ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

Experimental Investigation of the effect of Jatropha Straight Vegetable oil (JSVO) fuel on small scale Diesel Engine Lubricating oil Properties and Hardware

Thesis

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

Anwar Haregot

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Co-Adviser: Mr. Hadish Teklehaimanot

MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

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Adama

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**Experimental Investigation of the effect of Jatropha Straight Vegetable oil (JSVO)fuel on small scale Diesel Engine Lubricating oil Properties and Hardware**" in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from November , 2015 to May, 2016 under the supervision of N.Ramesh Babu, Associate Professor, Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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1. Main Advisor		
_____	_____	_____
2. Co-adviser		

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Approved by board of Examiners

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ACRONYMS AND ABBREVIATIONS

JSVO	Jatropha Straight Vegetable oil
ASTM	American Standard Test Method
SAE	Society of American Engineers
SVO	Sight Vegetable oil
ASTU	Adama Science and Technology University
AAS	Atomic absorption Spectropy
AL	Aluminum
CU	Copper
Ir	Iron
Pb	Lead
Mg	Magnesium
DDO	Distillate Diesel Oil
GHG	Greenhouse gas
DPF	Diesel Particle Filters
HSDI	High speed direct injection
ULSD	Ultra-low sulfur diesel fuel
TBN	Total base number
TAN	Total acid number
LOME	Linseed Oil Methyl Ester
ECR	Electrical Contact Resistant
HFRR	High Frequency Reciprocating Rig
CI	Compression Ignition Engine
API	American Petroleum Institute
cSt	Centistokes
VI	Viscosity Index
TDC	Top dead center
BDC	Bottom dead center
IS	Indian Standard

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ABSTRACT

Current demand of transport fuel requires exploring every possible plant resource of engine fuel which can deliver satisfactory performance, emission, combustion and engine durability. Straight vegetable oil (SVO) is an alternative fuel of petroleum diesel, and mainly used to reduce the environmental impact of emission without modifying engines. Until now, much of the primary research has focused on process technologies to produce straight vegetable oil as a fuel from different sources such as palm, sunflower, rapeseed and jatropha curcas. There have also been studies looking at the impact of the use of SVO on exhaust emission, engine performance, and fuel economy and fuel system compatibility. There is limited data on the effect of SVO use on engine lubricant which is necessary to investigate usability of different fuels and their impact on engine hardware and lubricant properties due to oil contamination in combustion engines which may affect the critical components and functions of lubrication necessary to maintain engine performance and useful service life of the engine. This research work presents experimental investigation of the effect of Jatropha straight vegetable oil (JSVO) fuel on the engine lubricant properties and hardware. An endurance test were made according to IS:10000 (Part IX)-1980 for a total 75 hours on two brand new identical Robin DY23-2D air cooled single cylinder diesel engines with two types of fuel (JSVO and diesel fuel) while the engines use the same engine oil SAE 30 according to the manufacturer recommendation. The engine oil samples were drawn at interval of 25 hours and tested with ASTM standard test methods D93, D189, D445, D482, D947, D2270, D2709 and D4052. The test results from the engine oil sample were analyzed for the basic lubricating oil properties (kinematic viscosity, viscosity index, density, carbon residue, water and sediment, total acid number, flash-point and Ash content) and it is found that the variation in these properties not much with JSVO when compared to diesel and the viscosity of oil with JSVO is within the range prescribed for lubrication oil SAE 30. So it can be conclude that usage of JSVO doesn't affect much the lubrication oil and it's possible to use JSVO as a fuel. From the analysis of the wear it is observed that the wear of the parts in combustion chamber are higher for JSVO which is due to high carbon deposits.

KEYWORDS: *Jatropha Straight Vegetable oil, engine oil, lubrication properties, lubrication characteristic, wear.*

1. INTRODUCTION

1.1. Background

Diesel engines are widely used in the transport, electricity generation, agriculture and shaft power etc. These sectors are heavy consumers of petroleum oils which can be partially or totally replaced by vegetable oils and their derivatives which are derived from agriculture and thus of renewable origin. Many studies have been done involving vegetable oils as a primary source of energy. Particularly, during the early 1980's, studies were completed that tested the possibility of using unmodified vegetable oils as a replacement for diesel fuel and there is no question that vegetable oil can be placed in the tank of a diesel powered vehicle and the engine will continue to run and deliver acceptable performance.

Despite the success when diesel engines are operated on vegetable oil for short term performance tests, the real measure of success when using vegetable oil as a diesel fuel extender or replacement depends primarily on the performance of vegetable oils in engines over a long period of time. The viscosity and chemical property differences between SVO and the diesel fuel for which direct inject diesel engines are designed, lead to several issues and the unburned fuel buildup can infiltrate the engine lubrication oil, potentially leading to the engine wear.

The major causes of engine malfunction due to lubricant quality are deposit formation, contamination, oil thickening, oil consumption, ring sticking, corrosion and wear. The environment in which it operates affects lubricant stability. Such factors as temperature, oxidation potential and contamination with water, unburned fuel fragments and corrosive acids limit the useful life of a lubricant. This is the area where additives have made a major contribution in improving the performance characteristics and extending the useful life of lubricants [2].

During cold start-up and stop-and go regimes in an internal combustion, the non-vaporized fuel condensed on the liner is scrapped by the piston rings and reaches the oil pan where it dilutes the lubricating oil. Some limited engine oil dilution by diesel engine fuel is acceptable and it happens in all diesel engines. But when the engine is fueled by biodiesel, biodiesel blends or SVO, engine oil dilution rates and their effects can be different than those from regular diesel fuel Gili et al [3]. This study was conducted to compare the wear, carbon deposit and lubrication oil properties of diesel fuelled with JSVO fueled engine, during the endurance test of 75 hours.

1.2 Statement of the problem

Straight vegetable oil (SVO) has been a recurring subject of study as a fuel for compression ignition engines. Rudolph Diesel developed the diesel cycle engine with peanut oil as the original fuel. More recent studies have examined the suitability of various agriculturally derived fuel oils as alternatives to petroleum products. SVO studies generate interest because of the potential benefits, compared to petroleum derived fuels, such as low cost, local production, and carbon-neutrality. Studies have considered a wide range of assessments of fuel quality, including combustion efficiency and emissions.

However, during any engine operation an amount of fuel will always penetrate into the sump and some limited engine oil dilution by diesel engine fuel is acceptable but when the engine is fueled by alternative fuels then engine oil dilution rate and it effects can be different than those from the regular diesel fuel. Hence, using JSVO as a fuel may affect engine oil performance, which is a very important factor regarding engine wear, frictional power loss, engine oil life and durability. Therefore, this thesis work investigates experimentally the actual impact of JSVO on engine lubricant and engine hardware by conducting a 75 hours test on two new Robin D23-DY engines.

1.3. Objectives of the study

1.3.1 General objective

The general objective of this study is to investigate the effect of JSVO fuel on small scale diesel engine lubricating oil properties, engine components wear and carbon deposit.

1.3.2 Specific objectives

- Characterization of fuel properties of JSVO which is provided by ASTU.
- Carry out endurance test for a period of 75 hours on Robin DY23-2D air cooled single cylinder engines using diesel fuel and JSVO.
- Determination of the effect of JSVO on engine lubricant oil parameters such as Kinematic viscosity ,Viscosity index , Density ,Carbon Residue, Water and sediment, Total acid number ,Flash-point, and Ash content
- Comparative analysis of carbon deposits on engine parts of diesel and JSVO fuelled engines after the endurance test.
- Comparative analysis of physical wear of diesel and JSVO fuelled engines after the endurance test.

1.4 Significance of the study

At present SVO is already start to use as diesel engine fuel in diesel engines without any major modification of engine, engine materials or engine oil. SVO is proved to be an energetically alternative to diesel engine fuel, in some aspects, especially in its chemical composition and fuel properties, SVO has some differences as compared to the regular petro-diesel fuel. Therefore, this type of wear and oil analysis is most effective as input to monitor equipment and lubricant conditions over time and provides insight to help maximize engine life and reliability while reducing maintenance costs.

1.5 Scope of the study

The scope of this study is to experientially investigate the effect of usage of JSVO on engine lubricant properties, physical wear and carbon deposit on engine parts by conducting 75 hours endurance test on two small scale identical engines.

1.6 Limitation of the study

Because of the difficulties of getting Atomic absorption spectropy (AAS) the analysis of lubricant sample for their elemental content such as Aluminum (AL), copper (CU), Iron (Ir), lead (Pb) and magnesium (Mg) etc. test was not performed. In addition to this, it was also difficult to find researches that have been done nationally and lack of reference books that is focused on engine oil analysis.

1.7 Organization of thesis

This thesis organized into five chapters as follows.

The first chapter covers the introduction: background, Statement of the problem, Objective of the study, Significance of the study, scope of the study and limitation of the study.

The second chapter reviews the following related literatures: overall over view of fluid interaction, principle of engine lubrication system, and engine friction and wear, it is also covers engine oil contamination by diesel engine, fuel lubrication properties of biodiesel diluted engine oil, lubricating oil contamination with SVO and test results using different methods, and basic engine oil parameters.

The third chapter presents the methodology used in this thesis. This includes descriptions of the approaches and methodology being taken to achieve objectives of this research paper in investigating the effect of JSVO on engine oil properties, physical wear and carbon deposits. The chapter generally describes: the engine robin used for test, Preparation of experimental set up, adaptations of diesel engines for use with SVO, Characterization of JSVO and ASTM standard test methods.

The fourth Chapter presents the result and discussion of: properties of JSVO fuel, comparative analysis of diesel and JSVO engine lubricants, Physical wear measurement of engine parts and wear analysis and comparative analysis of carbon deposit.

The final chapter presents the conclusion and recommendation of this thesis based on the results obtained.

2. LITERATURE REVIEW

2.1 Introduction

Development of the biofuel sector is a promising option for many developing countries. Given the impending energy crisis, they are much more vulnerable than wealthy countries and ensuring their energy supply at an affordable cost will become a serious challenge in the years to come. Moreover, most southern countries do not have large investment capacities, so they have to find economical solutions to launch new economic activities in the energy production field. In this context, biofuel production is a major opportunity, particularly where large arable land areas are available and a large share of the population is involved in agriculture [4].

One of the most advantageous branches in the biofuel sector is seen to be the production of straight vegetable oil (SVO) for direct use as fuel in diesel engines. There has been renewed interest in this activity in recent years, for stationary applications in the fields of agriculture, power generation and industry. These sectors are major consumers of fuel oils, either high distillates (diesel), medium distillates (DDO Distillate Diesel Oil) or heavy Fuel Oil 180 (FO180), which might be wholly or partially replaced with SVO [10]. This solution may contribute to reducing the cost of fossil fuel imports incurred by most developing countries, curb dependence on fossil fuels and limit greenhouse gas (GHG) emissions [14]. This is particularly true for African countries, which import 100% of the fossil fuels they need [19].

Because of this use of SVO as a fuel, it is essential to determine the impact of SVO on critical operation points of diesel engines. Figure 1 presents the interaction path of engine fuel with the engine lubricant. There are significant differences in composition between SVO and petroleum diesel fuels which have the potential to influence, for instance, ash emissions and thereby affecting after-treatment system performance. Although it is true that SVO can be used in diesel engine with no modification but still yields acceptable engine performance. Engine oil dilution effect on engine frictional and wear patterns and on emissions are still under investigation.

2.1.1. Overview of Engine Fluid Interaction.

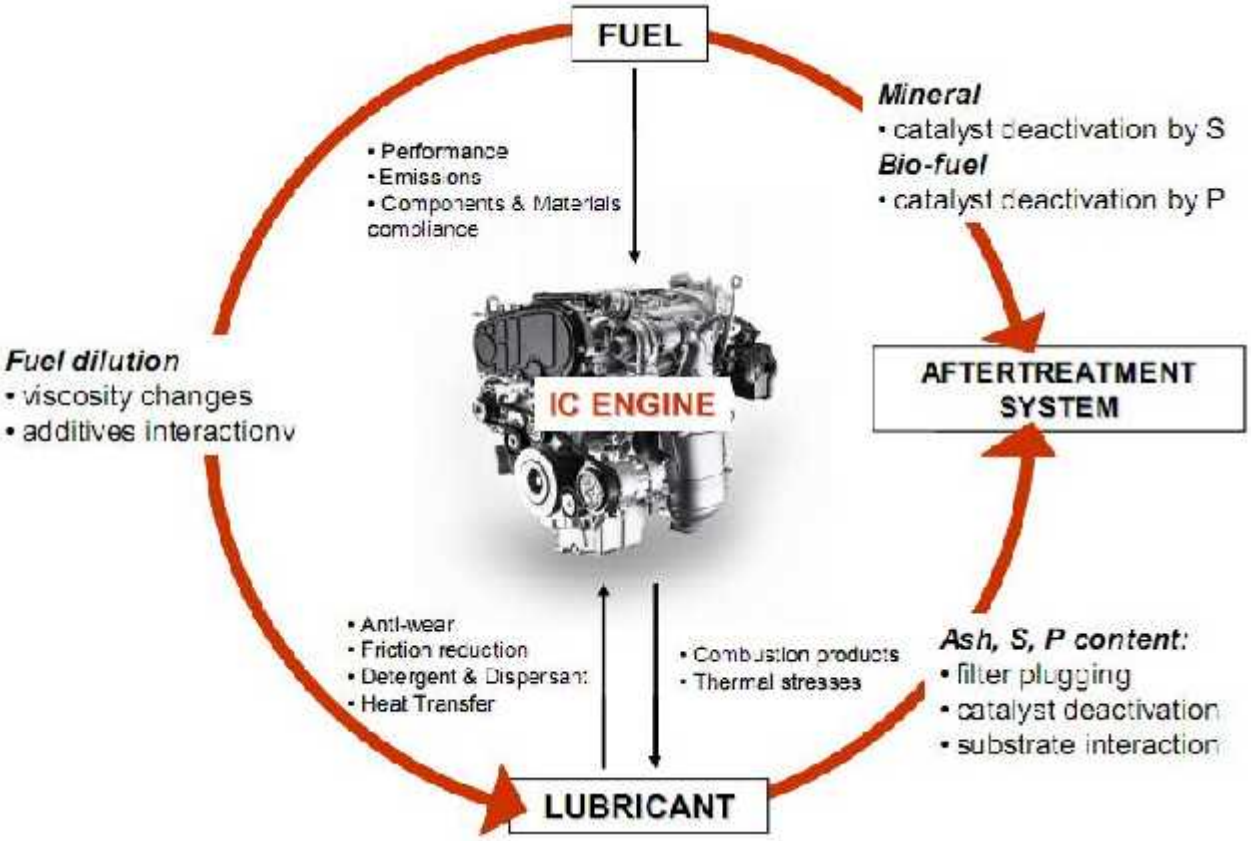


Figure 1: Overview of Engine Fluid Interaction.
(Gili, Igartua, Luther, & Woydt, 2010)

2.1.2. How Engine Oil Works

Engine lubricating oil is designed to facilitate enough oil film layer between sliding surfaces, protect engine parts from corrosion, transfer the combustion heat from surfaces and reduce total wear and friction of the engine. Wear of the engine parts is the main limiter of the lifetime of an engine. One can easily indicates the wear rate of engine with determining presence of a metallic element in a used oil sample by using appropriate technique, for instance, atomic absorption spectrometry. However, a certain amount of wear metals (also known as trace metals) in used oil is expected because of normal engine wear. In every internal combustion engine, there will be a certain amount of unburned fuel or the products from complete and incomplete combustion of fuel that passes through the piston rings and cylinder finally goes into the lubricating oil. Abnormal fuel dilution in engine oil which is the evidence of fuel delivery system malfunction

that results in thinning of oil, also small amount of fuel dilution increase oxidation, and hence oil viscosity increases more than normal rates [9] .

Engine oil provides for the lubrication of the engine moving parts. Figure 2 presents the elements of the lubrication circuit and flow path of oil in a typical engine. Lubricants are designed to reduce the friction between the surfaces that are or could be in contact with one another, which could cause wear at the contact point and they also hydro-dynamically separate the parts in relative motion. Along with the friction reduction modern diesel engine oil performs as a coolant, a cleaning agent and a sealant.

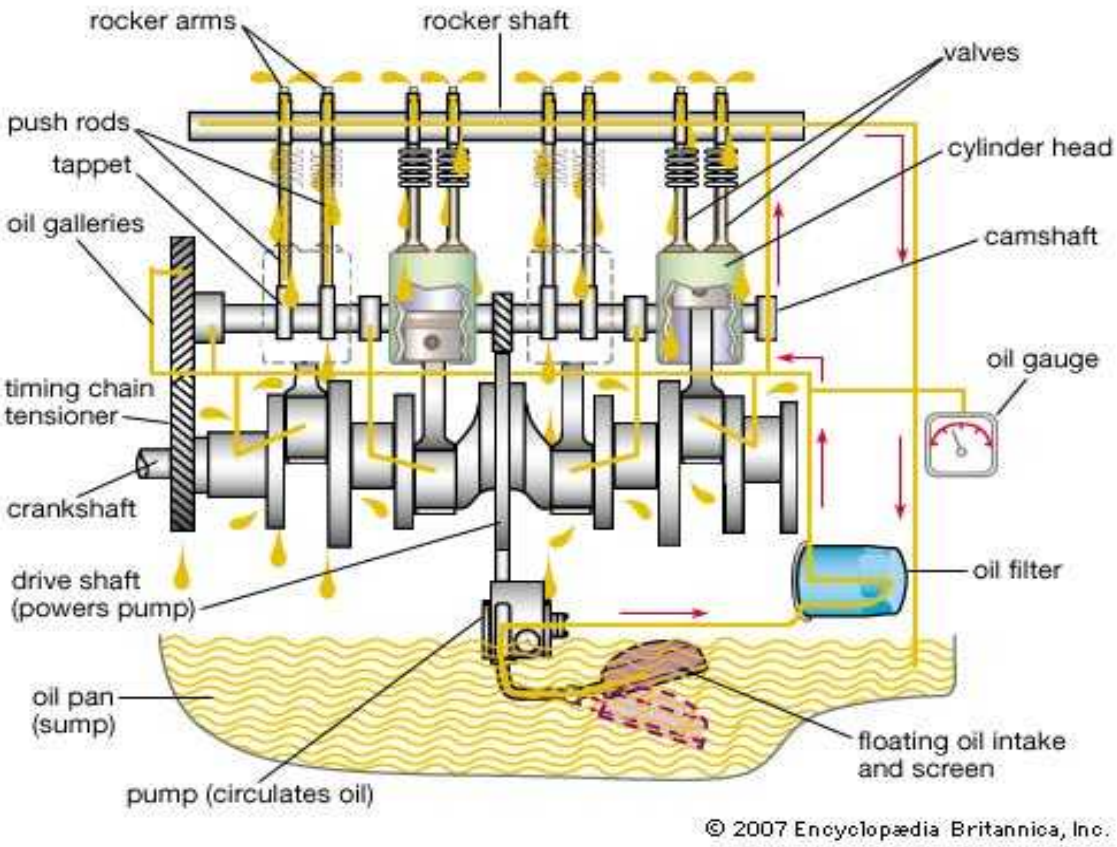
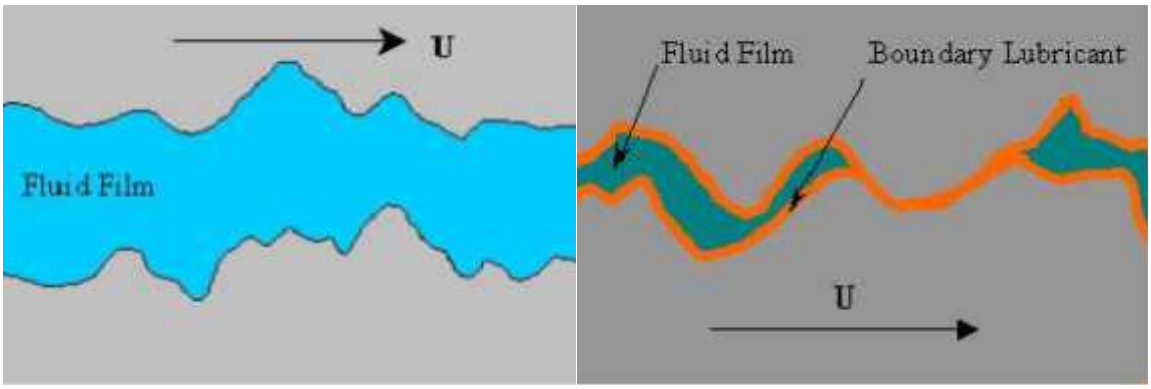


Figure 2: Lubrication Circuit and Flow Path of Oil in Engine [5]

Engine oil forms a film between the moving surfaces. The friction occurs in the oil itself preventing direct metal to metal contact. This phenomenon is known as fluid friction. Engine oil perform its lubricating action in two ways [5]:

1. **Thick Film Lubrication**: It occurs when the distance between two moving surface are wider, such as between rotating crankshaft and its main bearing. This lubrication is also known as hydrodynamic lubrication. Figure 3(a) presents the film thickness pattern of hydrodynamic lubrication.

2. **Boundary lubrication:** It occurs when metal to metal surface distance are very narrow such as those between crankshaft and its main bearing when engine is not running or during start and ideal periods. Boundary lubrication occurs when the lubricating film is of about same the thickness as that of the surface roughness. Figure 3 (b) presents the film thickness pattern of boundary lubrication. For a hydrostatic or hydrodynamic bearing this operating regime is undesirable, but during start-up, shutdown and low speed operation, the engine is in this boundary lubrication condition.



a) Hydrodynamic lubrication b) Boundary lubrication
Figure 3: The two typical lubricating condition of oil film formation [5]

2.1.3. Engine Friction and Wear

Diesel engine achieves a high fuel efficiency, which can approach to 50%.This means that 50% of heat of the combusted fuel is converted into useful work. Although most of the energy is dissipated due to inherent thermodynamic limitations, still 5% of the combustion heat and approximately 10% of the potential useful power are lost due to mechanical loss [6]. Various internal resistances determine the mechanical power loss of the diesel engine. About 70% of the mechanical power loss of the engine is due to frictional power loss. Power loss due to friction between piston and position rings is approximately 50-60% of the engine frictional loss [7]. Loss due to friction in crankshaft bearings is 30-35% of the frictional loss and loss due to friction in inlet/outlet distributing system is 10-12% of total engine frictional loss.

Therefore, the greatest frictional loss happens between piston and piston rings. Decrease the frictional loss is one of the main concerns of engine lubricant.

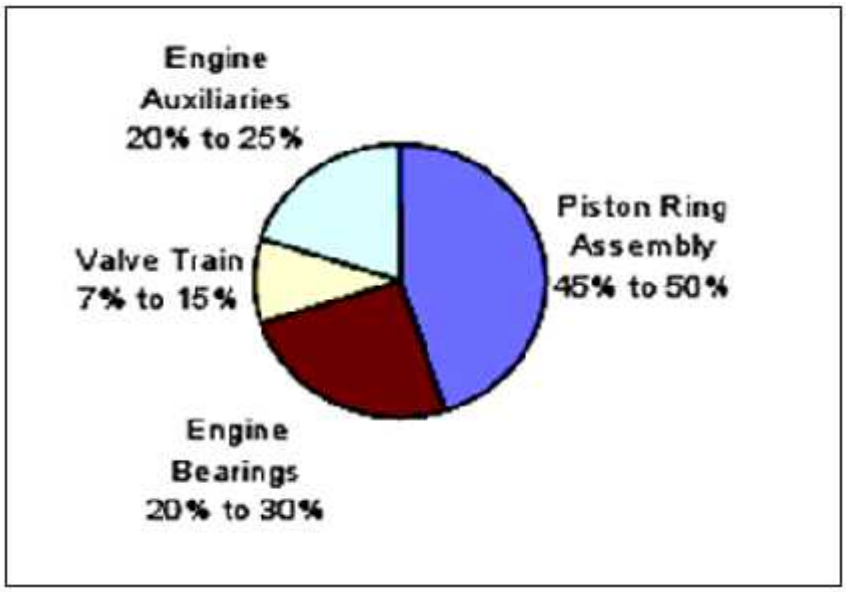


Figure 4: Distribution of total mechanical loss in a typical diesel engine [11].

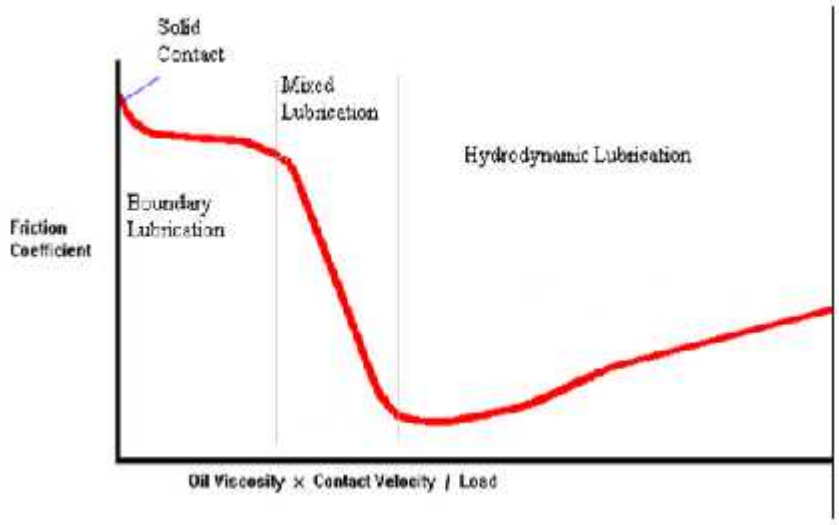


Figure 5: Typical Stribeck curve [11].

Engine friction can be generally classified into two groups. First one is Coulomb Friction or Dry Friction: This friction occurs when asperities come into contact between two relatively moving surfaces. Second one is Fluid Friction: This occurs when adjacent layers of fluid are moving at different velocities. In real cases it is very difficult to assign an actual degree of engine friction to either group, instead each friction component lies somewhere in between these two categories of

friction, and for engine friction there is a continuum between dry and fluid frictions. This continuum depends upon component geometry, surface roughness, and relative velocity of the moving surface, normal loads and various rheological properties of lubricant. This continuum approach can be expressed by the Stribeck curve. Figure 5 presents the regime of lubrication as described the Stribeck curve. Stribeck curve was initially developed for journal bearing studies but the result of those studies can be extended to other lubricated systems.

2.2. Factors for the Modeling of Diesel Engine Friction and Wear

There are six main factors whose effects must be addressed while performing the laboratory scale tests of engine lubricants and wear. Most of the factors, which are presented in Figure 6, are interrelated. Therefore, the change of one factor may affect the several other factors. This complexity makes it difficult to conduct friction and wear experiments with one controlled independent variable while considering everything else as constant.

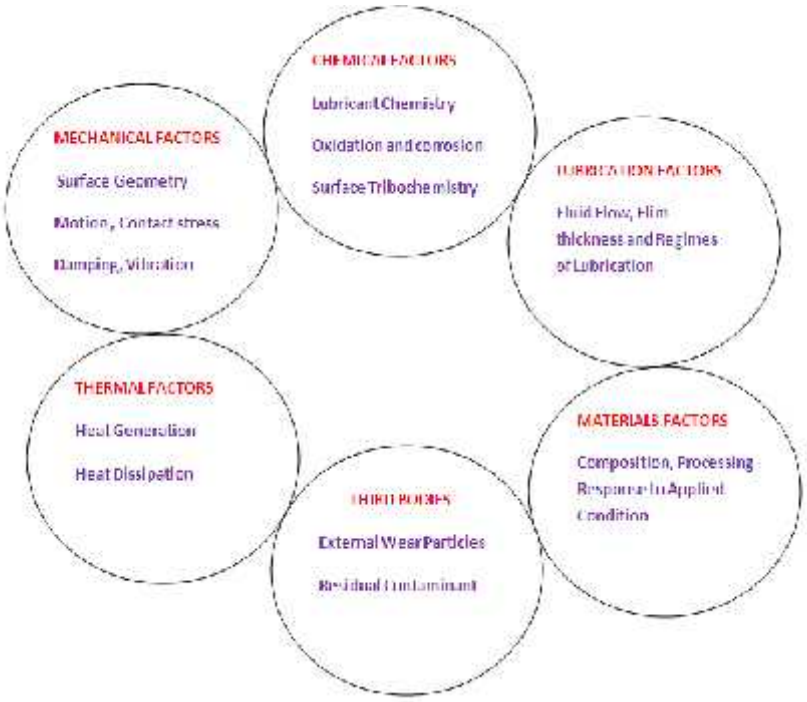


Figure 6: The factors that must be considered for developing accurate simulation of friction and wear in diesel engine.

Besides contact stress, relative motion, stiffness and damping capacity of the system is also considered important mechanical factors in friction and wear modeling. Under rubbing contact, chemical reactivity also change due to compound formation in the lubricant. But this chemical reactivity strongly varies with temperature and also third body particles need to consider. In

abrasive wear, some particle is removed from the surface and this wear particles at the interface need to be considered as third bodies. Lubricant chemistry, film thickness, lubrication regime, and surface tribo-chemistry may play an important role for modeling engine friction and wear. These factors are again strongly affected by engine oil characteristics. Therefore, to model engine friction and wear, engine oil dilution or change of lubricity property, chemical properties and corresponding interactions with the surface play very important roles.

2.3. Engine Oil Contamination by Diesel Engine Fuel

Engine oil contamination can be one main reason of early oil degradation and of eventual engine cessation. Engine oil can become contaminated when unburned or incomplete burnt fuel blows by through the piston rings and ends up in the crankcase. The presence of fuel in the crankcase can reduce oil viscosity and attenuate detergency or additives performance. Frequent engine starts, excessive idling and cold running conditions can lead to moderate and acceptable fuel dilution. Some fuel dilution is always expected and basically 0.36 percent of the total fuel consumption ends up in the crankcase in a typical engine [12]. Figure 7 presents the flow path of engine fuel towards the crankcase.

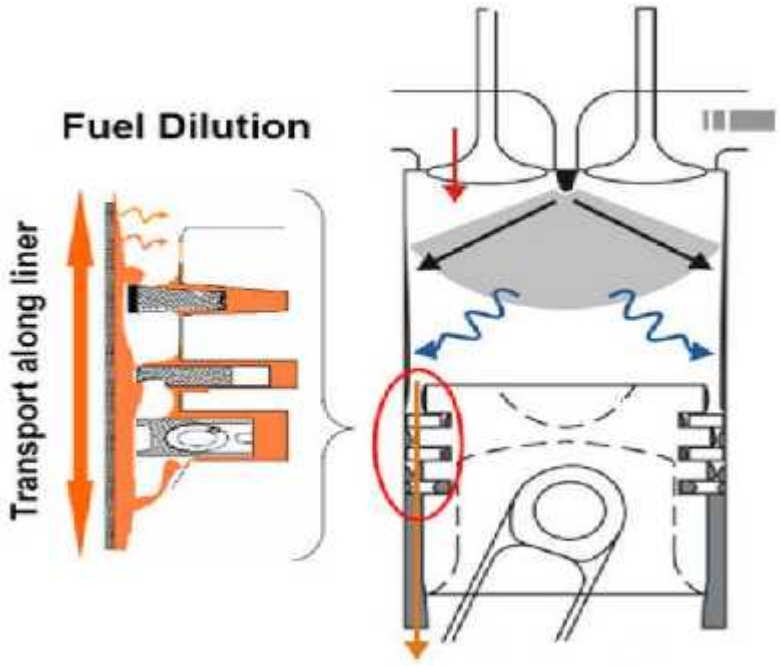


Figure 7: Basic path of the blow by of partially burn fuel as it enters the engine crankcase [12].

In four stroke diesel engines more than four percent of fuel dilution in oil is considered abnormal (U.S Oilchek). Fuel dilution above this percentage indicates that a potential problem may occur with injectors, fuel pumps, gaskets or seals. Faulty operation of fuel system then may lead to excessively rich mixture and defective pressure regulator, poor combustion, bad timing or worn piston. Leakage of oil/fuel heat exchanger may also cause the fuel to enter into the crankcase [12]. In some newer model diesel engines, late post- injection method is used as a strategy of emission control but it is also can create more oil dilution.

2.4. Primary Cause of Engine Oil Dilution by Biodiesel

Some limited engine oil dilution by diesel engine fuel is acceptable and it happens in all engines. But when the engine is fueled by biodiesel or biodiesel blend then engine oil dilution rate and its effect can be different than those from the regular diesel fuel. Gili at el. [13] discussed three reasons that are responsible for the biodiesel dilution in the engine oil.

1. Compared to the equi-viscous hydrocarbons (diesel fuel), ester fluids (biodiesel) have more penetrating and solvencies properties. These properties lead to more unburned biodiesel fuel dilution in the engine oil.
2. Today most of the diesel engines with DPF (Diesel Particle Filters), use filter generation system. This system involves a periodic injection of small quantity of a fuel with the burn fuel in order to increase the exhaust temperature and to burn-off all the unburned carbon at exhaust. This procedure increases the dilution of unburned biodiesel fuel in the engine oil.
3. The distillation temperature of the biodiesel is shifted by about 100°C lower than the diesel fuel, therefore it tends to accumulate in the engine oil and it leads to a long term dilution.

2.5 Problems Associated with Engine Oil Dilution by Diesel Engine Fuel

Service properties of the engine oil may change or sometimes oil can lose its working capacity when contaminated by fuel. Problems associated with engine oil dilution are [12]:

- In cold operating conditions, engine oil dilution can create wax which eventually leads to low oil pressure and to starvation during start up conditions.
- Fuel dilution can cause reduction of engine oil viscosity and have a detrimental effect on the critical oil film thickness. This results in premature combustion-zone wear and crankcase bearing wear.
- High fuel dilution changes the concentration of engine oil and their effectiveness presents a typical viscosity degradation of engine oil with the increase of fuel dilution percentage.
- If the fuel dilution is caused by a faulty fuel injector, it can wash-down cylinder liner oil. This may lead to piston ring, piston and cylinder wear. It can also increase blow-by and fuel consumptions.
- Engine oil diluted by biodiesel fuel can create some additional problems such as oxidation stability; filter plugging, deposit formation and crankcase accumulation.

2.7. Lubrication Properties of Biodiesel Diluted Engine Oil.

Engine oil dilution effect by biodiesel needs to be investigated. Biodiesel has lower distillation temperature and boiling point and tends to dilute the engine oil even at the small percentage in the fuel. This section reviews previous experimental work from available literature on the effects of biodiesel dilution of engine oil.

A recent research done by Thornton et al. [15] at the National Renewable Energy Laboratory evaluated the biodiesel fuel blend effect on oil dilution and associate engine performance. A 4 cylinder 2.15L high speed direct injection (HSDI) diesel engine was used as test cell and run by a 20% blend of soy-derived FAME with ultra-low sulfur diesel fuel (ULSD). The base engine oil used for the study was CJ-4 oil. After the test run of the engine the engine oil was examined for the presence of FAME and viscosity. Total base number (TBN) and total acid number (TAN) was also determined. Along with engine oil analysis, bearing, piston and PRA were inspected for signs of excessive wear. The result showed that viscosity decreased with increased oil age and increased with fuel dilution. TBN of the engine oil decreased sharply

with the increase of oil dilution while TAN increased slightly. Iron content in the oil also increased with the time. The researcher concluded that biodiesel in the engine oil caused oxidation which produced acid and a reduction in TBN. At the end of test, the engine was disassembled and none of the moving components showed signs of excessive wear or other signs of deterioration.

Agarwal at el. [16] carried out a detailed investigation to assess the wear effect on engine using biodiesel fuel. They investigated the effects of long term engine operation on engine wear for a 20% blend of LOME (Linseed Oil Methyl Ester). In their research, an engine was run for 32 cycles, each of 16hr of continuous running and engine oil samples were collected after each 128hr of running. After the completion of the test, the engine was disassembled for physical inspection of the wear of moving parts. The result indicated that the lowering of engine oil viscosity was lower in case of biodiesel-fueled system as compared to that of diesel fuel system. Agarwal at el. concluded that for biodiesel fueled engine, oil dilution was lower than that of diesel fueled engine. The quantitative analysis in their research showed that an ash content, which mainly represents the wear debris, was found to be less for biodiesel fueled engine. By use of atomic absorption spectroscopy on the engine oil they found that biodiesel fuel led to lower amount of metallic debris such as Fe, Cu, Zn, Mg, Cr, Pb and Co. This metallic debris originated from various moving parts of the engine. Which presents the amounts of metallic debris in engine oil for both biodiesel and diesel fueled engine. The physical investigation and oil analysis indicated that wear of the various vital parts reduced up to 30% because of the additional lubricity properties of biodiesel.

Fang and Yamaguchi [17] carried out an extensive study on a biodiesel contaminated engine oil by Electrical Contact Resistant (ECR), High Frequency Reciprocating Rig(HFRR) and Four ball test. Their research showed that partially oxidized biodiesel components competed with the typical oil anti-wear additives, mainly with ZDDP (Zinc Dialkyl Dithio Phosphate).They studied a complex formation between oxidized biodiesel component and the ZDDP with FTIR (Fourier Transform InfraRed spectrometer) and P-NMR (Phosphorous 31 Nuclear Magnetic Resonance) techniques. The result of their study showed that FAME fuel dilution had a negative impact on engine oil performance when methyl esters partially degraded and interacted with the ZDDP anti-wear additives. Even though fresh biodiesel (Fresh methyl ester) may have some potential benefits for engine oil, such as higher intrinsic lubricity and acting as friction

modifier. Based on the bench wear test and spectroscopic studies they concluded that engine oil dilution with the aged biodiesel increased wear up to concentration of 5% while fresh biodiesel actually decreased wear.

Ambesh M Shetye at el.[18] Carried out a detail investigation on tribological properties of lubricating oil for biodiesel (transesterified jatropha) fuelled single cylinder diesel engine. They try to test a comparative study of various properties and effect of mineral diesel and biodiesel (transesterified jatropha oil) on the lubricating oil.The experimental test was conducted for period of 30 hours for each biodiesel blend and diesel. In the first phase engine was run with diesel (B00) and in the second phase, the engine was run with B20 blend. Sample was taken after 15 hours. The lubricating oil samples were collected from both the engines and various properties were tested. A number of factors affect lubricating oil performance: oil thickening/thinning, depletion of wear protection additives, and deposit control additives, sludge formation, etc. Based on the experimental test and tribological investigations on the lubricating oil, it can be concluded that jatropha Viscosity and flash/fire point of lubricating oil have found to have increased with usage. Lower increase is observed with biodiesel fuelled engine. Viscosity (40°C) of used lubricating oil was higher in case of diesel fuelled engine but at 100°C, it was higher for B20 fuelled engine. Lower viscosity reduction is observed with increase in temperature in case of B20 fuelled engine. Thus it can be concluded from the results obtained from the experiments that Biodiesel can be used in combination with petroleum diesel to run diesel engine without any modifications.

Agarwal [20] studied on Biodiesel derived from vegetable oils by modifying their molecular structure through a transesterification process. Linseed oil methyl ester (LOME) was prepared using methanol in the presence of potassium hydroxide as a catalyst. Two identical engines were subjected to 512 hours long-term endurance tests, fuelled by an optimum biodiesel blend (20 per cent LOME) and diesel oil, respectively. A number of tests were conducted in order to evaluate the comparative performances of the two fuels such as density measurement, viscosity measurements, flashpoint determination, moisture content determination, pentane and benzene insolubles, thin layer chromatography, differential scanning calorimetry, etc. All these tests were used for an indirect interpretation of the comparative performance of these fuels. During the long-term endurance test on engines, the extent of durability problems such as fuel filter plugging, injector coking, carbon deposits in combustion chamber, ring sticking, contamination

of lubricating oils were found to be substantially lower for the biodiesel-fuelled engine compared with the diesel-fuelled engine. The fuel handling system also operated normally on bio- diesel blend. This suggests that the operational and durability problems associated with vegetable oil as fuel were not observed with biodiesel [41]. The Comparative studies on various samples of lubricating oil indicated that the density increased with the usage of lubricating oil. It was found that the amount of various possible contaminants such as wear debris, soot, resinous compounds, oxidation products, and moisture content was lower in the case of lubricating oil drawn from the biodiesel-fuelled engine compared with the diesel-fuelled engine. The improved performance of biodiesel-fuelled system is possibly attributed to the inherent lubricity of bio diesel, resulting in lower wear of vital moving components. Ash content, which mainly represents wear debris, is found to be lower in the lubricating oil from the biodiesel-fuelled engine. Viscosity of the lubricating oil decreased with usage mainly due to fuel dilution. The extent of fuel dilution was lower for the lubricating oil from the biodiesel-fuelled engine. Flashpoint studies also supported improved performance of the biodiesel-fuelled system. Pentane and benzene insoluble reflected the extent of wear of moving parts, oil oxidation, and additive depletion and these were lower for the lubricating oil from the biodiesel-fuelled engine. All these tribological investigations, except SPDSC, decisively proved that the lubricating oil from the biodiesel-fuelled system reflected a better condition of the engine parts. Biodiesel thus proves to be a strong candidate for partial replacement of mineral diesel fuel in existing diesel engines.

Avinash Kumar Agarwal [21] performed detailed assessment on blending smaller quantity of Jatropha oil with mineral diesel. After ensuring satisfactory performance, emission and combustion characteristics, engines were subjected to long term endurance test of 512 hour for comparing long-term performance of J5 and J10 blends vis-à-vis mineral diesel, in the experimental investigation. In the long-term endurance test, the effect of use of Jatropha oil blends on wear of various engine parts and lubricating vis-à-vis mineral diesel were evaluated. The results of the investigation, which are presented in Figure 8, 9, 10,11,12, and 13, indicated that the deposits on the vital engine parts were found to be slightly higher on J10 fuelled engine while it was comparable to mineral diesel for J5 fuelled engine. The piston rating carried out on the pistons of the three engines reflected that the J5 fuelled engines demonstrated reasonable long-term performance in comparison to mineral diesel fuelled engine while performance of J10 fuelled engine was slightly inferior. J5 and J10 fuelled engine's lubricating oil shows higher

reduction in lubricating oil viscosity and flash point compared to mineral diesel, thus indicating possibly higher fuel dilution. Fe, Pb, Cr, Zn wear metal debris in the lubricating oil are lower for J5 and J10 compared to mineral diesel engine's lubricating oil. however Al content in the lubricating oil is slightly higher for J5 and J10 compared to mineral diesel engine's lubricating oil. Physical wear measurement of vital engine parts indicate relatively higher wear of liner bore, piston rings and big end bearing for J5 and J10 fuelled engine while wear of valve mounting, piston, gudgeon pin, crank pin was found to be relatively lower than mineral diesel fuelled engine. It is found that the wear of J5 engine liners is higher compared to mineral diesel fuelled engine. However wear of J10 fuelled engine liner is found to be relatively lower compared to mineral diesel fuelled engine. Therefore it can be concluded that J5 and J10 can be safely used as substitute of mineral diesel in CI engine without any engine modification, however specialty lubricants need to be developed.

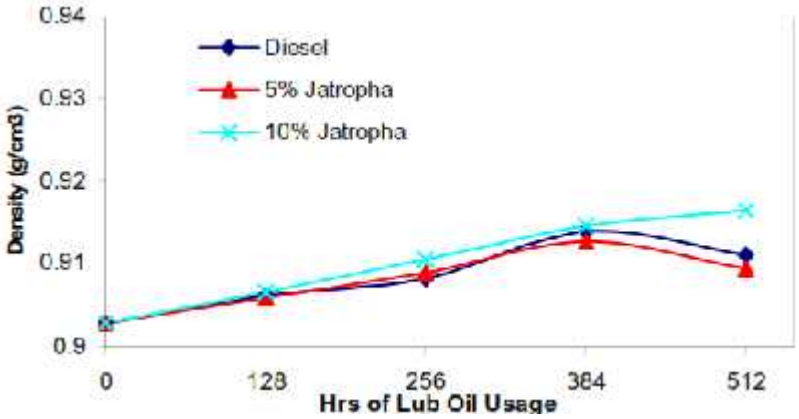


Figure 8: Density vs. hrs of lube oil usage

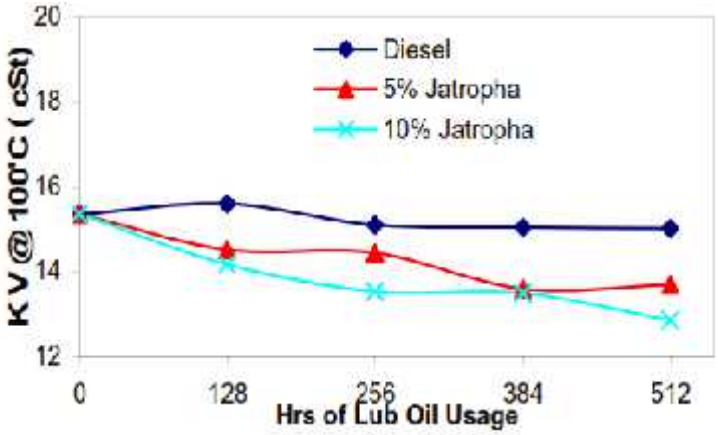


Figure 9: Viscosity @100 °C vs .hrs of lub oil usage

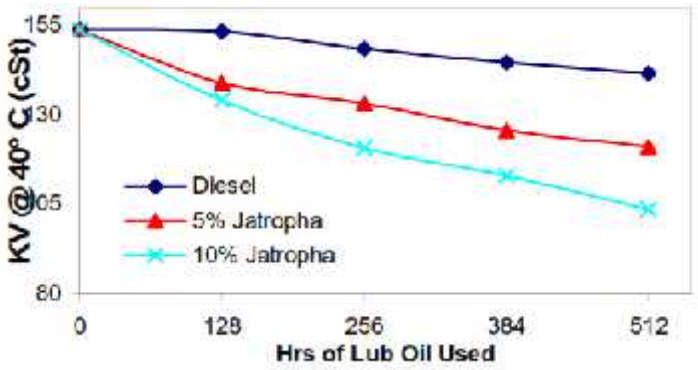


Figure 10: Viscosity @40 °C vs .hrs of lub oil usage

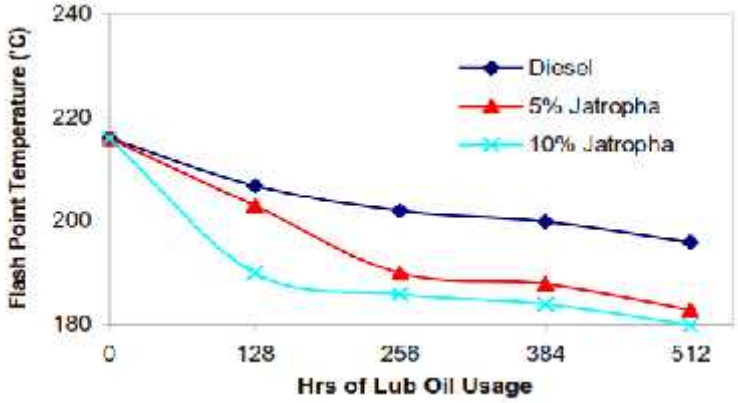


Figure 11: Flash point vs. hrs of lube oil usage

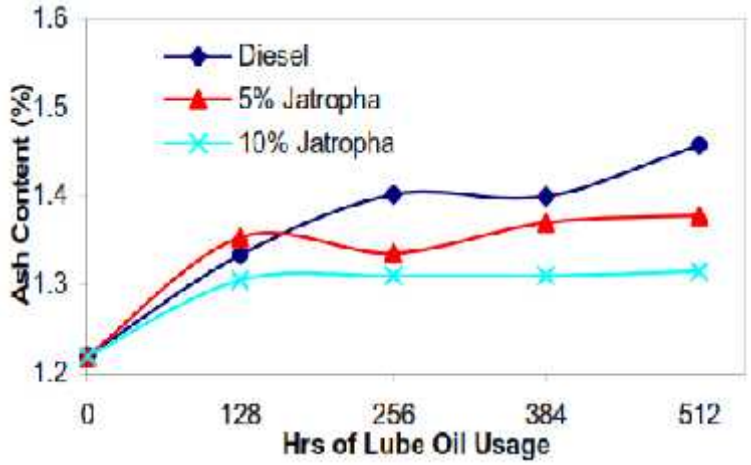


Figure 12: Ash content vs. hrs of lube oil usage

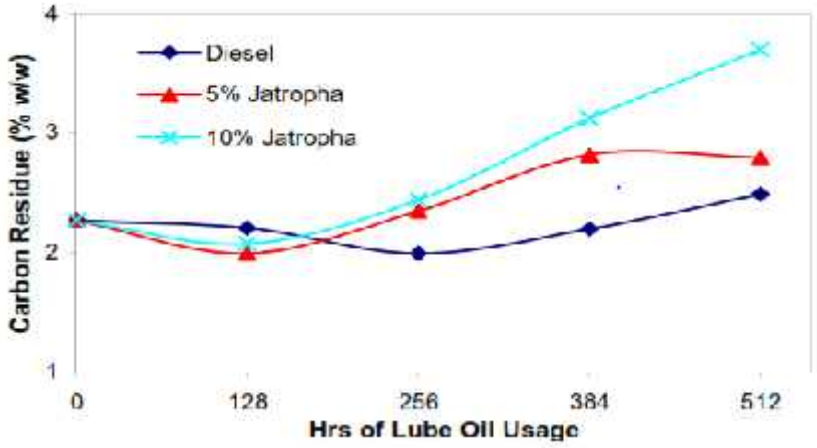


Figure 13: Carbon residue vs. hours of lube oil usage

2.8 Lubricating Oil Contamination with SVO and test results using different methods

Lubricating oil dilution by vegetable oil fuel is a commonly reported problem which occurs under a number of different engine test conditions. It occurs most rapidly under low speed and partial load which are the conditions favoring incomplete combustion [22, 23]. It is generally considered to occur more readily in direct injection engines, but is also reported in indirect injection engines which, are usually thought to be somewhat immune to the problems caused by use of vegetable oil fuels.

Rudolf Diesel (1900) demonstrated his engine running on 100% peanut oil at World Exhibition in Paris [24]. Seddon (1942) experimented with using several different vegetable oils in a Perkins P 6 diesel engine with great success during World War II. The results of this experiment showed that vegetable oils could be used to power a vehicle under normal operating conditions. However, it was noted that much more work was needed before vegetable oils could be used as a reliable substitute for diesel fuel [25].

Tahir et al. (1982) tested sunflower oil as a replacement for diesel fuel in agricultural tractors. Sunflower oil viscosity was 14% higher than diesel fuel at 37°C. Engine performance using the sunflower oil was similar to that of diesel fuel, but with a slight decrease in fuel economy. Oxidation of the sunflower oil left heavy gum and wax deposits on test equipment, which could lead to engine failure [26]. Bacon et al. (1981) evaluated the use of several vegetable oils as potential fuel sources. Initial engine performance tests using vegetable oils were found to be acceptable, while noting that the use of these oils caused carbon build up in the combustion chamber. Continuous running of a diesel engine at part load and mid-speeds was found to cause

rapid carbon deposition rates on the injector tips. Short 2-hour tests were used to visually compare the effects of using different vegetable oils in place of diesel fuel. Although short-term engine test results were promising, Bacon recommended long-term engine testing to determine the overall effects of using vegetables oils as a fuel in diesel engines [27].

Schoedder (1981) used rapeseed oils as a diesel fuel replacement in Germany with mixed results. Short term engine tests indicated rapeseed oil had similar energy outputs when compared to diesel fuel. Initial long-term engine tests showed that difficulties arose in engine operation after 100 hours due to deposits on piston rings, valves, and injectors. The investigators indicated that further long-term testing was needed to determine if these difficulties could be adverted [28]. Auld et al. (1982) used rapeseed oil to study the effects of using an alternative fuel in diesel engines. An analysis of the rapeseed oil showed a relationship between viscosity and fatty acid chain length. Engine power and torque results using rapeseed oil were similar to that of diesel fuel. Results of the short-term tests indicated further long term testing was needed to evaluate engine durability when rapeseed oil was used [29].

Pryde (1982) reviewed the reported successes and shortcomings for alternative fuel research. This article stated that short-term engine tests using vegetable oils as a fuel source was very promising. However, long-term engine test results showed that durability problems were encountered with vegetable oils because of carbon buildup and lubricating oil contamination. Thus, it was concluded that vegetable oils must either be chemically altered or blended with diesel fuel to prevent premature engine failure [30]. Engler et al. (1983) found that engine performance tests using raw sunflower and cottonseed vegetable oils as alternative fuels gave poor results. Engine performance tests for processed vegetable oils produced results slightly better than similar tests for diesel fuel. However, carbon deposits and lubricating oil contamination problems were noted, indicating that these oils are acceptable only for short-term use as a fuel source [31]. Pryor et al. (1983) conducted short and long-term engine performance tests using 100% soybean oil in a small diesel engine. Short term test results indicated the soybean performance was equivalent to that of diesel fuel. However, long term engine testing was aborted due to power loss and carbon buildup on the injectors [32]. In CI engine, more than 30 different vegetable oils have been used to operate compression engines since the 1900's (Quick, 1980) [33]. Initial engine performance suggests that these oil-based fuels have great potential as fuel substitutes. Extended operation indicated that carbonization of critical engine

components resulted from the use of raw vegetable oil fuels, which can lead to premature engine failure. Blending vegetable oil with diesel fuel was found to be a method to reduce coking and extend engine life.

Studies involving the use of raw vegetable oils as a replacement fuel for diesel fuel indicate that a diesel engine can be successfully fuel with 100% vegetable oil on a short-term basis. However, long-term engine durability studies show that fueling diesel engines with 100% vegetable oil causes engine failure due to engine oil contamination, stuck piston rings, and excessive carbon build-up on internal engine components.

Siekmann at el. (1982) studied the deterioration of different mixtures of vegetable oil and lubricating oils using a Mac Coull apparatus under simulated engine-bearing working conditions. Their laboratory test showed that the degradation of the oil, marked by a significant increase in viscosity and a sharp loss of alkalinity, depended on the concentration and the extent of unsaturation of the vegetable oil. Their gas chromatographic analysis showed that it was mainly the linoleic (18:2) and linolenic (18:3) acids that were degraded in the test. Similar studies by Rewolinski and Shaffer (1985a), and Rewolinski and Shaffer (1985b) indicated that the presence of metallic copper catalyst and oxygen were the two dominant factors in the loss of alkalinity and thickening of lubricating oil. They found metallic iron had no catalytic effect on such problems. Their wear analysis by the "Four-ball" method (ASTM Standard D4172) indicated that the contaminated lubricating oil exhibited low metal wear indexes even when the oil was severely degraded.

Analyses of the lubricating oil of engines operated on crude vegetable oils and with blended vegetable oil in diesel have been reported by several researchers. Ziejewski and Kaufman (1982) reported an increase in total solids, viscosity, and metals in the lubricating oil of engines running on vegetable oils. Yarbrough at el (1981) reported intense lubricating oil contamination after an hour of operation at full load with a 75:25 blend and a 50:50 blend of sunflower oil in diesel and with crude sunflower oil. Their test with degummed-dewaxed sunflower oil showed intense - lubricating oil contamination only after 40 hours of engine operation. Borgelt and Harris (1982) reported an increase in total solid and wear metal patterns in the lubricating oil with increasing fraction of soybean oil in the blend mixture

Sapaun et al. (1996) reported that studies in Malaysia, with palm oils as diesel fuel substitutes, exhibited encouraging results. Performance tests indicated that power outputs were nearly the

same for palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. Short-term tests using palm oil fuels showed no signs of adverse combustion chamber wear, increase in carbon deposits, or lubricating oil contamination.

Ryan et al. (1984) characterized injection and combustion properties of several vegetable oils. The atomization and injection characteristics of vegetable oils were significantly different from that of diesel fuel due to the higher viscosity of the vegetable oils. Engine performance tests showed that power output slightly decreased when using vegetable oil fuel blends. Injector coking and lubricating oil contamination appeared to be a more dominate problem for oil-based fuels having higher viscosities. Other studies by Hofman et al. (1981) and Peterson et al. (1981) indicated that while vegetable oil fuel blends had encouraging results in short term testing, problems occurred in long-term durability tests. They indicated that carbon build-up, ring sticking, and lubricating oil contamination was the cause of engine failure when vegetable oils were used in high percentages (50% or more) as diesel fuel substitutes.

Peterson et al. [8] report 160 percent increase in lubricating oil viscosity over a 100 hour oil change interval when an indirect injection engine is operated with pure linoleic safflower oil. The engines were operated at wide open throttle with the load cycled on and off at 15 minute intervals. The Engine Manufacturers Association considers that a 50 percent increase in lubricating oil viscosity over the length of an oil change is an indication of test failure. Yarbrough et al. [34] report a rapid buildup of total solids in the lubricating oil of an indirect injection engine operated by pure degummed, dew axed sunflower oil under full rated load at constant rpm. Lubricating oil would need to be changed two to three times more frequently than recommended by the engine manufacturer to maintain suitable lubri-cating oil quality.

Work has been done by several researchers in simulating the lubricating oil environ-ment within the engine. Unless otherwise noted, lubricating oil tested by cited researchers is API CD SAE 30. Bauer et al. [35] used ASTM D.943, “Oxidation Characteristics of Inhibited Steam Turbine Oils,” as the basis for test development. Lubricating oil was inten-tionally contaminated with soybean oil and then exposed to heat, air, agitation, and various metals of engine construction. Samples were heated in a constant temperature oil bath. Sample containers were glass test tubes. Air was supplied through 2 mm I.D. glass tubes from high pressure cylinders. Flow rates, of I 1/hr. gave sufficient agitation. Oil viscosity was measured to determine thickening. Copper and iron together, molyb-denum, manganese, chromium, and nickel were tested to determine effect

on rate of viscosity increase of 10 percent soybean oil in lubricating oil. The rate of viscosity increase with copper and iron was an order of magnitude greater than the other catalysts. The range of soybean oil dilution levels tested was 0% to 10%. There was little difference in the rate of viscosity increase through 1.0%, with the rate at 3.0% slightly higher and 10.0% signifi-cantly higher. Tests were run at 100 and 120°C. The rate of viscosity increase was significantly higher at the higher temperature. Adams et al. [36] tested a range of soybean oil dilution levels from 0% to 50%. Water levels from 1% to 9% were tested to simulate condensation in the crankcase. Test samples were held at 85 to 95 °C, and agitated by aeration. Catalytic amounts of cobalt and man-ganese were tested. Viscosity increase was independent of amount of water present. No significant viscosity increase occurred in 240 hours without the added metal, but samples containing 10.0% or more soybean oil became highly viscous in 94 hours with addition of manganese and cobalt.

Engine tests with a direct injection engine were also performed by Adams and co- workers [36]. The test schedule was based on the EMA's recommended test method. Lubricating oil viscosity measured at 75°C increased 385% after 200 hours engine operation on a 1:1 blend of soybean oil and diesel fuel. Even though lubricating oil viscosity increased only 3.2% at 100 hours of engine operation, the level of lubricating oil dilution was judged as unacceptable by the authors due to the potential for catastrophic thickening of the lub-ricating oil.

Lubricating oil deterioration when contaminated with methyl esters of soybean and babassu oils was tested in a MacCoull apparatus by Siekman et al. [37]. A MacCoull appa-ratus, which is used to determine the corrosion effect of a test fluid on a bearing material, consists of a rotating conical shaft submerged in the oil sample to be tested. A stationary shaft supports the rotating cone with a test bearing. Catalyst is added in the form of cop-per baffles. Oil is sprayed off the conical shaft and runs down the side of the glass beaker containing the test apparatus and oil sample. The sample is aerated by diffusion through holes in the cover of the beaker. Soybean oil is polyunsaturated, with an iodine number of 128 and babassu oil is essentially saturated, with an iodine number of 17. Iodine number is a measure of vegetable oil or fatty acid unsaturation, and is directly proportional to the degree of unsaturation. Dilution levels were 5.0%, 10.0%, and 20.0%. Test duration was 8 hours in all cases, and also 24 hours with 10.0% soybean oil ester. Temperatures tested were 150 and 170°C. Kinematic viscosity at 40°C and total base number (TBN) by ASTM D 2896, "Total Base Number of Petroleum Products by Potentiometric

Perchloric Acid Titrations," were evaluated as test parameters. Reduction in TBN, which indicates a drop in alkaline reserve and a rise in amount of free acids, rose with increasing contamination with ester. The effect is more pronounced with the soybean ester than with babassu ester, especially at higher dilu-tion rates and higher temperature. By assuming an iodine number of zero for the lubricating oil, and calculating the iodine number of the contaminated lubricating oil sample, a straight-line relationship is shown between the reduction in TBN and the amount of double bonds introduced. This indicates that acid-forming oxidation is taking place largely at points of unsaturation. The viscosity, TBN, and percent ester (analyzed by infrared spectroscopy) were eval-uated during the 24 hour test. The viscosity increased fairly quickly, doubling in 16 hours, and leveling off at 24 hours with total increase of 156%. The reduction in TBN was fairly constant with a slight leveling off at 24 hours, with a total drop of 44%. The drop of 16% in ester concentration during this time period was attributed to evaporation and reaction of the ester. The flash point of soybean oil .methyl ester (methyl soyate) is 178 $^{\circ}$C [38].

Bench and vehicle testing were also done by the Siekman group using indirect injec-tion engines fueled with pure methyl soyate. In both cases, the lubricating oil was inten-tionally contaminated with 5% methyl soyate. In a bench test of 100 hours, the viscosity increased to 5 times the initial value, while the TBN dropped only slightly. The soot con-tent of the oil increased to 4.0%. The increase in viscosity was attributed to this, rather than breakdown in the antioxidant capacity of the oil. The ester content of the lubricating oil dropped from 5.2% initially to 3.2% after 75 hours. In a reference test using methyl soyate as fuel, but with uncontaminated lubricating oil, the ester content never exceeded 1.0%. Vehicle testing was done under actual driving conditions of a light duty delivery van, with oil change intervals of 7500 km. Viscosity and TBN stayed essentially normal, with soot increasing only one tenth as much as in the bench tests.

Laboratory oxidation tests and bench engine tests were performed by Blackburn et al. [39].The laboratory test, ASTM D 2272, "Continuity of Steam-Turbine Oil Oxidation Stability by Rotating Bomb," used a bomb to measure time required for the oil to react with a given volume of oxygen at 150°C. Tests were done on 20 lubricating oils for gasoline and diesel engines which were diluted with ethyl soyate at a level of 17%. Oxidation life of uncontaminated oil ranged from 60 to 250 minutes, while the oxidation life of contami-nated oil ranged from 20 to 75 minutes.

Bench testing was done with a direct injection engine run 10 hours per day at full rated load and speed using ethyl soyate fuel. Six different lubricating oils, all SAE 30, five API CD, one API

CC were tested. Samples of lubricants were subjected to conventional used oil analyses, including TEN, viscosity and loss of dispersancy by blotter spot test. Concentration of ester was determined by infrared analysis. Tests were terminated when lubricant breakdown based on loss of dispersancy occurred. In all cases, lubricating oil viscosity decreased to a minimum of about 50 percent of initial viscosity at 40 hours followed by rapid viscosity increases at 60 to 70 hours. Tests were terminated at 60 to 75 hours. Ester content of the lubricating oil increased to about 20% at 60 hours. At this time, the concentration of ethyl linolate and ethyl linolenate dropped markedly, indicating depletion of the antioxidant additives in the oil. The TBN also fell to unacceptable limits indicating increasing acid content of the oil, while insoluble and wear metals (copper, lead, and iron) in the oil increased to unacceptably high values.

Valeria NAGY [40] makes experimental investigation on usability of different fuels and their impact on operation of the engine. For the research work they examined the effect of vegetable oil of fuels (RME, rapeseed oil with additive and diesel oil) and then evaluated the engine oil samples (S40, RME, TESSOL, GAZO) at the end of the cycles. In the research work 50 hours long term operating tests on D-240 type Diesel engine was performed with Junkers-brake and examined whether different kinds of fuels have any effect on engine oils by the same engine parameters or whether there are significant differences between the engine oils for lubrication.

At the end of 50 working-hour tests the engine oil samples were analyzed in the accredited testing laboratory at Metric Ltd. and in the Wearcheck Laboratory at Hungarian Oil and Gas Company (MOL Corporation) and the main parameters for lubrication, but not limited to, describe the engine oil, these typical properties were evaluated and analyzed in the experiments.

Based on the test it concluded that the rape oil fuel with additive TESSOL increased kinematic viscosity of engine oil at 40 °C. The same thing for kinematic viscosity at 100°C, the viscosity is increased by 38%. This may be due to the additive TESSOL. But the Viscosity of RME and GAZO samples did not change neither at 40 °C and nor at 100 °C. The difference between decreasing TBN and increasing TAN (TBN–TAND) are 4.1 mgKOH/g for S40 sample, 2.8 mgKOH/g for TESSOL, 2.27 mgKOH/g for RME and 2.91 mgKOH/g for GAZO. So RME sample has the lowest acid neutralizing capacity as a result of acidic effect. However, the relatively short time (50 working-hour) engine tests are not enough to define general professional conclusions. But the oil analysis results are reliable after 20 working-hour tests and describe the condition of the lubricating oil.

2.9 Basic Engine oil parameters

2.9.1. Viscosity

Viscosity, by definition, is oil's resistance to flow and shear. It is the single most critical physical property of the oil as it affects both the wear rate and the fuel efficiency. Water is a low viscosity fluid; syrup is a high viscosity fluid. With oil, like syrup, as you increase the temperature, the viscosity lowers, meaning it flows faster, or more easily. The most common unit of measure for viscosity is the Kinematic viscosity and this is usually quoted in data sheets at 40 and 100°C. The commonly used unit of measure is centistokes (cSt) but the correct SI unit of measure is mm2/s. Kinematic Viscosity is a measure of the fluids resistance to flow and shear under the forces of gravity, or how easily the oil flows to the different parts of the engine. The viscosity of the lubricating oil decreases due to the addition of fuel, water and other contaminants added to it during its time inside the engine. Viscosity of the oil plays a cardinal role in reducing friction and it should be high. It is routinely measured with ease and great precision in capillary viscometers suspended in constant temperature baths. Standard methods are ASTM D445/ISO3105, IP 71 [1, 42]. The importance of viscosity in an engine will determine how easily the oil is pumped to the working components, how easily it will pass through the filter, and how quickly it will drain back to the engine. The lower the viscosity the easier all this will happen. That is why cold starts are so critical to an engine because the oil is cold, and so relatively thick. But, the lower the viscosity, the less the load the oil can support at the bearing on the crankshaft. The higher the viscosity, the better the load it can support. Even this, however, has a trade-off, since the higher the viscosity, the more the drag at the bearing, and hence, potential power loss, or increased fuel consumption. So a compromise is chosen to minimize power loss, but maximize load support.

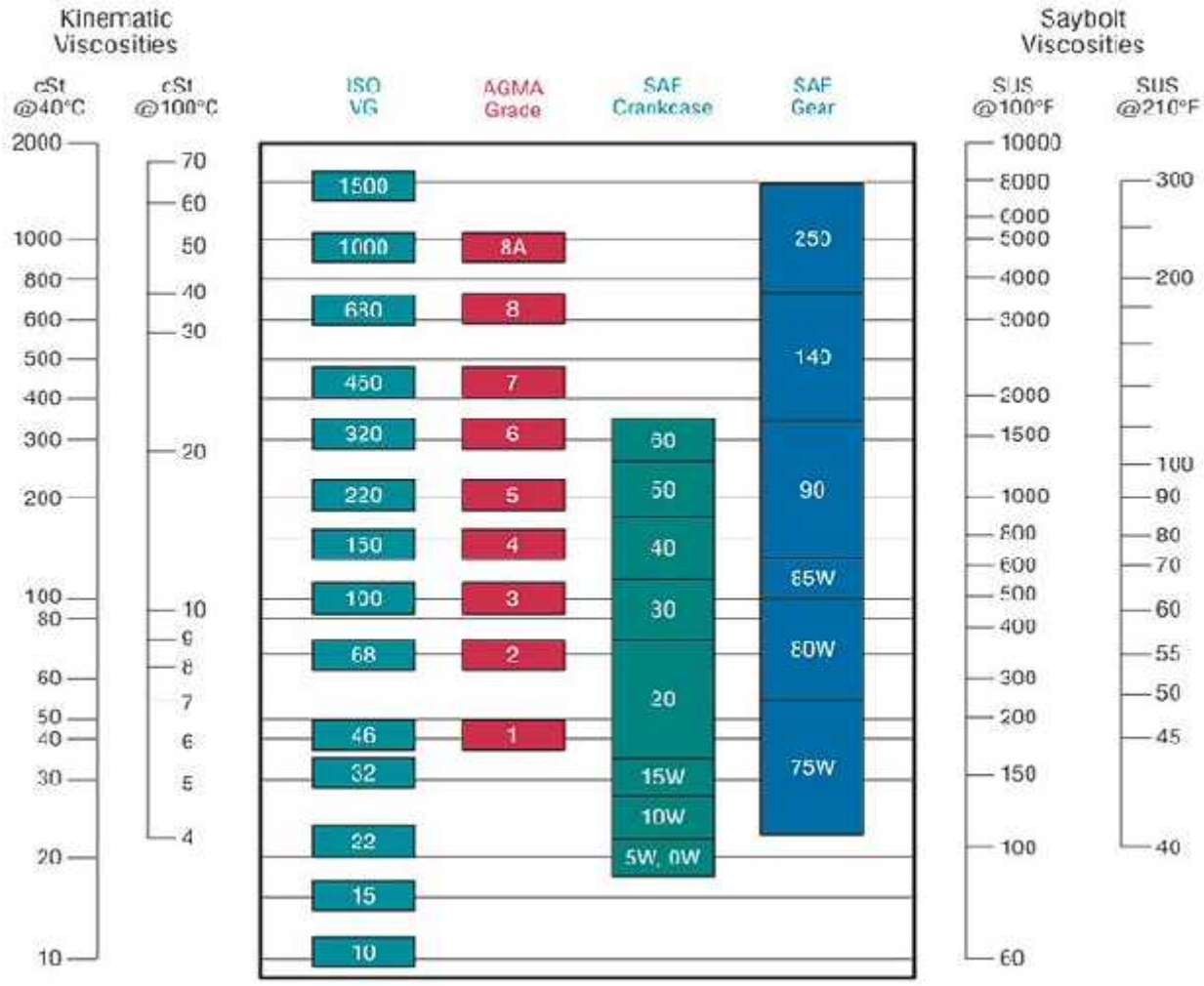


Figure 14: SAE Viscosity grades compared to each other [43]

2.9.2 Viscosity index (VI)

The most frequently used method for comparing the variation of viscosity with temperature between different oils calculates a dimensionless number, the viscosity index, VI. The kinematic viscosity of the sample oil is measured at two different temperatures, 40 and 100°C, and the viscosity change is compared with an empirical reference scale. The original reference scale was based on two sets of lubricant oils derived from separate crude oils a Pennsylvania crude, arbitrarily assigned a VI of 100, and a Texas Gulf crude, assigned a VI of 0 [43].The higher the VI number, the less the effect of temperature on the viscosity of the sample. Full definitions of the calculation methods are given in the ASTM 2270 or IP 226 manuals.

The VI is a useful tool in comparing base oils, but it is vital to recognize its arbitrary base and limitations. Extrapolation outside the measured temperature range of 40–100◦C may lead to false conclusions, especially as wax crystals form at low temperatures. VI is also used as a convenient measure of the degree of aromatics removal during the base oil manufacturing process. But comparison of VI is of different oil samples is realistic only if they are derived from the same istillate feed stock. Therefore, great care should be used in applying VI measurements as indicators of base oil quality.

2.9.3.Total acid number

The Total Acid Number (TAN) indicates the amount of acid content present in the oil. The TAN is the amount of potassium hydroxide required to neutralize the acid present in one gram of the oil. The engine oil undergoes oxidation at elevated temperatures producing carbonyl products and carboxylic acid. Higher TAN indicates the higher acid content and the oil needs replacement.

2.9.4 Flash Point

The flash point of oil is an important safety property because it is the lowest temperature at which auto-ignition of the vapor occurs above the heated oil sample. The FP of a lubricant refers to the minimum temperature at which there is sufficient vapour to cause a flash of the vapour/air mixture in the presence of an open flame. The main concern is to assess the potential for explosion or fire under the anticipated conditions of operation. Contamination by more volatile fluids, such as the dilution of an engine lubricant by fuel, greatly increases the potential for damage due to explosion and/or fire. If the FP of oil is significantly 25% lower than the original value, this indicates contamination by fuel. Repeatability of the test is poor with used oil, but a rop of 25 percent shows that excessive dilution has taken place Different methods are used, ASTM D92, D93, and it is essential to know which equipment has been used when comparing results.[44]

2.9.5 Ash Content

The term sulfated ash relates to the amount of metallic elements in engine oils, which are mostly derived from the engine oil's detergent and anti-wear additive chemistry. These additive packages contain multiple components based on metals such as calcium, magnesium, zinc, etc. Because a 100 percent seal between the piston rings can never be achieved, a certain amount of engine oil will enter the combustion burn [45].

As the engine oil enters the combustion chamber and burns, its residue form an ash-like material. This ash-like material contributes to deposits in the crown land above the piston ring as well as to deposits in the ring grooves. These deposits can lead to rubbing wear on the cylinder liner and cause the piston rings to not operate freely. Ultimately, as the cylinder liner-to-ring interface is compromised high oil consumption can occur.4 In addition to these deposits, inorganic compounds from the lubricating oil's additives can become oxidized during combustion and generate metal oxide particles. These particles can be carried downstream with the exhaust and collect on the diesel particulate filter. These ash particles cannot be removed by filter regeneration because they are not combustible. As the ash particles accumulate, they result in filter blockage that increases back pressure to the engine, increasing fuel consumption and decreasing power. Ash particle buildup also necessitates more frequent cleaning of the particulate filters by mechanical means such as compressed air or water-pulse methods.

Engine oil's sulfated ash content also directly relates to engine oil's acid neutralization capabilities (BN), because most of engine oil's BN comes from the metal-containing detergent additives. Generally, the higher an engine oil's BN, the higher its ash content and the greater its ability to prevent acidic corrosion in the engine. Fortunately, with the mandated use of ultra-low sulfur diesel fuel in on-highway applications, corrosion from fuel sulfur will require less of a need for BN control and thus lower ash content.

2.9.6. Carbon Residue

The base stock components of engine oils are mixture of many compounds that differ widely in their physical and chemical properties. Some vaporize at atmospheric pressure without leaving an appreciable residue. When destructively distilled, the nonvolatile compounds may leave a carbonaceous material known as carbon residue. Carbon residue has little value as a guide for predicting deposit-forming tendencies in automotive engines, but may relate to intake port deposits in certain large, two stroke cycle, natural gas fueled stationary engines [58].

3. MATERIALS AND METHODS

This experimental based thesis work, which aims to find the effect of usage of JSVO as a fuel on hardware and lubricating oil properties of a small scale diesel engine which is used for farm irrigation, was conducted in automotive workshop of ASTU. Two brand new engines of exactly same specification, one for diesel and another for JSVO, were used in this work. This chapter gives the details about various materials and standard equipment used and step by step procedure followed in achieving the objectives set.

3.1. Materials

The materials used in this work are listed in table 1

- The experiment was done at ASTU automotive work shop using the materials listed in table 1.

Table 1:List of materials

S/n	item	QTY	remark
1	DY23-2D Engines	2	Engine available in workshop
2	Jatropha SVO	23 lit	Available in the workshop. Which was produced by mechanical pressing
3	SAE 30 Engine oil	4 liter	From local market. (Including initial 25 operating hours.)
4	Diesel fuel	35 liter	From local market (Including initial 25 operating hours.)
6	Secondary fuel tank	1	Available in the work shop
7	Control valves	2	Available in the work shop

- Characterizations of JSVO and various samples of lubricant were tested in the laboratory of Ethiopian Petroleum Supply Enterprise, Addis Ababa. The testing equipment used for this purpose was listed in table 2.

Table 2: List of test equipment

s/n	Product name	specification	Remark
1	SETA.KV-8 viscometer bath	ASTM D 445	For both JSVO and oil
2	Digital Density Meter	ASTM D 4052	For both JSVO and oil
3	Pensky-Martens Closed Cup Flash Point Testing Machine	ASTM D 93	For both JSVO and oil
4	Automatic Centrifuge & centrifuge tube	ASTM D 2709	For both JSVO and oil
5	Gas Conradson	ASTM D 189	Only for engine oil
7	Ash content instrument	ASTM D 482	For both JSVO and oil
8	Acid and Alkali and Acidity Tester in Oil	ASTM D 974	For both JSVO and oil
9	Lovibond Petroleum Oils Comparator	ASTM D 1500	Only for JSVO
10	Copper Strip Corrosion Tester	ASTM D 130	Only for JSVO
11	Cloud point Tester	ASTM D 2500	Only for JSVO

- Disassembling and measurement of mechanical wear of various parts of engine as per standard procedure was done in automotive workshop. Various instruments used during this process are given in the table 3 and shown in figure 15.

Table 3: list of materials used for disassemble and wear measurement

s/n	Name	specification	Remark
1	Open and Box end wrench	10 to 19 mm	
2	Socket wrench	set	
3	Hammer	2 pcs	small (Ball pin and plastic)
4	Screw drivers	2 pcs	Flat and Philips
5	Torque wrench	<50 Nm	
6	Digital Varner caliper	< 200mm	
7	Micrometers	0 – 100 mm	0-25,25-50,50-75&75-100
8	Bore and telescopic gauge	set	
9	Filler gauge	0 - 100 mm	

Figure 15: Tools and measuring instruments for wear

3.2. DY23-2D Engine Description

Nearly all agricultural tractors pump sets, farm machinery, and transport vehicles use direct injection diesel engines. Keeping the specific features of diesel engines in mind, stationary diesel engines widely used in the agricultural sector has been selected for present experimental investigations.

The reason to select these stationary diesel engines is that they are designed to produce shaft power with high efficiency around the rated speed. They are generally used for applications where load variations are limited, which guarantees high combustion temperatures, provided the engines correctly sized. Unlike vehicle engines, stationary engines operate at slow speeds, with high compression rates (the compression ratio of DY23-2D engine is 21). These characteristics provide better combustion conditions, notably longer residence times and higher temperatures, so that fuels with lower cetane numbers can be used. These engines are therefore perfectly suitable for use with fuels such as DDO, Fuel Oil 180 or SVO with lower cetane numbers than diesel vehicles.

3.2.1. General specification of Robin engine

The specification of robin engine are seen in table 4

Table 4: Robin Diesel Engine specification

Model	**DY23-2D**
Type	Air-Cooled. 4-cycle, Overhead Valve, Single vertical cylinder, Diesel engine
Bore	70
Stroke	60 mm
Piston Displacement	230 cc
Compression Ratio	21
Output HP/rpm	4.8/3600
output HP/rpm	4.2/3600
Torque kg-m/rpm	1.07/2200
Rotation	Counterclockwise as viewed from PTO shaft side
Fuel	Automotive diesel fuel
Fuel Tank Capacity	3.2 liters
Combustion System	Direct injection type
Starting System	Recoil starter
Dry Weight	29 kg
Dimension L x W x H	329 x 357 x 402 mm

Figure 16: Robin engine DY23-2D Engine

3.2.2. Description of Function system of DY23 – 2D engines.

3.2.2.1. Fuel System

The schematic diagram for Robin engine DY23-2D is shown in figure 17 given below

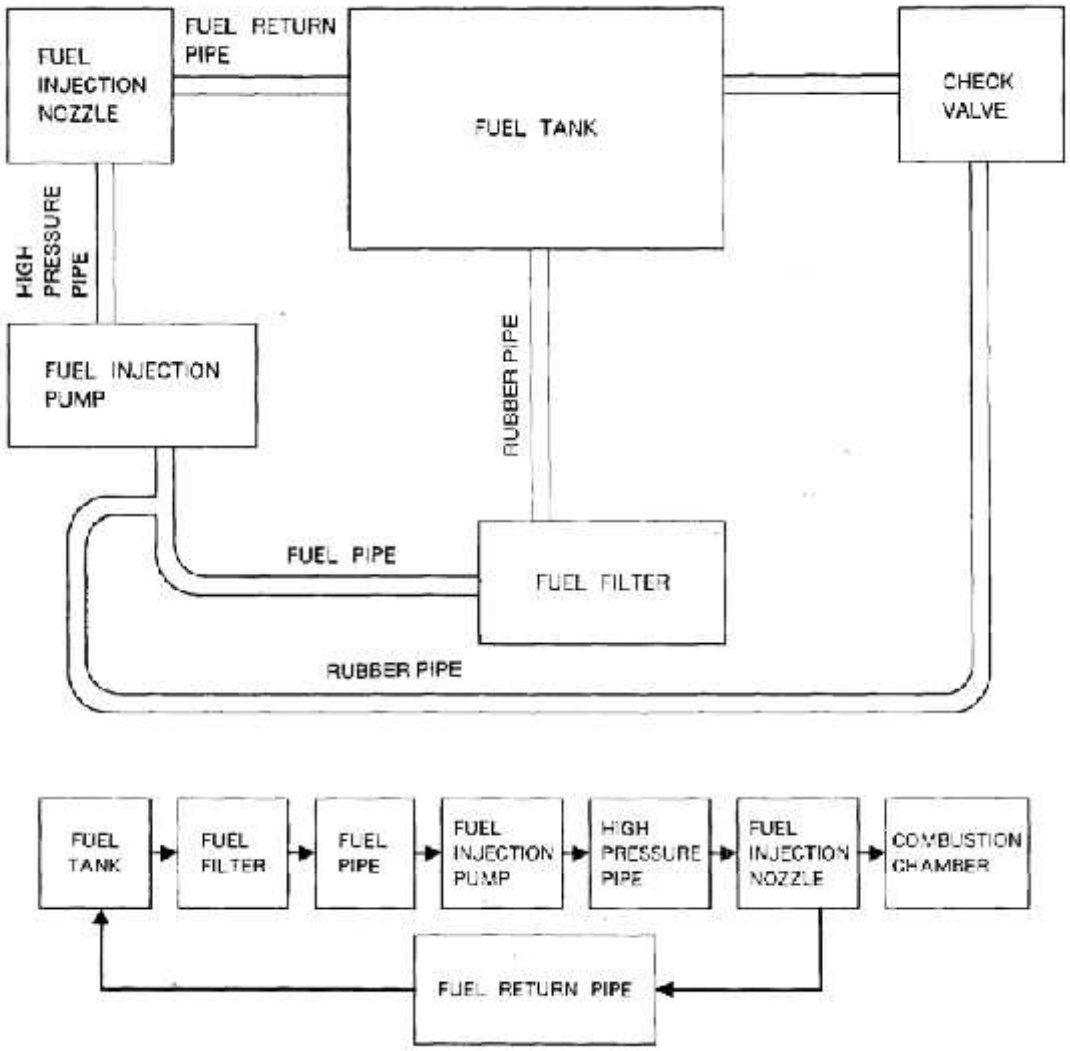


Figure 17: Fuel system schematic diagram for Robin engine DY23-2D Engines [46]

3.4.2.2. Lubrication system

Forced lubrication system is adapted to DY23 engines. The oil in the oil pan is filtered by the oil filter and is forcibly delivered by the oil pump to the crank journal and then to the crank pin lubricating the main bearing and the large end bearing. The oil splashes from the crank journal and the crank pin to lubricate cylinder wall, piston, small end, cam shaft and the

governor system. The rocker arms, valve system etc. inside of the rocker chamber are lubricated by the oil mist contained in the blow by gas supplied from crankcase. The blow- by gas enters into the combustion chamber through the breather valve, and the oil contained in the blow- by gas is finally burnt out. The schematic of diagram of lubrication system is shown in figure 18.

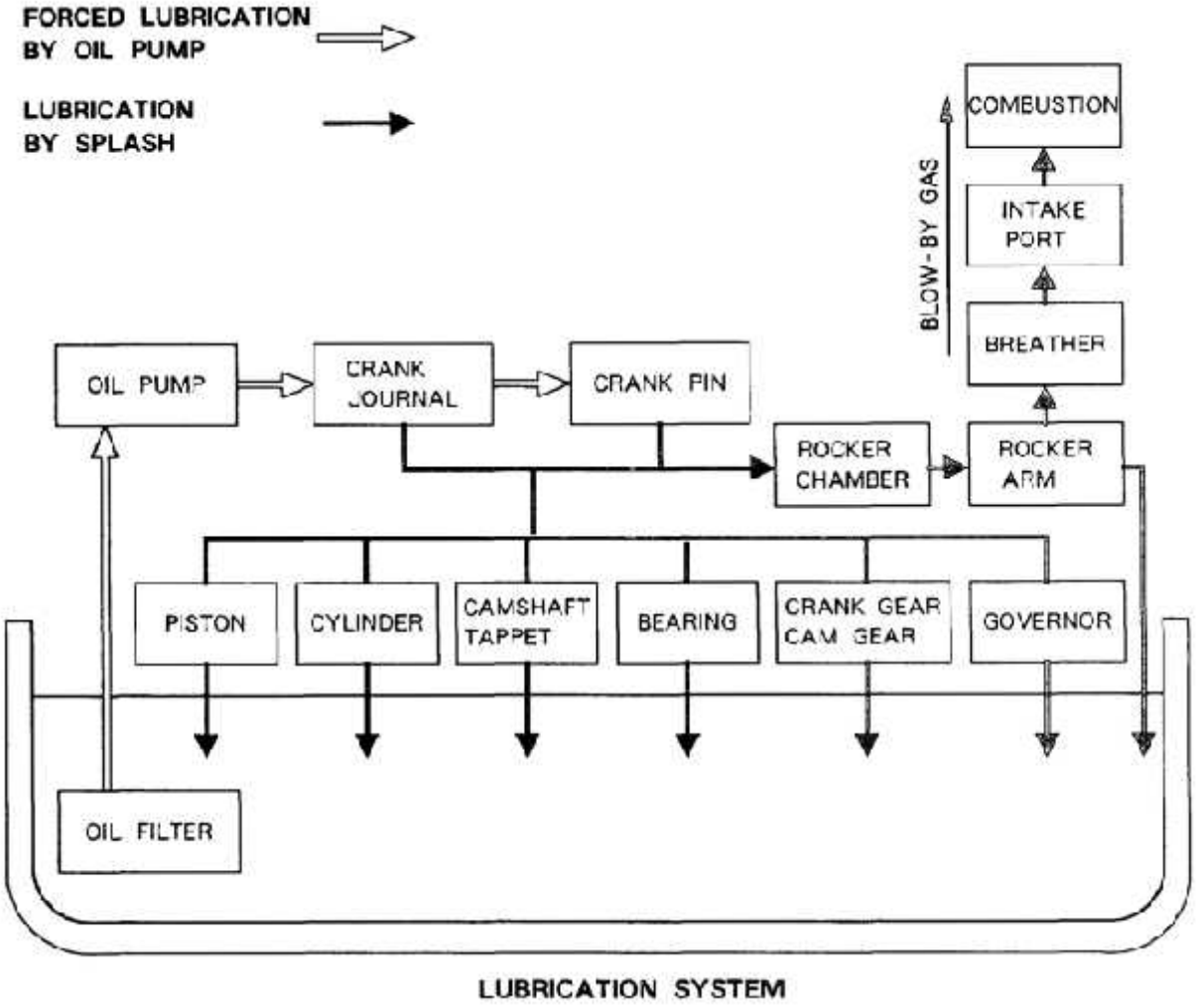
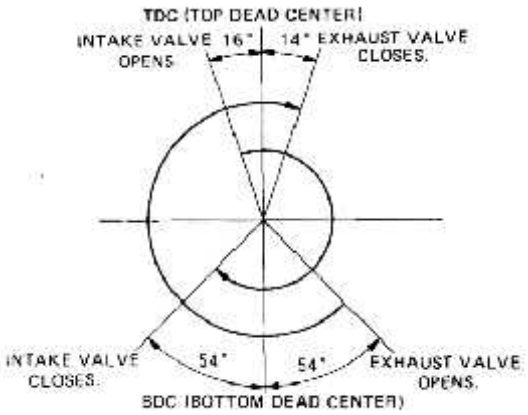


Figure 18; Lubrication system schematic diagram for Robin engine DY23-2D Engines [46]

3.2.2.3. Injection and Valve timing

Injection timing: influences all engine characteristics significantly. The reason is that injection timing influences the mixing quality of the air fuel mixture and hence the whole combustion process. Injection timing of this engine is fixed constant (23° before TDC) irrespective of engine rpm.

Valve timing: In a piston engine, the valve timing is the precise timing of the opening and closing of the valves and valve timing diagram of DY23 engine below gives a clear idea about the actual position of the piston during the opening & closing of inlet & exhaust valves. The valve timing diagram is shown in figure 19 below.



Intake valve opens at 16° before TDC.
Intake valve closes at 54° after BDC.
Exhaust valve opens at 54° before BDC.
Exhaust valve closes at 14° after TDC

Figure 19: valve timing diagram

3.2.3. Maintenance schedule

Periodic maintenance schedule is essential for safe, efficient and long life of engine operation. The maintenance schedule of robin DY 23 – 2D engine is given in table 5 below.

Table 5: Robin engine periodic Maintenance schedule.

Item	**Operating hours**			
	8 hours (daily)	**100 hours**	**500 hours**	**1000 hours**
Check for oil and fuel leakage	X			
Check bolts and nuts for tightness.	X			
Check engine oil	Refill every day up to upper level			
Replace engine oil	X initially 25 hrs.	X		
Check and adjust valve clearance.		X		
Discharge water from fuel filter.			X	
Replace or clean oil filter			X (300hrs)	X replace
Check nozzle and clean			X	
Check valve seat				X

3.3. Methodology

The methodology adapted in this work includes the steps as follows:

1. Preparation of experimental set up
2. Characterization of JSVO
3. Characterization of samples of lubricant
4. Disassembling of the engines
5. Wear measurement of engine parts

3.3.1. Preparation of experimental set up

3.3.1.1. Adaptations of diesel engines for use with SVO

Since their invention in 1892 by Rudolf Diesel, diesel engines have been improved to become highly efficient. Consequently, the current engines are optimized for the fuels they are designed for and are not flexible enough to enable optimum combustion of vegetable oils in the combustion chamber [54].

In order to alleviate the problems of SVO injection and combustion in engines due to their high viscosity and low cetane number, it is necessary to proceed in the same way as when heavy fuels are used. It is necessary to

i. pre-heat the fuel to make it more fluid
ii. Preheat the engine with diesel fuel in order to increase the average temperature inside the combustion chamber and enable rapid and complete combustion [47].

From a practical viewpoint, two options can be used to apply the principles described above to run stationary diesel engines on SVOs; it is necessary to either blend SVOs with diesel at a low oil content, or adapt engines for dual-fuelling [49, 55]:

In this study we use Dual-fuelling systems for the engine with JSVO. The engine started with diesel fuel, once the engine becomes hot, switched to 100% JSVO. It consists in equipping the stationary engine with an extra fuel tank for JSVO, and a system of valves manually controlled making it possible to switch the feed from one fuel to the other. The diesel/JSVO switch-over conditions are controlled as follows:

- ✓ *As long as the combustion chamber has not reached the target temperature levels for good vegetable oil combustion, the engine continues to be feed with diesel oil.*
- ✓ *As soon as the target temperature is reached, the valve is switched manually to feed the engine via the 100% JSVO circuit.*
- ✓ *Before the engine is stopped, fed again for a few minutes with diesel oil to flush the entire feed circuit and enable an easy cold start the next time.*

3.3.1.2. Experimental set up

Two new Robin DY23-2D engines one for diesel and another for JSVO were used to fulfill the set objectives. The basic specifications and important engine systems of the test engines are shown in table 4 and figure 15, 16, 17 and 18. The experimental test was conducted for period of 75 hours for JSVO and diesel. The first engine was run with diesel and the second one was run with JSVO. Sample was taken after 25 hours. The lubricating oil samples were collected from both the engines and various properties were tested. A number of factors affect lubricating oil such as viscosity, TAN. Density, flashpoint, ash and Carbon residue etc. were tested on the lubricating oil samples to assess the comparative condition of engine oil drawn from diesel and JSVO.

The long-term endurance test was carried out according to Indian Standards Code (IS:10000 (Part IX)-1980 Methods of tests for internal combustion engines) and the two similar engines were subjected to similar loading cycles and operating conditions. The engines were run for 25 hours before the endurance test according to the manufacturer recommendation for new engines and the oil was drained from the two engines and refilled with new oil SAE 30 while the recommended oil change interval by the manufacturer is 100 hrs. During the test, each engine was run for 8 cycles (each of 4 hr. continuous running) at rated speed as per IS: 10000, Part IX, 1980. The test cycle is specified in Table 6.

At 69 operating hours the engine running with JSVO makes a knocking sound and minor engine adjustments were made.

The engine was disassembled after completing this long-tern endurance test and was physically examined for carbon deposit and wear of various moving components. Lubricating oil samples were drawn from the oil sump after every 25 hours from these engines and a large number of tests were carried out in order to assess the effect of fuel on the lubricating oil residual useful life. The Schematic diagram and overall pictorial of experimental setup is shown in figure 20 and 21 below.

Table 6: Engine cycle for the endurance test (IS 10,000 Part IX [56])

Throttle position	Running time
Fully opened	1hr (including warm up period 10 min)
Partial opened	1hr
Fully opened	20 min
Idle	10 min
Fully opened	40 min
Partial opened	50 min

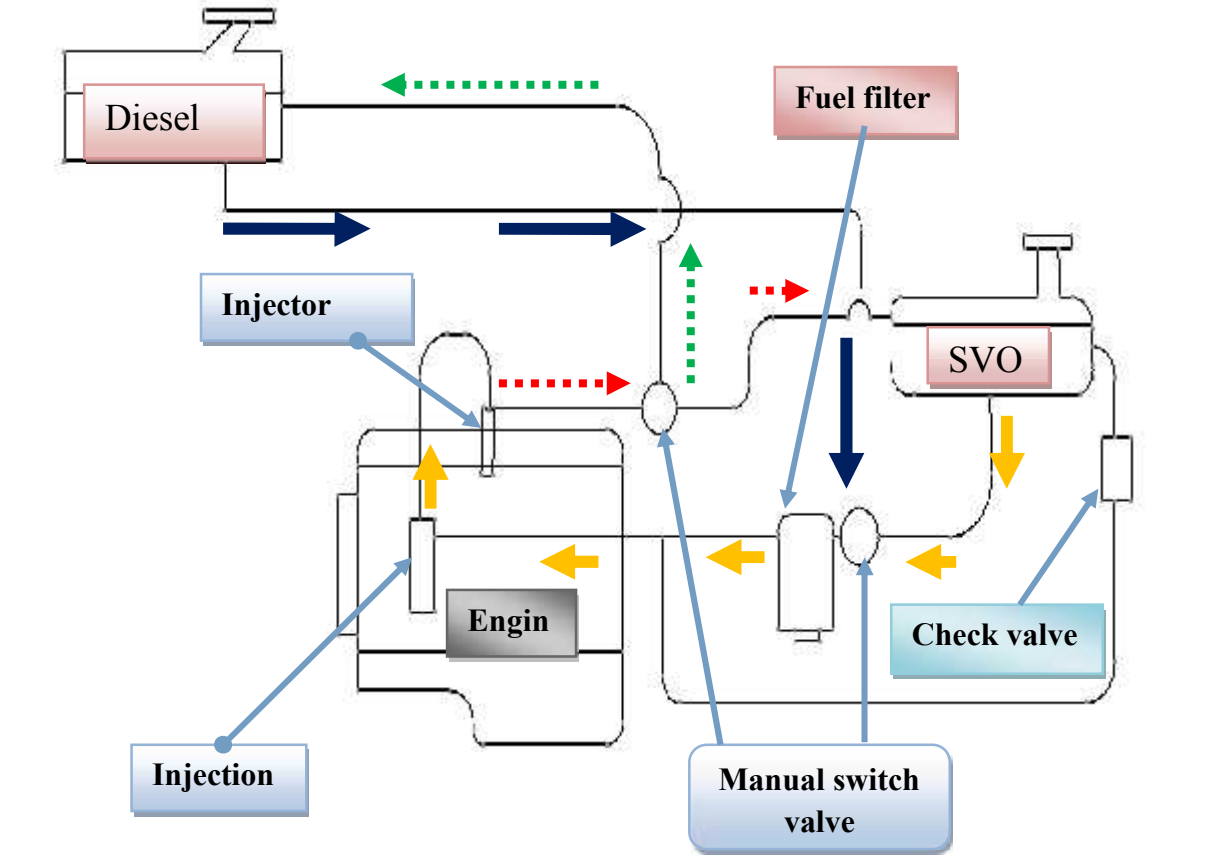


Figure 20: Schematic diagram of experimental setup for dual fueling.

Figure 21: Overall picture of experimental setup for dual fueling and diesel engine

3.3.2. Characterization of JSVO

Vegetable oils are mainly composed of triglycerides that consist of one molecule of glycerol combined with three molecules of fatty acids. The latter contain a long chain of carbon atoms, linked by single bonds and combined with hydrogen, ending with a carboxyl group [50]. Fossil fuel oils are complex mixtures of hydrocarbons which contain paraffins, naphthenes, olefins, and aromatics [47, 48]. Despite a different chemical composition, vegetable oils have similar fuel properties to petroleum-derived diesel fuels, so they are suitable for fuelling diesel engines [51, 52]. SVOs have several advantages over fuel oil for use as fuel in stationary diesel engines: i) local availability, ii) renewability, iii) relatively high HHV, iv) a lower sulphur content, avoiding the environmental issues caused by sulphuric acid, v) a lower aromatic content and vi) high biodegradability [47, 48, 53] .The physicochemical properties of the SVO were determined using the following standard methods.

3.3.2.1. Digital Density Meter ASTM D-4052

Density is a fundamental physical property that can be used in conjunction with other properties to characterize both the light and heavy fractions of petroleum and petroleum products. Determination of the density or relative density of the SVO is necessary for the conversion of measured volumes to volumes at the standard temperature of 15 and 20 °C. The general procedure of this test method is similar to section 3.3.3.2 presented below.

3.3.2.2. Flash Point ASTM D-93

The flash point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of the SVO. However, results of these test methods may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use. The general procedure of this test method is similar to section 3.3.3.5 presented below

3.3.2.3. Kinematic Viscosity ASTM D-445

Many petroleum products, and some non-petroleum materials, are used as lubricants, and the correct operation of the equipment depends upon the appropriate viscosity of the liquid being used. In addition, the viscosity of fuels is important for the estimation of optimum storage, handling, and operational conditions. Thus, the accurate determination of viscosity is essential to many product specifications. The general procedure of this test method is similar to section 3.3.3.3 presented below.

3.3.2.4. Color ASTM D-1500

This test method covers the visual determination of the color of a wide variety of petroleum products, such as lubricating oils, heating oils, diesel fuel oils, and petroleum waxes. Using standard light source a liquid sample is placed in the test container and compared with glass disks ranging in values from 0.5 to 8 when an exact match is not found and the sample colors is reported. Determination of the color of petroleum products is used mainly for manufacturing control purposes and is an important quality characteristic, since color is readily observed by the user of the product. In some cases, the color may serve as an indication of the degree of refinement of the material. When the color range of a particular product is known, a variation outside the established range may indicate possible contamination with another product. However, color is not always a reliable guide to product quality and should not be used indiscriminately in product specifications.

3.3.2.5. Water and Sediment ASTM D-2709

This test method is used as an indication of water and sediment in middle distillate fuels. Appreciable amounts of water and sediment in a fuel oil tend to cause fouling of the fuel-handling facilities and to give trouble in the fuel system of a burner or engine. An accumulation of sediment in storage tanks and on filter screens can obstruct the flow of oil from the tank to the combustor. Water in middle distillate fuels can cause corrosion of tanks and equipment, and if detergent is present, the water can cause emulsions or a hazy appearance. Water is necessary to support microbiological growth at fuel water-interfaces in fuel systems. The general procedure of this test method is similar to section 3.3.3.6 presented below.

3.3.2.6. Corrosiveness to Copper ASTM D-130

This test method covers the determination of the corrosiveness to copper of aviation gasoline, aviation turbine fuel, automotive gasoline, cleaners (Stoddard) solvent, kerosene, diesel fuel, distillate fuel oil, lubricating oil, and natural gasoline or other hydrocarbons having a vapor pressure no greater than 124 kPa (18 psi) at 37.8°C. A Polished copper stripe is immersed in a given quantity of sample and heated at a temperature of 100°C in a bomb for 3hrs. Then the strips are washed in a solvent and compared to the descriptions in Table 7. The test results are given as a number followed by a letter.

Table 7: Copper Strip Rating System ASTM D130

Classification	Designation	Description
1	Slight Tarnish	a. Light orange, almost the same as freshly polished strip
		b. Dark orange
2	Moderate	a. Claret red
	Tarnish	b. Lavender
		c. Multicolored with lavender blue or silver, or both, overlaid on claret red
		d. Silvery
		e. Brassy or gold
3	Dark Tarnish	a. Magenta overcast on brassy strip
		b. Multicolored with red and green showing (peacock), but no gray
4	Corrosion	a. Transparent black, dark gray or brown with peacock green barely showing
		b. Graphite or lusterless black
		c. Glossy or jet black

3.3.2.7. Acid Number ASTM D-974

This test method covers the determination of acidic or basic constituents. It is applicable for the determination of acids or bases whose dissociation constants in water are larger than 10^{-9}; extremely weak acids or bases whose dissociation constants are smaller than 10^{-9} do not interfere. Salts react if their hydrolysis constants are larger than 10^{-9}. Acidity in vegetable oils

can vary from 0.01% to 10% wt (which corresponds to 0.02 to 20 mg KOH/g oil) [57]. Free fatty acids have smaller molecular weights than the triglycerides they are derived from, which makes acidic vegetable oils more easily flammable. According to Vaitilingom, the free fatty acids of SVO are not a problem for use in diesel engines up to 10% wt. When acidity increases from 0.01% to 1% wt, and to 10% wt, the "flash point" is reduced by 20°C and 85 °C respectively. Despite the fact that some engine manufacturers, such as Wartsila, accept free fatty acid contents up to 15mg KOH/g SVO, The general procedure of this test method is similar to section 3.3.3.8 presented below.

3.3.2.8. Cloud Point ASTM D 2500

For petroleum products and biodiesel fuels, cloud point of a petroleum product is an index of the lowest temperature of their utility for certain applications. The inter laboratory program consisted of a product of Test Method D1500 color of 3.5 and lower. The precisions stated in this test method may not apply to samples with ASTM color higher than 3.5. As described in ASTM D 2500, the cloud point is determined by visually inspecting for a haze in the normally clear fuel, while the fuel is cooled under carefully controlled conditions. The sample was continuously monitored and the temperature that corresponds to the first formation of a cloud in the fuel was recorded. And the temperature at which the fuel solidifies is the pour point. The apparatus used for this test is shown in Figure 22.

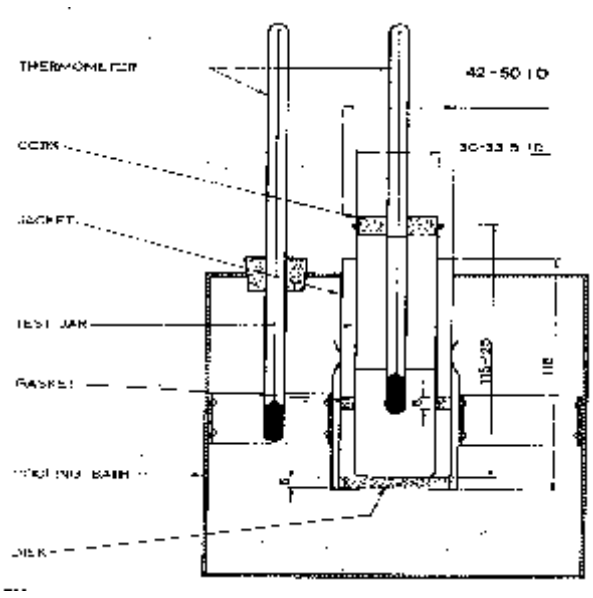


Figure 22: Cloud Point Apparatus

Note: The readings and results obtained from ASTM tests are presented on the next chapter 4.

3.3.3. Characterization of sample of lubricant

3.3.3.1. Engine oil for Robin engine DY23-2D

According to Robin DY23-2D manufacturer recommendation we use engine oil of grade SAE 30 for the temperature/season between 10°C to 40°C and pour the oil up to the upper level of the oil gauge (approximate 0.9 liter). The two engines were operated for 75 hours one with diesel and the other one with JSVO. The oil sample was taken at interval of 25 operating hour of the engine and we use ASTM standard measurements to determine basic properties of parent and used lubricating oil samples drawn from the two engines.

3.3.3.2. Determination of Density ASTM D 4052

Density is a fundamental physical property that can be used in conjunction with other properties to characterize oil. The digital density analyzer was calibrated at 15 and 20°C for the determination of the density of the samples at 15 and 20°C. The procedure for the determination was done according to ASTM D4052. A small volume of new and used oil of the samples (0.7mL) was introduced into an oscillating tube and the change in the oscillating frequency of the U-tube as a result of the change in mass of the tube was used together with calibration data to determine the density of the oil samples. The density of the sample was recorded when the instrument displayed a steady reading.

The results obtained from the methodology presented in this chapter will be presented and discussed in the next chapter 4.

Figure 23; Digital Density Analyzer

3.3.3.3. Determination of Kinematic viscosity ASTM D 445

This test method specifies a procedure for the determination of the kinematic viscosity, ν, of liquid petroleum products, both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer. The dynamic viscosity, η, can be obtained by multiplying the kinematic viscosity, ν, by the density, ρ, of the liquid. The time is measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled and known temperature. The test is usually conducted by measuring the time required for a volume of liquid to flow under gravity through a calibrated glass capillary tube. The kinematic viscosity is then equal to the product of this time and a calibration constant for the tube.

Cannon-Fenske glass capillary tube viscometer was used in a SETA KV-8 viscometer bath and the oil sample was kept in the bath for 30 minutes to reach the equilibrium temperature of 40^0C and 100^0C.The time (t) was measured for a fixed volume of liquid to flow under gravity through the capillary of calibrated viscometer figure 24 and at a closely controlled and known temperature. The kinematic viscosity is then equal to the product of this time and a calibration constant for the tube.

Kinematic viscosity = C x t… …… (i)

Where, C=calibration constant
t= time

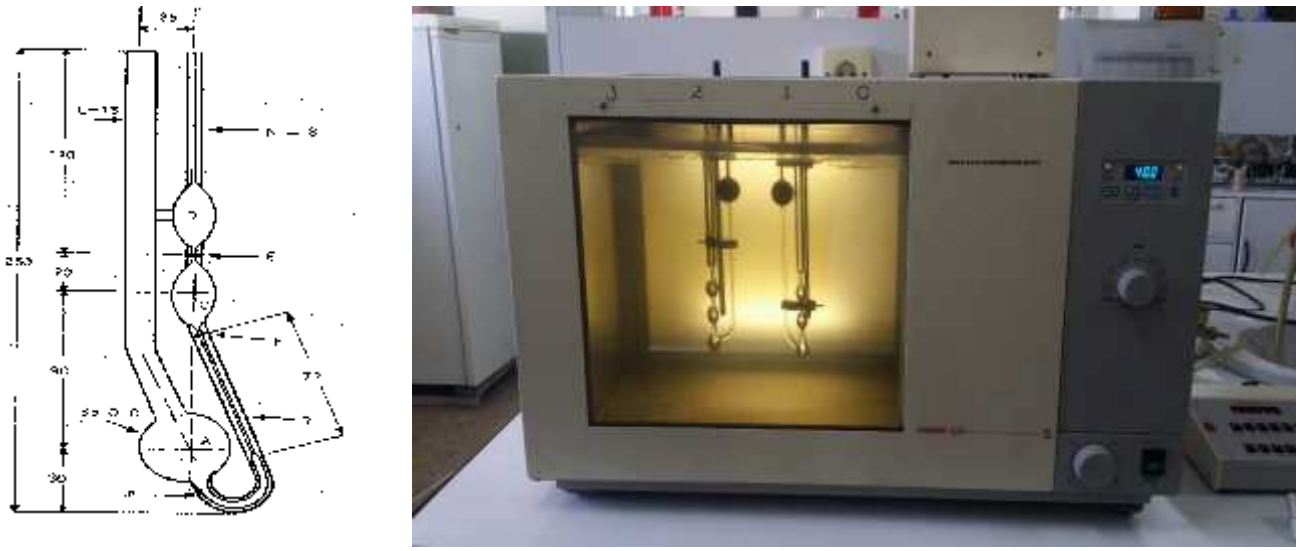


Figure 24: Cannon-Fenske style glass capillary tube in a SETA.KV-8 viscometer bath.

3.3.3.4. Determination of Viscosity Index ASTM D 2270

The Viscosity Index is a widely used and accepted measure of the variation in kinematic viscosity due to changes in the temperature of a petroleum product between 40 and 100°C. Viscosity index is an arbitrary number used to characterize the variation of the kinematic viscosity of a petroleum product with temperature. For oils of similar kinematic viscosity, the higher the viscosity index the smaller is the effect of temperature on its kinematic viscosity. This practice specifies the procedures for calculating the viscosity index of petroleum products, such as lubricating oils, and related materials from their kinematic viscosities at 40 and 100°C. The calculation of viscosity index from kinematic viscosities at 40 and 100°C is exact, and no precision limits can be assigned to this calculation. The accuracy of the calculated viscosity index is dependent only on the accuracy of the original viscosity determination.

Procedure to calculate Kinematic viscosity: The measured kinematic viscosity at 100°C of the new and used oil was less than 70mm^2/s (cSt) and we extract the corresponding value from the basic values for L and H for kinematic viscosity in 40 – 100°C system. For those measured values within the range and less than 70mm^2/s (cSt) but not listed on the basic values for L and H for kinematic viscosity in 40 – 100°C system, we obtained by linear interpolation.

The kinematic viscosity above 70 mm^2/s (cSt) at 100°C, calculate the value of L and H as follows:

$$L=0.8353Y^2+14.67-216 \quad \text{(i)}$$

$$H=0.1684Y^2+11.85Y-97 \quad \text{(ii)}$$

Where,

L= kinematic viscosity at 40°C of an oil of 0 viscosity index having the same kinematic viscosity at 100°C as the oil whose viscosity index is to be calculated, mm^2/s (cSt)

Y= kinematic viscosity at 100°C of the oil whose viscosity index is to be calculated, mm^2/s (cSt)

H = kinematic viscosity at 40°C of an oil of 100 viscosity index having the same kinematic viscosity at 100°C as the oil whose viscosity index is to be calculated, mm^2/s (cSt)

Formula to calculate viscosity index (VI) of oil

$$VI= [(L-U)/ (L-H)] \times 100 \quad \text{(iii)}$$

Where,

U= kinematic viscosity at 40°C of the oil whose viscosity index is to be calculated, mm^2/s (cSt)

3.3.3.5. Determination of Flash Point ASTM D 93

The flash point is the lowest temperature at which an applied ignition source will cause the vapors of a sample to ignite. Therefore, it is a measure of the tendency of a sample to form a flammable mixture with air. As a side note, the value of the flash point is used for the classification of flammable and combustible materials needed for safety and shipping regulations. The standard procedure for measuring the flash point for oil is ASTM D 93. The flash point is determined by heating a sample of the oil in a stirred container and passing a flame over the surface of the liquid. If the temperature is at or above the flash point, the vapor will ignite and an easily detectable flash can be observed. The flash need not correspond to a sustained flame. Test cup for ASTM D 93 Flashpoint Test The equipment shown in Figures 25 are used to measure the flashpoint. Figure 25 also shows the test cup for the apparatus. The cup is filled with oil and heated with an external heater. The agitator ensures that the fuel temperature is uniform. A small open flame is maintained from an external supply of natural gas. Periodically, the stirrer is stopped and the flame is pivoted down to an opening in the top of the cup to see if the oil vapors will ignite. The ignition source is shown in this position in Figure 25. When the flash point has been reached, there will be a small flash that is sometimes accompanied by an audible popping sound. Occasionally, the flash may actually extinguish the flame on the ignition source. Figure 25 shows the test cup with its heat source and a heat shield that ensures uniform heating.

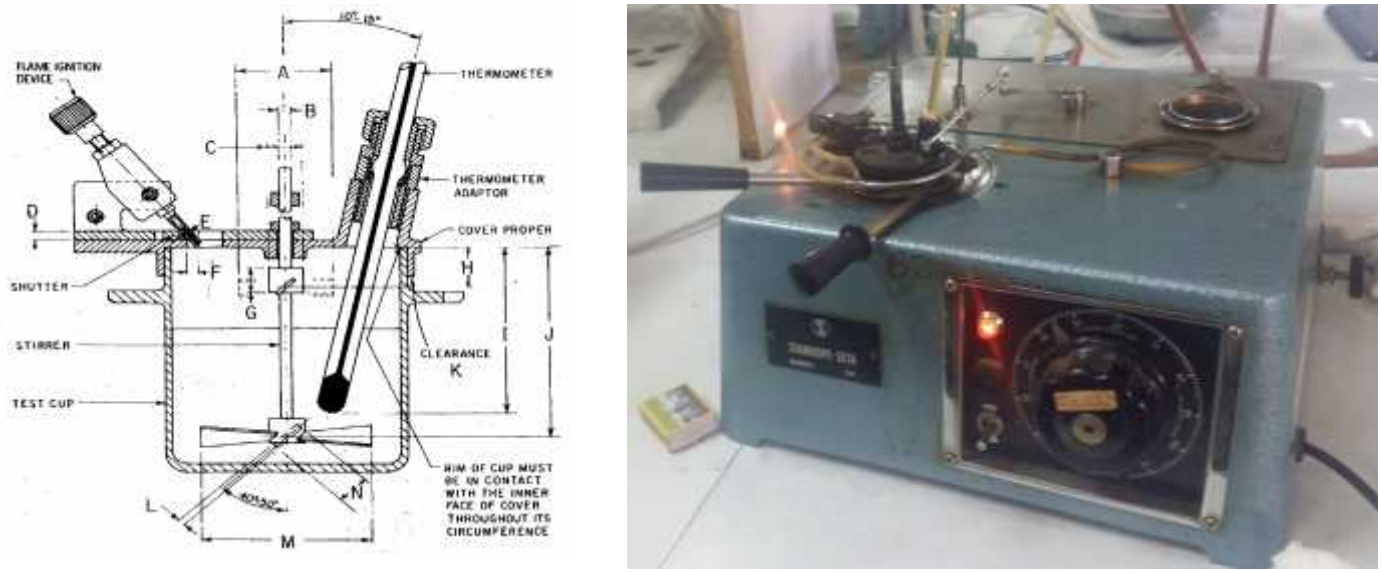


Figure 25: Test cup and Pensky-Martens Closed Cup Flash Point Testing Machine

3.3.3.6. Determination of water and Sediment ASTM D 2709

This test method is used as an indication of water and sediment in oil. Appreciable amounts of water and sediment in oil tend to cause fouling of the oil-handling facilities and to give trouble in the lubrication system of the engine. An accumulation of sediment in sump and on filter screens can obstruct the flow of oil throughout the system.

The test was made by a 100 mL of well-shaken sample is poured into a centrifuge tube and spun at 800±60 rcf for 10 minutes. After centrifugation, the volume of water and sediment which has settled into the tip of the centrifuge tube is read to the nearest 0.005 mL and recorded as the volumetric percent water and sediment by centrifuge. Then reported the volume of the combined water and sediment read from the tube as a percentage of the total sample, since 100 mL of sample was used results lower than 0.005% is reported as either 0 or 0.005 volume%

Figure 26: Petrotest Bench centrifuge for 230V and centrifuge tube

3.3.3.7. Determination of Sulfated Ash 482

This test method covers the determination of ash in the range 0.001–0.180 mass %, from distillate and residual fuels, gas turbine fuels, crude oils, lubricating oils, waxes, and other petroleum products, in which any ash-forming materials present are normally considered to be undesirable impurities or contaminants. The test method is limited to petroleum products which are free from added ash-forming additives, including certain phosphorus compounds.

The oil sample contained in a suitable vessel was ignited and burned as shown in figure 26 until only ash and carbon remain. The Carbonaceous residue was reduced to an ash by heating in a muffle furnace at 775°C, cooled and weighed. Knowledge of the amount of ash-forming material present in a product can provide information as to whether or not the product is suitable for use in a given application. Ash can result from oil or water-soluble metallic compounds or from extraneous solids such as dirt and rust.

Calculation

Calculate the mass of the ash as a percentage of the original samples as follows:

$$\text{Ash, mass\%} = (w/W) \times 100 \quad \text{..... (i)}$$

Where, w = mass of ash, g.

W = mass of sample

Figure 27: Chamber furnace and oil sample ignited and burned

3.3.3.8. Determination of Acid number ASTM D 974

Acid Number is an indicator of oil serviceability. It is useful in monitoring acid buildup in oils due to depletion of antioxidants. Oil oxidation causes acidic byproducts to form. High acid levels can indicate excessive oil oxidation or depletion of the oil additives and can lead to corrosion of the internal components. By monitoring the acid level, the oil can be changed before any damage occurs.

This test method covers the determination of acidic or basic constituents in petroleum products and lubricants soluble or nearly soluble in mixtures of toluene and isopropyl alcohol. It is applicable for the determination of acids or bases whose dissociation constants in water are larger than 10−9; extremely weak acids or bases whose dissociation constants are smaller than 10−9 do not interfere. Salts react if their hydrolysis constants are larger than 10−9.

The Acid value was determined by the acid acid ‑ base titration technique in accordance with ASTM D 974, 2002. Into 250 mL Erlenmeyer flask, about 20 g of sample, 100 mL of titration solvent and 0.5 mL of indicator solution (P-Naphtholbenzein) were added. The mixture was stirred until the sample was entirely dissolved by the solvent. The mixture was titrated with standardized KOH solution by Shaking vigorously to green-black endpoint.

Figure 28: indicator solution P-Naphtholbenzein

3.3.3.9. Determination of Conradson carbon residue ASTM D 189

This test method covers the determination of the amount of carbon residue left after evaporation and pyrolysis of an oil, and is intended to provide some indication of relative coke-forming propensities. This test method is generally applicable to relatively nonvolatile petroleum products which partially decompose on distillation at atmospheric pressure. Petroleum products containing ash-forming constituents as determined by Test Method D482 or IP Method 4 will have an erroneously high carbon residue, depending upon the amount of ash formed

The carbon residue is a measure of carbonaceous material left in an oil after all the volatile components are vaporized in the absence of air. The significance of the Conradson carbon test results also depends on the type of the engine, in which the fuel is used. Pressure jet and steam atomizing type burners are not very sensitive to the carbon residue of the fuel used. The Conradson carbon residue was measured according to ASTM D 189. In the method, a weighed quantity of sample is placed in a crucible and subjected to destructive distillation. The residue undergoes thermal cracking and coking reactions during a fixed period of severe heating. At the end of the specified heating period, the crucible containing the carbonaceous residue is cooled in a desiccator and weighed. The residue is calculated as a percentage of the original sample, and reported as CCR.

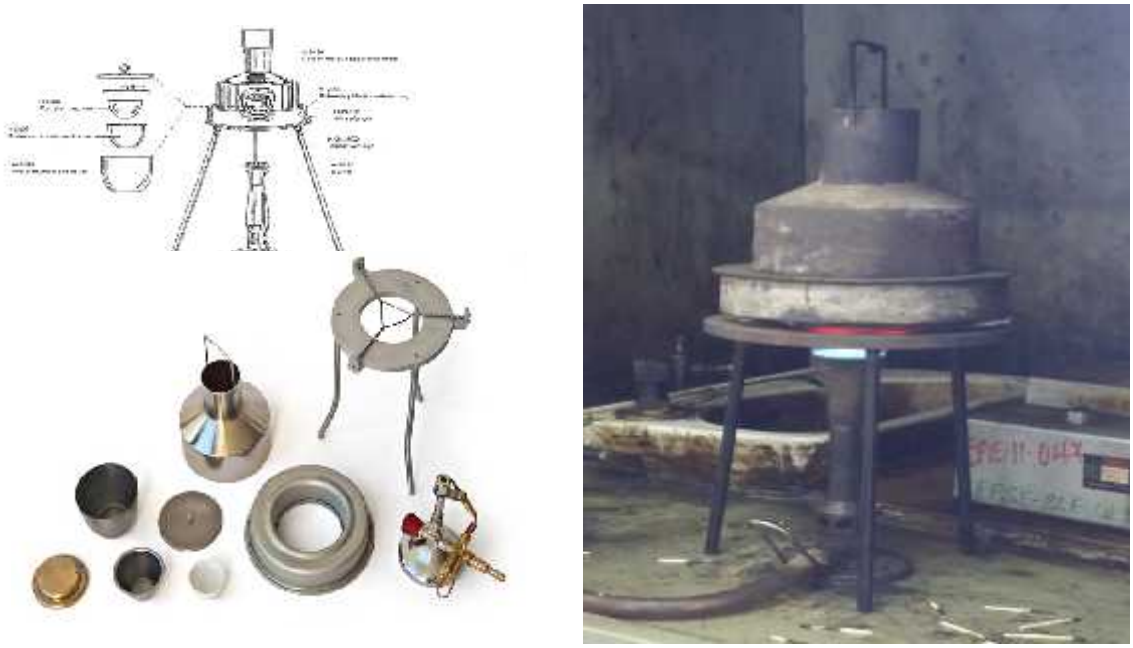


Figure 29: Conradson Carbon Residues Apparatus and Carbon Residue Tester (Conradson Method)

3.3.4. Disassembly of the Engine

To disassemble the engine we use the correct procedure recommended by the manufacturer and we take care of on handling of the disassembled parts not to be damaged. The following table 8 shows the procedure used during disassembling and figure 30 shows the disassembled component part of DY23 – 2D Engines

Table 8: disassembling procedure of DY23 engine

Steps	Part removed	Procedures followed	Tools used
1	Engine oil	i. Oil was discharged from the crankcase by removing the drain plug on the side of the crankcase. ii. The oil gauges was removed to discharge oil quickly.	14 mm spanner
2	Fuel	The fuel was discharge from fuel tank by removing drain plug from fuel filter	10 mm spanner
3	Injection pipe	The two joint nuts at both ends of injection pipe were loosening first to remove it.	12 mm spanner
4	Air cleaner	i. The cleaner cover was removed first from the cleaner body. then, ii. Loosen the wing bolt to remove element. iii. Finally the cleaner body was removed from intake manifold The flange bolts were 6ø x 12 mm.....2pcs.	10 mm box wrench 12 mm box wrench
5	Recoil starter	The recoil starter was removed from Recoil starter blower housing. The flange bolts were 6ø x 10 mm…….4pcs	10 mm spanner
6	Fuel tank	The step to remove the fuel tank was i. Disconnecting fuel pipe from fuel tank. ii. Disconnecting fuel return pipe. ii. Disconnecting rubber pipe from the check valve. iv. Removing the fuel tank. 8ø x 20mmbolt…….. 1 pcs 8Ø X 30mmbolt…….2pcs	12 mm spanner
7	Muffler	First muffler cover from muffler was removed by loosening the bolts with 8ø x 20mm….1 pcs and 8Ø X 30mm...2pcs. then, remove the muffler by loosening the nut and spring washer respectively.	12 mm Box wrench
8	Fuel filter	The fuel filter was removed from the blower housing. By untightening the flange bolts of 6 ø x 20 mm …..2pcs.	10 mm spanner
9	Blower housing	The blower housing was removed from the crankcase.by untightening the bolts and washer of 8 ø x 20 mm...2pcs.	12 mm Box wrench

Steps	Part removed	Procedures followed	Tools used
10	Rocker cover	The rocker cover was removed from the cylinder head by loosening the flange bolts of 6 ø x 40 mm …..4pcs	10 mm Box wrench
11	Fuel injection nozzle.	The first step was removing the bracket nozzle; then the fuel injector from the cylinder head. During the removal of the injector nozzle we give taken care of not to lose the gasket at the bottom end of the nozzle.	10 mm box wrench
12	Rocker arm	The steps during removal of rocker arms was: i. Loosening the adjusting bolts on the rocker arms. ii. Pushing the rocker shaft out from the cylinder head to remove the rocker arms then after the push rods also were removed. The pushrods and rocker arm were marked to easily identify the intake and exhaust.	10 mm spanner
13	Cylinder head	The cylinder head was removed from the cylinder by removing the flange nuts of 8 ø …..4pcs while giving taking care for spacers.	12 mm spanner
14	Main bearing cover	First the bolts joining the main bearing cover and crankcase 8Ø **x** 35 mm….11 and 8ø **x** 40 mm….1 were loosening. Then, lightly tap the cover with aplastic hammer to remove from the crankcase.	12 mm Box wrench Plastic hammer
15	Connecting rod	The connected rod was removed by loosening the connecting rod bolts and removing the large end cap. Then, by pushing the connecting rod up until it completely out from the cylinder while the crankshaft is turned to top dead center.	10 mm Box wrench
16	Piston and piston pin	The removal of the piston was started by removing the two clips at both ends of piston pin and pushing the piston pin out from the piston which is used to remove the piston from the connecting rod. The piston rings also removed from the piston by spreading their open ends.	

Figure 30: Component parts of the two engines after disassembled

3.3.5. Physical Wear Measurement of Engine Parts

The wear of various moving parts take place due to prolonged engine operation. The two engines were operated under identical conditions and the loading cycles of the engines were also similar. The only variation in the operation was that the engines were operated using different fuels so that the effect of each fuel on the life of engine hardware could be compared directly. The dimensions of the following main working parts were checked and recorded according [(IS: 10000 (Part V)) (Preparation for Tests and Measurements for Wear)]. The wear of critical components was recorded in proformae prepared by Indian standard (IS) and compared with the declarations made by the manufacturer.

Before we start the measurement all engine parts was thoroughly cleaned, and free of all dirt, oil, carbon deposits of any kind. The working area also cleaned and well organized to perform the job in a very convenient way. The measurement was done in ASTU workshop. To insure proper wear measurement a logical, step-by-step procedure in accordance to the proformae provided by IS standard were use.

The main engine component parts included in comparison wear measurements are:

1. Cylinder bore
2. Connecting rod
3. Connecting Rod (Gudgeon Pin, Pin Bore and Small End Bush)
4. Piston,
5. piston rings
6. Inlet and exhaust valve
7. Valve spring and
8. Rocker arm.

3.3.5.1. Measurement of cylinder bore

The cylinder and crankcase of DY23 engines are single piece aluminum die casting. The cylinder liner, made of special cast iron, is built into the aluminum casting. The measurement procedure for cylinder bore and measuring equipment are described below

Measuring equipment used

- Bore gauge and Micrometer

Procedure to measure cylinder bore

To achieve the reading, 60-75 extension road from various lengths was selected. Then the gauge was set to zero. This was done by measuring across the gauge with an outside micrometer of 50-75 set to the specified bore size 70 mm and rotating the dial face until 0 aligns with the needle. The gauge was then inserted into the bore to depth of 1,2,3,4 and 5 at two direction of X and Y that is indicated by *IS standard* for measurements of cylinder Bore as shown in the figure 31 and rocked back and forth until the lowest reading was achieved. When the gauge is square to the bore and the indicator needle reverses direction, then the lowest reading was recorded.

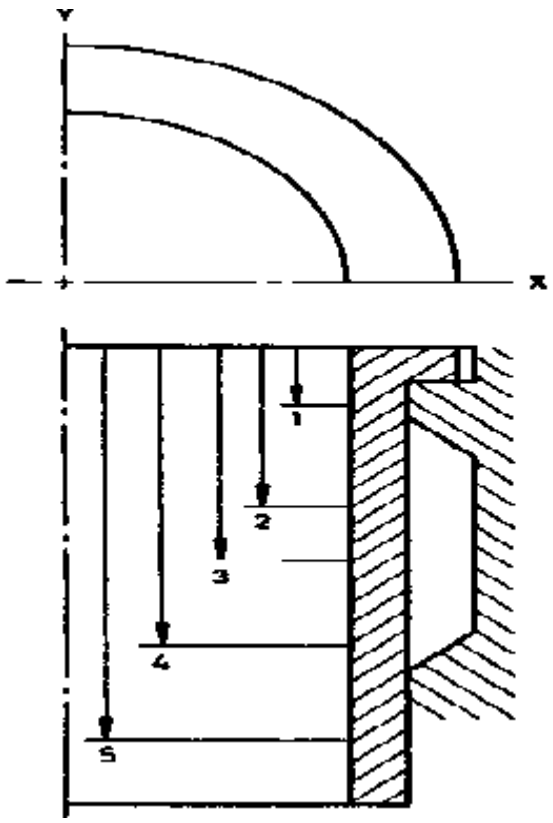


Figure 31: Measurement of cylinder bore (IS standard) [56]

3.3.5.2. **Measurement of Connecting Rod Bearing Bore**

Connecting rod is made from forged aluminum alloy which withstands high combustion pressure and tension under heavy load and high speed operation. Kelmet bearings are provided as large end bearing, while the material of connecting rod itself serves as small end bearing. The measurement procedure for connecting rod and measuring equipment are described below.

Measuring equipment used

- Telescopic gauge and Micrometer

Procedure to measure Connecting Rod Bearing

The measurement of connecting rod was started by selecting the appropriate size of telescopic gauge. Telescoping gauge is "transfer-type" measuring instrument. They are not calibrated and are used to record a distance which is then transferred to a micrometer. To measure the connecting rod we use 30 – 35 mm of telescopic gauge and insert to the two ends of the connecting rod "C" and "D". The measurement was taking place at "l" center position and "m" and "n" at 40° distance from each other as shown in the figure 32 which indicated by *IS standard* (measurements of connecting rod bearing bore).Then by making the handle of the gauge in line with the centerline of the bearing bore lock the handle and remove the gauge to measure and record its setting with a micrometer.

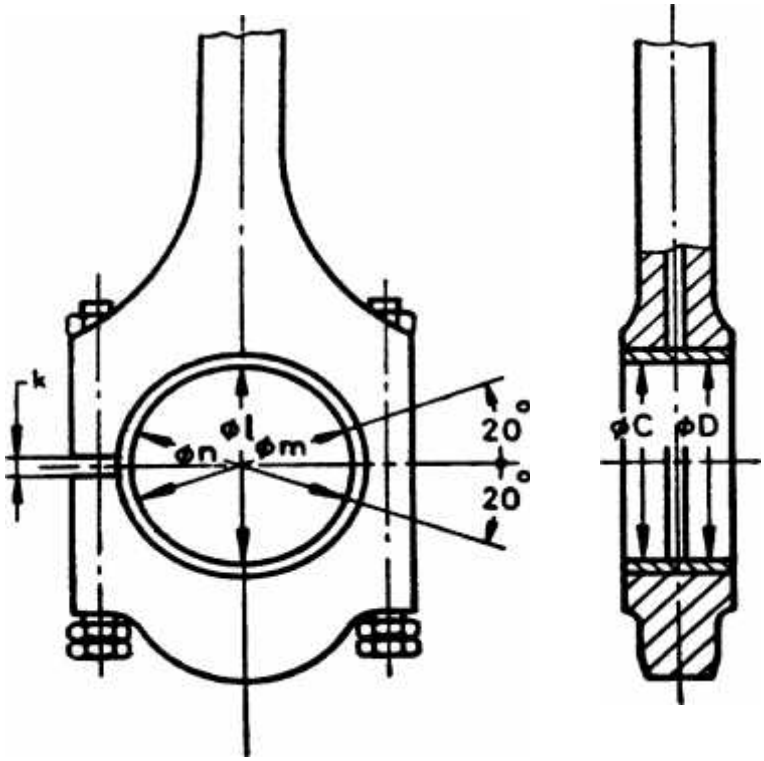


Figure 32: Measurement of connecting rod bearing (IS standard) [56]

3.3.5.3. Measurement of Connecting Rod (Gudgeon Pin, Pin Bore and Small End Bush)

The definition similar to section 3.3.5.2.but the measurement procedure for connecting rod (Gudgeon Pin, Pin Bore and Small End Bush) and measuring equipment are described below.

Measuring equipment used

- Telescopic gauge and Micrometer

Procedure to measure Gudgeon Pin, Pin Bore and Small End Bush

The steps to use the measuring equipment are the same as the procedure described in section 3.3.5.2. But the position and measuring location points are different as shown in the figure 33 below. The measurement was done on Gudgeon pin bore (in piston) at point a_1 and a_2 in X and Y direction, Gudgeon pin (piston pin diameter) at point b_1, b_2 and b_3 in X and Y direction and Small end bush at point c_1 and c_2 in X and Y direction. The telescopic gage and micrometer used were 15 to 20 and 0 to 25 respectively.

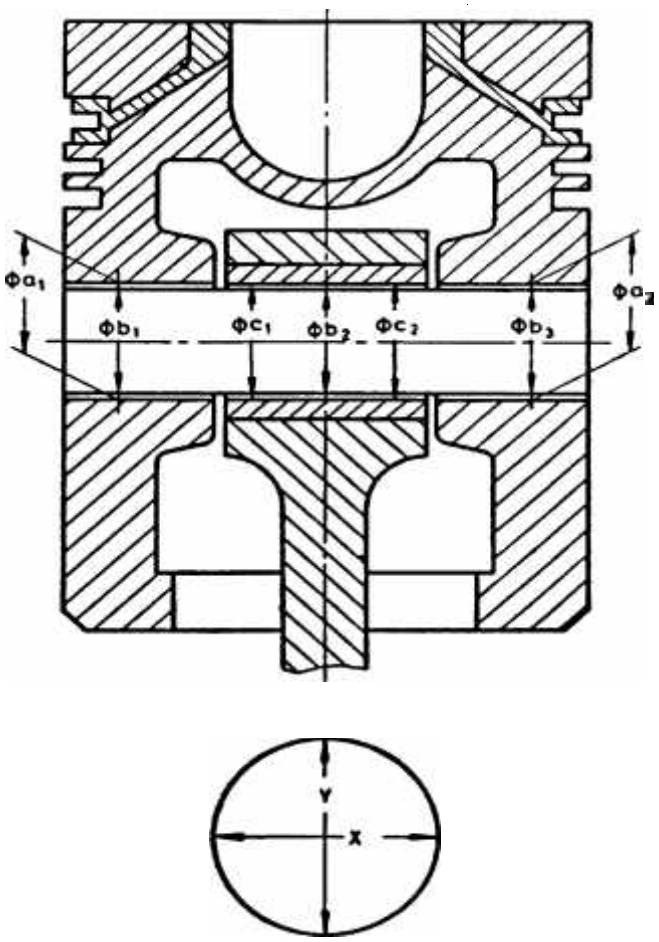


Figure 33: Measurement of connecting rod Gudgeon Pin, Pin Bore and Small End Bush (IS standard) [56]

3.3.5.4. Measurement of Piston

The Piston is made of aluminum alloy casting, and it has three grooves for piston rings. On the piston top, a combustion chamber is arranged where the injected fuel mixes with air and ignites. The piston profile is so designed as to minimize piston noise. The measurement procedure for piston and measuring equipment are described below.

Measuring equipment used

- Micrometer

Procedure to measure Piston

The wear measurement for piston was done at point a, b and c in both direction of X and Y as shown in the figure 34 below. To perform the measurement we use micrometer with range of 50 - 75 which is very fine and precise. The dimension measurement was recorded by positioning and rotating the thimble of micrometer until the two faces of micrometer touch the piston at the points required.

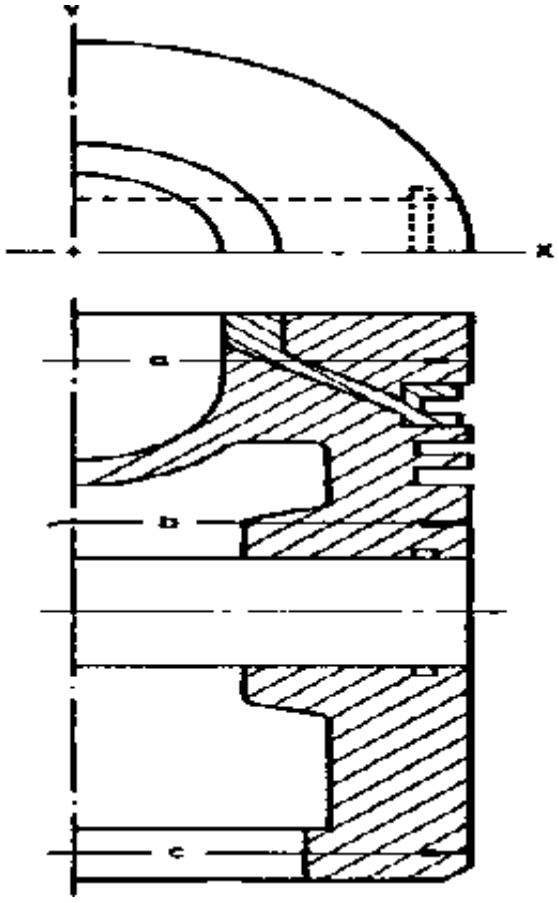


Figure 34: Measurement of piston (IS standard) [56]

3.3.5.5. Measurement of Piston rings

The piston rings are made from special cast iron. The profile of top ring is barrel face, and that of second ring is taper with undercut. The oil ring is the combination of cutter rings and an expander which is excellent in gas sealing and reducing oil consumption. The measurement procedure for piston and measuring equipment are described below.

Measuring equipment used

- Micrometer and feeler gauge and venier caliper

Procedure to measure piston ring

Four types of measurement were done on the piston rings as shown in the figure 35 below. The first two types of measurement Radial wall thickness a1 and Axial Width h1 was performed using micrometer 0-25 mm range and the other two types ring closed Gap s1 and piston ring end gap was by using viernier caliper and feeler gauge respectively. To read a vernier dial caliper, simply add the reading on the blade to the reading on the dial while the measurement technique of feeler gauge is by increasing or decreasing the steel of different thicknesses with measurements marked on each piece on the gap until the gauge of the correct size just fits inside the ring gap. For micrometer reading it's already described in section 3.3.5.4.

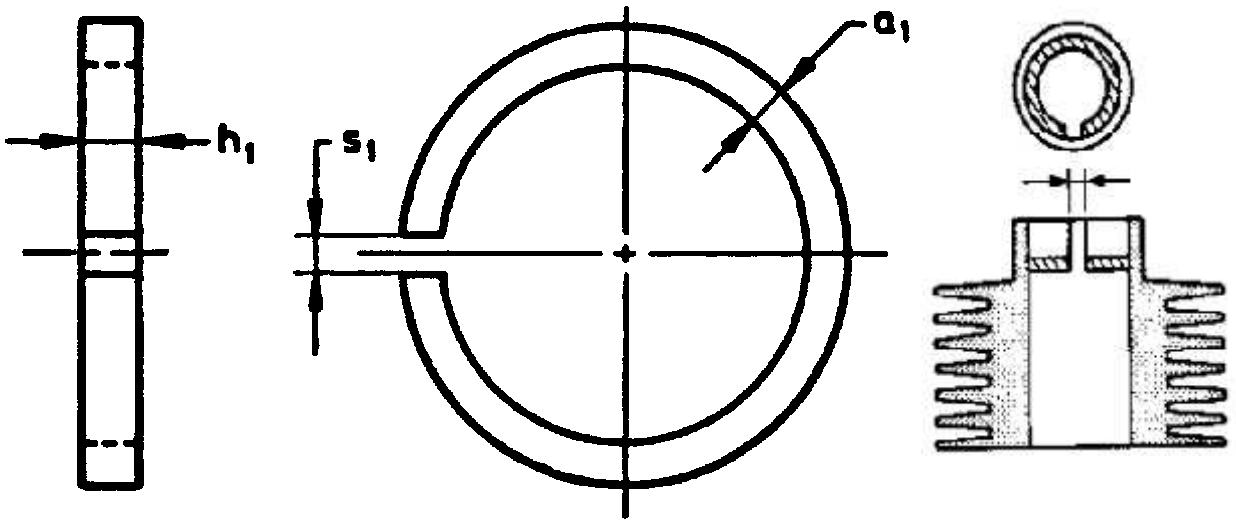


Figure 35: Measurement of piston rings (IS standard) [56]

3.3.5.6. Measurement of inlet and exhaust valve

The valves are made from forged heat resistant alloy. Stellite is fused to the head of exhaust valve for added durability. The measurement procedure for valves and measuring equipment are described below.

Measuring equipment used

- Micrometer and venier caliper

Procedure to measure intake and exhaust valve

The steps to use the measuring equipment are the same as the procedure described in section 3.3.5.5. The valve length was measured with a venier caliper < 200 mm while the steam diameter measured with Micrometer 0-25 mm. measuring position are shown in figure 36 below.

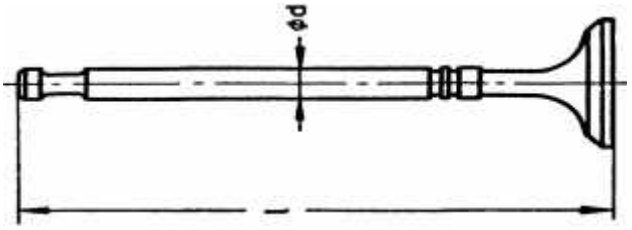


Figure 36: Measurement of piston rings (IS standard) [56]

3.3.5.7. Measurement of rocker arm

Rocker arms are made from forged steel and are wholly sintered. A screw for adjusting valve clearance is provided at the end of rocker arm. Rocker arms are lubricated by the oil mist contained in the breathing air from crankcase. The measurement procedure for rocker arm and measuring equipment are described below.

Measuring equipment used

- Telescopic gauge and Micrometer

Procedure to measure rocker arm

The measuring points are shown in the figure 37 below. The steps to use the measuring equipment are the same as the procedure described in section 3.3.5.2.

Figure 37: Measurement of rocker arm (IS standard) [46]

4. RESULTS AND DISCUSSION

This chapter covers:

- The result obtained from JSVO characterization by testing as per ASTM standard.
- Comparative analysis of the effect of properties of Diesel and JSVO on engine lubricant properties.
- Physical engine parts wear comparison between Diesel and JSVO engines.
- Comparative analysis of Carbon deposit in Diesel and JSVO engines.

4.1. Properties of JSVO fuel.

So far, there has been no generic standard for SVO, whatever the nature of the oil. The evaluation mainly based on diesel standards, some parameters, limit values, or even test methods that are relevant for hydrocarbon products are not suitable for characterizing SVOs.

However, the important properties of JSVO oil used in the study were characterized by ASTM standard test methods and the results are given in table 9.

Table 9: Properties of JSVO

S/N	Property	Test Method (ASTM)	Test Result for SVO
1	Density @15^{0}C,g/ml	D 4052	0.9193
2	Density @20^{0}C,g/ml	D 4052	0.9162
3	Flash point (PMCC),^{0}C	D 93	>207
4	Kinematic viscosity at 40^{0}C	D 445	34.48
5	ASTM Color	D 1500	1.5
6	Water and Sediment,% Vol,	D 2709	<0.05
7	Copper corrosion	D 130	1a
8	Total Acidity, mgKOH/g	D 974	9.05
9	Cloud point,^{0}C	D 2500	-3

4.2. Comparative analysis of Diesel and JSVO Engine lubricant

Investigation on the effect of any new alternative fuel on properties of the lubricating oil is very important for assessing the suitability of new fuel for existing engines. Various lubricating oil investigations were carried out to get an assessment about the health of lubricating oil and the engine. All these tests were used for indirect interpretation of the performance of new fuels in unmodified engines. A comparative study was done on performance of engine oil using both diesel and JSVO as a fuel and the measured results of the tests conducted on lubricating oil samples are discussed below.

4.2.1. Kinematic viscosity

The data for viscosity at 40°C and 100°C of the lubricating oil for diesel fuelled and JSVO fuelled engines is shown in figures 38 and 39 respectively.

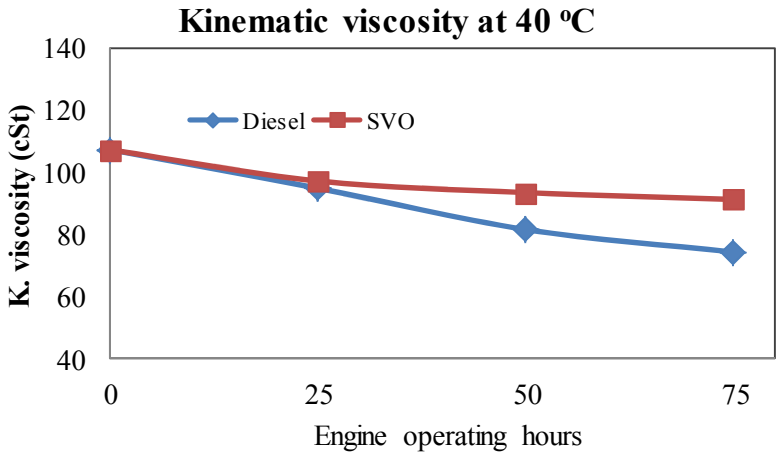


Figure 38: variation of Kinematic viscosity @ 40°C

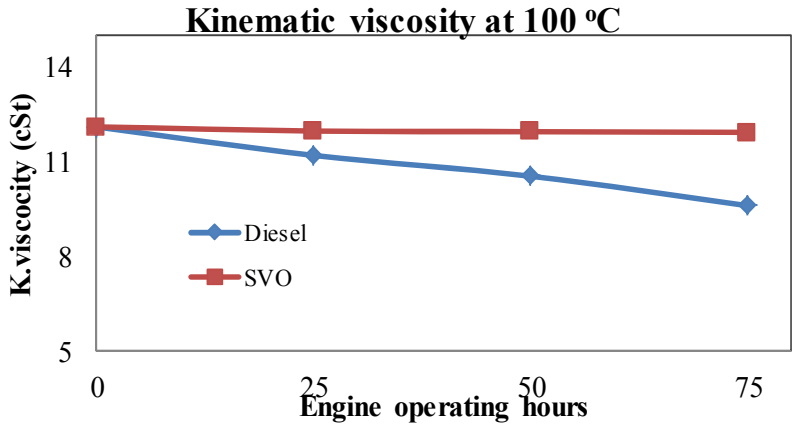


Figure 39 variation of Kinematic viscosity @ 100°C

Viscosity changes should be in acceptable limit as it affects the lubricating efficiency of the engine lubricant. With usage, the viscosity of lubricating oil may either increase or decrease. Inadequate viscosity of oil affects oil film thickness, film formation and load bearing capacity of the engine leading to excessive wear of bearings, and other components, low oil pressures resulting in poor oil economy. There are two main contributing factors responsible for the viscosity changes affecting the oil in opposite directions. Formation of resinous products due to oil oxidation, evaporation of lighter fractions, depletion of anti-wear additives, and contamination by insoluble tend to increase the viscosity, while fuel dilution, moisture addition and shearing of viscosity index improvers tend to bring down its viscosity. The extent of dominance of both the mechanisms, however differ from system to system. Hence, the net result can be reflected in either direction.

If the first factor is dominating and the feasibility of fuel dilution is almost insignificant, the viscosity of used oil becomes higher than the fresh oil. However, viscosity can decrease, if fuel dilution is a more dominating mechanism. In the present case, an important observation is that the extent of lowering of viscosity of the lubricating oil is higher in the case of Diesel fuelled engine compared to JSVO fuelled engine. This should be because of the lower viscosity of diesel fuel from JSVO. The reason for JSVO not decrease similar to diesel is due to large molecular sizes of the triglycerides contained in it which results in higher viscosity.

4.2.2. Density

Density of the lubricating oil increases mainly due to wear debris addition, base-stock polymerization, chemical changes in the lubricating oil due to fuel dilution, and addition of moisture in the lubricating oil. Therefore, change in density is the net resultant which tends to increase or decrease lubricating oil density.

The density of lubricating oil samples at 15 and 20°C from JSVO fuelled engine has shown an increasing trend with the engine operating time while from diesel fuelled has shown a decrease with lubrication oil usage. The following figure 40 and 41 shows change in density and the overall change of density over a period of 75 hours

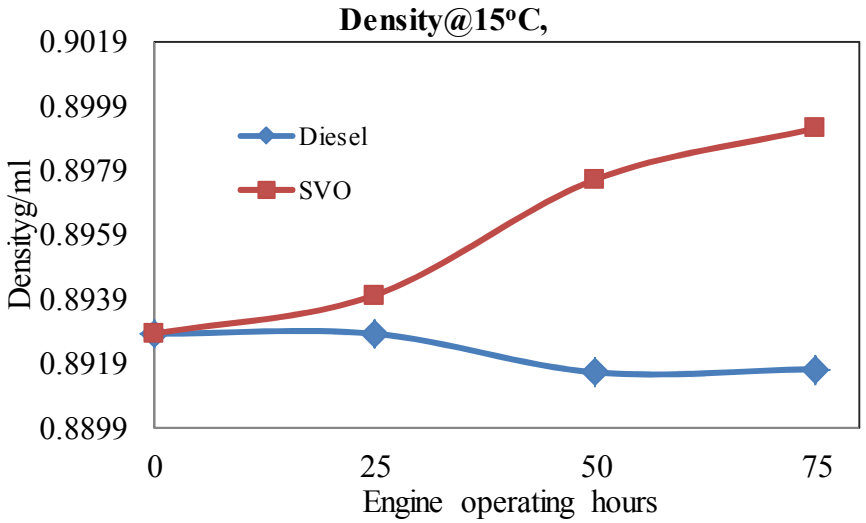


Figure 40: Variation of density of lube oil @ 15°C

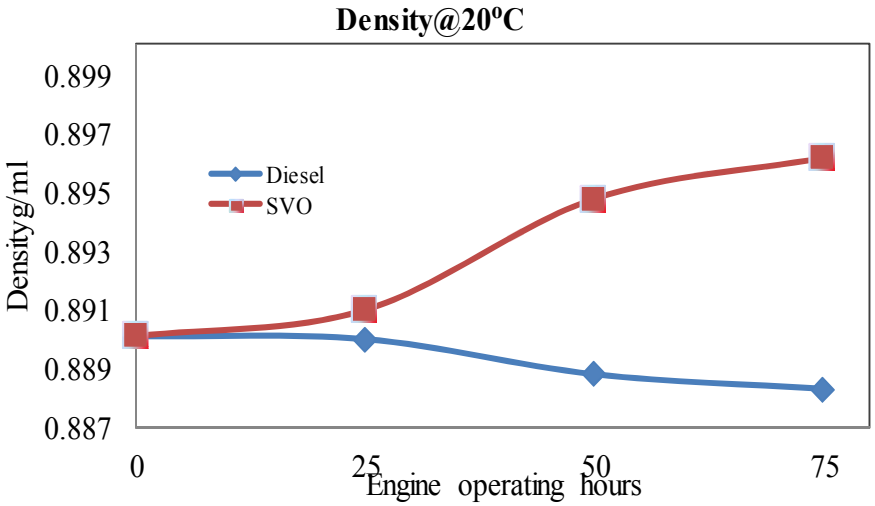


Figure 41: Variation of density of lube oil @ 20°C

From the figure 40 and 41 it is observed that the density of lubricating oil at both temperatures is increasing in case of JSVO engine whereas the density is decreasing in case of diesel engine. The overall change of density over the period of 75 hours indicates that the oil sample drawn from JSVO shows +72 % increments while the oil sample drawn from diesel shows -12 % decrement with respect to the parent engine oil sample.

The increment in density in JSVO results from the large molecular sizes of the triglycerides contained in vegetable oils which results in higher viscosity, higher density and lower volatility

compared to diesel fuel. This also, causes poor fuel atomization due to in part to the large size of droplets upon injection into the cylinder which increases the fuel dilution.

Another reason for the change density is due to difference in density between JSVO, Diesel fuel and Engine oil. Density of JSVO and SAE 30 engine oil was 0.9193 and 0.8928 (g/cm^3) respectively. Therefore, fuel dilution of lubricating oil by JSVO causes to increase in density of lubricating oil in comparison to mineral diesel. In diesel engine the density of diesel fuel was 0.820(g/cm^3) which is less than the density of engine oil SAE 30.this causes the fuel dilution of lubricating oil by diesel fuel to decrease in density of lubricating oil.

However, density measurement alone does not provide any conclusive information regarding comparative effect of fuel chemistry on the lubricating oil.

4.2.3. Flash Point

The data on flash point of lubricating oil for diesel and JSVO fuelled engines is presented in the figure 42.

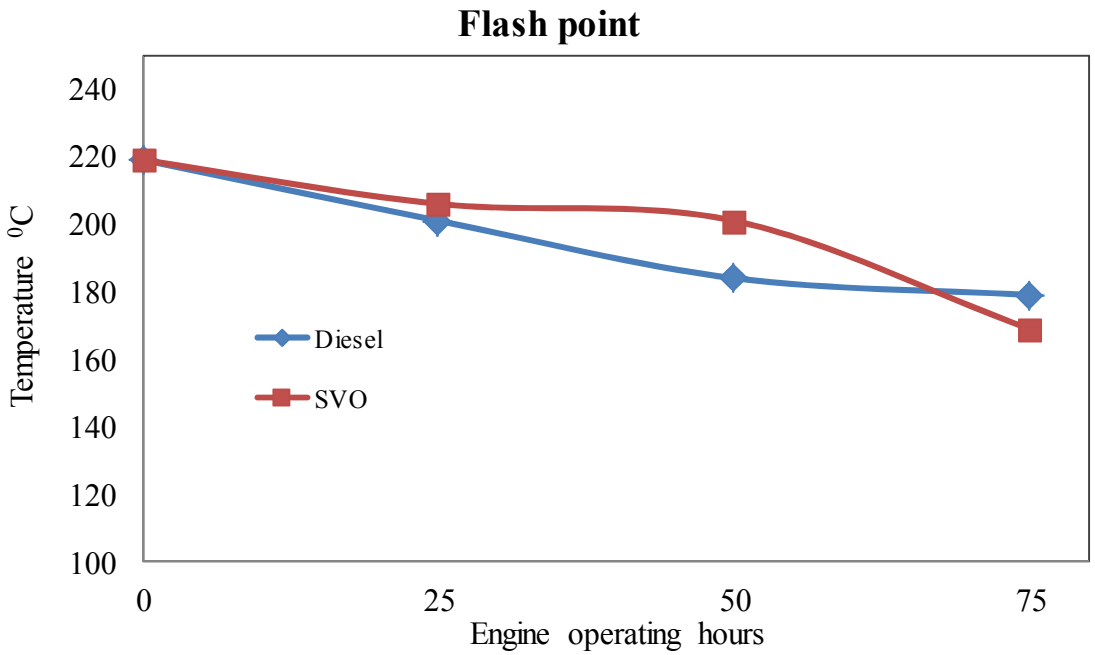


Figure 42: Variation of Flash point of lube oil

For vaporization of lubricating oil, energy has to be supplied in the form of heat. The oil or fuel molecules experience Vander-waals forces on each other. Higher the extent of Vander-waals forces, higher will be the energy required for vaporizing and hence higher will be the flash point.

The flash point of oils from the two engines decreases with duration of operation figure 42. The flash point of engine oil used for JSVO fuel and diesel used in this study were 219 °C. It is observed that in both cases there exists a reduction in flash point. But in case of JSVO engine, the rate of decrement in flash point of lubricating oil is higher after 50 operating hours of the engine which verifies the fuel dilution is higher in lubricating oil samples drawn from JSVO fueled engine.

4.2.4. Viscosity index

Viscosity index is strictly an empirical number and indicates the effect of change in temperature on viscosity figure 43. For engine oils, a relatively small change in viscosity with temperature (high VI) is desirable to provide a wide range of operating temperatures over which a given oil will provide satisfactory lubrication. At low temperatures, a relatively low viscosity oil is desirable to permit adequate cranking speed during starting and then adequate flow to the oil pump and the entire engine oiling system after starting.

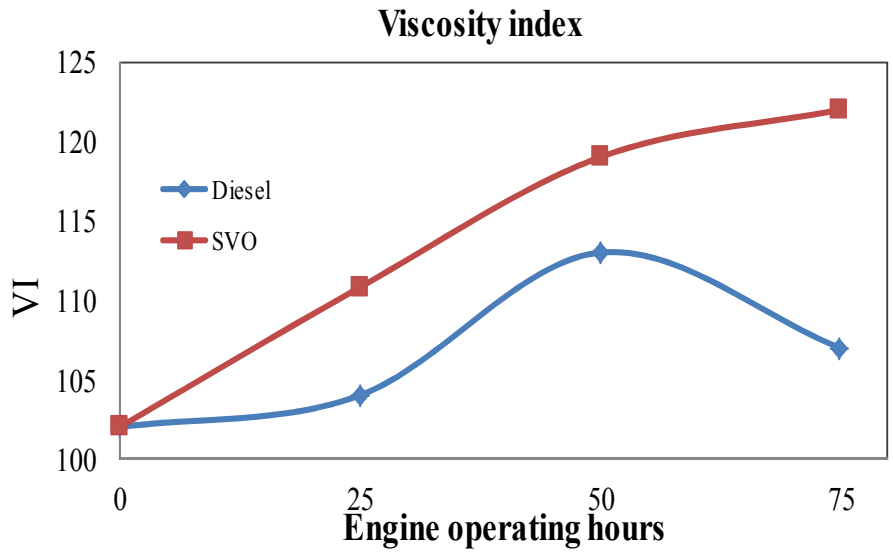


Figure 43: Variation of Flash point lube oil

As shown in the figure 43 the viscosity index for lubrication oil of JSVO fueled engine continually increases in comparison to diesel fueled engine. Where a high viscosity index indicates a small change in viscosity with temperature, which also means better protection of an engine that operates under vast temperature variations. It also means good thermal stability and low temperature flow behaviors.

4.2.5. Carbon Residue

Figure 44 shows the variation of carbon residue of the lubricating oil samples drawn from mineral diesel and JSVO fuelled engines. It is observed there exists an overall increment in carbon residue in both cases. Measured carbon residue of the lubricating oils from diesel fueled engine is a little bit higher at 50 h as shown in the figure 44. Change in carbon residue is a qualitative indicator of polymerization of lubricating oil because increasing content of non-combustible polymerized part of higher molecular weight base-stock remains as carbon residue after combustion/pyrolysis of the lubricating oil.

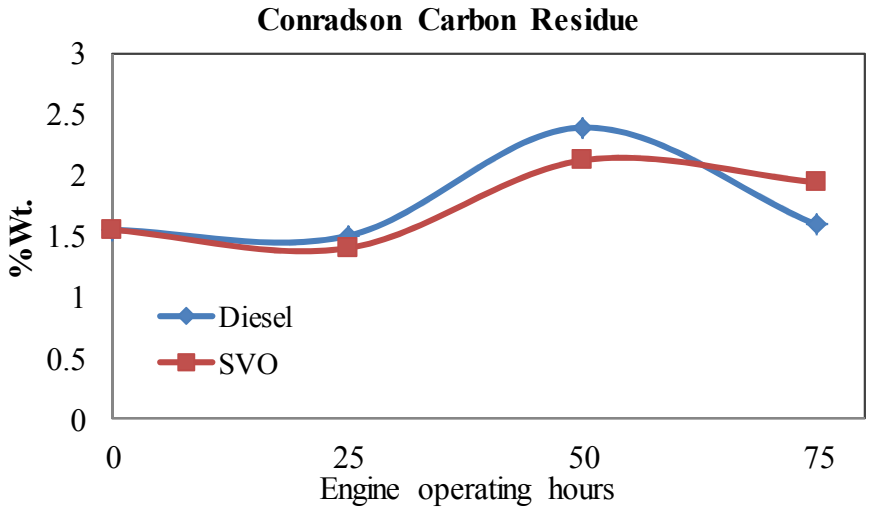


Figure 44: Variation of Carbon residue lube oil

4.2.6. Water and Sediment

Water contamination of engine oil affects the oil quality, condition and wear of engines in service. The water content in engine oil is governed by the oil composition, physicochemical properties, production technology and conditions of storage and use. Water created in engine oil is a result of: absorbing moisture directly from the air (oil is hygroscopic), condensation (humid air entering oil compartments), heat exchanger (corroded or leaky heat exchangers), combustion (fuel combustion forms water which may enter the lubricant oil through worn rings), oxidation (chemical reaction) and neutralization (when alkalinity improvers neutralize acids formed during combustion), and free water entry (during oil changes). Water can prompt a host of chemical reactions such as hydrolysis of compounds and atomic species including oil additives base stock and suspended contaminants.

In combination with oxygen, heat and metal catalyst, water is known to promote the oxidation and the formation of free radicals and peroxide compounds. Water attacks additives such as oxidation inhibitors, rust inhibitor, viscosity improver and the oil's base stock forming sludge. The water and sediment content of engine oil is significant because it can cause corrosion of equipment and problems in processing. In this study as shown in figure 45 Water and sediment is <0.05 for diesel fueled engine throughout the endurance test, whereas it increase to 0.3 for JSVO fueled engine after 25 operating hour as shown in the figure 45. The increment of water and sediment for JSVO can be due to the certain impurities like wax in the JSVO.

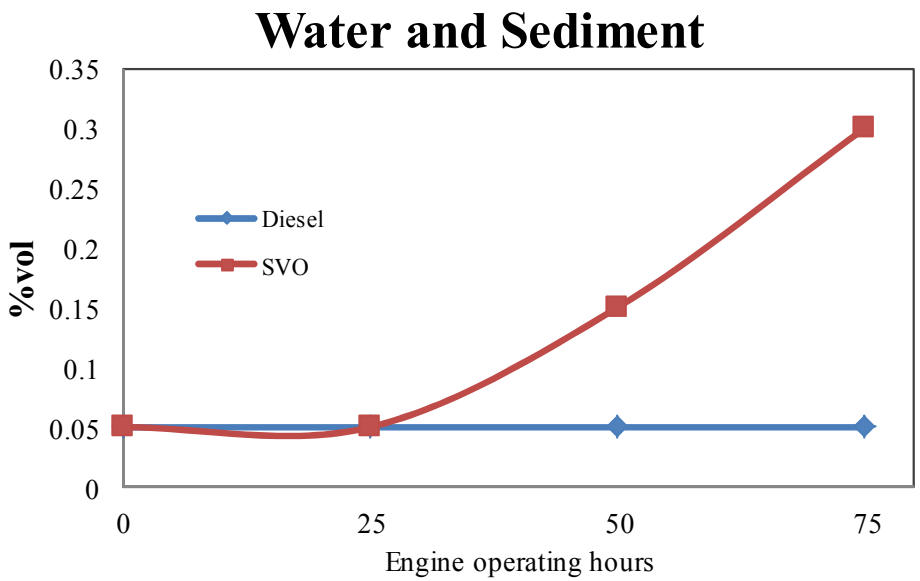


Figure 45: Variation of Water and sediment lube oil

4.2.7. Ash Content

Figure 46 depicts the variation of ash content of the lubricating oils from diesel and JSVO fuelled engines. It is observed that the ash content is higher in the lubricating oil of JSVO fuelled engine after 50 h. Diesel fuelled engine showed relatively lower ash content throughout the endurance test. Since the engines are operating under similar ambient conditions, the effect due to atmospheric dust may be assumed to be same. Therefore, any difference in ash content value will be due to difference in the wear of the engine components.

The physical wear measurement also confirmed that the wear of JSVO fueled engine is higher than diesel engine. But these results should be further confirmed by atomic absorption spectroscopy (AAS) tests conducted on the lubricating oil samples.

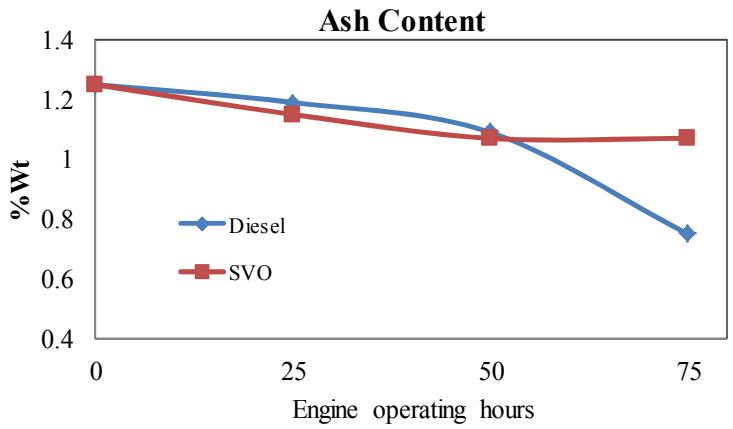


Figure 46: Variation of Ash Content

4.2.8. Total Acid number

Total acid number (TAN) has been considered to be an important indicator for engine oil quality, specifically in terms of defining oxidation states. The presence of oxygen, in most engine oils environments, and hydrocarbons which make up the base oil lead to some reactions. This reaction may lead to the formation of carbonyl-containing products (primary oxidation products), subsequently these undergo further oxidation to produce carboxylic acids (secondary products) which results in an increase in the TAN value.

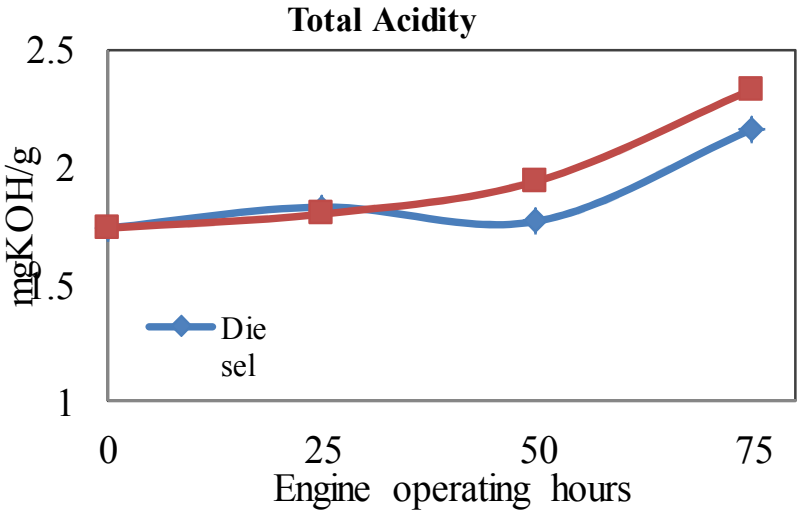


Figure 47: Variation of Total acid number

In addition, with time and elevated temperature, the oxidation products formed then polymerize leading to precipitation of sludge which decreases the efficiency of engine oil and causes excessive wear. As shown in figure 47, the total acid numbers of lubricating oils from both engines are observed an increment by 24 % diesel engine and 33% JSVO engine. But in case of lubricating oil from JSVO engine the TAN is higher than lubricating oil from diesel engine.

This is due to the presence of higher TAN on the JSVO which is 9 .05 mgKOH/g that is much higher than diesel fuel and the other cause may be due to organic, inorganic, heavy metal salts, resin, water and corrosive materials which result from the oxidation.

4.3. Physical wear measurement of engine parts

The primary function of engine oil is to minimize metal-to-metal contact reducing friction and wear. With friction generates heat, which causes more wear and distorts moving engine parts. The oil in an engine maintains a thin, lubricating film on all metal parts that lets them glide over each other safely and efficiently, minimizing friction and wear.

In the long-term endurance test of DY23-2D engine, the effect of use of JSVO' in comparison to mineral diesel fuel were studied. For this purpose, the two new identical engines were subjected to similar loading cycles and operating conditions. The only variation in the operation was that the engines were operated using different fuels so that the effect of each fuel on the life of engine hardware could be compared directly.

The assessment of wear of various parts of JSVO and diesel fuelled new engines was done after 75 h of endurance test and dismantling various parts of the engine. During the running-in period, none of the critical components were replaced. After physical examination, the dimensions of various moving parts were recorded. The engine parts measured are cylinder bore/ cylinder liner, piston, piston-rings, gudgeon pin, valves (inlet and exhaust), valve springs, connecting rod, big-end bearing, small-end bush, and rocker arm etc.

The wear of various moving parts take place due to prolonged engine operation. The difference of these dimensions gives wear of these parts in the given period of engine operation. The following table 10 to 26 reports the wear of the engine parts in % with respect to maximum wear limit recommended by the manufacturer. These observations of wear of the vital engine parts were useful to compare the performance of JSVO fuelled engine with diesel fuelled engine.

4.3.1. General Description of Diesel Engine Component Wear

Piston rings and cylinder

The piston-rings have a reciprocal sliding motion. The out- side of most piston-rings is rounded and chrome-plated to produce the best oil film thickness and wear resistance.

As the pistons start to move in the cylinders, a hydrodynamic oil film is formed between the ring and cylinder surface which helps to prevent wear. When there is little or no relative motion between the rings and the cylinder (e.g. prior to start and at top and bottom dead center), the fluid film is thin. This is when wear will most likely occur, since the oil is being squeezed from the contact area. If the combustion by-products and particulate contamination drawn in with the air and fuel bridge the oil film between the ring and cylinder, wear occurs. Wear particles can also be

supplied to the contact areas by contaminants already present in the oil. The major sources of these contaminants are prior blow by, lubricant breakdown, and component wear. Particles generated by wear between piston ring and cylinder are abrasive to other engine components as well as to the rings and cylinders. Thus, the data analysis and comparison of wear between JSVO fuelled and Diesel fuelled engines for cylinder and piston ring are presented below.

Piston skirt and cylinder

Contact between the piston skirt and the cylinder or liner is often overlooked as a form of wear. Scuffing can occur between these two parts during cold starts and other severe operating conditions. Particles generated by this type of contact are quite abrasive as a result of work hardening. These metal particles contribute to the chain reaction of wear, causing extensive damage if not controlled. Thus, the data analysis and comparison of wear between JSVO fuelled and Diesel fuelled engines for piston are presented below.

Valve train

The valve train functions to open and close the intake and exhaust ports to the combustion area at a specified time. The rotational sliding speed and high lifting loads between the cam lobes and follower cause lubrication problems. In many diesel engines, this cam-to-follower interface receives the heaviest wear because of low oil film thicknesses. Extremely small particles circulating in the lube oil can bridge the space between the surfaces and cause wear. Location of the valve train at the top of the engine also generates extensive carbon deposits due to heat. These carbon deposits have been shown to adversely affect the anti-wear additives in the oil.

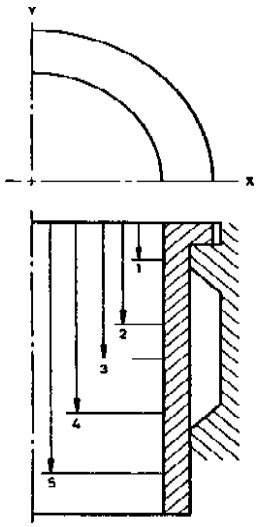
Rocker arms and followers are often supported by plain bearings. These bearings are lightly loaded and have restricted movement. However, high temperatures and poor lubrication produce small lubricant film thickness and lead to severe abrasive wear problems (scoring). Under cold start conditions, the lube oil can take several minutes to reach these rocker arm bearings, further reducing film thickness. Thus, the data analysis and comparison of wear between JSVO fuelled and Diesel fuelled engines for valve, valve spring and rocker arm are presented below.

4.3.2. Measured data for components wear analysis and comparison

4.3.2.1. Measured Data *(all dimensions are in mm)*

- **Cylinder bore**

Table 10: Data measured from cylinder bore

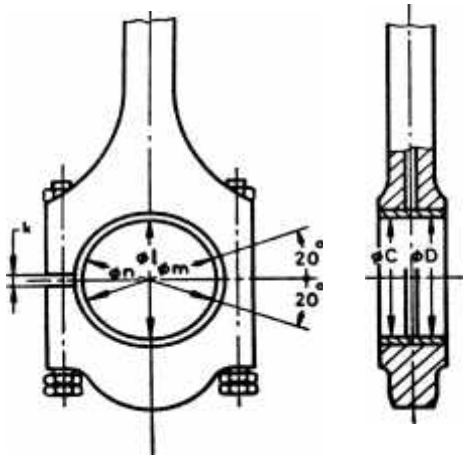


Before endurance test for Diesel and JSVO (X direction)					**After endurance test**									
					Diesel					**JSVO**				
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
70	70	70	70	70	70	70	70	70	70	70.02	70.02	70.01	70	70
Diesel and JSVO (Y direction)					**Diesel**					**JSVO**				
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
70	70	70	70	70	70.01	70	70	70	70	70.02	70.01	70.01	70	70
Surface condition					**Diesel**				smooth					
					JSVO				Small Roughness on top but the other surface are smooth					
Max limit= 70.25					▪ Difference 70-70.25=**0.25**									

Figure 48: cylinder bore

- **Connecting rod bearing bore**

Table 11: Data measured from connecting rod



Measuring points		Dimensions		
		Before Endurance Test	After Endurance Test	
		Diesel and JSVO	Diesel	JSVO
C	l	33.06	33.06	33.07
	m	33.06	33.07	33.06
	n	33.06	33.06	33.06
D	l	33.06	33.07	33.06
	m	33.06	33.06	33.06
	n	33.06	33.06	33.07
Max limit		33.2	33.2-33.06……**0.14 (100%)wear**	

Diesel

JSVO

Figure 49: Connecting rod of diesel and SVO

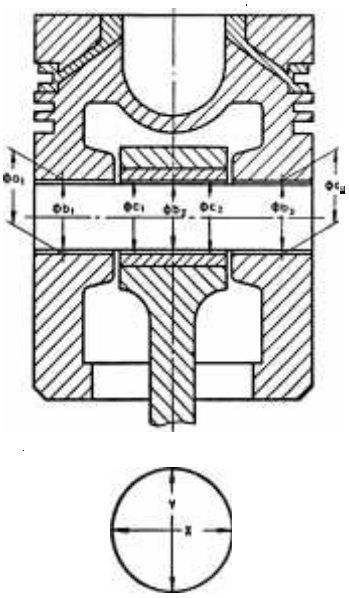
- **Rocker arm**

Table 12: Data measured from rocker arm

	IN/EX	Before test	After endurance test	
			Diesel	JSVO
	Intake	12	12.01	12
	Exhaust	12	12	12.01
Max Limit = 12.08			12- 12.08 = **0.08**	

- **Gudgeon, Pin and Small end bush of connecting rod**

Table 13: Data measured from gudgeon, pin and small end bush of connecting rod

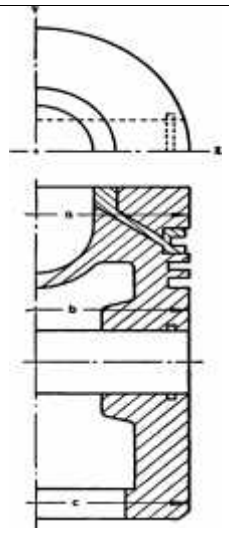


Dimensions											
Before Endurance Test diesel and JSVO											
Gudgeon pin bore (in piston)			Gudgeon pin diameter			Clearance between		Small end bush		Clearance between	
	a_1	a_2	b_1	b_2	b_3	a_1 & b_1	a_2 & b_3	c_1	c_2	b_2 & c_1	b_2 & c_2
X (mm)	18.001	18.001	18	18	18	0.001	0.001	18.013	18.013	0.013	0.013
Y (mm)	18.001	18.001	18	18	18	0.001	0.001	18.013	18.013	0.013	0.013
Max limit: a = 0.029, b=0.02 and C=0.021	Max limit between a, b and c a+b = **0.049(100% wear)** b+c = **0.041 (100% wear)**										

After Endurance Test																					
Diesel											**JSVO**										
Gudgeon pin bore (in piston)			Gudgeon pin diameter			Clearance between		Small end bush		Clearance between	Gudgeon pin bore (in piston)		Gudgeon pin diameter			Clearance between		Small end bush		Clearance between	
	a_1	a_2	b_1	b_2	b_3	a_1 & b_1	a_2 & b_3	c_1	c_2	b_2 & c_1	b_2 & c_2	a_1	a_2	b_1	b_2	b_3	a_1 & b_1	a_2 & b_3	c_1	c_2	b_2 & c_1	b_2 &
X	18.002	18.002	18	18	18	0.002	0.002	18.013	18.013	0.013	0.013	18.002	18.002	18	18	18	0.002	0.002	18.013	18.013	0.013	0.013
Y	18.001	18.001	18	18	18	0.001	0.001	18.015	18.015	0.016	0.016	18.001	18.001	18	18	18	0.001	0.001	18.015	18.015	0.015	0.015

- **Piston**

Table 14: Data measured from piston



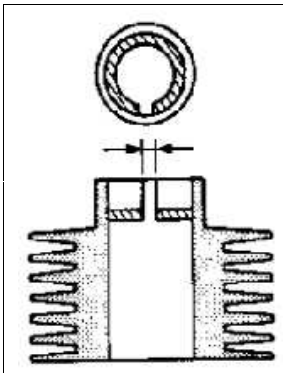
position	Before Endurance Test Diesel & JSVO		After Endurance Test			
			Diesel		JSVO	
	ϕX	ϕY	ϕX	ϕY	ϕX	ϕY
a	69.98	69.98	69.97	69.97	69.96	69.97
b	69.98	69.98	69.98	69.98	69.97	69.98
c	---	-----	--	----	-------	
Max limit = 69.87			69.98- 69.87= **0.11 (100% wear)**			

Surface condition						
	Diesel	Crown	smooth		Crown	smooth
		Top Land	smooth	**SVO**	Top Land	rough
		Skirt	smooth		Skirt	smooth

Figure 50: Piston

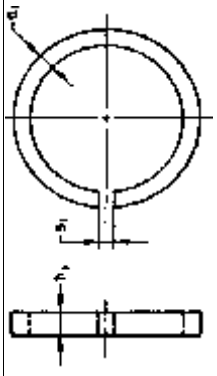
- **Piston rings**

Table 15: Data measured from piston rings end gap



Ring No	Before test	Diesel	JSVO
Top (1st)	0.3	0.3	0.35
Middle (2nd)	0.4	0.45	0.50
Oil ring (3rd)	0.3	0.3	0.3
surface condition	Small scratches		
Max limit	Limit =1.0 for all then 1st 0.3-1.0=**0.7 & oil** 2nd 0.4-1.0= **0.6**		

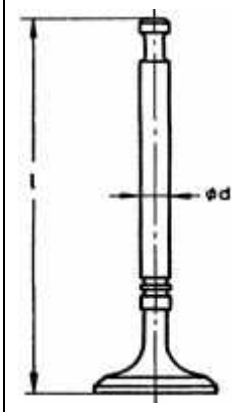
Table 16: Data measured from piston rings radial, axial and closed gap



Dimensions of Piston Rings (all measurements are in mm**)**									
		Before Endurance Test				After Endurance Test			
Engine type	Ring No.	Radial Wall Thickness a_1	Ring Closed Gap, s_1	Axial Width h_1	Sur-face Condition (Specify)	Radial Wall Thick-ness **a_1**	Ring Closed Gap, s_1	Axial Width **h_1**	Surface Condition (Specify)
Diesel	1 (top)	3	10	1.3	Smooth & clean	3	10.1	1.3	scratches
	2 (mid)	3	13	1.5	Smooth & clean	3	13.1	1.5	Smooth & clean
	3(botom)	2	8.5	3.5	Smooth & clean	2	8.5	3.5	Smooth & clean
JSVO	1 (top)	3	10	1.3	Smooth & clean	2.9	10.2	1.3	scratches
	2 (mid)	3	13	1.5	Smooth & clean	2.9	13.2	1.5	scratches
	3(botom)	2	8.5	3.5	Smooth & clean	2	8.6	3.5	Smooth & clean
Max limit	1st ring s_1= 10.7 **(0.7 mm)** a_1= 2.65**(0.35 mm)**		2nd ring s_1= 13.6 **(0.6 mm)** a_1= 2.7 **(0.3 mm)**			3rd ring s_1= 9 **(0.5 mm)** a_1= 2.25 **(0.25 mm)**			

- **Intake and Exhaust valve**

Table 17: Data measured from intake and exhaust valve



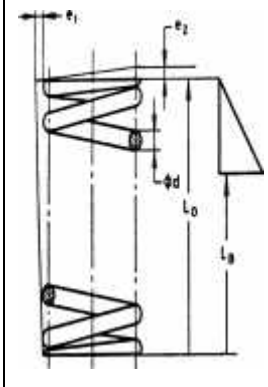
Dimensions				
Measuring points	IN/EX	Before Endurance Test	After Endurance Test	
			Diesel	JSVO
Stem Diameter	Inlet valve	5.42	5.42	5.41
	Exhaust	5.42	5.42	5.41
Length l	Inlet valve	71	71	71
	Exhaust	71	71	71

Max limit	Steam diameter.. 5.422	Limit 5.35	Difference 5.422-5.35**….0.072(100%**

Visual Surface Condition (Specify)	IN/EX	Valve Stem		Valve Face	
		Diesel	JSVO	Diesel	JSVO
	Inlet	Smooth &	C. deposit	C. deposit	C. deposit
	Exhaust	C. deposit	C. deposit	C. deposit	pitting

- **Valve Spring**

Table 18: Data measured from intake and exhaust valve



Engine	IN/EX	Before Endurance		After Endurance Test	
		Unloaded Length L_0	Wire Diameter d	Unloaded Length L_0	Wire Diameter d
Diesel	Inlet	32.5	2.3	32.5	2.3
	Exhaust	32.5	2.3	32.5	2.3
JSVO	Inlet	32.5	2.3	32.5	2.3
	Exhaust	32.5	2.3	32.4	2.3
Max limit=31	32.5-31 = 1.5 (**100 %**)				

4.3.2.2. Components wear analysis and comparison *(all dimensions are in mm)*

- **Wear for cylinder bore/ liner**

Table 19: Wear comparison SVO and Diesel cylinder bore

	wear								
		Diesel		**JSVO**					
		1		**1**		**2**		**3**	
	X	0		0.02	8%	0.02	8%	0.01	4%
	Y	0.01	4%	0.02	8%	0.01	4%	0.01	4%
wear Comparison	X	**--**		**8 %**		**8 %**		**4 %**	
	Y	**--**		**4 %**		**4 %**		**4 %**	

- **Wear of Connecting Rod Bearing Bore**

Table 20: Wear comparison JSVO and Diesel connecting rod

	Cylinder number		**Diesel**		**JSVO**		**wear Comparison**	
							Diesel	**JSVO**
	C	***l***	0		0.01	7 %	**---**	**7 %**
		m	0.01	7 %	0		**7 %**	**---**
	D	***l***	0.01	7 %	0		**---**	**7 %**
		n	0		7 %	0.01	**7 %**	**---**

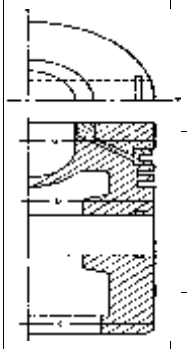
- **Wear of Gudgeon Pin, Pin Bore and Small End Bush of Connecting Rod**

Table 21: Wear comparison JSVO and Diesel Gudgeon Pin, Pin Bore and Small End Bush

	Diesel								**JSVO**							
	Clearance between								**Clearance between**							
position	a_1 and b_1		a_2 and b_3		b_2 and c_1		b_2 and c_2		a_1 and b_1		a_2 and b_3		b_2 and c_1		b_2 and c_2	
X	0.001	2%	0.001	2%	0		0		0.001	2%	0.001	2%	0		0	
Y	0		0		0.003	7 %	0.003	7 %	0		0		0.002	5%	0.002	5%
wear Comparis	---		---		---		---		---		---		---		---	
	---		---		**2 %**		**2 %**		---		---		---		---	

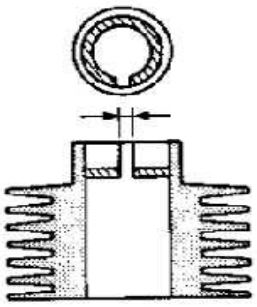
- **Wear of Piston**

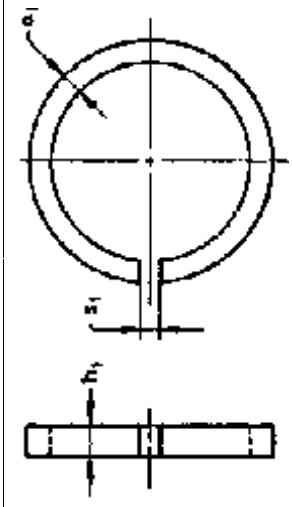
Table 22: Wear comparison JSVO and Diesel piston

	position	**Diesel**				**JSVO**				**wear Comparison**	
		ϕX		**ϕY**		**ϕX**		**ϕY**		**X**	**Y**
	a	0.01	9%	0.01	9%	0.02	18%	0.01	9%	**9 %** (JSVO)	**---**
	b	0.00		0.00		0.01	9%	0.		**9 %** (JSVO)	**---**

- **Wear of Piston Rings**

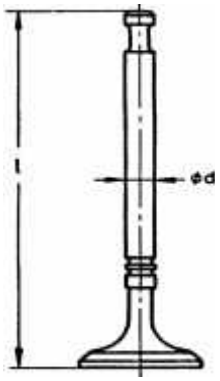
Table 23: Wear comparison JSVO and Diesel piston ring

	Ring No	wear				wear Comparison	
		Diesel		**JSVO**		**Diesel**	**JSVO**
	Top (1st)	0		0.05	7%	---	**7%**
	Middle (2nd)	0.05	8%	0.10	16 %	---	**8 %**

	Ring No.	Engine	Radial Wall Thick-ness **a1**		Ring Closed Gap, **s1**		wear Comparison: Radial Wall Thick-ness **a1**	wear Comparison: Ring Closed Gap, **s1**
	1 (top)	**Diesel**	0		0.1	14%	---	---
	2 (middle)		0		0.1	16%	---	---
	1 (top)	**JSVO**	0.1	28%	0.2	28%	**28 %**	**14 %**
	2 (middle)		0.1	33%	0.2	33%	**33 %**	**17 %**
	3 (bottom)		0		0.1	20%	---	**20%**

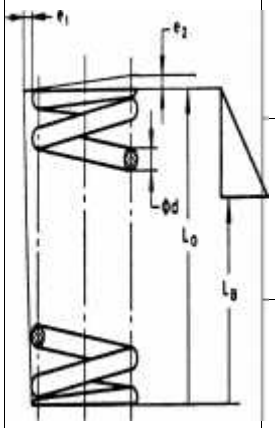
- **Wear of Inlet and Exhaust Valves**

Table 24: Wear comparison JSVO and Diesel Inlet and Exhaust valve

	position	IN/EX	Diesel	JSVO		wear Comparison
	Stem Diameter *d*	Inlet valve	0	0		---
		Exhaust valve	0	0.01	13%	13 % (SVO)
	Length *l*	Inlet valve	0	0		---
		Exhaust valve	0	0		---

- **Wear of Valve spring**

Table 25: Wear comparison JSVO and Diesel valve spring

	Engine	EX/IN	Un- loaded Length L_0		Wire Diameter d	wear Comparison	
						Diesel	JSVO
	Diesel	Inlet	0		0	---	---
		Exhaust	0		0	---	---
	SVO	Inlet	0		0	---	---
		Exhaust	0.1	6%	0	---	**6 %**

- **Wear of rocker arm**

Table 26: Wear comparison JSVO and Diesel rocker arm

		Diesel		JSVO	
	Inlet	0.01	12%	0	
	Exhaust	0		0.01	12%
wear Comparison		**12 % (Intake)**		**12 %(Exhaust)**	

These observations of physical wear were useful to compare the performance of JSVO fuelled engine with diesel fuelled engine on the wear of the vital engine parts. Results shows that except the connecting rod big end bearing, Gudgeon Pin, Pin Bore, Small End Bush of Connecting Rod and rocker arm, wear of all other components is higher in JSVO fuelled engine compared to mineral diesel fuelled engine. The highest wear recorded specially on cylinder, piston ring, piston and exhaust valve from JSVO engine. This may be due to the high amount of carbon deposit accumulated on the piston, piston groove and piston rings. It may also due to the change in composition of lubricating oil protective layer between the cylinder liner and piston interface which affects the cylinder lubricating mechanism directly, that leads to increase wear of liner. However, it is clearly evident that the wear of vital moving parts of the JSVO fuelled engine is higher as compared to mineral diesel fuelled engine.

4.4. Carbon deposit

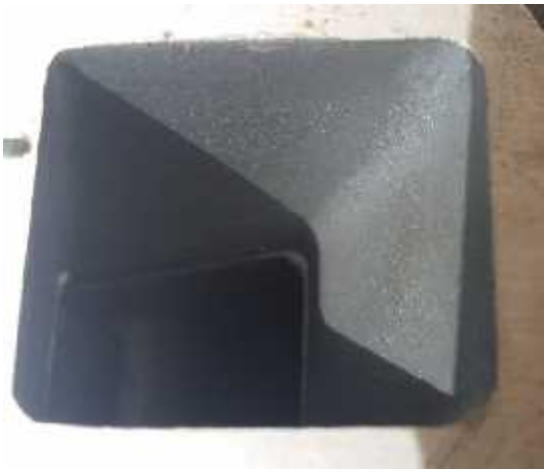
The physical conditions and carbon deposits of the new engine parts after the endurance test are shown in the table 27 which shows the carbon deposits on the piston top, fuel injectors, cylinder head, intake port, exhaust port, intake and exhaust valve, of mineral diesel and JSVO fuelled engines after 75 hours of endurance test. The two engines were operated successfully for 75 hours and replacement/ cleaning of injector was not required during the test but only a valve adjustment for JSVO at 69 operating hours was made. Then after completion of the long-term endurance test, visual inspection was done for deposit assessment. In visual inspection of engine vital parts, higher amount of carbon deposits on the vegetable oil fuelled engines compared to mineral diesel was observed.

Major findings after completion of the test are as follows:

1. It was found high carbon deposit on top of two compression ring of JSVO.
2. The remaining third compression ring was found in good condition.
3. The inlet and exhaust valves were found with higher carbon deposit in JSVO fuelled engines than diesel fuelled engines (Table 27, No 7 & 8).
4. The inlet and exhaust port were found with higher carbon deposit in JSVO fuelled engines than diesel fuelled engines (Table 27, No 5 & 6).
5. Excessive carbon deposit was noticed at the upper face of the piston and cylinder head for JSVO fuelled engines. (Table 27, No 1 & 2).
6. The space for the piston ring on the piston groove was found reduced for JSVO fuelled engines. (Table 27, No 4).
7. Higher carbon deposit was noticed at the tip of the injectors for JSVO fuelled engines. (Table 27, No 3).
8. Some scratches on the cylinder were observed which are due to carbon deposit on the rings and piton groove for JSVO fuelled engines.

Table 27**:** Carbon deposits on different engine parts after 75 hours

Engine Parts	Diesel fuelled engine	JSVO fuelled engine
1.Carbon deposit on piston heads		
2. Cylinder heads		
3. Injector tips		

Engine Parts	Diesel fuelled engine	JSVO fuelled engine
4. Piston side		
5. Exhaust port		
6. Intake port		

Engine Parts	Diesel fuelled engine	JSVO fuelled engine
7. Exhaust valve		
8. Intake valve		

After completion of endurance test, the carbon present on the top of the piston and cylinder head was carefully scraped, collected and weighed. As the result shown in figure 51 and 52 the carbon deposit from JSVO fuelled engine was much higher than diesel fuelled engine, which is 135.9 % higher on the piston head and 165.8 % on cylinder head. This indicates JSVO are more problematic than diesel fuel in the accumulation of carbon deposit point of view.

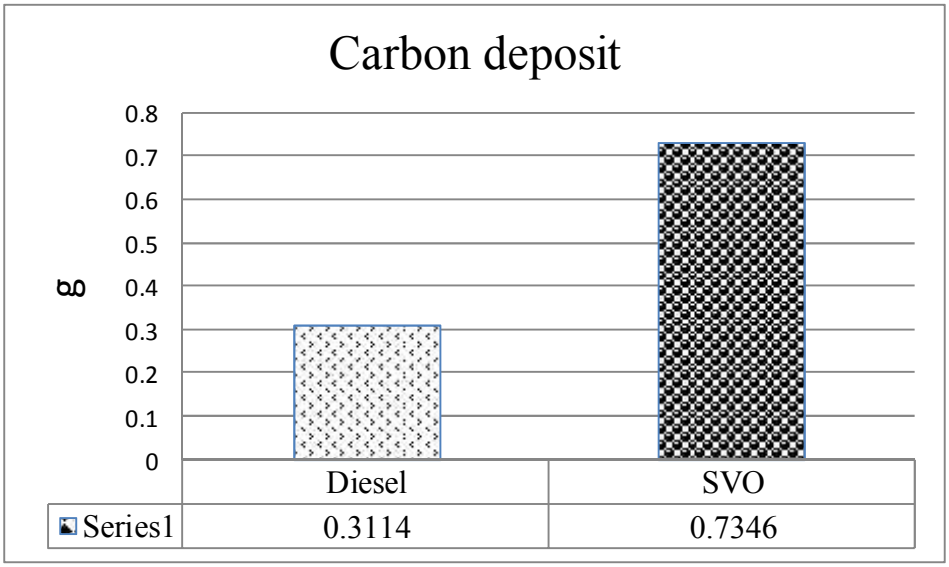


Figure 51: Carbon deposit on top of piston from SVO and diesel

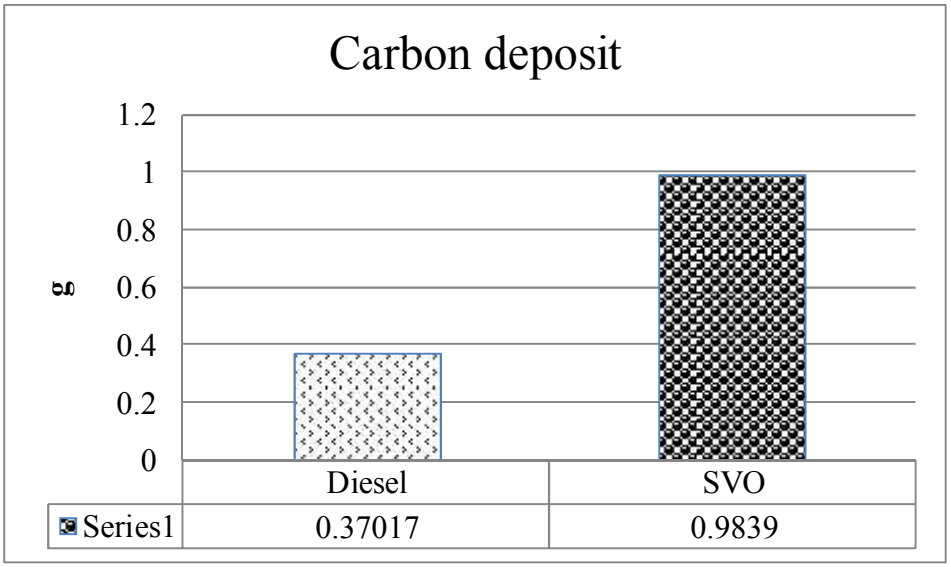


Figure 52: Carbon deposit on top of cylinder head from SVO and diesel

5. CONCLUSIONS AND RECOMMENDATIONS

Overall, the research illustrated that the effect of JSVO on engine lubricant, physical wear and carbon deposit. There are many reasons which contribute for early engine lubricant degradation and engine wear. Engine oil contamination/dilution can be one of the main reasons of early engine oil degradation and of eventual engine cessation. Oil can be become contaminated when unburned or incomplete burnt fuel blows by through the piston rings and ends up in the crankcase. Although some limited engine oil dilution by diesel engine fuel is acceptable but when the engine is fueled by alternative fuels then engine oil dilution rate and it effects can be different than those from the regular diesel fuel.

In this thesis work, two new brand identical diesel engines were used to experimentally investigate the effect of usage of JSVO on engine hardware and lubricating oil properties without any modification for the engines. Engines robin DY23 - 2D, single cylinder, four stroke, air cooled direct injection were operated for 75 hours as per the Indian standard test methods for internal combustion engine endurance tests (IS:10000 PART IX 1980) to inspect the effect of long term engine operation on lubricating oil properties, carbon deposit and engine wear (by physical dimensioning). The lubricating oil sample were collected from engines after every 25 operating hours and tested using ASTM standard test methods D 93, D189, D 445, D 482, D 947, D 2270, D 2709 and D 4052 for the selected parameters. After the endurance test was completed the two engines were completely disassembled and subjected to measurement following the Indian standard test methods IS: 10000 (Part V) – 1980 for comparative analysis of wear and carbon deposit. The two engines were operated successfully for 75 hours. Replacement or cleaning of injector was not required during the test but only a valve adjustment for JSVO fuelled engine at 69 operating hours was made to prevent the knocking sound produced.

From the experimental results and comparative analysis obtained, conclusions are drawn based on engine oil properties, engine wear and carbon deposit as described below.

5.1 Conclusions

5.1.1 Engine oil analysis

Oil analysis studies proved to be a powerful tool to estimate the condition of the engines, and moving parts as well. These tests provide valuable and relevant information on the effect of JSVO on the lubricating oil system.

Comparative studies on various samples of lubricating oil indicated that the density of JSVO fuelled engine increases +72 % with the usage of lubricating oil when it compared to diesel fuelled engine. The flash point testing result also indicate a similar level of lowering for JSVO and diesel lubricating oil but the flash point of JSVO fuelled engine lubricating oil decreases at higher level again after 50 operating hours of the engine in comparison to Diesel fuelled engine. The test results from density and flash point clearly indicate that the fuel dilution is higher in JSVO fuelled engine. The higher kinematic viscosity @40°C and 100°C indicates that, even if the fuel dilution is high for JSVO the large molecular sizes of the triglycerides contained in SVO fuel allows the kinematic viscosity to remain higher than diesel engine. The highest amount of ash content in JSVO fuelled engine indicates that the increment rate of engine wear is increasing with increasing operating hours of the engine. However, the change in lubrication properties from JSVO is not much when it compares to mineral diesel engine and the viscosity of lubrication oil from JSVO fuelled engine is within the standard range which is described by "SAE viscosity grade comparison" for SAE 30 oil. Therefore, it can be concluded that JSVO can be used as substitute of mineral diesel in CI engines.

5.1.2 Engine physical wear

In the long-term endurance test, the effect of use of JSVO as a fuel on various engine parts was evaluated. Physical wear measurement of vital engine parts indicates increased wear of cylinder, piston ring, piston and exhaust valve of JSVO engine while wear of Gudgeon Pin, Pin Bore and Small End Bush of Connecting Rod and rocker arm are similar. However use of JSVO as fuel results a higher possibility of physical wear, especially around the combustion chamber which is due to the high amount of carbon deposit accumulation and contamination of oil lubrication mechanism at the cylinder walls. Wear of these components leads to loss of performance, increased maintenance costs, lower fuel efficiency, and shorter lube oil service life.

Therefore, it can be concluded that usage of JSVO is possible if the problems associated with accumulation of carbon deposit in the combustion chamber are solved where the high wear rate of the engine parts are recorded.

5.1.3 Carbon deposit

After completion of endurance test, visual inspection was done for deposit assessment. The inspection of engine vital parts indicated JSVO has higher amount of carbon deposits which is 165% higher on the cylinder head and 135 % higher on the piston head compared to mineral diesel. The high amount of carbon deposit on the combustion chamber leads to overheating of the engine while the carbon deposit on the valve produced hard particles lodged between the valve and guide. This causes the timing of the port openings and closings to vary, causing incomplete combustion in the cylinder it may also result in a permanent power loss. Therefore, it can be concluded that JSVO can be used as substitution if the amount of carbon deposit are minimized.

5.2 Recommendations

Key recommendations are as follows.

- The use of JSVO as an alternative fuel in diesel engines looks possible, but there still is a lot of areas that need testing and improvements.
- To have a clear understanding on the effect of JSVO a long term engine endurance test in different types of engines should be done with complete measurement of properties as per ASTM standards.
- By applying additional loads for different engine speeds better supporting information on the effect of JSVO for engine life could be provided.
- ASTU must keep in creating opportunities for students to participate in different research areas like the opportunity given to me.
- ASTU must establish laboratories with ASTM standard test method equipment to prevent the scarcity of test equipment for research purpose, time wastage and extra cost and also to motivate students and researches to work more.
- The department of mechanical and vehicle engineering must prepare room for engine endurance test with all safety requirements and dynamometer.

5.3 Future Works

- One of the major drawbacks of these JSVO is its high accumulation of carbon deposit on engine parts and this would be the area that should be studied.
- By blending JSVO with diesel fuel in different ratios one could look at how they can affect the engine lubricant, engine wear and carbon deposit and compare which ratio will be good for the engine life.

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APPENDIX A

Indian Standard

METHODS OF TESTS FOR INTERNAL COMBUSTION ENGINES
PART V PREPARATION FOR TESTS AND MEASUREMENTS FOR WEAR

IS: 10000 (Part V) – 1980 (Reaffirmed 2001) Edition 1.1 (1985-03)

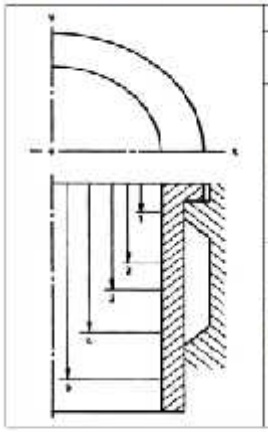
- Proformae For Recording Dimensions Of Critical Components Of Engines And Measurements For Wear After Endurance Tests

6. Measurements for Wear

6.1 *Final Inspection* — At the completion of type tests, the engine shall be dismantled. Its condition shall be noted and the dimensions of critical parts mentioned in 3 shall be recorded in the proformae given in Appendix A.

6.1.1 The wear of critical components shall be recorded in proformae given in Appendix A and shall be compared with the declarations made by the manufacturer.

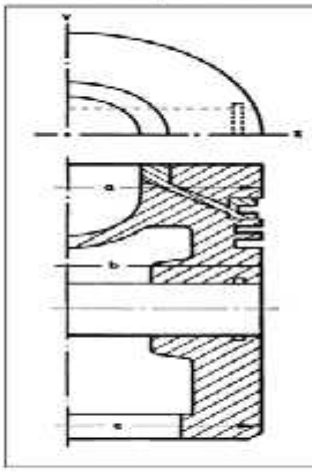
A-2. Measurements of Cylinder Bore/Cylinder Liner



	Dimensions at Positions Indicated in Fig.														
	Before Endurance Test					After Endurance Test					Wear				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Along Crank-shaft Axis															
Perpen-dicular to the Crank-shaft Axis															

Surface Condition (specify) (Add or Cross Out)	Burning, Pitting, Erosion, Scratches, Warping, etc

A-3. Measurement of Piston Dimensions (*See also* IS : 9508 1977 Technical supply conditions for pistons for I. C. Engines)

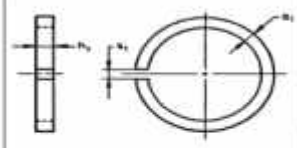


		Before Endurance Test		After Endurance Test		Wear	
		φX	φY	φX	φY	φX	φY
Diameter of Piston at Position	a						
	b						
	c						

Surface Condition (Specify)	Crown	
	Top Land	
	Skirt	

Note — Measurements shall be made for each piston.

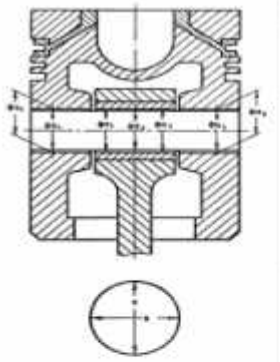
A-4. Measurements for Piston Rings — (*See also* IS : 5791-1977*)



Ring No.	Dimensions of Piston Rings													
	Before Endurance Test					After Endurance Test					Wear			
	Radial Wall Thickness a_1	Ring Closed Gap, s_1 when in the Nominal Bore Specified in IS : 3511†		Axial Width b_1	Surface Condition (Specify)	Radial Wall Thickness a_1	Ring Closed Gap, s_1 when in the Nominal Bore Specified in IS : 3511†		Axial Width b_1	Surface Condition (Specify)	Radial Wall Thickness a_1	Ring Closed Gap, s_1 when in the Nominal Bore Specified in IS : 3511†		Axial Width b_1
		Compression	Oil control				Compression	Oil control				Compression	Oil control	
1														
2														
3														
4														
5														

Note — These measurements shall be taken for each cylinder.

A-5. Measurements of Gudgeon Pin, Pin Bore and Small End Bush of Connecting Rod

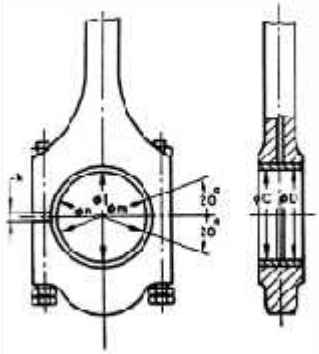


	Dimensions											
	Before Endurance Test											
	Gudgeon pin bore (in piston)			Gudgeon pin diameter			Clearance between		Small end bush		Clearance between	
	ϕa_1	ϕa_2		ϕb_1	ϕb_2	ϕb_3	ϕa_1 and ϕb_1	ϕa_2 and ϕb_3	ϕc_1	ϕc_2	ϕb_2 and ϕc_1	ϕb_3 and ϕc_2
X												
Y												

Surface Condition		Before Endurance Test	After Endurance Test
	Gudgeon Pin	Specify	Burnt, Pitted, Scured, Corroded, Lacquered, Other (Specify)
	Small End Bush	Specify	Burnt, Pitted, Scured, Corroded, Lacquered, Other (Specify)

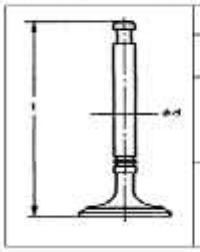
Note — These measurements shall be taken for each cylinder.

A-10. Measurement of Connecting Rod Bearing Bore



		Dimensions																	
		Before Endurance Test						After Endurance Test						Wear					
Cylinder number		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
ϕC	ϕl																		
	ϕm																		
	ϕn																		
ϕD	ϕl																		
	ϕm																		
	ϕn																		
Gap *t*																			

A-12. Measurements for Inlet and Exhaust Valves — [*see also* IS : 810-1974 Specification for inlet and exhaust valves for I. C. engines (*first revision*)].

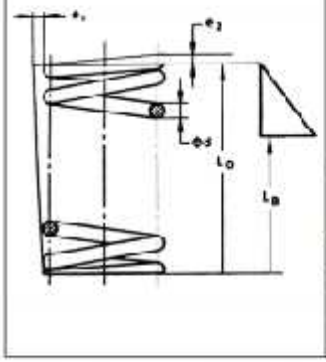


		Dimensions		
		Before Endurance Test	After Endurance Test	Wear
Stem Diameter *d*	Inlet valve			
	Exhaust valve			
Length *l*	Inlet valve			
	Exhaust valve			

Surface Condition (Specify)		Valve Stem	Valve Face
	Inlet		
	Exhaust		

Note — The measurements shall be taken for each cylinder.

A-15. Measurements for Valve Springs and Governor Springs (Wherever Applicable) — [*see also* IS : 7906 (Part 1)-1976 Helical compression springs: Part I Design and calculations for springs made from circular section wire].



		Before Endurance Test						After Endurance Test						Wear					
		Unloaded Length L_0	Block Length L_B	Spring Rate S_c	Wire Diameter d	e_1	e_2	Unloaded Length L_0	Block Length L_B	Spring Rate S_c	Wire Diameter d	e_1	e_2	Unloaded Length L_0	Block Length L_B	Spring Rate S_c	Wire Diameter d	e_1	e_2
Valve Spring	Inlet																		
	Exhaust																		
Governor Spring (if Applicable)																			

Note — These measurements shall be taken for each spring.

The revised methods of tests covered by IS: 10000 have been aligned with the current international practices in the field of I.C. engines. These parts are in general agreement with the following ISO standards, issued by the International Organization for Standardization:

a) ISO 3046/I-1975 Reciprocating internal combustion engines — performance: Part I Standard reference conditions and declarations of power, fuel consumption and lubricating oil consumption
b) ISO 3046/II-1977 Reciprocating internal combustion engines — performance: Part II Test methods
c) ISO 3046/III-1979 Reciprocating internal combustion engines — performance: Part III Test measurements
d) ISO 2710-1978 Reciprocating internal combustion engines — vocabulary This Part V of IS: 10000 covers the procedure for measurement of wear of critical components for engines. Although the wear after the endurance test has not been specified, it is expected that data collected by implementation of this standard will enable the committee to lay down the specification limits for acceptance at a later date.

APPENDIX B

Indian Standard

(Reaffirmed 2005)

METHODS OF TESTS FOR INTERNAL COMBUSTION ENGINES

PART IX ENDURANCE TESTS

Internal Combustion Engines Sectional Committee, EDC 14; Methods of Test and Codes of Practice for Engines Subcommittee, EDC 14:3 [Ref : Doc : EDC 14 (3130)]

1. Scope — Specifies the method of conducting endurance tests on constant speed and variable speed internal combustion engines.

2. Section I - Endurance Tests for Constant Speed Engines — These tests shall be performed after the initial performance tests specified in IS : 10000 (Part VIII)-1980 'Methods of tests for internal combustion engines: Part VIII Performance tests'.

2.1 After completion of the initial performance test the engine shall be run for 32 cycles (each of 16 hours continuous running) at rated speed.

2.1.1 *Test cycle for IS Rating A*

Load (Percent of Rated Load)	*Running Time* (Hours)
100	4 (including warm-up period of 0·5 h)
50	4
110	1
No load (Idling)	0·5
100	3
50	3·5

2.1.2 *Test cycle for IS Rating B*

Load (Percent of Rated Load)	*Running Time* (Hours)
100	4 (including warm-up period of 0·5 h)
50	4
100	1
No load (Idling)	0·5
100	3
50	3·5

2.2 At the end of each 16 hours cycle, the engine shall be stopped and necessary servicing and minor adjustments may be carried out in accordance with the manufacturer's schedule.

2.3 Before starting the next cycle, the temperature of the engine sump oil shall have reached within 5 K of the room temperature.

2.4 The engine shall be topped up with engine oil, if required and the quantity consumed recorded. In case the duration of the endurance test is longer than the period of oil change recommended by the engine manufacturer, the oil shall be changed according to the manufacturer's recommended schedule. The amount of make up oil used during the tests shall be used to establish the lubricating oil consumption rate.

Adopted 31 December 1980 | © May 1981, BIS | Gr 2

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