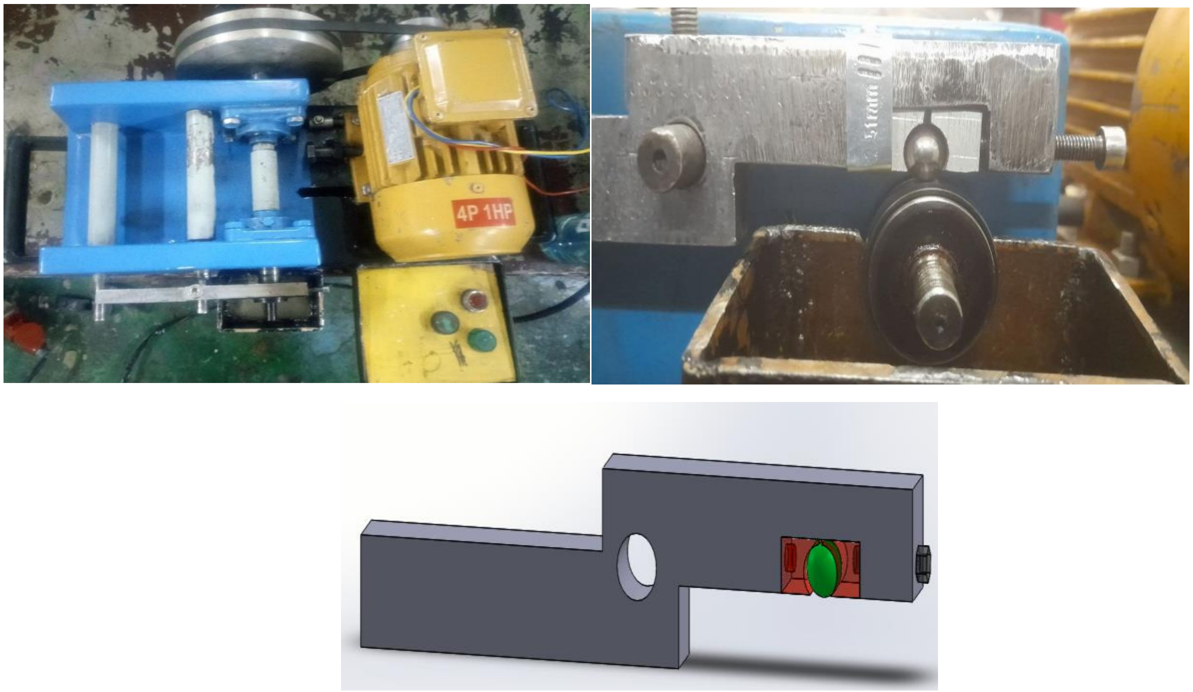


Figure 4.5 modification of block on ring in to ball on cylinder tribometer

4.2.2 Tribological test

4.2.2.1 Coefficient of friction

Friction According to the experiment samples design using ball on cylinder testing machine:

- Evaluating at the load of 100 N and 1 minutes of operation, for additive (CBO/CSO) experiment run number #7 (1%), #5(0.75), #2(0.5%), and #11(100%) normal diesel (Figure 4.6 a) the result shows that the friction coefficient is lowest for 1% additive, experiment run number # 7 concerning the other experimental samples.
- Evaluating at the load of 40 N and 1 minutes of operation, for additive (CBO/CS0) experiment run number #4 (1%), #8(0.75), #3(0.5%), and #12(100%) normal diesel (Figure 4.6 b) the result shows that the friction coefficient is lowest for 1% additive, experiment run number # 4 concerning the other experimental samples.
- Evaluating at the load of 10 N and 1 minutes of operation, for additive (CBO/CSO) experiment run number #9(1%), #1(0.75), #6(0.5%), and #13(100%) normal diesel (Figure 4.6 c) the result shows that the friction coefficient is lowest for 1% additive, experiment run number # 9 concerning the other experimental samples.

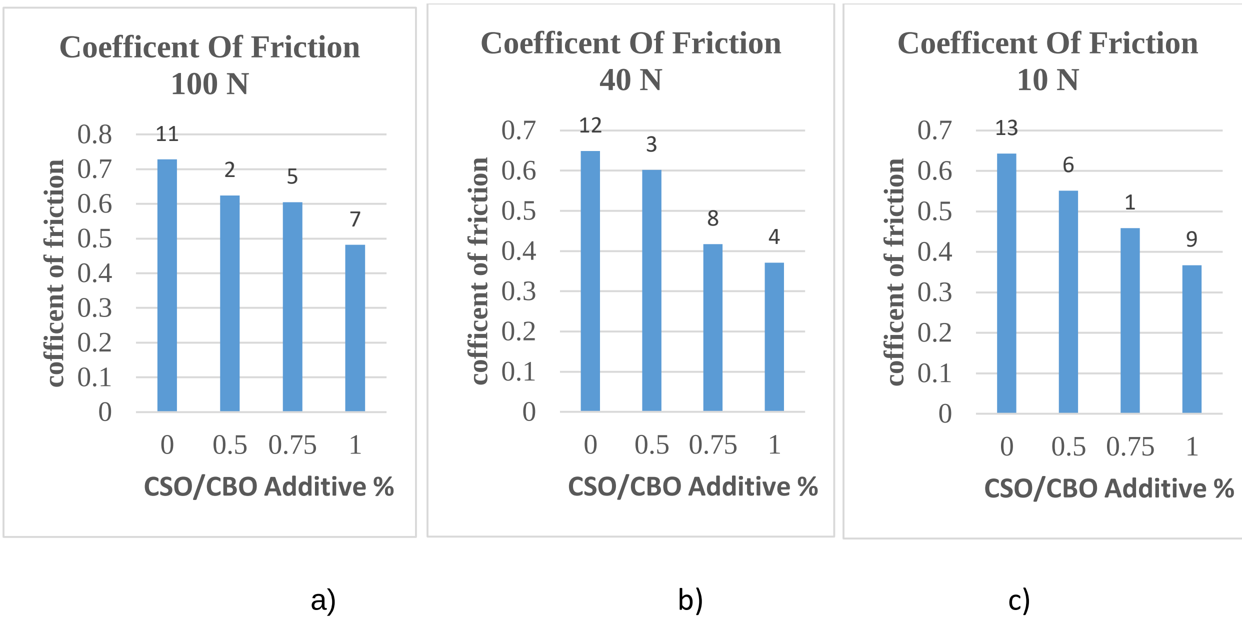


Figure 4.6.Friction coefficient comparisons a) 100 N b) 40 N c) 10 N.

The coefficient of friction from the experiment on the tribometer was acquired. During the test ADD samples acquired by DOE were used as additives between the ball on cylinder on the tribometer And 10 and100 Newton applied loads and for 1 minute's operation. And 1%, 0.75%, 0.5 ADD and the coefficient of friction measure by digital wattmeter its pick with different seconds , difference and show the result table 4.7and 4.8 Experiment 1-13.

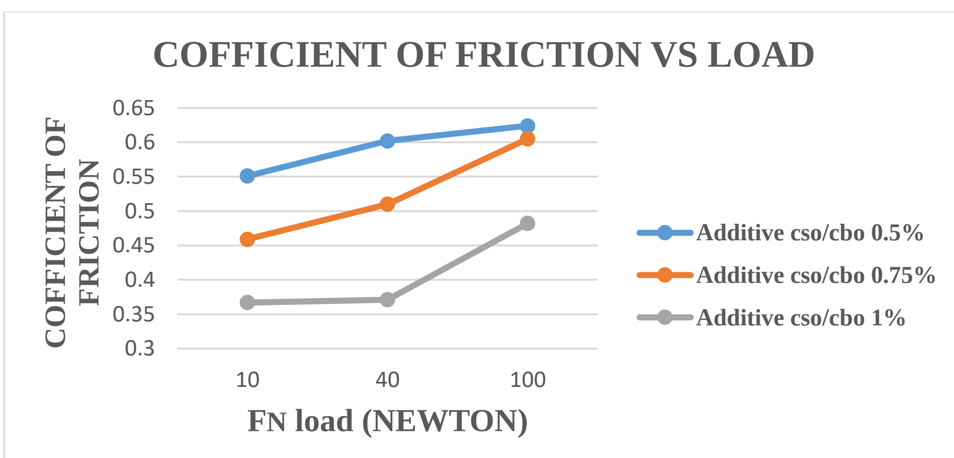


Figure 4.7.coefficient friction vs load

Figure 4.7 shows the coefficient of friction compare with load, when the percent of CSO/CBO increases the friction coefficient decrease; the effects of load increase the value of the friction coefficient increase.

The Pareto chart shows each of the estimated effects in decreasing order of importance. The length of each bar is proportional to the standardized effect, which is the estimated effect divided by its standard error. This is equivalent to computing a t-statistic for each effect. The vertical line can be used to judge which effects are statistically significant. Any bars which extend beyond the line correspond to effects which are statistically significant at the 95.0% confidence level. In this case, 2 effects are significant.

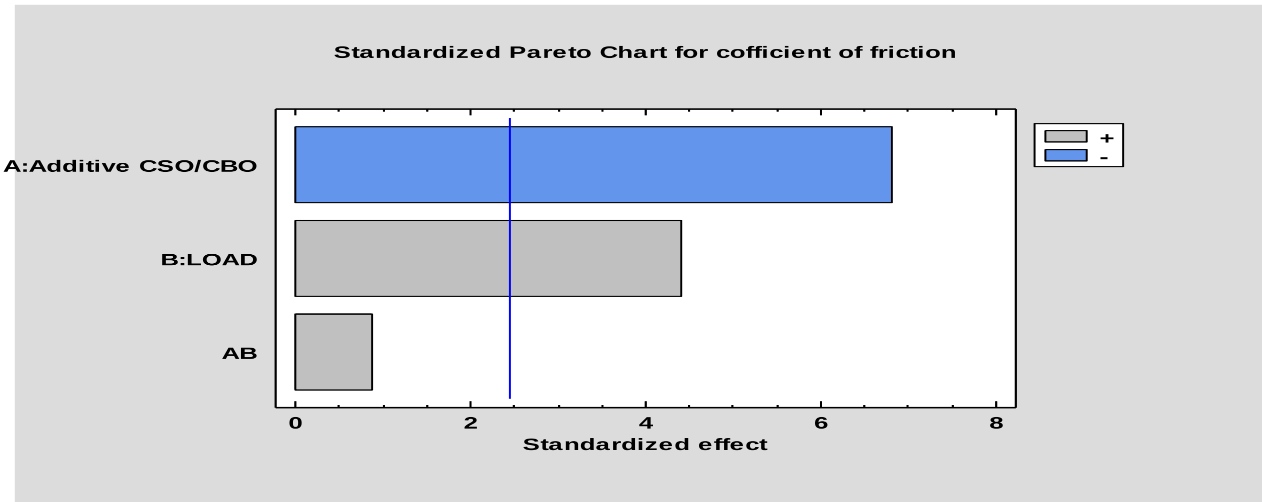


Figure 4.8 standardized Pareto chart for COF

Figure 4.8. Show the standardized Pareto chart for COF; the interaction of response variable and standardized effects and its influence on the optimization model for COF. The highest effects and interaction for A (CBO/CSO), B (LOAD) are obtained and there is some influence for AB others were removed from the model that the signs are very low for the level of confidence given to simplify the model. It can see in table 4.14 on the Variance analysis for the level of significance.

Table 4.14 Variance analysis for the level of significance

Analysis of Variance for coefficient of friction

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
A:Additive CSO/CBO	0.0556479	1	0.0556479	46.47	0.0005
B:LOAD	0.0231559	1	0.0231559	19.34	0.0046
AB	0.000900792	1	0.000900792	0.75	0.4191
Total error	0.00718482	6	0.00119747		
Total (corr.)	0.0917376	9			

The ANOVA table partitions the variability in coefficient of friction into separate pieces for each of the effects. It then tests the statistical significance of each effect by comparing the mean square against an estimate of the experimental error. In this case, 2 effects have P-values less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level.

The R-Squared statistic indicates that the model as fitted explains 92.1681% of the variability in coefficient of friction. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 88.2521%. The standard error of the estimate shows the standard deviation of the residuals to be 0.0346045. The mean absolute error (MAE) of 0.021114 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 5.0%, there is no indication of serial autocorrelation in the residuals at the 5.0% significance level.

The main factor effects are shown in the following figure.

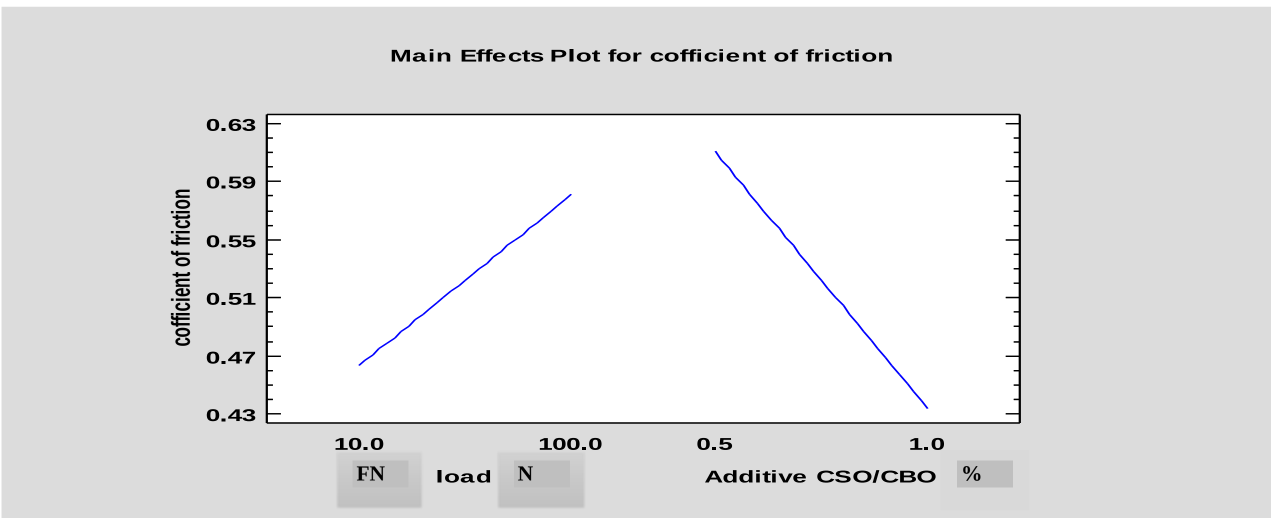


Figure 4.9 Graph of mean effects for friction coefficient.

Figure 4.9 shows the estimated coefficient of friction as a function of each experimental factor. In each plot, the factor of interest is varied from its low level to its high level, while all other factors are held constant at their central values. That the main effects of the factors on the friction coefficient, when the percent of CSO/CBO increases the friction coefficient decrease; the effects of load increase the value of the friction coefficient.

From the analysis of software to see, the combined effects of the factors on the COF for different samples, it is shown in the estimated response surface result for COF.

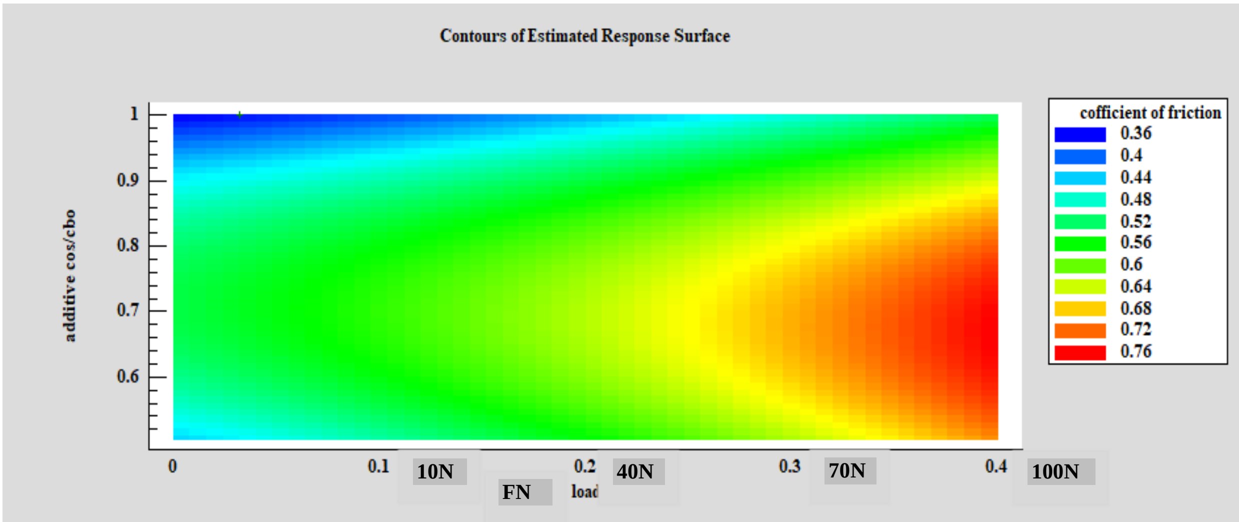


Figure 4.10 Contours of the estimated response surface for COF.

In figure 4.10 is shows contours for coefficient of friction as a function of load and additive COS/CBO. Each contour line represents combinations of load and additive COS/CBO which give a selected value for coefficient of friction. The additive value high and the load value is low the COF will be less or decrease

4.2.2.2 Wear

Wear according to the experiment samples design using Ball on Cylinder testing machine:

- ❖ Evaluating at the load of 100 N and 1 minutes of operation, for additive (CBO/CSO) experiment run number #7 (1%), #5(0.75), #2(0.5%), and #11(100%) normal diesel (Figure 4.11 a) the result shows that the wear is lowest for 1% additive, experiment run number # 7 concerning the other experimental samples.
- ❖ Evaluating at the load of 40 N and 1 minutes of operation, for additive (CBO/CSO) experiment run number #4 (1%), #8(0.75), #3(0.5%), and #12(100%) normal diesel (Figure 4.11 b) the result shows that the wear is lowest for 1% additive, experiment run number # 4 concerning the other experimental samples.
- ❖ Evaluating at the load of 10 N and 1 minutes of operation, for additive (CBO) experiment run number #9(1%), #1(0.75), #6(0.5%), and #13(100%) normal diesel (Figure 4.11 c) the result shows that the wear is lowest for 1% additive, experiment run number # 9 concerning the other experimental samples.

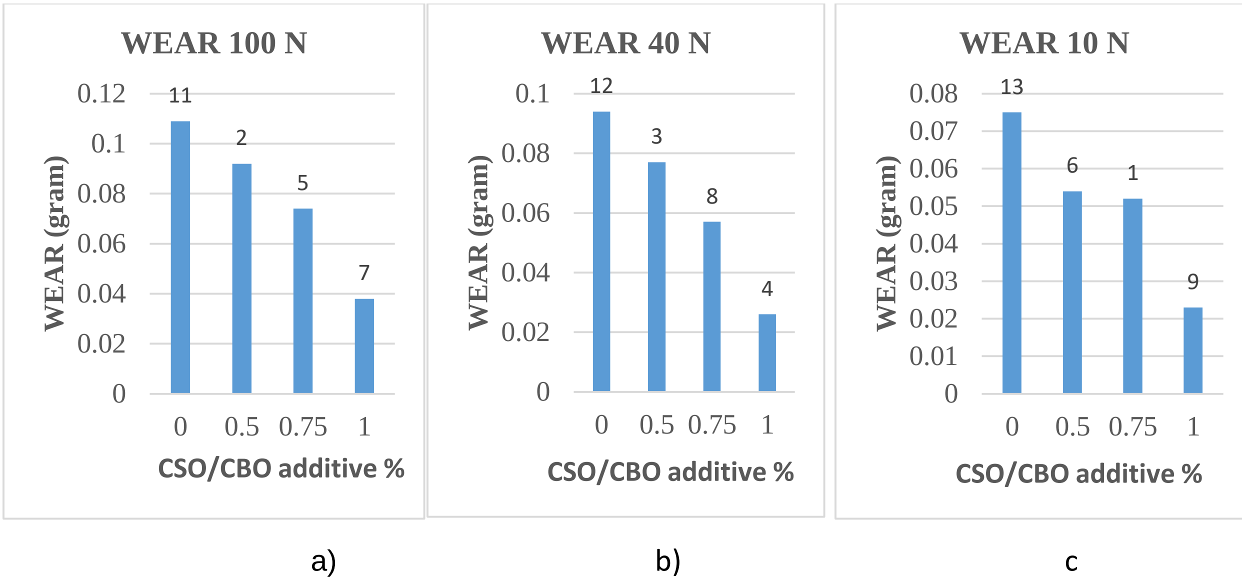


Figure 4.11 Wear comparison a) 100 N b) 40 N c) 10 N.

The amount or level of wear is acquired by the difference of mass between the ball before and after testing, during the test additive (CBO/CSO) 1%, 0.75%, 0.5 experiment number 1-10 obtained by DOE and 11-13 without DOE, its run for the computation purpose is using as a pure fuel and additive fuel between t h e ball on cylinder on the tribometer at the operating condition. And the using load has0.032-0.32 KG applied loads, and the time of operation 1 minutes. And the diameter of the ball is 12.7 mm. And after run the test results are and show the results in the above table.4.7 and 4.8 Experiment number 1-13.

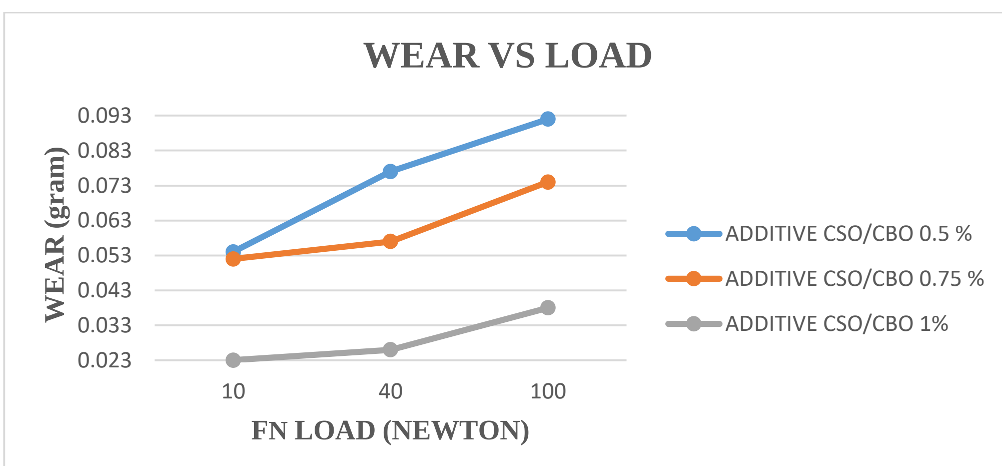


Figure 4.12.wear vs load

Figure 4.12 shows the wear compare with load, when the percent of CSO/CBO increases the wear decrease; the effects of load increase the value of the wear increase.

The Pareto chart shows each of the estimated effects in decreasing order of importance. The length of each bar is proportional to the standardized effect, which is the estimated effect divided by its standard error. This is equivalent to computing a t-statistic for each effect. The vertical line can be used to judge which effects are statistically significant. Any bars which extend beyond the line correspond to effects which are statistically significant at the 95.0% confidence level. In this case, 2 effects are significant.

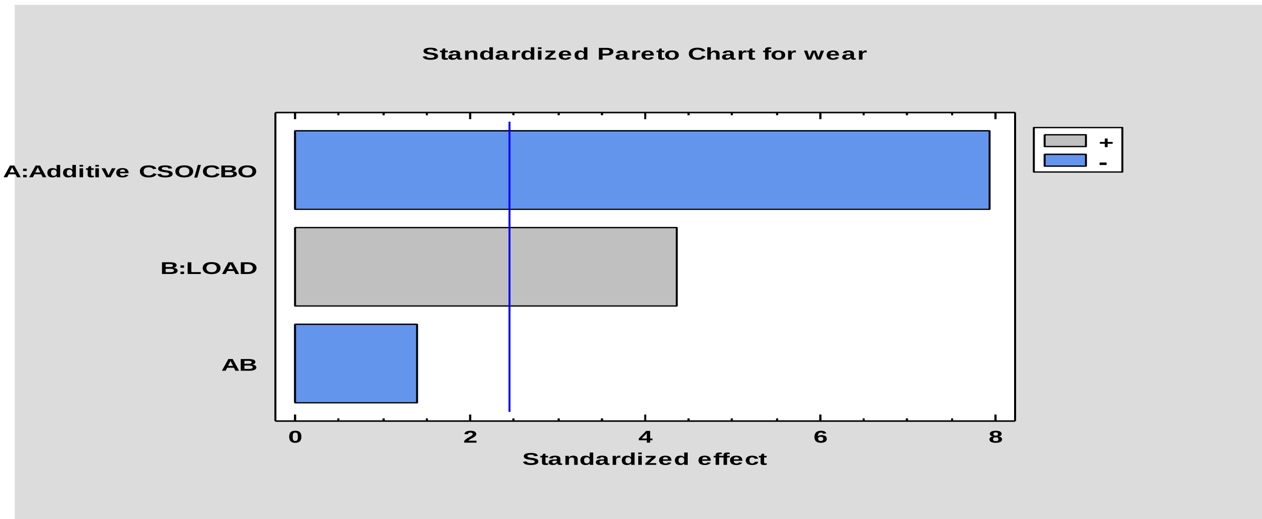


Figure 4.13 standardize Pareto chart for wear

Figure 4.13 shows the standardized Pareto chart for wear; the interaction of the response variable and standardized effects and its influence on the optimization model for wear. The highest effects and interaction for A (CBO/CSO), B (LOAD) are obtained and there is an influence for, AB and others were removed from the model that the values are very low. For the level of confidence given to simplify the model, it can see in table 4.15 on the Variance analysis for the level of significance

The Pareto chart shows each of the estimated effects in decreasing order of importance. The length of each bar is proportional to the standardized effect, which is the estimated effect divided by its standard error. This is equivalent to computing a t-statistic for each effect. The vertical line can be used to judge which effects are statistically significant. Any bars which extend beyond the line correspond to effects which are statistically significant at the 95.0% confidence level. In this case, 2 effects are significant.

Table 4.15 Variance analysis for the level of significance.

Analysis of Variance for wear

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
A:Additive CSO/CBO	0.00372862	1	0.00372862	62.85	0.0002
B:LOAD	0.00112603	1	0.00112603	18.98	0.0048
AB	0.000113953	1	0.000113953	1.92	0.2151
Total error	0.000355974	6	0.000059329		
Total (corr.)	0.0054885	9			

The ANOVA table partitions the variability in wear into separate pieces for each of the effects. It then tests the statistical significance of each effect by comparing the mean square against an estimate of the experimental error. In this case, 2 effects have P-values less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level.

The R-Squared statistic indicates that the model as fitted explains 93.5142% of the variability in wear. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 90.2713%. The standard error of the estimate shows the standard deviation of the residuals to be 0.00770253. The mean absolute error (MAE) of 0.0051901 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 5.0%, there is no indication of serial autocorrelation in the residuals at the 5.0% significance level.

The main factor effects are shown in the following figure.

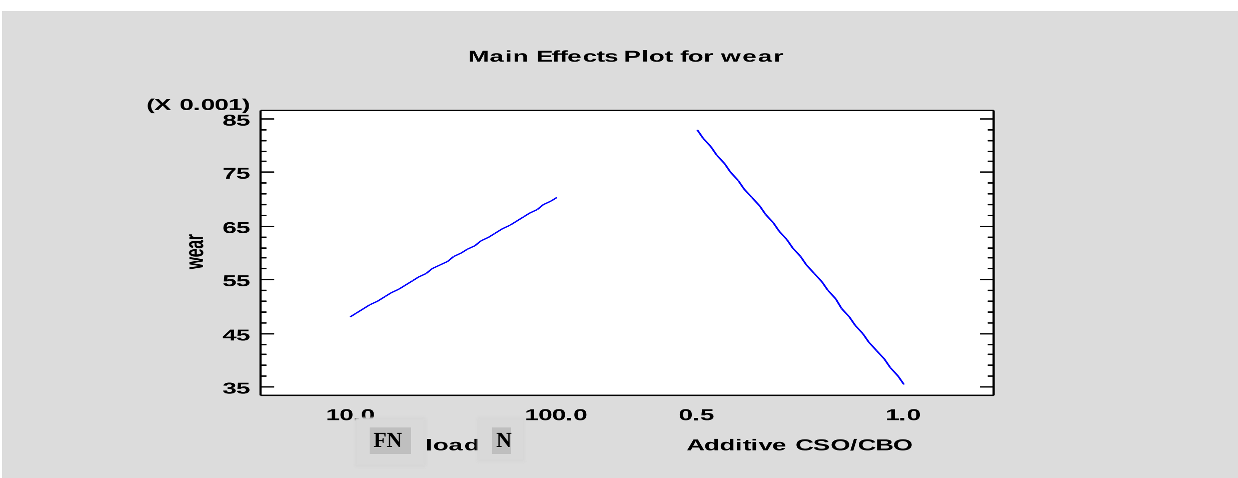


Figure 4.14 Graph of main effects for wear.

Figure 4.14 shows the estimated wear as a function of each experimental factor. In each plot, the factor of interest is varied from its low level to its high level, while all other factors are held constant at their central values. That the main effects of the factors on the wear, when the percent of CSO/CBO increases the wear decrease; and the load value decrease the wear decrease.

From the analysis of software to see, the combined effects of the factors on the COF for different samples, it is shown in the estimated response surface result for COF.

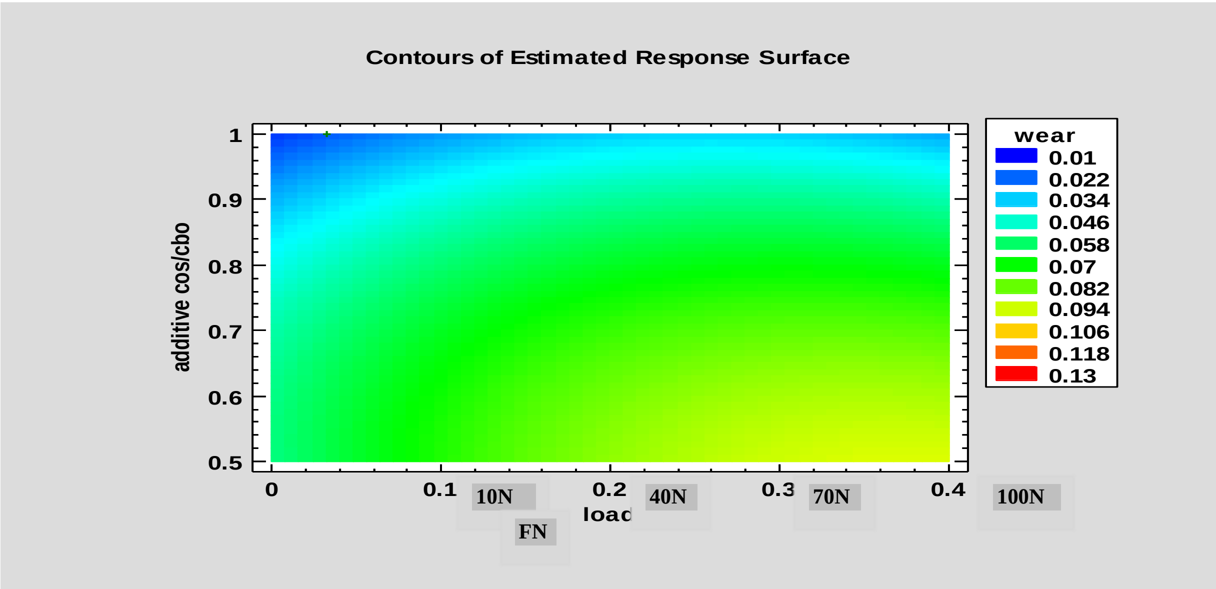


Figure 4.15 Contours of the estimated response surface for Wear.

Figure 4.15 shows contours for wear as a function of load and additive COS/CBO. Each contour line represents combinations of load and additive COS/CBO which give a selected value for wear. When the value of additive increase the wear is decrease and the load decrease the wear will be decrease.

4.2.3 Characterization of Experimental Fuels

Density

The density of new diesel is higher than a new diesel fuel. The density is measured by using Portable Density/specific gravity Figure 4.16 shows the density of the test fuel samples measured in Ethiopia's petroleum supply enterprise. The lower value of the density is necessary to obtain the additional engine power through the fuel flow control in the injection pump. Fuel consumption influences density. Thus, it is desired to have a less density fuel while consumption would be less. From the test results, it is found that the density of the D100 is the highest 850 kg/m^3 as shown in Figure 4.16.

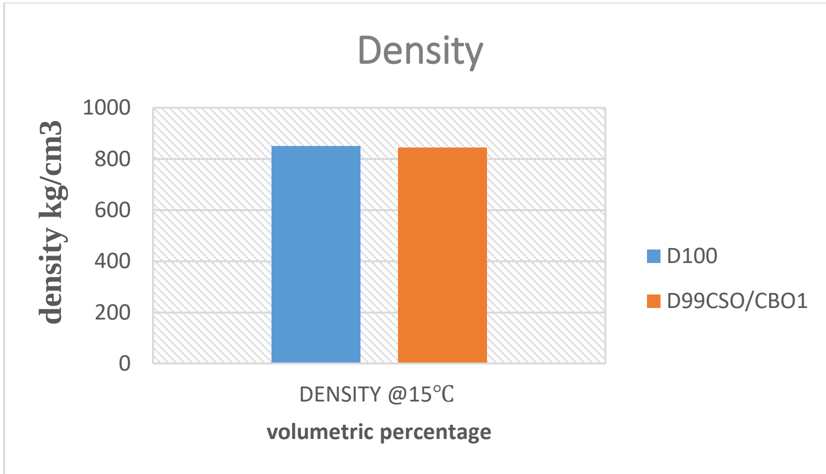


Figure 4.16 Density comparison.

Viscosity

Viscosity can be defined as the resistance of oil to flow by overcoming internal friction. Vegetable oils have very high viscosity to use as fuel in diesel engines. Under low temperatures viscosity has a greater impact on fuel to flow smoothly from the storage tank into the engine. Higher viscosity causes poor atomization of the fuel spray and inaccurate fuel injectors operation causes improper combustion in the engine cylinder. The following figure has shown the comparison between the results of the viscosity test, as it can see the viscosity for the samples D99CSO/CBO1 is less than with the D100 regarding the viscosity obtained.

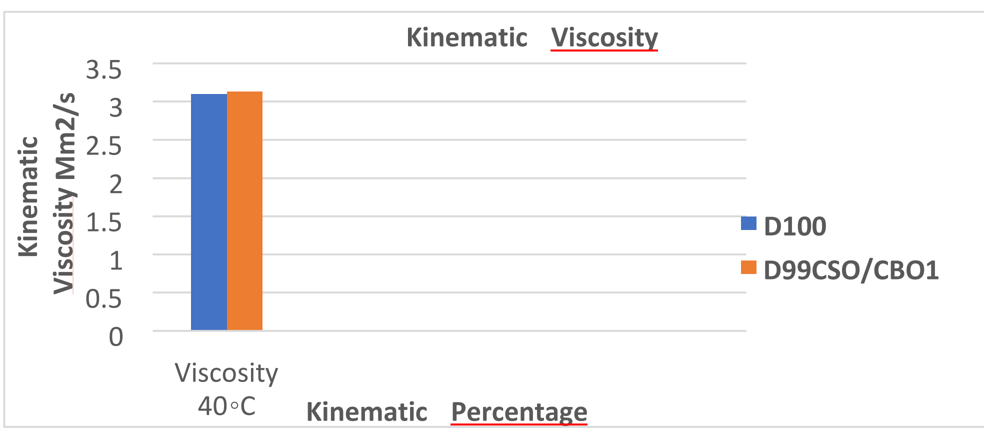


Figure 4.17 Viscosity comparison.

4.2.4 Performance

4.2.4.1 Break power

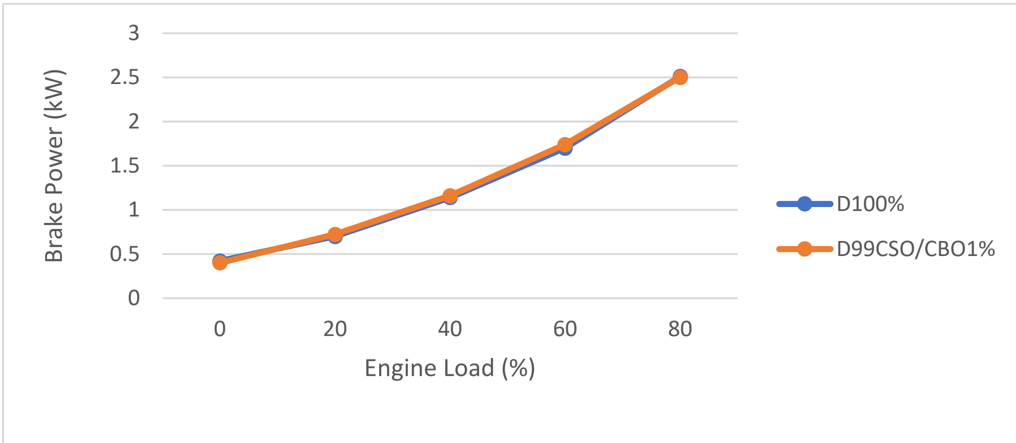


Figure 4.18 Break power vs engine load

(Figure 4.18) shows variations of brake power with engine load for new diesel substitution and diesel fuel. It is observed that brake power of diesel fuel is minimum as compared to new diesel substitution. The maximum increment of 8.8% brake power is achieved for D99CSO/CBO1 at 60% engine loads.

4.2.4.2 Break torque

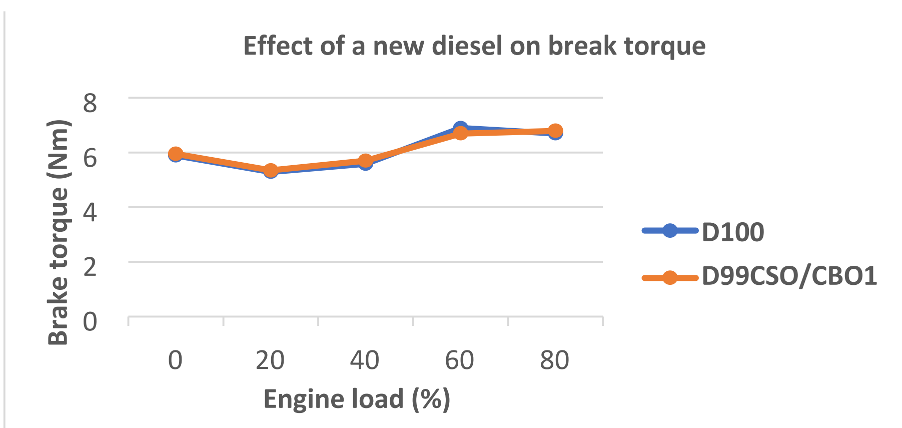


Figure 4.19 brake torque vs engine load

Brake torque variation with engine load is shown in Figure 4.19 above. Similar to power brake torque of diesel fuel is minimum as compared to a new diesel. The maximum increment of 15.8% is recorded for D99CSO/CBO1 at 60% load of the engine.

4.2.4.3 BSFC

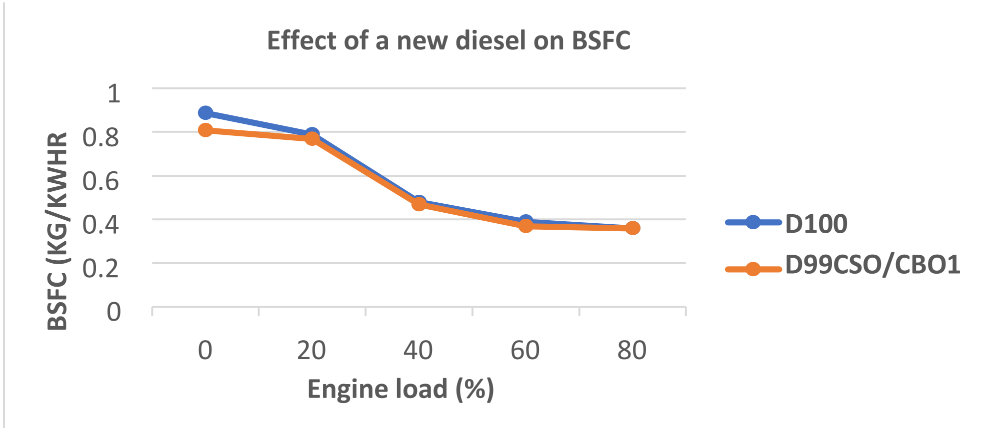


Figure 4.20 Brake specific fuel consumption vs engine load

Figure 4.20 shows the variation of brake specific fuel consumption with engine load for all tested fuel samples. It is observed that brake specific fuel consumption of diesel fuel is minimum as compared to a new diesel substitution with higher improvement beyond 40% engine loads. The D99CSO/CBO1 fuel showed maximum fuel consumption than other substitutions at lower loads (050%) conditions. Similarly, it was reported that the fuel consumption of a CI engine fueled with new diesel fuel is higher than diesel fuel especially for higher fuel content.

Even there are some differences, when it made the statistical analysis (using Stat graphics software) with different test to know if there are or not statistically significant difference between the results; as ANOVA, Verification of Variance and Kruskal-Wall is test, the following result was obtained:

ANOVA: Since the P-value of the F-ratio is greater than or equal to 0.05, there is no statistically significant difference between the means of the 2 variables with a 95.0% confidence level.

Verification of Variance: The statistics shown in this table evaluate the null hypothesis that the standard deviations within each of the 2 columns are equal. Of particular interest is the P-value. Since the P-value is greater than or equal to 0.05, there is no statistically significant difference between the standard deviations, with a 95.0% confidence level.

Kruskal-Wall is test: The Kruskal-Wall is test evaluates the null hypothesis that the medians within each of the 2 fuels is the same. First, the data from all the columns are combined and ordered from least to greatest. Then the average rank is calculated for the data in each column. Since the P-value is greater than or equal to 0.05, there is no statistically significant difference between the medians with a 95.0% confidence level. As it can see for all above result, there is no statistically significant difference between the results.

4.2.5 BTE

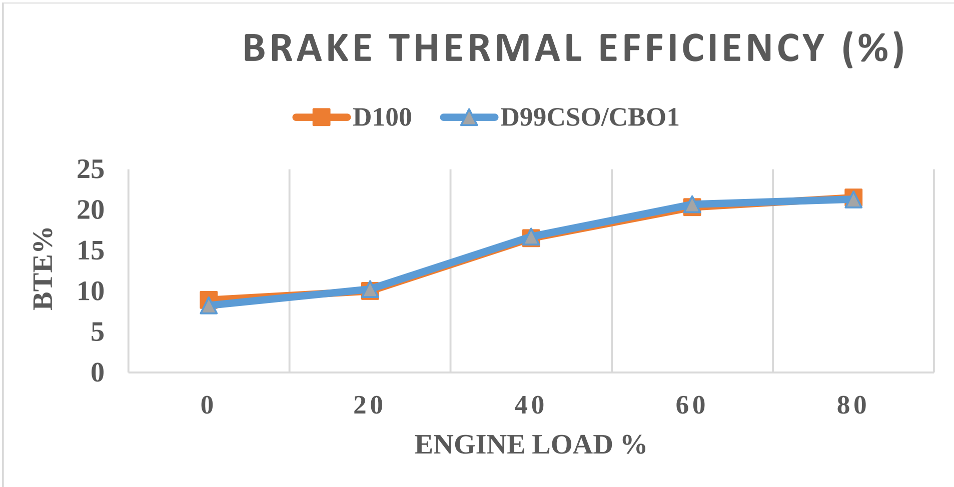


Figure 4.21 Variation of brake thermal efficiency with engine load

The variation of brake thermal efficiency of the engine with the new diesel fuel is shown Figure 4.21 and compared with the brake thermal efficiency obtained with diesel. It was observed that brake thermal efficiencies of new diesel fuel were found to be lower at all load levels. D99CSO/CBO1 is less thermally efficient than other ethanol dual fuels with maximum energy degradation of 24.4% at 60% engine load operation. Relating with Figure 4.21 brake thermal efficiency is the inverse implication of brake specific fuel consumption. So the effect of lower heating value was manifested as expected.

4.2.6 Exhaust emissions

Emission standards are requirements that set specific limits to the amount of pollutant that can be released into the environment. Many emission standards focused on regulating pollutant released by automobile and other powered vehicles but they can also regulate emissions from industry, power plants and diesel generators. In this investigation the emission outputs such as CO, CO2, HC and excess NOX of new diesel substitution fuels were measured and compared with reference diesel fuel emissions.

4.2.6.1 Carbon monoxide emission

The CO emission depends on the oxygen content, carbon content and combustion efficiency of a fuel. During combustion, the carbon present in the fuel oxidizes to form CO emission, which is then converted into CO2. However, if the available oxygen is lower, it causes incomplete combustion and hence comes with higher CO value.

The figure represents the variation of carbon monoxide for the load. Incomplete combustion of fuel results in the formation of carbon monoxide. Diesel fuel does not contain any inherent oxygen therefore combustion does not take place completely. As new diesel fuel is not oxygen-rich fuel because the content of cottonseed fuel is very low, therefore results in almost the same carbon monoxide emission

Table 4.16 CO Emission results for various fuels

Engine load %	CO Emissions in (% vol)	
	D100	ADD 1%
0	0.099	0.086
20	0.109	0.088
40	0.119	0.098
60	0.141	0.118
80	0.168	0.123

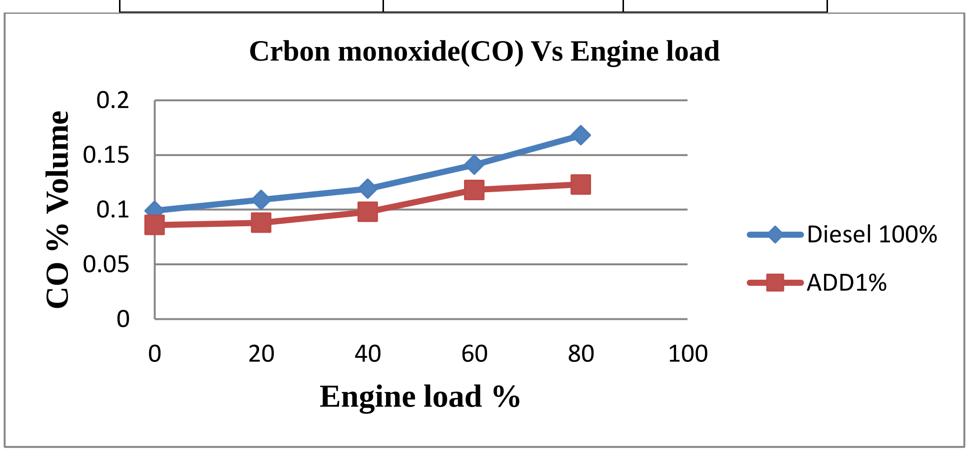


Figure 4.22 Variation of HC emissions with engine load

4.2.6.2 Carbon Dioxide Emission (CO_2)

Table 4.17 CO2 Emission results for various fuels

Engine load %	CO2 Emissions in (% vol)	
	D100	ADD 1%
0	2.05	2.03
20	3.1	3.2
40	4.6	4.3
60	4.1	4.6
80	6.2	6.3

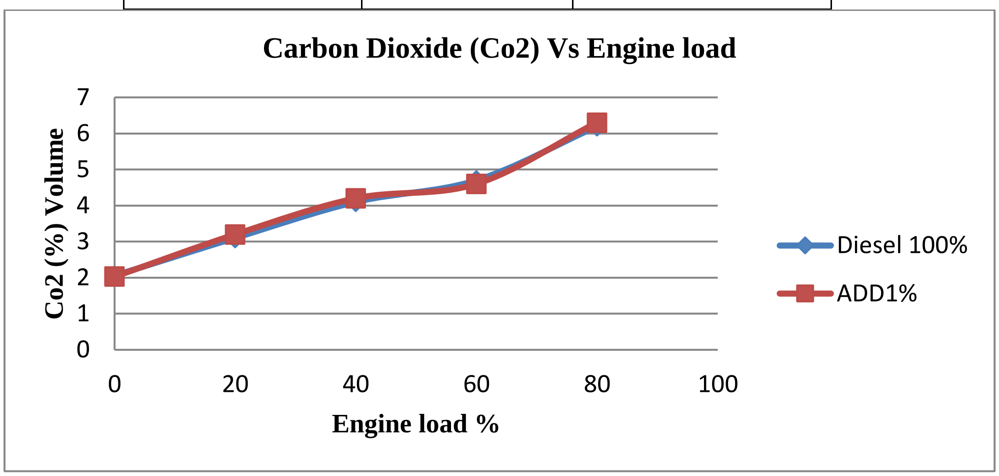


Figure 4. 23 Variation of CO2 emissions with engine load

(Figure 4.23) shows the variation of carbon dioxide (CO2) emission with respect to load. It is observed that the CO2 emission increases with load for both fuels. They may be due to more complete combustion favored of increased cylinder temperature to accelerate vaporization and ease of ignition initiation at higher loads. It is seen that the fuel at D100 substitution produces maximum percentage of CO2 at different load conditions. The average CO2 emission increment of both fuels D100 and D99CSO/CBO1 was the same. This may be due to the fact that CSO/CBO content of a new diesel which results no variation of CO2.

4.2.6.3 Hydrocarbon (HC) emission

The unburned hydrocarbon emission affects the engine performance unfavorably due to incomplete combustion of fuel. Figure 4.24 shows the emission of HC with respect to load for both fuels. It found that hydrocarbon emissions increased slightly with engine load for both tested fuels. This may be due to increased fuel injection to increase brake torque while engine rpm is kept constant.

Hydrocarbons in the exhaust are a result of incomplete burning of the carbon compounds in the fuel. Initially, both fuels have lower values owing to higher combustion chamber temperature which helps in cracking and faster burning. But as the load is increased, fuel consumption increases which results reduction of oxygen in the fuel-air mixture and leads to higher exhausts.

Table 4.18 HC Emission results for various fuels

Engine load %	**HC emissions in (ppm)**	
	D100	ADD 1%
0	20	18
20	17	15
40	20	18
60	19	17
80	20	12

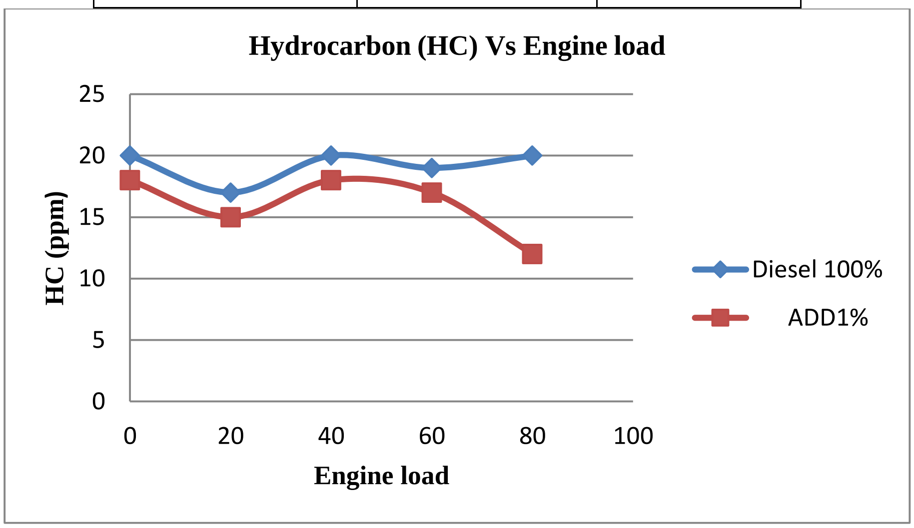


Figure 4. 24 Variation of HC emissions with engine load

4.2.6.4 Nitrogen oxide emissions

Table 4.19 NOX Emission results for various fuels

Engine load %	**HC emissions in (ppm)**	
	D100	ADD 1%
0	24	24.5
20	38	37
40	59	58.9
60	64	63.5
80	85	85

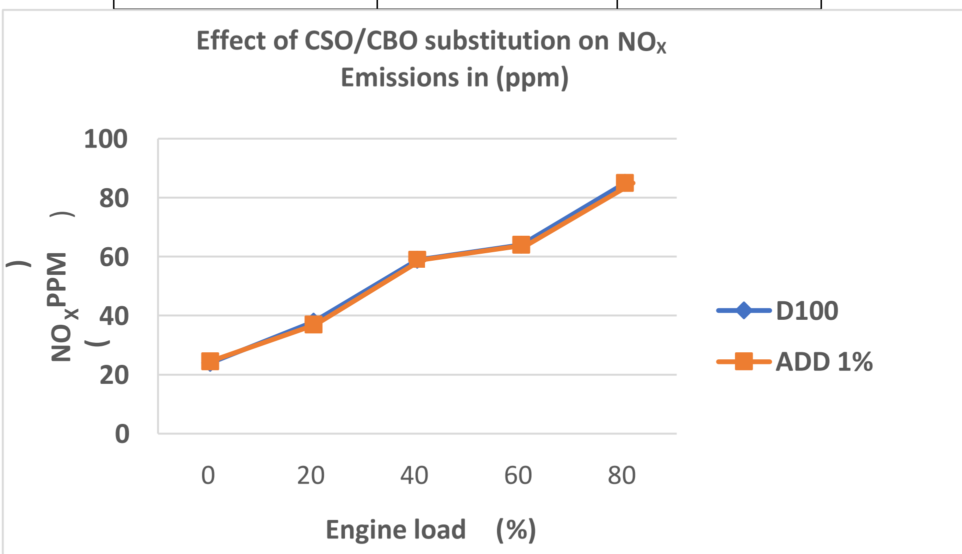


Figure 4.25 Variation of NOx emissions vs engine load of all tested

The variation of NOx emission for both diesel fuel is indicated in Figure 4.25. The NOx emission for net diesel and new diesel with an additive cottonseed and castor bean oil fuels followed an increasing trend with respect to load by slight increment up to 40% with steep transition to 60% and nearly flat curve for 60-100% loads. This is due to higher exhaust temperature which increases with load, but beyond 60% temperature increment is insignificant due to lower volumetric efficiency.

CHAPTER FIVE

5. Conclusion and Recommendation

5.1 Conclusion

The main objectives of this research were to characterize castor bean and cotton seed oil as an additive in diesel fuel; to investigate its tribological behavior experimentally and evaluate performances in terms of wear, friction coefficient, lubricity, and emission. In this thesis work cotton seed oil and castor bean was selected for experimentation as an additive of diesel fuel. Essential physical and chemical properties of the cotton seed oil and castor bean oil As a result, the following conclusive findings have been obtained.

1. As compared with pure diesel fuel, adding 1% of cotton seed and castor bean oil (which is the highest ratio selected for the investigation) As the percentage of castor bean and cotton seed oil added to the pure diesel fuel is increased (maximum ratio of 1%), the coefficient of friction was seen decreasing for the same load and duration of the operation.
2. As compared with pure diesel fuel, adding 1% of cotton seed and castor bean oil (which is the highest ratio selected for the investigation) As the percentage of cotton seed and castor bean oil added to the pure diesel fuel is increased (maximum ratio of 1%), the wear in the unit of gram was seen decreasing for the same load and duration of the operation.
3. The result of data analysis using ANOVA and standardized Pareto chart for dependent variable wear, time (duration of operation) has no level of significance as a percentage of load and cotton seed, castor bean oil have. This means that wear increases as a percentage of load increases while wear decreases as the cotton seed and castor bean oil ratio increases.
4. Lubricity is seen greatly improved when cotton seed and castor bean oil is used as an additive rather than using pure diesel fuel.
5. Engine performance and efficiency in terms of brake power, brake torque, fuel consumption, and brake thermal efficiency show the same effect at different engine loads for pure diesel fuel and castor bean and cotton seed oil blend of 1%.
6. Castor bean and cotton seed oil blend tends to decrease Carbon monoxide (CO) and hydrocarbon (HC) emissions, at different engine loads, as compared to pure diesel fuel.
7. Carbon dioxide (CO_2) emission increases with an increase of engine load showing no significant effect whether castor bean and cotton seed oil blend or pure diesel fuel is used.

5.2 Recommendation

This thesis was done only with fuel of D99.5CSO/CBO 0.5 D99.25CSO/CBO 0.75 and D99CSO/CBO 1 and checks the performance and emission comparing with the low sulfur conventional diesel. The researcher recommends this result can be used as starting point for further study to evaluate more details and other properties and to evaluate the possibility to use castor bean and cotton seed oil as an additive in other fuels and additives. To improve its tribological properties. And the study of castor bean and cotton seed oil has can be used as a resource to obtain additives. This allows the generation of country side growth and increasing profits. So the development on testing extra fuel property and fuel characteristics blending situation there is no experimental equipment in Ethiopia. Ethiopian petroleum supply enterprise only 3 tests are done and engine performance and emission tests are necessary. Ethiopia is superior in the agricultural sector; the plantation coverage of caster bean and cotton seed is located in different areas. The performance and emission test is done on a Computer-controlled taste bench. For single cylinder-engine.7.5kw which is found in Addis Ababa Science and Technology University Department of Electrical and Mechanical Engineering College. Therefore the accuracy of the measurement is sufficient to measure different speeds, engine load, power, torque, mass airflow meter, and volumetric efficiency of the fuel. By product of castor bean oil in other European countries could be used for different purposes.

5.3 Future work

This thesis study on evaluation on the tribological properties of a diesel fuel mixed with cottonseed castor bean oil as an additive, these issues are still interesting and are proposed as future work. This thesis was done only with the fuel of D99.5CSO/CBO0.5, D99.25CSO/CBO0.75and D99CSO/CBO1 and checks lubricity comparing with the conventional diesel and also this thesis will measure performance and emission. In the future it is recommendable to conduct with other high or low percentage of cotton seed and castor bean oil.

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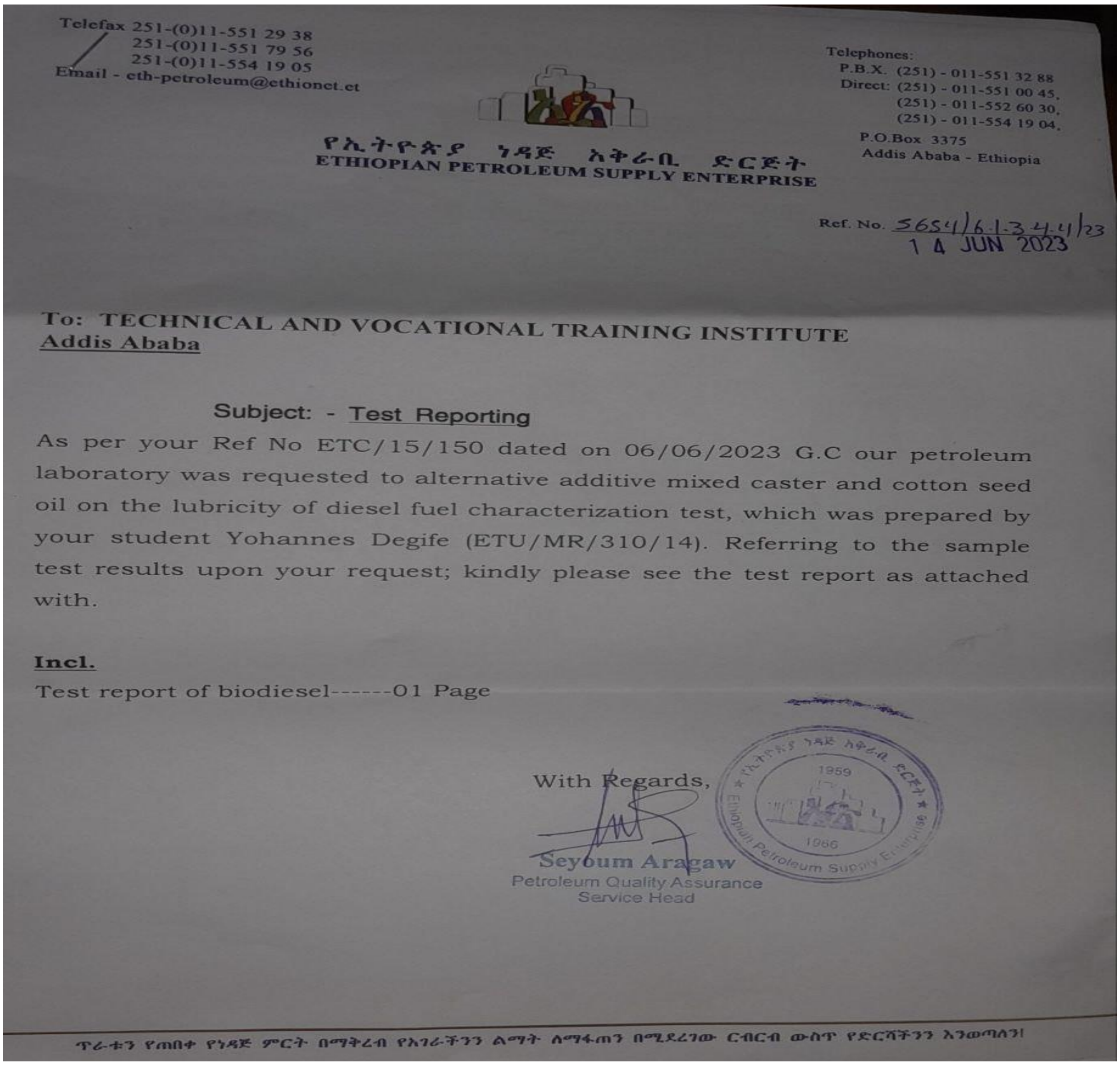
APPENDICES

Appendix-A

The below data show the results of the fuel samples characterized by Ethiopian Petroleum Supply Enterprise (EPSE).



Telefax 251-(0)11-551 29 38
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Addis Ababa - Ethiopia

የኢትዮጵያ ነዳጅ አቅራቢ ድርጅት
ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE

Ref. No. 5654/6.1.3.4.4/23
14 JUN 2023

To: TECHNICAL AND VOCATIONAL TRAINING INSTITUTE
Addis Ababa

Subject: - Test Reporting

As per your Ref No ETC/15/150 dated on 06/06/2023 G.C our petroleum laboratory was requested to alternative additive mixed caster and cotton seed oil on the lubricity of diesel fuel characterization test, which was prepared by your student Yohannes Degife (ETU/MR/310/14). Referring to the sample test results upon your request; kindly please see the test report as attached with.

Incl.
Test report of biodiesel------01 Page

With Regards,

Seyoum Aragaw
Petroleum Quality Assurance
Service Head

ጥራቱን የጠበቀ የነዳጅ ምርት በማቅረብ የአገራችንን ልማት ለማፋጠን በሚደረገው ርብርብ ውስጥ የድርሻችንን እንወጣለን!

[ET]HIOPIAN PETROLEUM SUPPLY ENTERPRISE QUALITY ASSURANCE SERVICE

Document No: OF/EPSE/QAS/033

Page 1 of 1

ENAO

TITLE: **CERTIFICATE OF TEST REPORT**

Issue No.: 2 | Date of Issue: August,2020

Prepared by: QT | Approved by: Tadesse H/Mariam

Sample Originator: TECHNICAL AND VOCATIONAL TRAINING INSTITUTE	Request No: ETC/15/150
Sample Type: BIODISEL	Analytical Method: ASTM /IP/ISO.
Sample Number: 01	Analytical Result: Interpreted with stds.
Lab. Number: 2023- ADO-EXT-18	Report No: QA/0020/2023
Sample Submitted By: CUSTOMER	Test date: 12/06/2023
Date Submitted: 08/06/2023	Issued Date: 14/06/2023
Customer Address: ADDIS ABABA	Telephone. +251- 922-16-63-21

S.N	Property	Test method ASTM	Limits	Test results of the BIODIESEL sample D99% & CBO/CSO 1%	MU
1	Density@15°C, g/mL	D4052	Report	0.8448	0.0002
	Density@20°C, g/mL	D4052	Report	0.8406	0.0002
2	Kinematic viscosity @ 40 °c	D 445		3.2692	
3	Calorific value, calc, BTU/LB	Calculated		19,566.80	

Liability:- Ethiopian Petroleum supply Enterprise, its Laboratory, its Servants or agents Shall not be held liable for any damages, loss, claims or expenses direct or indirect howsoever caused, arising in connection with the laboratory test carried out on **BIODIESEL** sample submitted to it for analysis whether in tort or in contract, due to any act, omission or error of whatever nature, whether or not negligence and howsoever caused. Furthermore all expenses and implied warranties are specifically disclaimed. This test report shall not be reproduced or given to a third party without written approval of the **Petroleum Quality Assurance Service**.

Lab. Expert	Senior expert	Quality Control Head
Name--Melaeb. M.	Name------------------	Name--
Signature--	Signature-------------	Signature--

1959 Ethiopian Petroleum Su[pply] Enterprise 1966

PLEAS MAKE SURE THAT THIS IS THE CORRECT ISSUE BEFORE USE

The below data show the results of the fuel samples performance and exhaust emission by Addis Ababa Science And Technology University.

Addis Ababa Science and Technology University

✓ Performance and exhaust emission test result

Table 1 Engine power under varying engine load for different volume flow rates of net diesel fuel

14 June 2023	16:08:53	Diesel 100%										
Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power (kW)
792.3	19.583	68.804	24.041	84.03	31.267	91.755	6.961	0.958	7.464	3577	54.745	2.51
1001.4	20.713	144.574	25.423	82.393	31.816	86.865	0.000	0.966	5.9	2352	55.481	1.7
1092.9	20.948	195.872	26.426	84.146	34.721	79.045	0.000	0.965	5.6	1943.963	57.804	1.14
1254.5	21.183	236.283	26.085	87.018	39.329	62.666	0.000	0.96	5.3	1261.277	64.305	0.7
1260.6	21.220	216.185	26.464	89.963	37.88	42.005	0.000	0.952	5.9	679	72.291	0.42

Table 2 Engine power under varying engine load for different volume flow rates of diesel fuel with and additive of cottonseed oil

14 June 2023	16:08:53	Diesel 99 % and CBO / CSO 1 %										
Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	SC-1	SC-2	SP-1	Torque	SV-1	ST-6	Power (kW)
83.2	21.951	88.271	25.08	69.723	33.843	92.266	8.883	0.965	6.8	3510.77	50.263	2.5
166.7	22102	100.89	25.214	71.444	31.764	86.759	0.000	0.964	6.7	2479.966	50.677	1.74
249.7	22.066	99.29	25.369	72.269	31.268	75.29	0.000	0.965	5.7	1943.365	52.312	1.16
326	22.107	83.948	25.291	72.058	31.341	58.482	0.000	0.964	5.35	1285.139	54.258	0.72
370.1	22.191	75.505	25.311	71.761	30.316	29.91	0.000	0.963	5.95	691.969	55.387	0.4

Head, Department of Mechanical Engineering

Table 3 Exhaust Emission under varying engine load for net diesel fuel

Exhaust Emission 14 June 2023 16:08:53 Diesel 100%				
Engine Load (%)	Hydrocarbon (Hc)(ppm)	Carbon Monoxide (CO)(% vol)	Carbon Dioxide (CO2)(% vol)	Nitrogen oxide (NOX)(ppm)
0	20	0.099	2.05	24
20	17	0.109	3.1	38
40	20	0.119	4.6	59
60	19	0.141	4.1	64
80	20	0.168	6.2	85

Table 4 Exhaust Emission under varying engine load for diesel fuel with and additive of cottonseed and castor bean oil.

Exhaust Emission 14 June 2023 16:08:53 Diesel 99 % And CBO / CSO 1 %				
Engine Load %	Hydrocarbon (Hc) (ppm)	Carbone Monoxide (CO) (% vol)	Carbone Dioxide (CO2)(% vol)	Nitrogen oxide (NOX)(ppm)
0	18	0.086	2.03	24.5
20	15	0.088	3.2	37
40	18	0.098	4.3	58.9
60	17	0.118	4.6	[illegible]
80	12	0.123	6.3	[illegible]

Head, Department of
Mechanical Engineering

Appendix-B Tribometer

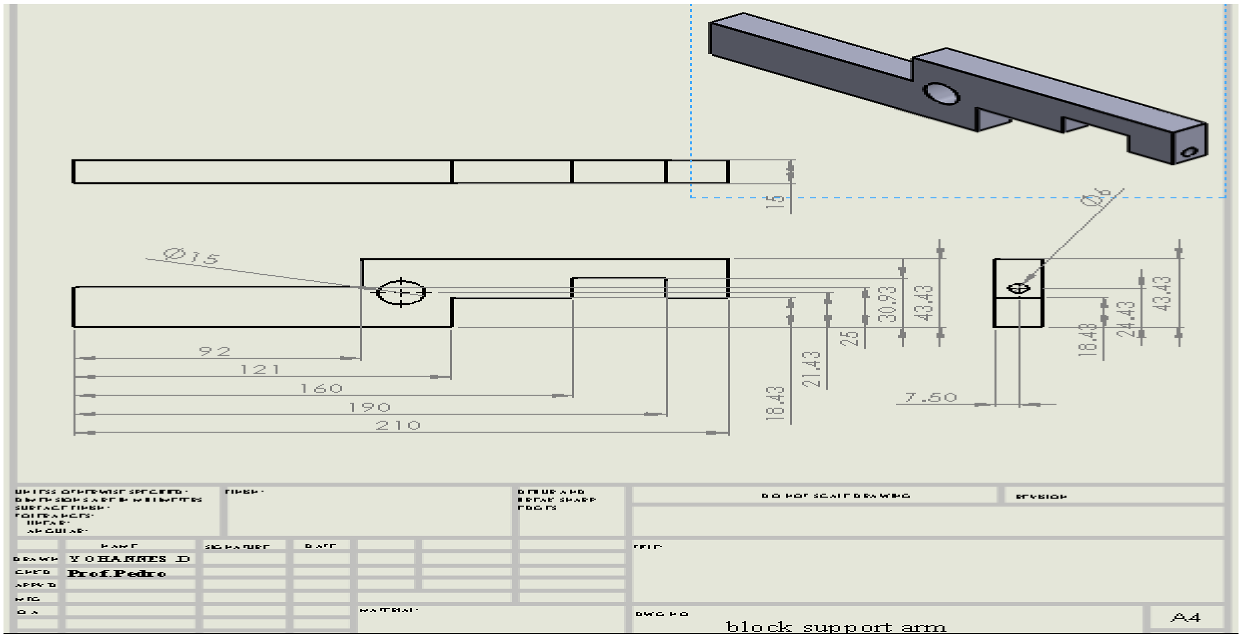
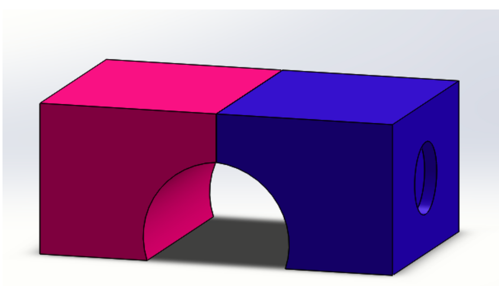


Figure B 1: modified Specimen support arm



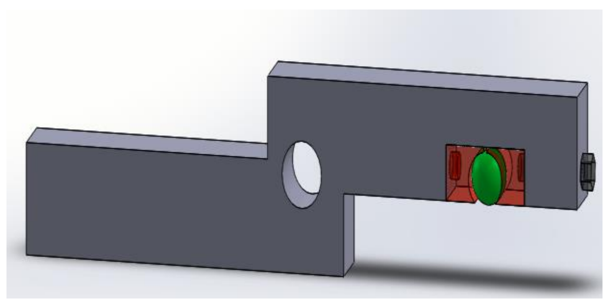


Figure B 2: Modified Ball holder

Figure B 3: modified Specimen support arm

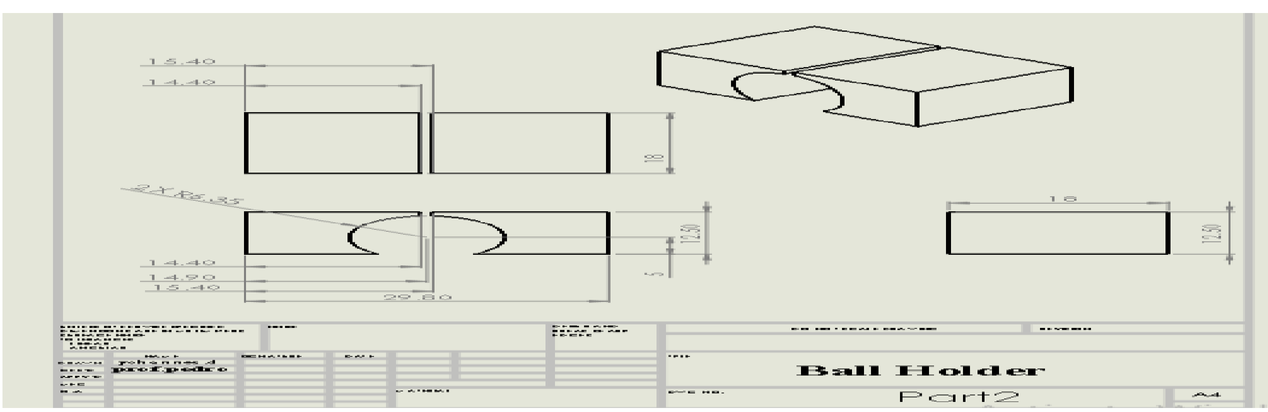


Figure B 2: dimension of modified ball holder

Appendix-C

Steps for experimental design wizard of statgrahics for diesel fuel with an additive of cottonseed oil and castor bean oil

Experimental Design Wizard

Table c 1 Step 1: Define the response variables to be measured

Name	*Units*	*Analyze*	*Goal*	*Target*	*Impact*	*Sensitivity*	*Low*	*High*
wear	gram	Mean	Minimize		3.0	Medium	0.01	0.5
cofficient of friction		Mean	Minimize		3.0	Medium	0.3	0.8

Table c 2 Step 2: Define the experimental factors to be varied

Name	*Units*	*Type*	*Role*	*Low*	*High*	*Levels*
A:load	N	Continuous	Controllable	10	100	
B:additive cos/cbo	%	Continuous	Controllable	0.5	1.0	

Table c 3 Step 3: Select the experimental design

Type of Factors	*Design Type*	*Centerpoints Per Block*	*Centerpoint Placement*	*Design is Randomized*	*Number of Replicates*
Process	Multilevel factorial	0	Random	Yes	0

Type of Factors	*Total Runs*	*Total Blocks*	*Error D.F.*
Process	12	1	6

Number of samples per run: 1

Table c 4 Step 4: Specify the initial model to be fit to the experimental results

Factors	*Model*	*Coefficients*	*Excluded effects*
Process	2-factor interactions	4	

Step 5: Select an optimal subset of the runs (optional)
10 runs selected

Step 6: Select tables and graphs to evaluate the selected runs
To display design diagnostics, use the checkbox on the Analysis Options dialog box.

Step 7: Save the experiment
Design file: C:\Users\jo \Desktop\jone 1.sgx

Table c 5 Step 8: Analyze the experimental results

Model	*wear*	*cofficient of friction*
Transformation	none	none
Model d.f.	5	5
P-value	0.0051	0.0120
Error d.f.	4	4
Stnd. error	0.00759883	0.037515
R-squared	96.53	94.62
Adj. R-squared	92.20	87.88

<u>Step 9: Optimize the responses</u>
Response Values at Optimum

<u>Step 10: Save the results</u>
The results of the analysis may be saved in a StatFolio.

<u>Step 11: Augment design</u>
Execute this step to add additional runs to the design.

<u>Step 12: Extrapolate model</u>
Execute this step to find better operating conditions.

Appendix –D Material and equipment's

a. Front view b. Rear view

Figure: D 1 Experimental setup of TBM3 test bench for single-cylinder diesel engine

Figure: D 2 Visco meter

Figure: D 3 the exhaust gas analyzer SV-5

Figure: D 4 Power meter

Figure D 5: flash point tester

Appendix-E

PHOTO GALLERY

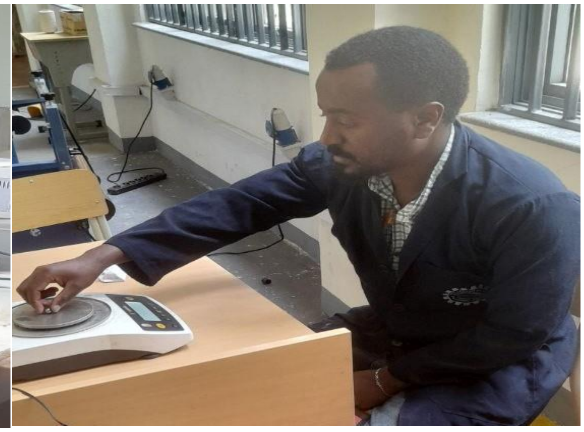


Figure E 1: oil density test

Figure E 2 : Specimen measuring

Figure E 3: Wear loss and COF testing

Figure E 4: preparing for testing

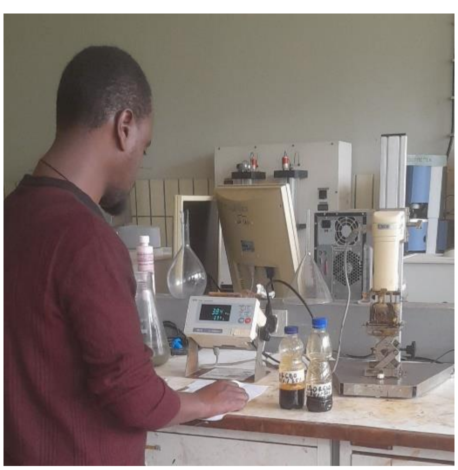


Figure E 5 oil visco meter test

figure E 6: drilling

figure E 7: lathe operation

Figure E 8: ball holder grinding

Coefficients of friction calculation

$$\mu = \frac{P_{load} - P_{not\ load}}{V_{linear} * N}$$

Where: μ= coefficient of friction

P_{load}= Power measured in the electric motor when it is loaded with the test.

$P_{not\ load}$= Power measured in the electric motor when it is working without load.

V_{linear} = Linear speed of the ring in contact with the element subjected to friction.

Linear speed = angular velocity *x radius of the rotation*

V_{linear} = ωr

V_{linear} = linear speed (m/s)

ω = angular speed (radians/s)

r = radius of the rotation of ring (m)

ω= 2π (rpm)/60

N= Normal force of the element subjected to friction on the ring.

P_{not} load= 282w

r= 0.02m

Rpm= 520, 515, and 510 and 505 this rpm value is given based on applied load which are 10N, 20N, 50Nand 100N respectively. According to the above parameter, the coefficients of friction were calculated for each blended fuel and applied load as follows.

V_{linear} = ωr

V_{linear} = 2π (520)/60*0.02m= 1.0885m/s

V_{linear} = 2π (515)/60*0.02m= 1.07806m/s

V_{linear} = 2π (510)/60*0.02m= 1.0676m/s

V_{linear} = 2π (502)/60*0.02m= 1.0571m/s

1. Using D- 99.25% and CBO/CSO 0.75 % at load 10N, 20N, 50N and 100N respectively.

$$\mu = \frac{287w - 282w}{\frac{1.0885m}{s} * 10N} = 0.459$$

$$\mu = \frac{304w - 282w}{\frac{1.07806m}{s} * 40N} = 0.510$$

$$\mu = \frac{322w - 282w}{\frac{1.0676m}{s} * 70N} = 0.535$$

$$\mu = \frac{346w - 282w}{\frac{1.0571m}{s} * 100N} = 0.605$$

2. Using D-99.5% and CBO/CSO 0.5% at load 10N, 20N, 50N and 100N respectively.

$$\mu = \frac{288w - 282w}{\frac{1.0885m}{s} * 10N} = 0.551$$

$$\mu = \frac{308w - 282w}{\frac{1.07806m}{s} * 40N} = 0.602$$

$$\mu = \frac{328w - 282w}{\frac{1.0676m}{s} * 70N} = 0.618$$

$$\mu = \frac{348w - 282w}{\frac{1.0571m}{s} * 100N} = 0.624$$

3. Using D-99% and CB0/CSO 1% at load 1015.32N, 1353.76N, and 1692.2N respectively.

$$\mu = \frac{286w - 282w}{\frac{1.08853m}{s} * 10N} = 0.367$$

$$\mu = \frac{298w - 282w}{\frac{1.07806m}{s} * 40N} = 0.371$$

$$\mu = \frac{315w - 282w}{\frac{1.0676m}{s} * 70N} = 0.449$$

$$\mu = \frac{333w - 282w}{\frac{1.0571m}{s} 100N} = 0.482$$

TRIBOLOGICAL TEST RESULT							
	applied load	**time**	**temperature**	**Normal load**	**power consumption**	**wear loss**	**coefficient of friction**
D-99.25% and CBO/CSO 0.75%	**gram**	**min**	**℃**	**N**	**watt**	**gram**	
1	32	1	41	10	287	0.052	0.459
2	64	1	55	40	304	0.057	0.510
3	160	1	66	70	322	0.072	0.535
4	320	1	70	100	346	0.074	0.605
D-99.5% and CBO/CSO 0.5%							
1	32	1	42	10	288	0.054	0.551
2	64	1	50	40	308	0.077	0.602
3	160	1	56	70	328	0.087	0.618
4	320	1	60	100	348	0.092	0.624
D-99% and CBO/CSO 1%							
1	32	1	55	10	286	0.023	0.367
2	64	1	56	40	298	0.026	0.371
3	160	1	60	70	315	0.028	0.449
4	320	1	68	100	333	0.038	0.482
D-100%							
1	32	1	40	10	293	0.075	0.643
2	64	1	45	40	303	0.094	0.649
3	160	1	51	70	320	0.101	0.711
4	320	1	61	100	335	0.109	0.728