University of Southern Queensland

Faculty of Health, Engineering & Sciences

Friction and Wear Analysis of Biodegradable Lubricants used with Engine Components

A dissertation submitted by

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in fulfilment of the requirements of

ENP4111

towards the degree of

Bachelor of Engineering (Honours) (Mechanical Engineering)

Submitted: 8th December 2024

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University of Southern Queensland

School of Engineering

ENP4111 Dissertation Project

(This is a 2-unit research project in Bachelor of Engineering Honours Program)

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ABSTRACT

In a world dominated by automotive engines, efficient and effective lubrication is key. To ensure that performance is optimised, lubricants must be carefully considered to ensure that they have suitable properties. While lubricants play a key role in engine efficiency and engine durability, focus is also shifting towards producing lubricants that are environmentally friendly. Creating an effective lubricant from a renewable source has several benefits, it is low cost, easy to produce and is environmentally friendly. Vegetable oils fit these criteria well, and while their potential as a bio-lubricant is high, they are yet to be commonly found in the automotive industry. Currently, problems arising from low viscosity leads to high wear rates in engine components. To solve this issue, further research is required into the frictional and wear behaviour of such lubricants. Often, consumable vegetable oils such as canola oil, olive oil and sunflower oil are tested as potential bio-lubricants, however issues associated with human consumption (limited supply, high expenses) would lead to availability issues if this became a widespread application. Therefore, significant work has recently been put in to finding a potential bio-lubricant that is formed from a non-edible vegetable oil. Submitting a potential lubricant under simulated operating conditions is the best way to determine its tribological properties. The study of tribology is mainly concerned with friction and wear, and this report details a form of tribological testing that determines the properties of several variants of a bio-lubricant. Neem Seed oil is used as the base for this bio-lubricant and a 50% ratio of Neem Seed oil to SAE-30 oil was found to have the most promising results. This report discusses these results further and makes recommendations for additional research in this area.

ACKNOWLEDGMENTS

I would like to sincerely acknowledge my supervisor Belal Yousif for his continued guidance during this dissertation. Additionally, my deepest gratitude goes out to Adrian Blokland, Brian Lenske and Nathan Strenzel for their assistance during the different stages of the project. Many thanks to my family and friends for supporting me during my completion of this project.

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NOMENCLATURE

μ – coefficient of friction

λ – film thickness ratio

w – weight

ρ – density

L – normal load

D – sliding distance

F_f – frictional force

F_L – force applied by the normal load

GLOSSARY

SEM – Scanning electron microscope

COF – Coefficient of friction

BOR – Block on ring

MSDS – Material safety data sheet

RMP – Risk Management Plan

SWR – Specific Wear Rate

CHAPTER 1: INTRODUCTION

1.1 OUTLINE OF THE STUDY

All mechanical systems contain moving parts, and therefore require lubrication. This makes lubrication an essential service. Appropriate lubrication has the potential to reduce energy losses to friction and increase wear performance of components (Mang & Dresel, 2007). This makes the science of lubrication a highly researched area. While lubrication seems a simple concept, it is essential that engineers contain a thorough understanding of the complex behaviour and systems involved in lubrication.

Within the automotive industry, there is always a focus on pushing for further performance, efficiency and longevity. While there have been developments in each of these areas in the last few decades, it is important that the industry continues to strive for further expansion. Efficiency of motor vehicles is especially important, with a global shift towards promoting sustainability and reducing climate change. This, coupled with the number of vehicles on the road increasing, means that there is a requirement to find ways to improve the efficiency of motor vehicles (Lee, 2019). Friction is one of the main forces that reduces the efficiency of an engine. Up to 15-20% of an engine's power is used up by friction within an engine's components. This leads to increased fuel usage and additional wear upon engine components, reducing the life of such components. As engine components wear, their efficiency often decreases further (Waqas et al, 2022).

Bio-lubricants have been recently developed and offer an environmentally friendly alternative to traditional lubricants that are used within the automotive industry. They help to reduce the environmental impact of internal combustion engines which is a major setback of traditional oil lubricants (Carrell, 2018). Traditional oils have a large environmental impact as they are made from fossil fuels. Additionally, when the oil must be disposed, it poses a biohazard that is a risk to the natural environment. Of the 5.2 million tons of lubricant that is consumed in Europe each year, it is estimated that 20% is emitted into the environment. On top of this, a single litre of mineral oil is capable of polluting a million litres of water, meaning that the effect of lubricant pollution is widespread and a crucial issue (McNutt, 2016). Bio-lubricants are formed from biodegradable and renewable resources. This allows for a much more environmentally friendly oil. It is difficult for traditional oils to be recycled, whereas bio lubricants can be recycled much easier. For these reasons, bio lubricants are an exciting prospect for the automotive industry, as the world pushes toward a cleaner, greener future (Veny et al, 2023).

This project aims to investigate the relatively new technology of bio lubricants with the longstanding problems of engine efficiency and engine component wear. This project will gather data and analyse results before providing recommendations on whether these technologies have the potential to improve current engine performance.

1.2 PROJECT OBJECTIVES

The main aim of this project is to evaluate the performance of new bio-lubricants. This technology has the potential to revolutionise a large part of the automotive industry, and it is the objective of this project to provide evidence as to whether this technology is currently developed enough to be implemented into industry.

These aims will be explored by using traditional lubricants and bio-lubricants in a machine to test their tribological performance. Once the sample pieces are tested under load, the fatigue of the sample due to wear loading condition will be examined and analysed. This will then allow for the project to make overall recommendations as to whether these new technologies have the potential to be implemented into industry.

Specific Objectives:

- Conduct wear and fatigue analysis of sample pieces and relating this to engine components.
- Obtain a co-efficient of friction for each lubricant that is used and compare.
- Perform wear testing of sample pieces used during testing to determine the effectiveness of the lubricant
- Compare the results with real-world data and data collected from similar projects.

Expected Outcomes:

- Identify the wear patterns present in engine components.
- Identify the effects of friction upon engine components.
- Identify the cause of engine component wear.
- Identify the life cycle of engine components.
- Understand the relationship between the co-efficient of friction and the performance of engine components.
- Understand the relationship between the co-efficient of friction and the durability of engine components.

- Understand the relationship between the co-efficient of friction and the engine power efficiency.
- Provide recommendations as to whether bio-lubricants are a viable option for the automotive industry.
- Provide recommendations on lubricants that allow for better performance, efficiency and durability.
- Provide recommendations as to whether bio lubricants could successfully be used in the automotive industry.
- Provide recommendations for which lubricant suits the automotive industry the best.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter aims to review the available literature on the topic of this dissertation. This report will allow for a better understanding of all the components that are involved within this project and will be a starting point. This report will discover what research has been completed, what sort of results prior research in this area has produced, any areas of this project that do not have existing research, and any gaps in knowledge that should be filled before this project is undertaken.

This project covers a broad range of topics that are to be investigated. Therefore, it is important that a large amount of background knowledge is gathered to ensure that this project produces accurate results and can be related to other studies in a similar area. The report will explore the issue of friction within internal combustion engines, explore how lubrication can reduce this friction and explore the validity of using bio lubricants within internal combustion engines.

It is also important that this literature review acknowledges the areas of information or knowledge that is not addressed by previous research.

2.2 THE STUDY OF TRIBOLOGY

2.2.1 INTRODUCTION

The word tribology originated in a 1996 report from Peter Jost. The word describes the science of wear, rubbing and lubrication due to friction, and comes from the Greek word *Tribos,* or rub. Tribology applies in many different scenarios and can be used in many contexts. Tribology includes contact mechanics, physics, chemistry, materials science and fluid science (Jin & Fisher, 2014).

Tribology can be described as the interaction between two surfaces that are in motion, relative to each other. Applying the principles of friction, lubrication and wear are key in the study of tribology, which has become a source of interest for many researchers. Tribology has become its own area that is associated with materials research, physics, chemistry and somewhat surprisingly, biology (Bushan et al., 2003).

Tribological testing is highly beneficial for determining the properties of a lubricant. This form of testing aims to determine how a lubricant may perform under operating conditions, but with a closer observation possible. Additionally, tribological testing is beneficial when testing new lubricants that have unknown tribological properties, and therefore may cause harm if they are tested within an engine. In tribological testing, important parameters are speed, conformity, load, motion, materials, lubricant, surface roughness, temperature and test time. A field test of lubricants in their proposed testing conditions may give the most reliable results, but the cost often is a major limitation of this (Galda et al.,2009)

Tribological testing can be completed in many different ways. Researchers often use pin on disk, ball on three plates, block on ring, ring on ring, four balls or pin and vee block configurations, as seen in Figure 1 (Menon & Rajasekaran, 2023). These configurations allow for contact and motion between surfaces, which leads to friction and wear, which can then be observed and measured. The sample piece that is being tested is often in contact with a counter surface or counterface, which is formed from a material that is often more resistant to wear than the sample material. This allows for wear upon the sample piece to be measured, without wear from the counterface as well.

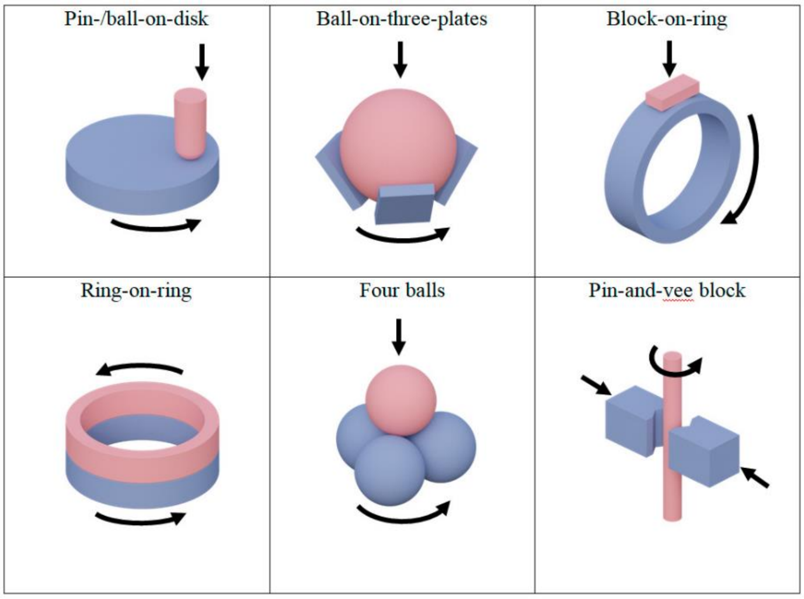


Figure 1: Different Tribology Testing Methods

Source: Menon, K. S., & Rajasekaran, A. (2023). Evaluation of tribological properties and sustainability of bio-lubricant developed from neem seed oil for real-life application. *Tribology International*, *190*, 108998.

2.2.2 WEAR

Wear refers to the loss of material from a surface due to its interaction with another surface, involving contact, motion, and friction. During wear, particles from the affected surface may be transferred to the counter surface, redistributed across the original surface, or entirely lost from the system. The quantification of wear during tribological testing is commonly achieved by measuring and recording the weight loss of the sample material. To facilitate comparisons between different contact conditions and materials, the specific wear rate is often employed. This parameter is defined as the worn volume normalized by the applied normal force and the sliding distance of the interacting bodies. The specific wear rate, extensively documented in tribological literature (Booser, 1994), provides a valuable metric for assessing the suitability of a tribological combination. Additionally, it serves as an important comparative measure for evaluating the performance of different lubricants, with lower specific wear rates indicating superior resistance to wear and better tribological performance.

There are several wear types commonly found in tribological testing. The first of these is abrasive wear, this generally occurs when a softer material is in contact and in relative motion to a much harder surface. Abrasive wear causes grooves, scratches and debris in the surface of the softer surface (Gates, 1997). Adhesive wear generally occurs between two hard surfaces. While this wear can lead to large amounts of wear, it can be difficult to measure as both surfaces may be affected. Additionally, the presence of an effective lubricant decreases the chance of adhesive wear occurring (Nirmal et al., 2018)

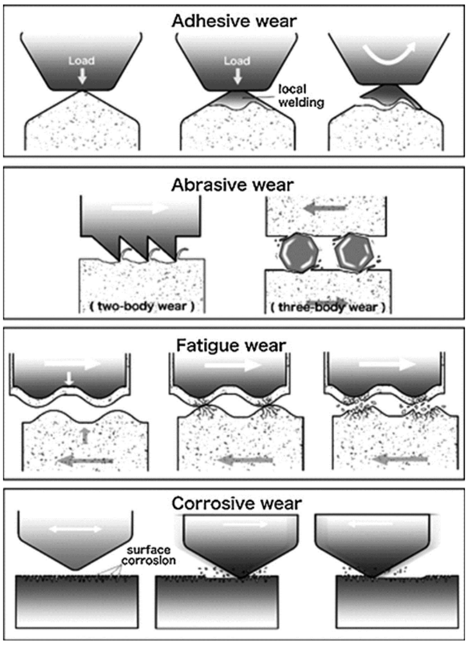


Figure 2: Different types of wear

Source: Kumar, P. (2022). Wear Particle Analysis. *wear*.

Running-in wear and steady-state wear are also commonly used to describe wear behaviour in tribological settings. For engine component design, this is an important factor that must be understood to ensure that durability and performance are up to standard. Typically, the wear rate of a new specimen or component is extremely high at the initial stages (running-in wear), before it rapidly reduces and reaches a steady state (steady-state wear) (Kumar et al., 2002). Figure 3 shows a further explanation of this. Running-in wear and steady-state wear will play an important role in the testing stages of this project and an understanding of these stages of wear will be required to determine the effect of such behaviour.

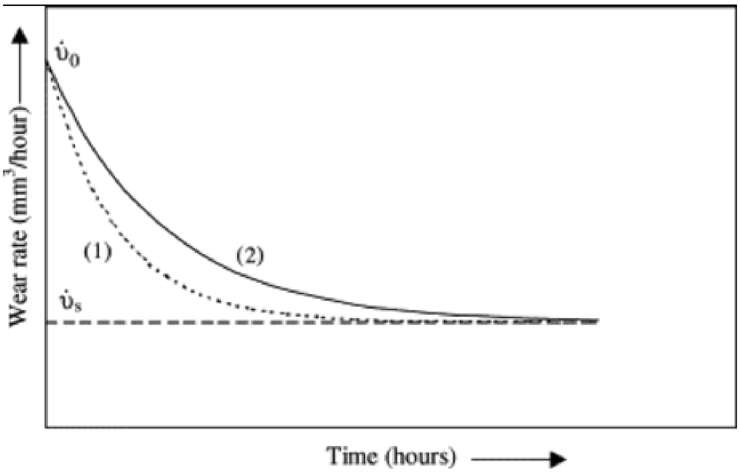


Figure 3: Running-in Wear Versus Steady-state Wear

Source: Kumar, R., Prakash, B., & Sethuramiah, A. (2002). A systematic methodology to characterise the running-in and steady-state wear processes. *Wear*, *252*(5-6), 445-453.

2.2.3 FRICTION

The coefficient of friction (μ) is defined as the tangential force required to sustain constant motion of a body, divided by the normal load exerted by the body on the sliding counter surface. In contrast, static friction represents the force required to initiate motion. Friction and wear are often interrelated phenomena, with friction comprising two primary components: adhesive and ploughing forces, as described by Bowden (1943). The adhesive component arises from forces at the contact of surfaces, while the ploughing component results from the deformation caused by asperities scraping against the softer counter surface. The total friction experienced by a system is the sum of these components. Lubrication predominantly reduces the adhesive friction component and, in cases where a lubricant forms a separating film, it can also diminish the ploughing effect. Changes in load may also alter frictional behaviour by modifying contact mechanisms (Kumar, 2022).

Tribological contacts typically involve multiple wear mechanisms, making them challenging to identify. Advanced imaging tools, such as optical microscopes or scanning electron microscopes (SEM), are often necessary to analyse the contact surfaces in detail. For instance, abrasive and adhesive wear marks on a worn journal bearing, can be effectively observed through SEM. Other prevalent wear mechanisms include corrosion, fatigue, and erosion.

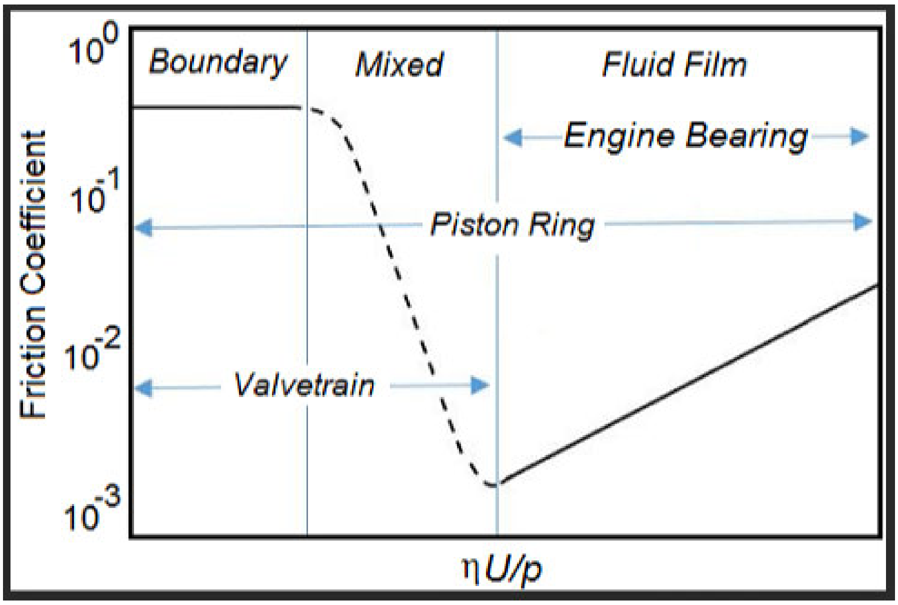
Predicting the friction coefficient and wear rate in boundary-lubricated contacts is highly complex due to the multifaceted nature of these interactions. Numerous researchers have attempted to develop predictive models for friction and wear with varying degrees of success (Gupta, 2001; Ludema, 1996). While these models often demonstrate accuracy within narrow intervals and specific conditions, the probability of accurately forecasting tribological performance in boundary lubrication without experimental validation remains minimal.

2.3 LUBRICATION

Richard Stribeck is a prominent figure in the field of tribology, with his research on plain journal bearing friction remaining highly influential, despite being conducted a century ago. One of his most significant contributions is the Stribeck Diagram, which plots the coefficient of friction against the rotational speed of the shaft in a journal bearing. Over time, as the understanding of lubrication regimes has advanced, the Stribeck Diagram has evolved to incorporate the film thickness ratio, or lambda (λ) (Maru et al., 2007).

The Stribeck Diagram delineates three primary lubrication regimes: boundary, mixed, and full film lubrication (Stribeck, 1902). Boundary lubrication ($\lambda<1$) occurs when surface asperities come into direct contact, separated by only one or a few molecular layers of lubricant, typically measuring 1–10 nanometers. In this regime, viscosity plays a minimal role in load-carrying capacity, while lubricant additives serve as critical friction modifiers and wear reducers. These additives interact with contact surfaces by forming layers that are physiosorbed, chemisorbed, or chemically reacted (Galda et al., 2009).

Full film lubrication ($\lambda>3$) is characterised by complete separation of surfaces by a continuous lubricant film, with the film thickness heavily dependent on lubricant viscosity. In mixed lubrication ($1<\lambda<3$), both hydrodynamic film formation and boundary lubrication mechanisms coexist, reflecting a transitional state between the two extremes. Comprehending the lubrication regimes within a tribological setting will allow for a deeper understanding when completing this project.



$where\ \eta = viscosity, U = velocity\ (sliding\ speed)\ and\ p = normal\ load$

Figure 4: Stribeck's Diagram

Source: Delprete, Cristiana & Razavykia, Abbas. (2017). Piston ring/liner lubrication and tribological performance evaluation: A review. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology. 232. 10.1177/1350650117706269.

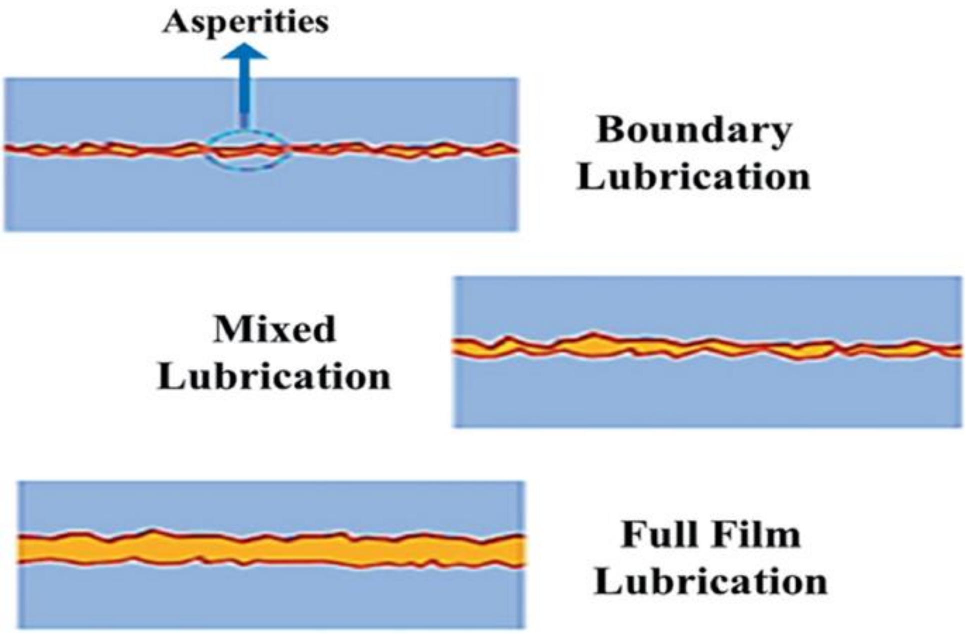


Figure 5: The Three Lubrication Regimes

Source: Kim, IJ. (2022). Frictional Behaviours and Mechanisms. In: Engineering Metrology for Pedestrian Falls Prevention and Protection. Springer, Cham. https://doi.org/10.1007/978-3-030-95746-9_4

2.4 INTERNAL COMBUSTION ENGINES

2.4.1 ENGINE COMPONENTS AND TRIBOLOGICAL LOADING

For the last half a century, there has been a huge focus on increasing the fuel efficiency of automobile engines, while also making them more compact and powerful. Along with these technical constraints, is the increased awareness of environmental impacts of automobile engines. For engineers, this means that there are many increased loads, speeds and temperatures within the engine, which all creates more frictional force. To ensure the best tribological performance, lower viscosity oils and decreasing oil thicknesses between surfaces is becoming more common in modern engines.

The tribological performance of each engine component is complex, and the design must incorporate an understanding of the desired lubrication methods. This becomes even more important if the design is looking to improve the performance of the engine, as frictional forces can greatly decrease the overall output and efficiency of an engine.

The thickness of the oil film specifically is an important concept in design, as it will determine the surface interaction to occur between engine components. This design concept relies heavily upon the magnitude of the loads, as well as the roughness and topography of the surfaces themselves.

Some of the engine components that require the most meticulous lubrication are the piston rings, the cam and engine bearings. These components heavily depend upon different methods of lubrication for suitable performance and if this is not achieved, the performance of the entire engine may suffer. This provides one of the biggest challenges to design teams, as they try to compete with pressure to improve performance and efficiency, all while reducing harmful emissions. Additionally, engines components are generally becoming more compact and must move at higher speeds compared to traditional internal combustion engines. The answer to this is currently to trend towards lubricants with lower viscosities such as OW/30 SAE, which is becoming a strong market in some parts of the world. While lubricants with lower viscosity helps to reduce losses due to friction, it also reduces oil fil thicknesses and therefore increases wear, reducing the durability of engine components. Analytical modelling of lubricant performance and behaviour has become more important than ever (Lee, 2019).

When an oil film is thick enough to prevent two surfaces from coming into contact, then it is referred to as a "fluid film condition". Traditionally, this is considered to be the optimal method of lubrication, as it greatly reduces friction between the two surfaces. Alternative methods of lubrication are important in the different tribological components of the engine, and a single engine component may undergo a vast array of lubrication methods during a cycle.

2.4.2 LUBRICANT REQUIREMENT

For an internal combustion engine, lubrication allows engine parts to be cooled, lower frictional forces, reduce wear between surfaces, clean engine components, seal gaps, and absorb forces from engine operation.

Lubricants can be liquid, semi-solid, such as grease, and even solid, such as graphite. Lubricants are mainly used to reduce friction and wear between two surfaces. Traditionally, internal combustion engines use mineral oil as a lubricant, made by the refinement of petroleum. Each lubricant possesses a number of properties (viscosity, oil, flash point, fire point, etc.) that must be suited to its function to ensure that it performs as desired.

In 2012, Holmberg et al. conducted a study that revealed that up to one third of the total energy produced by fuel within an internal combustion engine is wasted due to frictional losses. Additionally, their study found that if friction-reducing technologies could be reduced in automotives, then friction losses could be decreased by up to eighteen percent in the next decade. This would result in the saving of almost 300 million AUD (Holmberg et al., 2012).

Priest and Taylor's studies also found that in a typical internal combustion engine, only twelve percent of the potential energy being transferred to the flywheel, with approximately fifteen percent accounting for mechanical losses, which is mainly due to frictional forces (Priest & Taylor, 2000). The implications of this are felt across the world, and even slight improvements in this efficiency would be highly beneficial. It has been calculated that a 10% reduction in mechanical losses has the potential to reduce fuel consumption by 10% (Bartt et al., 2013).

To overcome the design difficulties provided by frictional forces, it is important that the correct lubrication methods are used. The main role of lubricants, as previously stated, is to optimise the coefficient of friction between surfaces. However, it should also be recognised that lubricants allow for reduced wear on surfaces and increase durability of components. This makes them integral to the functioning and performance of an internal combustion engine. Enhancing lubricant properties to ensure the most effective and efficient performance is of the utmost importance and will allow for the design and manufacturing of the next generation of internal combustion engines.

2.5 LUBRICANT TECHNOLOGY

2.5.1 TRADITIONAL LUBRICANTS

There are two main types of traditional engine lubricants that are used. These are mineral oil-based lubricants and synthetic oils. Mineral oil-based lubricants are derived from a highly refined version of petroleum oil, retrieved from the Earth. Synthetic oils are formed using chemical reactions and are becoming highly popular in modern engines. While the performance of these oils is adequate and is being improved over time, there is a need to find a more renewable source of lubrication (Soni et al., 2014). There is not currently a widespread shortage of fossil fuel based oils, but this source is definitely exhaustible, and the demand for engine lubricants is increasing each year. These oils are also widely unable to be recycled, and a large drawback of them is their difficulty of sustainable disposal. It is therefore proposed that a renewable and biodegradable source of oil is found, such as a vegetable oil that is readily available. However, there are several issues with this, as most vegetable oils have a much lower viscosity than mineral or synthetic oils. As previously mentioned, a shift towards lubricants with a lower viscosity may be in the favour of using vegetable oils. A lower viscosity value means that the oil is less resistant to flow, and therefore is less likely to produce frictional losses. Often, engines that are lubricated by vegetable oils either suffer from large friction losses, affecting output and efficiency, or by component wear. This increases maintenance levels and therefore costs, labour and other associated factors. Additives have been proven to increase the properties of such vegetable oils, however this can also affect their low cost and biodegradability, two of their most beneficial attributes.

2.5.2 BIO-LUBRICANTS

In a world that relies heavily on transportation for many industries, it is important that more renewable alternatives to petroleum-based products are found. Bio-lubricants provide an option that is potentially much more renewable and abundant when compared to petroleum-based oils. Additionally, traditional lubricants can be found to be leaked back into the environment, causing serious damage to ecosystems. Biodegradable lubricants have recently been recognised as a possible solution to the previously mentioned issues, and they will play as a significant role in the future of the transport industry. In some cases, bio-based lubricants have been found to present results that suggest superior lubricant properties when compared to traditional mineral lubricants. The added bonus of renewability and biodegradability make bio-lubricants an important technology that must be explored further.

Soufi et al. states that "it can be concluded that bio-based lubricant is a promising substitute for various applications due to their availability in wide arrays of properties which are essential for some applications. However, for certain applications, prior chemical modification is required to overcome the limitations including substandard low temperature characteristics and oxidative stability. With proper base oil and additive packages formulation, bio-based lubricants can perform better than the conventional lubricants" (Soufi et al., 2019).

2.5.3 RECENT WORK ON LUBRICANTS

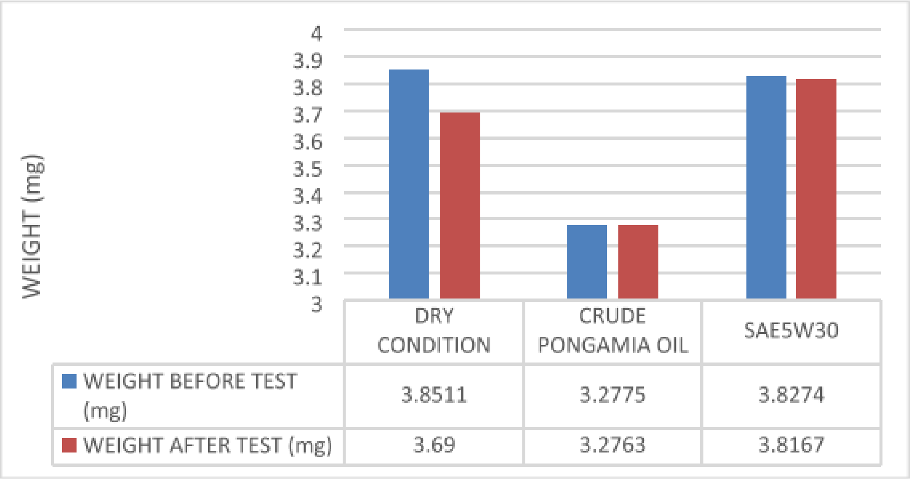
2.5.3.1 BIO-LUBRICANTS

Bio-lubricants are a technology that have recently become closely investigated. With the automotive industry pushing towards becoming more sustainable, bio-lubricants have the potential to solve some of the environmental issues associated with the automotive industry. Therefore, many studies have been completed on the effectiveness and the validity of using bio-lubricants within an automotive engine. The methodology, results and final observation of each of these studies will be analysed to ensure that a thorough understanding of the existing literature is achieved.

A study performed by John et al. explored the development of an environmentally friendly lubricant derived from Pongamia (from the Millettia pinnata tree) oil, integrated with biodegradable additives. Their research aimed to analyse and formulate the lubricant with the objective of creating a lubricant that was more environmentally friendly than traditional lubricants. By using Pongamia oil, which has potential as a renewable resource, as a base product for the lubricant, the project aspires to address the concerns of sustainability that are present within the lubrication industry.

To achieve results, a number of experiments were conducted to characterise and evaluate the performance of the Pongamia oil-based lubricant. They focused on assessing various properties such as viscosity, thermal stability, and friction reduction capabilities. These results could then be used to assess the validity of using this oil as a substitute for traditional oils. Additionally, by incorporating biodegradable additives into the lubricants, the study aimed to enhance the lubricant's effectiveness while ensuring minimal environmental impact.

Throughout their analysis, the researchers found promising results regarding the eco-friendliness and performance of the formulated lubricant. Notably, the lubricant displayed favourable biodegradability characteristics, aligning with the growing demand for sustainable lubrication solutions. Furthermore, the performance tests indicated that the Pongamia oil-based lubricant, fortified with biodegradable additives, showed potential for practical applications across many different industries. This specific project incorporated the use of a pin on ring configuration. Below, the diagram shows the weight of a pin before and after it has been wear tested with a load of 10 kg. It can be seen that when lubricated with the Pongamia oil, the pin had the least amount of weight loss, indicating that it had the strongest resistance to wear.



	DRY CONDITION	CRUDE PONGAMIA OIL	SAE5W30
🟦 WEIGHT BEFORE TEST (mg)	3.8511	3.2775	3.8274
🟥 WEIGHT AFTER TEST (mg)	3.69	3.2763	3.8167

Figure 6: Results from John et al. study

Source: John, A. R., Anoop, P. V., Kuriyakose, A., Krishnan, A., Mohan, L., & Aravind, A. (2023). Characterization and formulation of an environment-friendly lubricant from Pongamia (Millettia Pinnata) oil using biodegradable additives. *Materials Today: Proceedings*.

Overall, the study highlighted the feasibility of developing an environmentally friendly lubricant by using renewable resources such as Pongamia oil, as well as integrating biodegradable additives. The results from this study provided an environmentally friendly lubricant that performs similarly to traditional lubricants. The findings are promising, as they highlight the potential of sustainable lubricants as an alternative to petroleum-based lubricants, without sacrificing performance standards.

The article "Evaluation of tribological properties and sustainability of bio-lubricant developed from neem seed oil for real-life application" delves into the assessment of a bio-lubricant derived from neem seed oil, with a particular focus on its tribological properties and sustainability aspects for use in the real-world. In this study, Neem seed oil is explored as a potential lubricant base, addressing the growing need for eco-friendly lubrication requirements.

This research aimed to evaluate the tribological performance of the neem seed oil-based bio-lubricant under various operating conditions that simulated real-life applications. Tribology, the study of friction, wear, and lubrication, is a critical aspect in determining the effectiveness of lubricants in practical settings. By conducting extensive tribological tests, including friction and wear measurements, Menon & Rajasekaran aimed to gauge the lubricant's efficacy in reducing friction and minimising the wear between two interacting surfaces.

Furthermore, the study placed significant emphasis on sustainability considerations that were associated with the bio-lubricant. Sustainability in lubrication involves assessing the environmental impact that occurs throughout the lubricant's lifecycle, from production and usage to disposal. Neem seed oil, which is biodegradable and a renewable resource, presents a clear solution for creating sustainable lubricants. The study closely examined the bio-lubricant's eco-friendliness, considering factors such as biodegradability, toxicity, and resource renewability.

The findings provided by the study provide valuable insights into both the tribological performance and the sustainability aspects of the neem seed oil-based lubricant. Results from tribological tests offer data that proves the lubricant's ability to mitigate friction and wear, an essential role of lubricants in all industries. Additionally, the assessment of sustainability parameters sheds light on the environmental credentials of the bio-lubricant, supporting its potential as a greener alternative to conventional lubricants derived from non-renewable sources. As can be seen in the below diagram, the neem seed oil-based lubricant was tested with different additives and against a traditional lubricant, being SAE20W40. With the correct make-up formula, the neem seed oil-based lubricant performed extremely similar to the SAE20W40 lubricant, suggesting that it has the potential to be used in industry as an alternative for some traditional lubricants.

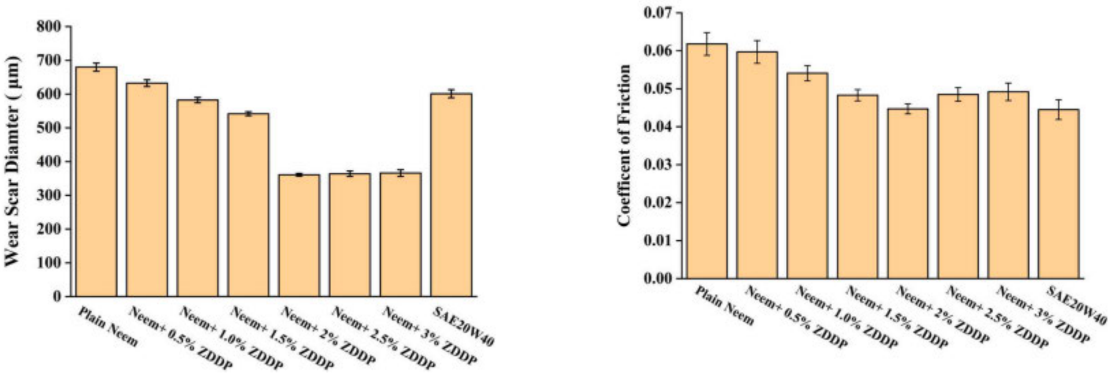


Figure 7: Results from Menon & Rajasekaran's Study

Source: Menon, K. S., & Rajasekaran, A. (2023). Evaluation of tribological properties and sustainability of bio-lubricant developed from neem seed oil for real-life application. *Tribology International*, *190*, 108998.

In summary, this research allows for a further understanding of bio-lubricants derived from renewable sources. The study offers a holistic evaluation that encompasses both technical performance and sustainability factors. The findings underscore the potential of neem seed oil-based lubricants being used in industry and the collected data emphasises the need to promote environmentally friendly lubricants.

The article "Study on the tribological characteristics of plant oil-based bio-lubricant with automotive liner-piston ring materials" by Shahabuddin et al. delves into the investigation of the performance of a formulated bio-lubricant. By testing a plant oil-based lubricant against materials commonly found in liner-piston rings from engine assemblies, it produces results that clearly define whether bio-lubricant could be applied to the automotive industry. Tribology, the science of friction, wear, and lubrication, is of extreme importance in automotive engineering to ensure optimal performance, efficiency, and longevity of engine components. The study aims to assess how the bio-lubricant performs in reducing friction and wear between the liner and piston ring, crucial interfaces within an engine.

The study employed a comprehensive experimental approach to evaluate the tribological characteristics of the plant oil-based lubricant. This included conducting friction tests to measure the resistance to motion between the liner and piston ring, as well as wear tests to assess the extent of material loss under simulated operating conditions. By subjecting the lubricant and materials to controlled tribological testing, the study was able to gain insights into the efficacy of the lubricant and the wear-reducing properties that are present.

Additionally, the study considered the compatibility and interaction between the bio-lubricant and automotive materials. Given the complex composition of plant oils and the variety of liner and piston ring materials used in automotive engines (such as steel, aluminium alloys, and composites), understanding the lubricant-material interaction is crucial for ensuring compatibility and performance. The study investigated potential issues such as material degradation, harmful surface interaction, and the formation of protective boundary layers to explain the overall tribological behaviour when using the bio-lubricant.

The findings of the study provided valuable insights into the feasibility and performance of plant oil-based lubricants in automotive applications. Results from the tribological tests offered quantitative data on friction reduction and wear mitigation, aiding in the analysis of the lubricant's effectiveness compared to conventional lubricants. Furthermore, understanding the lubricant-material interaction in this instance has the potential to assist in design challenges regarding material selection, lubricant formulation, and engine design. The implications of these design decisions include improving efficiency and durability while minimising environmental impact.

In conclusion, the research completed in this study contributes to advancing the knowledge and application of bio-lubricants in automotive engineering. By investigating the tribological characteristics with automotive liner-piston ring materials, the study supports the development of eco-friendly lubricants that are tailored to meet the performance and sustainability demands of modern automotive systems. The results highlight the potential role of plant oil-based bio-lubricants in promoting greener and more efficient automotive technologies.

The article titled "The effect of tribology behaviour on machining performances when using bio-based lubricant as a sustainable metalworking fluid" is a study completed by Talib and Rahim in 2022. The study explores the impact of tribological behaviour on machining performance, particularly in the context of using bio-based lubricants as sustainable alternatives to conventional metalworking fluids. In this study, all factors of tribology (friction, wear and lubrication) are carefully examined to ensure that efficient material removal, tool life, and surface quality can be achieved. Without these qualities, the bio-lubricant cannot be successful in the industry. The study aims to investigate how the use of bio-based lubricants influences the tribological interactions during machining operations and subsequently, the performance of such operations when using bio-lubricants.

To accomplish this objective, Talib and Rahim conducted a series of experiments to evaluate the tribological behaviour of bio-based lubricants in machining applications. These experiments involved analysing frictional forces, wear mechanisms, and lubricant performance under various machining conditions (cutting speed, feed rate, depth of cut). By systematically varying these parameters and monitoring tribological responses, the researchers sought to understand how bio-based lubricants interact with cutting tools, workpiece materials, and chip formation processes during machining.

The study also assesses the influence of tribological behaviour on machining performances, including factors such as cutting forces, surface finish, and tool wear. By correlating tribological data with machining outcomes, the researchers aimed to explain the effect that bio-lubricants have on overall machining efficiency and quality. This approach allowed for a comprehensive understanding of the interplay between lubrication, friction, and wear in metalworking processes, with implications for optimising machining parameters and enhancing sustainability within the industry.

The final results of the study provide rational support to the potential benefits and challenges of using bio-based lubricants in metalworking applications. Results from the tribological analysis offered crucial information regarding the lubricant's ability to reduce friction, minimise wear, and improve machining performance compared to traditional lubricants. Understanding this tribology-machining relationship enables researchers and practitioners to optimise lubricant formulations, machining parameters, and tooling strategies for sustainable and efficient metalworking operations.

Overall, the research contributes to this current project by advancing the knowledge and application of bio-based lubricants as sustainable metalworking fluids. By investigating their tribological behaviour and its impact on machining performances, the study provides a foundation for implementing environmentally friendly lubrication solutions in industrial manufacturing processes. The findings outline the potential of bio-based lubricants to enhance both the sustainability and effectiveness of metalworking operations, paving the way for greener and more efficient machining technologies.

The study "A review of recent advances in the synthesis of environmentally friendly, sustainable, and nontoxic bio-lubricants: Recommendations for the future implementations," was completed by Malik et al. in 2023. The project provides an extensive analysis of the latest developments in the synthesis of bio-lubricants that prioritise environmental friendliness, sustainability, and non-toxicity. With growing concerns over environmental degradation and health hazards associated with traditional lubricants, there is a pressing requirement to explore alternative lubricants that are eco-friendly and environmentally safe.

Initially, the significance of transitioning towards bio-based lubricants, emphasising their potential to reduce greenhouse gas emissions, minimising reliance on finite resources, and mitigating environmental pollution is discussed. The study highlights the recent advancements in bio-lubricant synthesis, including enzymatic processes, chemical modification of natural oils, and the utilisation of renewable feedstocks. These approaches enable the production of lubricants with desirable properties such as high biodegradability, low toxicity, and desirable lubricating performance.

The study then provides a comprehensive overview of the key characteristics and properties that define environmentally friendly bio-lubricants. These include biodegradability, renewability of raw materials, low environmental impact throughout the lifecycle, and compatibility with existing lubrication systems. The authors analyse various bio-based feedstocks, such as vegetable oils, animal fats, and microbial oils, assessing their suitability for lubricant formulation.

The article also discusses emerging trends and future directions in bio-lubricant research and development. It identifies areas for further exploration and improvement, such as enhancing the stability and oxidative resistance of bio-lubricants, optimising production processes for scalability and cost-effectiveness, and addressing regulatory challenges related to bio-lubricant implementation. Moreover, the review emphasises the importance of interdisciplinary collaboration between scientists, engineers, and policymakers to drive innovation and develop the widespread adoption of sustainable lubrication technologies.

In conclusion, the article provides valuable insights and recommendations for advancing the synthesis and implementation of bio-lubricants. By highlighting recent progress, identifying challenges, and proposing future research directions, the review contributes to the ongoing efforts towards achieving a more sustainable and environmentally responsible lubrication industry. The literature available in this study is promising and it further supports the knowledge that the current project is necessary and achievable.

The next piece of literature to be reviewed was “A Review on Bio-Lubricant Production from Non-Edible Oil-Bearing Biomass Resources in Iran: Recent Progress and Perspectives” by Almasi et al. This study supplies important literature for the current project as it focuses on non-edible biomass oils, which are a desirable bio-lubricant as they do not affect the use of edible oils that are used for human consumption. This study found that the production of bio-lubricants from non-edible oil-bearing biomass resources has gained significant attention in recent years due to the growing demand for environmentally friendly lubricants. Iran, with its abundant reserves of non-edible oil-bearing biomass, presents a promising opportunity for the development of bio-lubricants. The study aimed to assess the quality of recent bio-lubricant production from non-edible oil-bearing biomass in Iran, highlighting key advancements, challenges, and future prospects in this field.

This study focused in on the use of these lubricants in Iran. Iran boasts a diverse range of non-edible oil-bearing biomass resources, including jatropha, castor, pongamia, and camelina. These biomass sources offer potential for bio-lubricant production due to their high oil content and suitability for cultivation in Iran. Recent studies have focused on exploring the feasibility of utilising these biomass resources for bio-lubricant synthesis, highlighting their abundance and accessibility as key advantages.

The study explored various techniques that have been employed for the production of bio-lubricants from non-edible oil-bearing biomass. These include conventional methods such as transesterification and esterification, as well as emerging approaches such as enzymatic catalysis and supercritical fluid extraction. Each method has its advantages and limitations in terms of process efficiency, product quality, and environmental impact. Recent research has focused on optimising these techniques to enhance the yield and quality of bio-lubricants while minimising energy consumption and waste generation.

The article completed by Almasi et al. evaluated the chemical properties and tribological performance of bio-lubricants derived from non-edible oil-bearing biomass in Iran. These bio-lubricants exhibit favourable characteristics such as high viscosity index, low pour point, and good oxidative stability, making them suitable for a wide range of industrial applications. The tribological tests demonstrated their effectiveness in reducing friction and wear, highlighting their potential as sustainable alternatives to petroleum-based lubricants.

Despite the significant progress in bio-lubricant production from non-edible oil-bearing biomass in Iran, several challenges remain to be addressed. These include technical challenges related to processing techniques, product quality control, and scale-up of production, as well as economic challenges associated with cost competitiveness and market acceptance. Almasi et al. found that future research efforts should focus on overcoming these challenges through innovation in feedstock selection, process engineering, and product development. Collaborative initiatives involving academia, industry, and government stakeholders are essential to accelerate the commercialisation and widespread adoption of bio-lubricants in Iran's lubricants sector.

In summary, the study found that Iran holds considerable potential for the production of bio-lubricants from non-edible oil-bearing biomass resources. Recent progress in this field has demonstrated the feasibility of utilising locally available biomass feedstocks to produce environmentally friendly and sustainable lubrication solutions. By addressing technical, economic, and regulatory challenges, Iran can capitalise on its biomass resources to advance bio-lubricant production and contribute to the transition towards greener and more sustainable lubricants. While this study focused on the implementation of bio-lubricants in Iran, this study relates to bio-lubricant technologies globally.

Joshi et al. recently completed a study in 2023 titled “A Review on Bio-Lubricants from Non-Edible Oils: Recent Advances, Chemical Modifications, and Applications.” This study found that the production and utilisation of bio-lubricants derived from non-edible oils have garnered significant attention in recent times due to the ever-increasing demand for sustainable and environmentally friendly solutions in all technologies. This study is another recent advance in the field of bio-lubricants derived from non-edible oils, focusing on innovative production methods, chemical modifications, and diverse applications.

The main research completed in this study found that non-edible oils sourced from plants, seeds, and microorganisms serve as promising feedstocks for bio-lubricant production due to their abundance, renewability, and potential for sustainable cultivation. Non-edible oils such as jatropha, castor, camelina, and pongamia have emerged as key candidates for bio-lubricant synthesis, offering favourable fatty acid profiles and physicochemical properties conducive to lubricant applications.

Throughout this study, it was found that various production methods have been employed to convert non-edible oils into bio-lubricants, including transesterification,

esterification, hydrolysis, and enzymatic catalysis. These methods facilitate the conversion of triglycerides present in non-edible oils into monoesters and diesters, which exhibit superior lubricating properties compared to their parent oils. Recent advancements in production techniques have focused on enhancing process efficiency, product purity, and environmental sustainability. Additionally, it was discovered that chemical modifications of non-edible oils represent a promising approach to tailor the properties of bio-lubricants to meet specific performance requirements. Strategies such as epoxidation, hydroxylation, and polymerisation enable the introduction of functional groups and molecular structures that enhance lubricity, oxidative stability, and biodegradability. These modifications offer versatility in designing bio-lubricants with tailored properties for specialised applications in automotive, industrial, and aerospace sectors.

The study found that the bio-lubricants derived from non-edible oils can fit diverse applications across various industries, including automotive lubrication, hydraulic fluids, metalworking fluids, and marine lubricants. Their superior lubricating performance, biodegradability, and low toxicity make them attractive alternatives to petroleum-based lubricants, particularly in environmentally sensitive applications. Case studies and performance evaluations demonstrate the efficacy of bio-lubricants in reducing friction, wear, and environmental impact while maintaining operational efficiency and equipment longevity.

Despite the significant progress in bio-lubricants from non-edible oils, several challenges were identified by this study. These include including feedstock availability, production scalability, cost competitiveness, and regulatory compliance. These issues must be addressed before bio-lubricants can be successful within engineering industries.

Future research efforts should focus on optimising production processes, developing novel feedstock sources, and advancing performance testing methodologies to accelerate the adoption of bio-lubricants in mainstream lubrication applications.

In conclusion, the study recognised that bio-lubricants derived from non-edible oils offer a promising avenue for sustainable lubricants. Recent advances in production methods, chemical modifications, and applications have demonstrated the potential of non-edible oils as renewable feedstocks for bio-lubricant synthesis. By addressing key challenges and leveraging emerging technologies, the widespread adoption of bio-lubricants can contribute to a more sustainable and environmentally responsible lubricant industry.

The last study that provided important literature for the current project was completed by Hamnas & Unnikrishnan: “Bio-Lubricants from Vegetable Oils: Characterisation, Modifications, Applications, and Challenges – A Review.” As suggested by the title, this study was similar to others that have been recently completed, however it focussed on the specific use of vegetable oils, rather than non-edible oils or other alternatives. The main interest of the study was that the utilisation of vegetable oils as bio-lubricants has garnered significant interest in recent years due to their renewability, biodegradability, and potential to mitigate environmental impacts when compared to traditional lubricants. This study also provides an interesting perspective on the challenges that remain on the implementation of bio-lubricants, rather than just their potential benefits.

The study explores vegetable oils, such as soybean, rapeseed, sunflower, and palm oils, which possess unique fatty acid compositions. Characterisation studies within the study involve assessing key factors such as viscosity, oxidative stability, pour point, and lubricity to evaluate the performance of vegetable oil-based bio-lubricants under different operating conditions.

The study found that there are several modifications that must be made to make vegetable oils a viable option as a bio-lubricant. Chemical modifications of vegetable oils are commonly employed to enhance their lubricating properties, oxidative stability, and compatibility with industrial equipment. Techniques such as epoxidation, hydroxylation, transesterification, and polymerisation enable the synthesis of modified vegetable oil derivatives with tailored properties for specific lubrication requirements.

Finally, the study attempted to discover the possible application of such bio-lubricants. It was found that bio-lubricants derived from vegetable oils fit diverse applications across various industries, including automotive, aerospace, marine, and metalworking. Their superior lubricating performance, biodegradability, and low environmental impact make them a desirable alternative to traditional lubricants which perform similarly but are less environmentally friendly.

It is worth mentioning however, that Hamnas & Unnikrishnan discovered that despite their numerous advantages, vegetable oil-based bio-lubricants face several challenges and limitations that hinder their widespread adoption. These include issues related to oxidative stability, low-temperature performance, compatibility with elastomers and seals, and cost competitiveness compared to conventional lubricants. Addressing these challenges requires advancements in feedstock selection, production processes, additive technologies, and performance testing methodologies.

Finally, the study was able to present the future prospectives of these bio-lubricants. It was found that future research directions in the field of vegetable oil-based lubricants should focus on addressing existing challenges and expanding their applications in emerging sectors such as renewable energy, biomedicine, and additive manufacturing. Key areas of focus also include the development of high-performance additives, optimisation of lubricant formulations, and exploration of further processing techniques to enhance the sustainability and performance of bio-lubricants.

In conclusion, this study proved that bio-lubricants derived from vegetable oils offer promising solutions to address environmental concerns associated with conventional lubricants. Vegetable oil-based bio-lubricants demonstrate their potential to meet the lubrication requirements of various industries while reducing the environmental footprint of such sectors. Overcoming existing challenges and embracing future opportunities will facilitate the widespread adoption of bio-lubricants as sustainable alternatives in the lubrication industry.

2.5.3.2 LIMITATIONS

While the above studies provide important literature that will assist in the completion of this project, it is important to note that there are several limitations in the available studies. Each of the studies prove that there is great potential for the implementation of bio-lubricants into engineering fields, but there are reasons as to why these bio-lubricants are not already a part of industry. While these issues are somewhat mentioned, they are seldom addressed or highlighted within such studies. It is hoped that this project will be able to delve deeper into the issues that are preventing bio-lubricants from currently being used within the automotive industry. Additionally, it is hoped that this project will be able to offer some solutions to such problems, allowing the possibility of bio-lubricants becoming part of everyday life. It is also hoped that this project will inspire further studies to be completed, which will only benefit the engineering community.

2.4 GAPS IN LITERATURE

While there is a large amount of existing literature on this topic, there are still some gaps in the literature that were unable to be explored. While many studies have previously simulated bio-lubricants being used in an automotive setting, there is none or very little literature that has tested bio-lubricants in a real-world setting. While this is a large gap in the literature for this project, it is realistically unlikely that this gap will be able to be addressed in this specific project. However, this project has the potential to pave the way for further studies to be completed, which will allow for this gap to be addressed. Once this has been completed, it can be truly evaluated whether bio-lubricants will be able to be implemented into the automotive industry.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the selection and preparation of the bio-lubricant to be used in the testing. The characteristics that this bio-lubricant displays will be introduced and highlighted against the objectives of the testing. The sample selection and its fundamental properties will be presented and connected back to the original objectives of this project. Finally, the experimental setup and procedure will be laid out, in preparation for the testing stage of this project to take place.

3.2 EXPERIMENTAL SELECTION

3.2.1 SELECTION OF BIO-LUBRICANT

For this project, it has been decided that a bio-lubricant shall be formulated by combining pure neem seed oil with a synthetic oil, with a number of ratios to be tested. This has been chosen so that results can be compared between the differing ratios of the neem seed oil and synthetic oil mix and to allow for performance to be directedly compared with pure synthetic oils. As shown in the study completed by Menon & Rajasekaran, Neem Seed Oil has previously been proven to produce results that are similar to that of current mineral-based oils. By mixing Neem Seed Oil with a mineral oil, a bio-lubricant can be created, and the result is more biodegradable and renewable than a stock standard mineral oil. Neem Seed Oil is produced from the fruit of the neem tree, making it a renewable resource. Importantly, Neem Seed Oil is not fit for human consumption, as opposed to other oils that are used in bio-lubricant mixtures (canola, vegetable oil etc.). This ensures that Neem Seed oil remains a readily available and inexpensive option as a bio-lubricant.

The Neem Seed Oil will be purchased off the shelf. To ensure that the results are not affected by any outside factors, it will be ensured that the purchased Neem Seed oil is in a pure form and does not contain any additives. Additionally, the synthetic oil to be used in this project will be purchased off the shelf, to ensure that results are realistic and can be related to real world use. The synthetic oil to be used in this project has been selected to be SAE-30 commercial grade lubricant. This is a common lubricant that is used within small engines, such as mowers, brush cutters and motorbikes. This lubricant has known values for viscosity at ambient temperature, viscosity at operating temperature and flash point, meaning that this can be directly compared with the properties that the bio-lubricant mixtures contain. It has been decided that 0%, 25%, 50%, 75% and 100% synthetic oil mixtures will be used as the bio-lubricant. This will mean that there will be a pure mineral oil lubricant (0%), then three different mixtures of Synthetic Oil with Neem Seed Oil (25%, 50%, 75%), as well as a pure Neem Seed oil (100%), to be used in the experiments. This is similar to a study completed by Shalwan, Yousif and Alajami (Shalwan et al., 2021), where such ratios of canola oil was blended with a commercial mineral-based lubricant to create a bio-lubricant. The different bio-lubricant blends will be carefully blended by heating the combined oils to a temperature of 80ºC, and then using a drill-powered mixer to blend the oils together, as also referenced in previous studies (Shalwan et al., 2021). This method will ensure that the oils are correctly blended and is in line with the literature. Overall, the data produced from these experiments will provide comparable results that can be further analysed. Having results from these 5 different classifications of bio-lubricants will allow for further analysis of the difference in wear patterns, frictional forces and wear rates. This will allow for a thorough evaluation of the tribological properties of bio-lubricants. The properties of both SAE-30 oil, and Neem Seed Oil are reported below.

Table 1: Properties of SAE-30 Engine Oil (composition retrieved from Penrite)

Density at 20ºC	0.894 kg/L
Kinematic Viscosity at 40ºC	93 cSt
Kinematic Viscosity at 100ºC	11 cSt
Viscosity Index	113

Table 2: Properties of Neem Seed Oil (composition retrieved from Neeming Australia provider)

Density at 20ºC	0.85 kg/L
Kinematic Viscosity at 40ºC	50 cSt
Kinematic Viscosity at 100ºC	6 cSt
Viscosity Index	120

Table 3: Fatty Acid Composition of Neem Seed Oil (composition retrieved from provider)

Fatty Acid	Percentage
Palmitic	13.6-16.2
Stearic	14.4-24.4
Oleic	49.1-61.9
Linoleic	2.3-15.8

Past literature shows that oleic and linoleic additives have previously been used as lubricant additives to reduce the friction coefficient between two surfaces (Madjoub et al, 2014). Additionally, stearic has been found to be an important fatty acid when it comes to reducing friction and wear between surfaces (Ikeda et al, 2014). The high concentration of these beneficial fatty acids in the neem seed oil will aid its tribological performance during the testing, verifying the decision to use this as part of the bio-lubricant blend.

3.2.2 SELECTION OF SAMPLE MATERIAL

For these experiments, the sample material will be 6060 grade aluminium. This sample piece will be placed under load via a dead weight, which will provide a force, pushing it against the counterface, which is coupled to a 24v DC motor. This friction created between the two materials allows for the frictional performance of the lubricant to be analysed. It is important to ensure that the correct materials are selected for these components of the experiment. To ensure that the conditions are as closely simulated as possible to that of an automotive engine, the materials will be based off those found in most common car engines. In automotive engines, most cylinders are generally made from aluminium alloys. The countersurface material to be used in these experiments is a stainless-steel ring, while the samples themselves will be prepared from aluminium. As seen in the reviewed literature, this is one of the most common materials used in lubricant tribology testing, and it can also simulate an internal combustion engine, as many engines contain aluminium pistons and connecting rods (Sharma, 2022).

The selection of 6060 grade aluminium was also justified by the requirement to select a material that had a lower hardness than the couterface surface. The selection of a softer material when compared to other materials such as brass or mild steel, allows for higher wear rates to be observed in the sample piece.

To ensure consistency throughout the testing process, it is important that the initial roughness of each of the sample and counterface materials are kept the same. Before the start of each testing process, the roughness of both the sample piece and the counterface material will be recorded and adjusted to a uniform value.

3.2.3 SELECTION OF TESTING PROCESS

The testing of tribological properties can be completed in several ways. Generally, machines are used in various configurations such as pin/ball on disc, ball on three plates, block on ring, ring on ring, four balls or pin/vee on block. While all of these configurations are popular in the field of tribological testing, block-on-ring setups are a typical configuration used when researching lubricants. For this project, a block-on-ring (BOR) configuration will be used, using a tribological machine from Alotaibi et al.'s study.

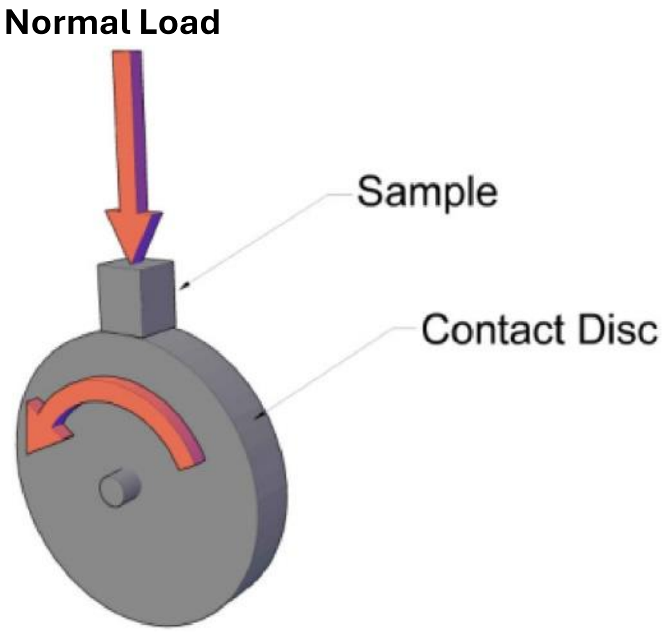


Figure 8: Block on Ring Configuration

Taken from: Tier et al. (2020). *Effect of heat and cryogenic treatment on wear and toughness of HSS AISI M2.* Retrieved on May 10, 2024 from https://www.researchgate.net/figure/Wear-test-configuration-block-on-ring_fig3_344356603

The setup of the tribological machine is shown in Figure 9. The machine will operate in the same conditions that it was used in during Alotaibi et al.'s study. This process involves a counterface being spun by a motor against the sample piece, that will be placed under pressure via a 'dead weight'. This weight will provide the frictional force between the two materials and can be adjusted as needed. The counter face, as well as the sample material, will be immersed in the lubricant, to ensure that the sample piece is able to be entirely lubricated.

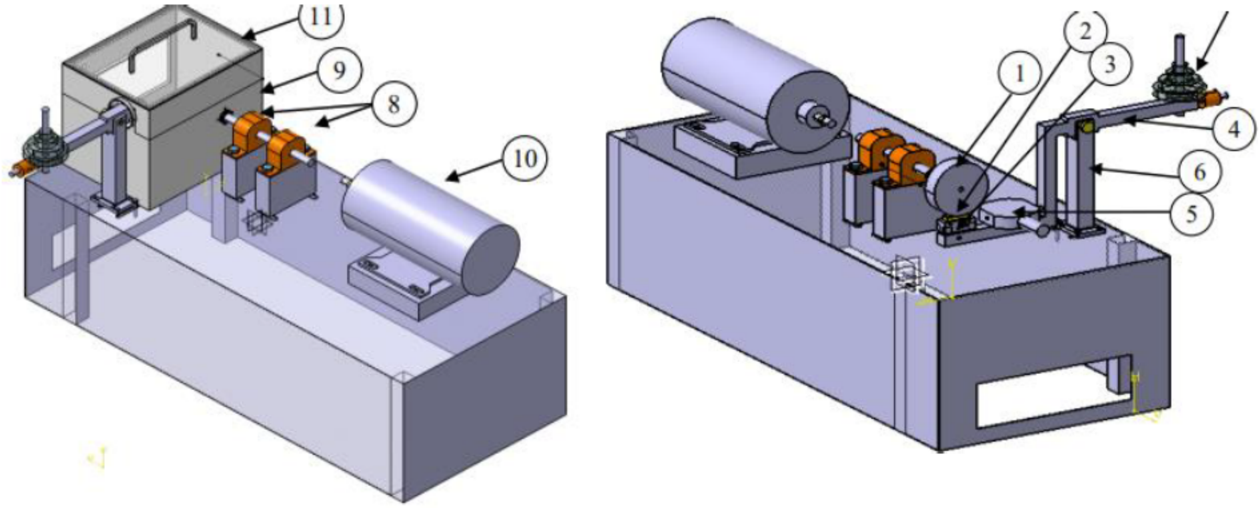


Figure 9: 3D Models of The Tribology Machine to be Used

Taken from: Alotaibi, Jasem. 2014. Wear and frictional performance of metals under dry/waste cooking oil lubricant conditions. PhD Thesis Doctor of Philosophy. University of Southern Queensland.

After each sample piece is tested, the oil will be replaced to ensure that accurate results are produced. To remove the old oil, a drill-powered pump will be used. This will ensure that the majority of the oil is removed, before acetone is used to remove any residue oil that remains. Further pictures of the experimental setup of this procedure can be viewed in the appendix chapter of this report.

3.2.4 SELECTION OF VARIABLES

There are a number of variables that will be altered throughout the testing process of this project. The alteration of these variables will allow for a large array of results from the testing process. The variables that are to be altered in this project is the speed of the sliding ring and the lubricant that is being used within the tribology machine. Altering these variables throughout the testing process will allow for results that clearly outline the influence that each of these variables have on the final result of the experiments. There will be a number of variables that will be kept the same throughout the testing process, and these include the material of the sample piece, the temperature of the oil and the force between the sample and the counter face.

The testing process will span for a total of 40 minutes for each sample piece. There will be a total of 45 different samples being tested, with 5 different oil ratios and 3 different speeds to be tested, each combination of variables being tested 3 times to produce accurate results. The sliding speed of the counterface will be determined by using a tachometer. Once the 40 minute testing period is complete, the machine will be stopped, and the sample piece will be cleaned using acetone, evaluated for wear and weighed using a high accuracy scale (Figure 43). The tribological properties of the sample piece will be able to be compared to those that the sample piece displayed before the testing process, as well as the sample pieces that have been used in the other tests.

3.3 ANALYSING DATA TO PRODUCE RESULTS

3.3.1 FRICTIONAL CO-EFFICIENT

The frictional co-efficient for each sample piece can be observed via a load cell that is a part of the tribology machine. This load cell measures the frictional forces that each sample undergoes and takes a reading of this force at each second of the testing process, which can be further converted to a value for the coefficient of friction. These values can be observed live and recorded for further analysis by connecting the load cell to a laptop via usb-connection. The software for the Lorenz Messtechnik load cell was accessed and downloaded via their online website. The recording of these values will allow for comparison in the results chapter of this report, therefore allowing for review of the frictional forces present between the sample and counterface when the variables are altered.

Additionally, the Stribeck Curve can be used in the results of this project to detetrmine the lubrication regime that is occurring for each sample piece. As the sliding speed of the couterface will be altered, the effect of this upon the coefficient of friction will be able to be observed. As mentioned in the Literature Review, by utilising the Stribeck Curve, friction is able to be plotted as a function of viscosity, speed and load (Bruker et al., 2021). If the viscosity and normal load (dead weight in block-on-ring configuration), is kept the same, and only the sliding speed is altered, then the direct effect of the sliding speed can be examined. The Stribeck Curve can be seen below, with the co-efficient of friction on the vertical axis while the horizontal axis is a function of lubricant viscosity, sliding velocity and normal load.

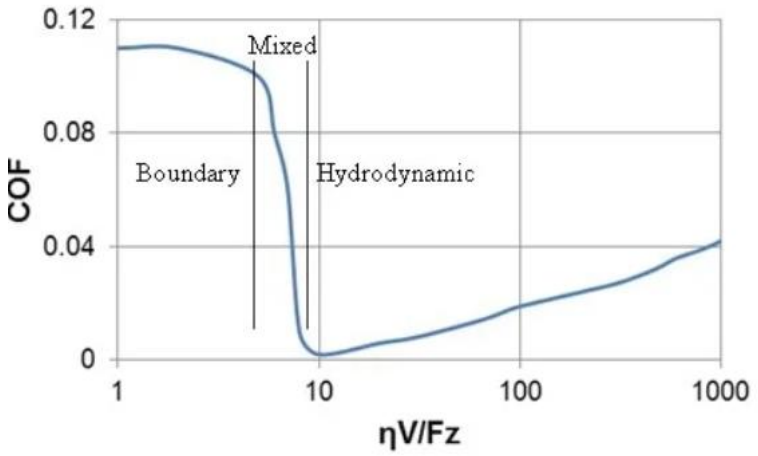


Figure 10: Stribeck Diagram

Source: Bruker Nano Surfaces and Metrology. (2021). *Characterizing Lubricants for Research and Development, Quality Control and Application Engineering*. Retrieved on May 12, 2024 from https://www.azom.com/article.aspx?ArticleID=12811

$$\frac{\eta V}{Fz}$$

Where η =lubricant viscosity, V =sliding velocity and Fz=the normal load.

3.3.2 SPECIFIC WEAR RATE OF SAMPLE

When two surfaces are in contact with each other and there is significant movement and friction between the two, there will always be wear of the materials (Ray et al., 2023). The wear of a material can be measured via a loss of volume, or a more easily measurable quantity of loss of weight. Specific wear rate of a material is the amount of volume lost compared to the normal load and the sliding distance. This measurement will be used in this project, as the specimens will contain different sliding distances due to a difference in sliding speed. Specific wear rate of a material depends on several factors, such as the sliding speed, the hardness of the material and the form of lubrication. Wear is an important property of any engine component, and by comparing the specific wear rate of each of the samples, this project will be able to make recommendations as to whether a bio-lubricant would be suitable for use in an automotive engine. A high resistance to wear is desirable in engine components, so a lower specific wear rate will be considered a superior property in the results chapter of this report.

3.3.3 SCANNING ELECTRON MICROSCOPY

Another important step in collecting raw data from the testing process will be the use of the Scanning Electron Microscope (SEM). The SEM will be able to produces images of the surface at a high magnification, allowing for the wear patterns present in the sample piece to be analysed and identified. Using this technology will allow for an in-depth and visual analysis of the frictional and wear patterns that have occurred on the sample piece during the testing process, and will also allow for a direct comparison between different samples. This technology will be extremely beneficial for recording and displaying results once the testing process has been completed.

When using the SEM, it is important to ensure that the sample pieces are completely dry and free of any residue oil, fingerprints or any other contaminants. This will allow for the clearest images to be produced and ensure that the machine is not damaged. To achieve this, all sample pieces will be handled with care using gloves, and all samples will be cleaned with acetone before being placed in a desiccator. This process will ensure that any residue oil will be removed and that the sample piece will be completely dry before being used in the SEM.

3.3 CONCLUSION

Overall, this chapter has been written with the objective of setting out the experimental setup to be used in this project. This chapter has considered all factors that will form a part of this project, and aims to produce accurate, valid results. The risks that were evaluated throughout the creation of this chapter have been formulated into a risk management plan that is included in the appendix chapter of this report.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the raw data collected from the research design and methodology, as well as the further analysis of this data. This analysis forms the main findings of this report in response to the research objectives, and this will be discussed further in this chapter.

4.2 WEAR RATE OF SAMPLE PIECES

As discussed in the methodology, the weight of the samples pieces was recorded before and after testing, using a high precision scale (Figure 43). This allowed for direct comparison of the weight loss due to wear for each sample. The Specific Wear Rate allows for the wear to be analysed while incorporating the normal load and the sliding distance. The specific wear rate (SWR) can be calculated using the following equation:

$$SWR = \frac{\Delta V}{L \times D}$$

$$further\ simplified\ to:$$

$$SWR = \frac{\Delta \mathrm{w} \times \rho}{L \times D}$$

$where\ \Delta w\ is\ the\ difference\ in\ weight, \rho\ is\ the\ density\ of\ the\ material, L\ is\ the\ load\ placed\ on\ the\ material\ and\ D\ is\ the\ sliding\ distance.$

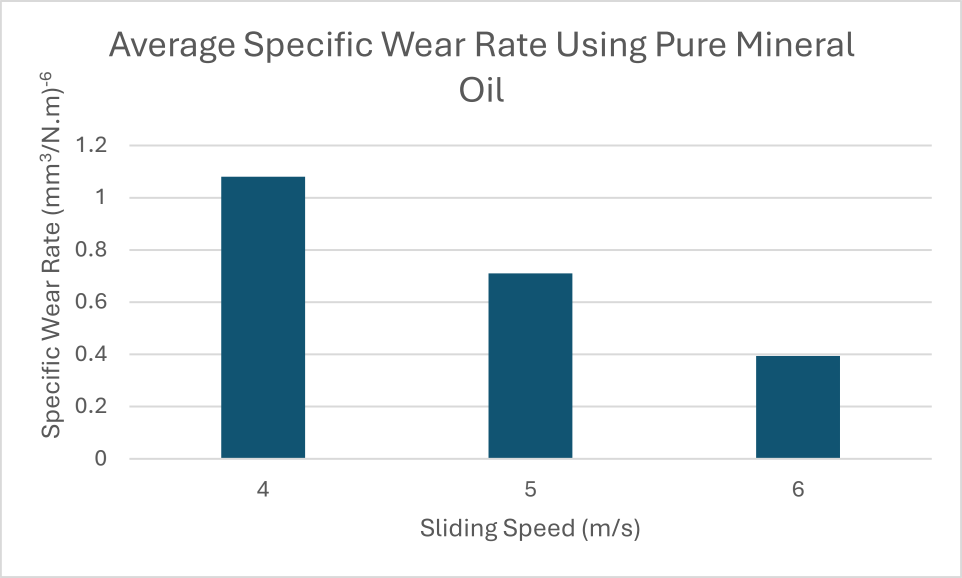


Figure 11:The mean specific wear rate of samples using pure mineral oil (0% bio-lubricant blend) at different sliding speeds

It can be seen from the figure above that in the case of the pure mineral oil, the increase of sliding speed reduces the specific wear rate. The linear decrease of specific wear rate is a consistent trend with each of the bio-lubricant blends, as seen in the following figures. This indicates that for each lubricant type, a thicker fluid film is formed between the surfaces when at higher sliding speeds. This causes the asperities of the surfaces to be further separated, and leads to lower frictional losses and better wear performance.

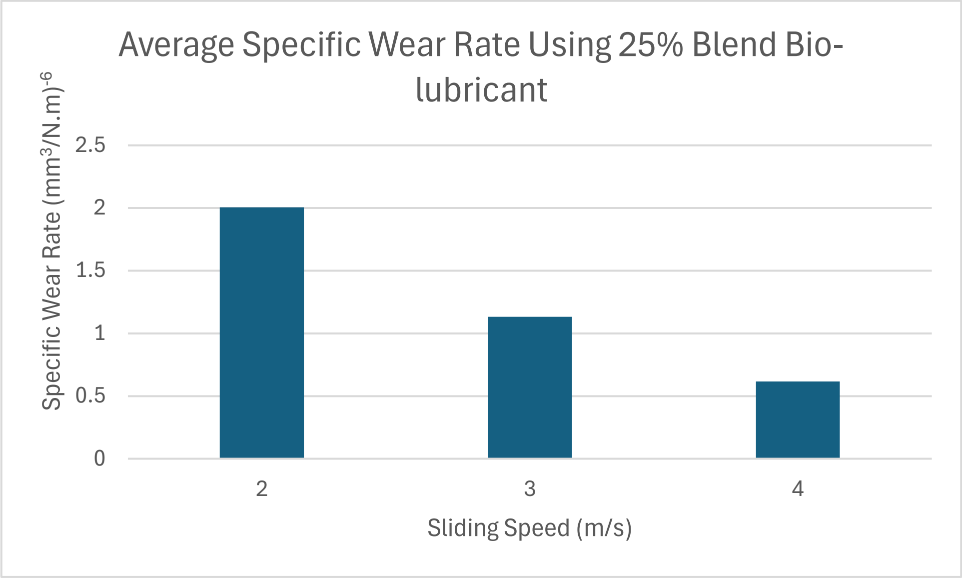


Figure 12:The mean specific wear rate of samples using 75% mineral oil and 25% Neem Seed oil (25% bio-lubricant blend) at different sliding speeds

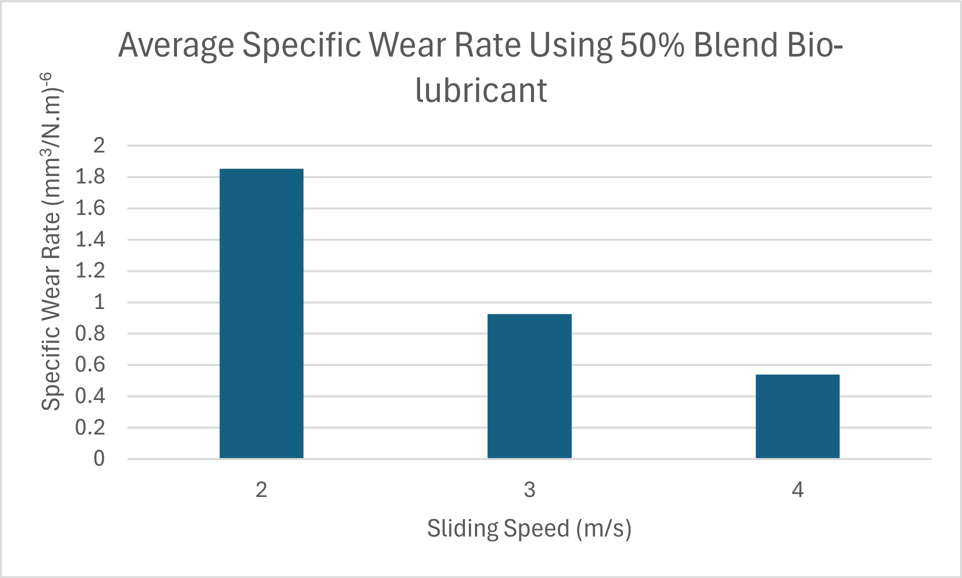


Figure 13: The mean specific wear rate of samples using 50% mineral oil and 50% Neem Seed oil (50% bio-lubricant blend) at different sliding speeds

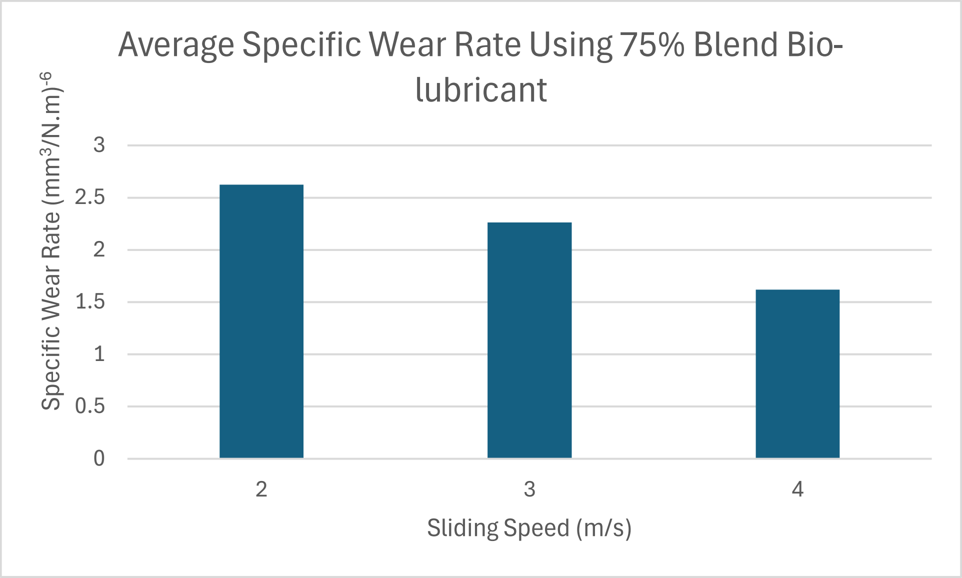


Figure 14: The mean specific wear rate of samples using 25% mineral oil and 75% Neem Seed oil (75% bio-lubricant blend) at different sliding speeds

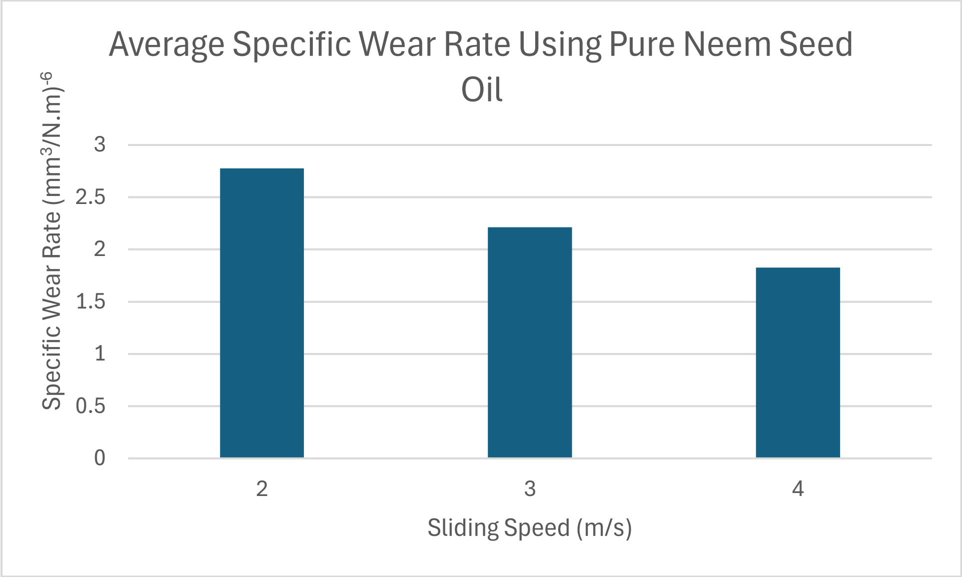


Figure 15: The mean specific wear rate of samples using 0% mineral oil and 100% Neem Seed oil (% bio-lubricant blend) at different sliding speeds

In each of the 5 previous figures, it is clear that there is a trend of specific wear rate declining with an increase of sliding speed. There are several explanations for this. A main explanation of this is the increase in sliding distance. As each of the tests were performed for the same timeframe (40 minutes), the sample pieces exposed to higher sliding speeds also experienced larger sliding distances. With a larger sliding distance, the sample pieces are likely to have experienced a larger amount of time in ‘steady state’ wear, rather than in the ‘running in’ stage of wear. This process would increase the specific wear rate for specimens with a lower sliding distance, which is reflected by the consistent results produced in this project. In a study completed by Jinag and Arnell, similar results were found from tribological testing, with reports of significant decreases in specific wear rate when sliding speeds were increased (Jiang & Arnell, 1998).

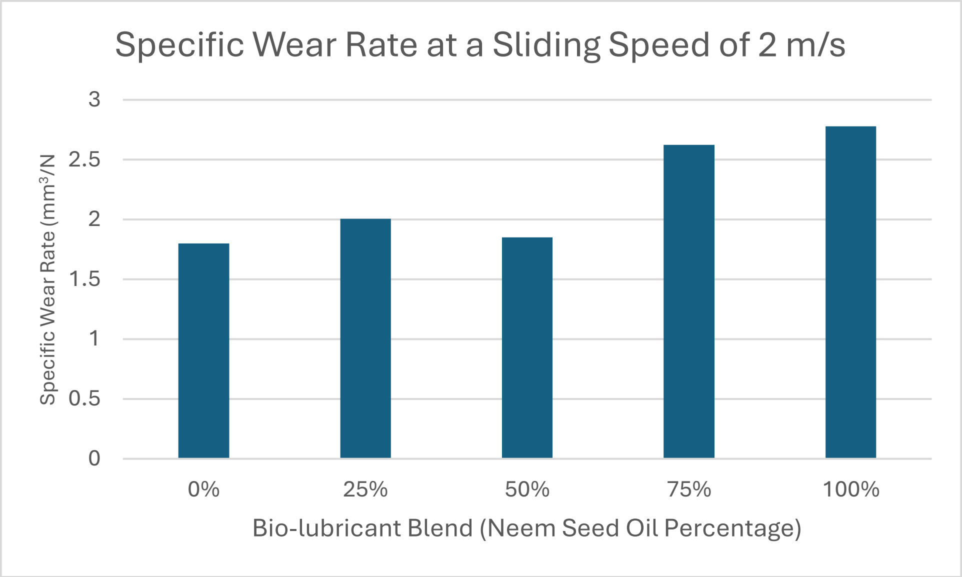


Figure 16: The mean specific wear rate of samples using different bio-lubricant blends at a sliding speed of 2 m/s

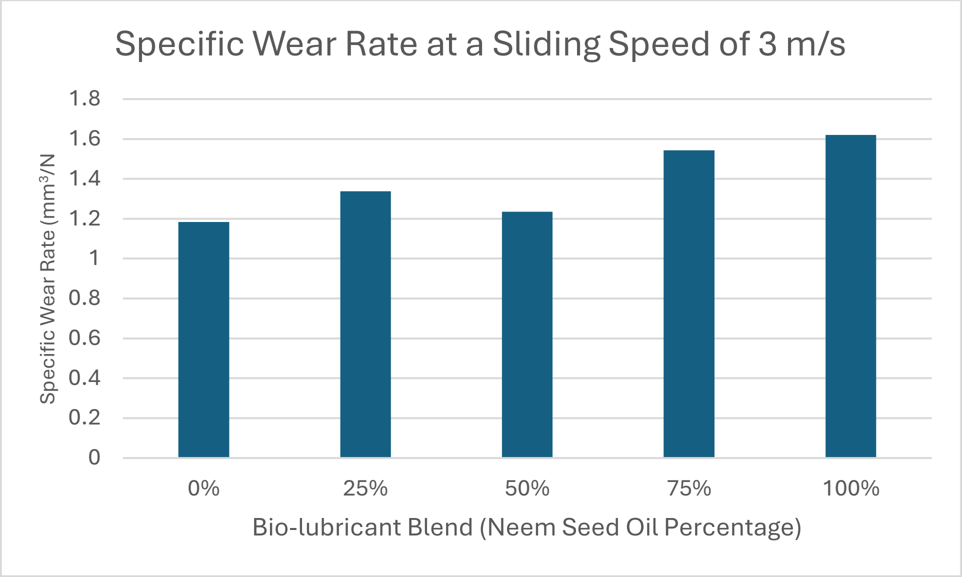


Figure 17: The mean specific wear rate of samples using different bio-lubricant blends at a sliding speed of 3 m/s

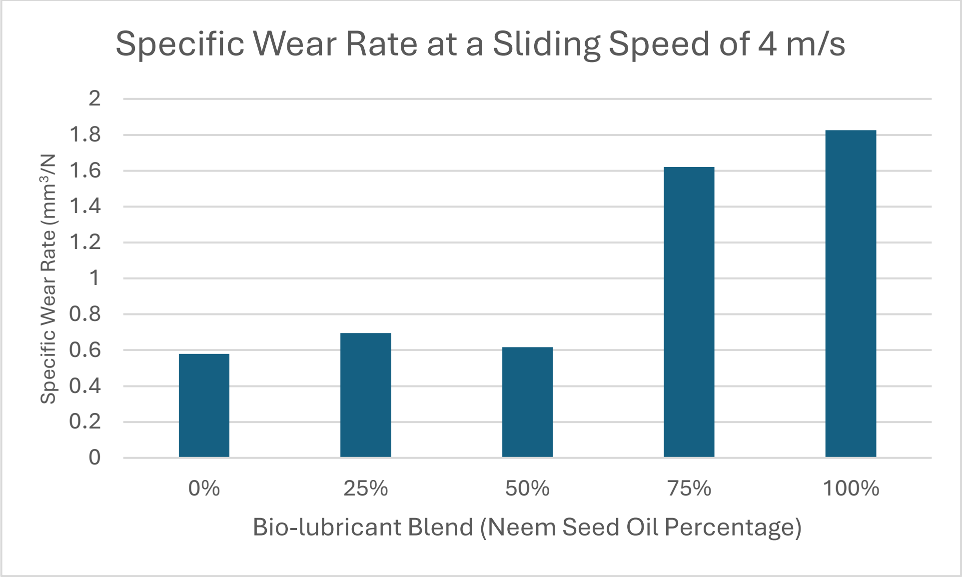


Figure 18: The mean specific wear rate of samples using different bio-lubricant blends at a sliding speed of 4 m/s

As seen in the previous three figures, there are several interesting patterns in the data collected during this project. Both the 75% and 100% bio-lubricant blends show extremely poor performance compared to the other bio-lubricant blends when it comes to wear, especially as the sliding speed is increased. This suggests that a pure or high-percentage vegetable oil, or at least Neem Seed oil, blend exhibits qualities that are not suitable to be used with an automotive engine. This verifies the examples in literature and validate the decision within the methodology of this report to create blends between the mineral oil and the Neem Seed oil to formulate a bio-lubricant. While the 25% bio-lubricant exhibits a specific wear rate that is still within the range of the pure mineral oil (0%), it is still higher than the specific wear rate of the 50% bio-lubricant blend. This provides an interesting comparison, as it was assumed that with a higher percentage of mineral oil, the 25% bio-lubricant blend would be able to replicate the performance of the pure mineral oil more closely. However, the 50% bio-lubricant blend consistently displayed the lowest specific wear rate for any lubricant that contain the Neem Seed oil. It showed extremely similar values to that of the pure mineral oil, making it the best option as a possible bio-lubricant. To determine whether it may be suitable for potential use as a bio-lubricant within an automotive engine, the coefficient of fricition that was present between the two surfaces when using the 50% bio-lubricant, will also have to be analysed to ensure that this is not a weakness of the bio-lubricant.

4.3 COEFFICIENT OF FRICTION

The coefficient of friction is an important factor in lubricants and tribology. The coefficient of friction is a unitless number, which determines the ability of two surfaces to move, relative to each other. A high coefficient of friction suggests that it will require a large force for the two surfaces to slide against each other, while a lower value suggests that the two surfaces will be able to slide more freely against each other. In terms of tribology, the relationship between both coefficient of friction and wear rates is complex. While it is difficult to make a direct correlation between the two, a large amount of research suggests that a higher coefficient of friction generally coincides with better wear performance. This is beneficial for applications such as braking systems, however, for systems such as internal combustion engines and their components, this can be counter-intuitive (Kchaou et al., 2019). For such models, a low coefficient of friction combined with a high wear performance can allow engine components to maximise efficiency while requiring minimal maintenance.

As discussed in the previous chapter, the tribology machine that was used for testing was fitted with a load cell (Figure 44). This load cell is able to measure and record the frictional force that is present within the test rig. This force changes when both speed and oil type are altered, providing data on the frictional coefficient that is present. The co-efficient of friction can be calculated using the following equation:

$$\mu = \frac{F_f}{F_L}$$

$where\ \mu$

$= \ coefficient\ of\ friction, F_f\ is\ the\ frictional\ force\ (measured\ by\ the\ load\ cell), and$

$F_L\ is\ the\ force\ applied\ by\ the\ load.$

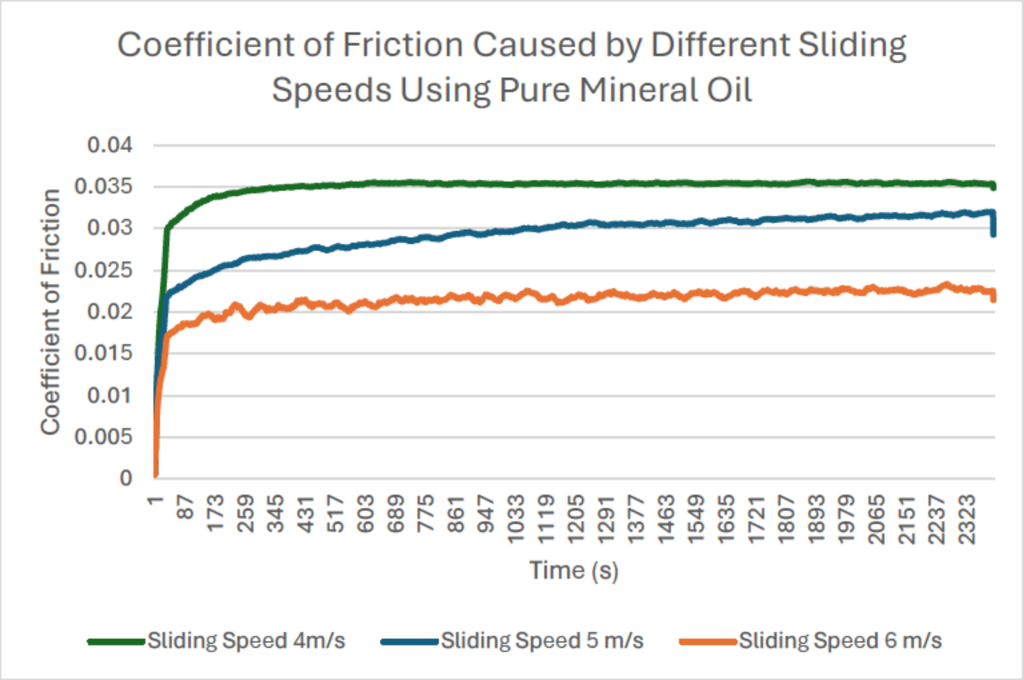


Figure 19:The mean COF reading at each sliding speed for pure mineral oil (0% bio-lubricant, 100% SAE-30 blend)

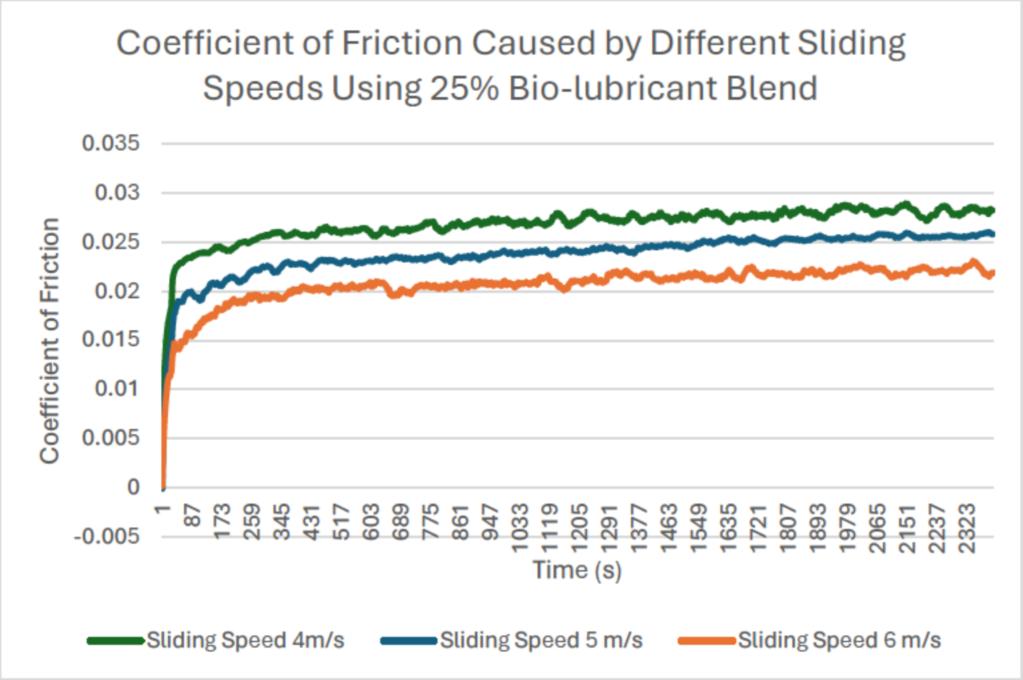


Figure 20:The mean COF reading at each sliding speed for 25% bio-lubricant blend (25% Neem Seed Oil, 75% SAE-30 blend)

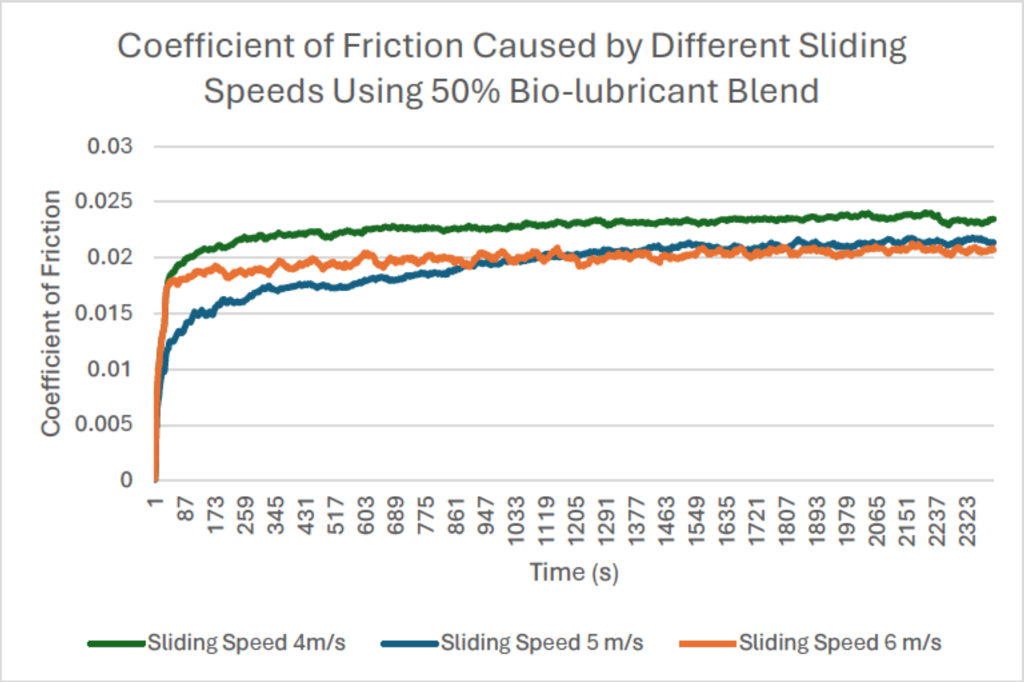


Figure 21:The mean COF reading at each sliding speed for 50% bio-lubricant blend (50% Neem Seed Oil, 50% SAE-30 Oil blend)

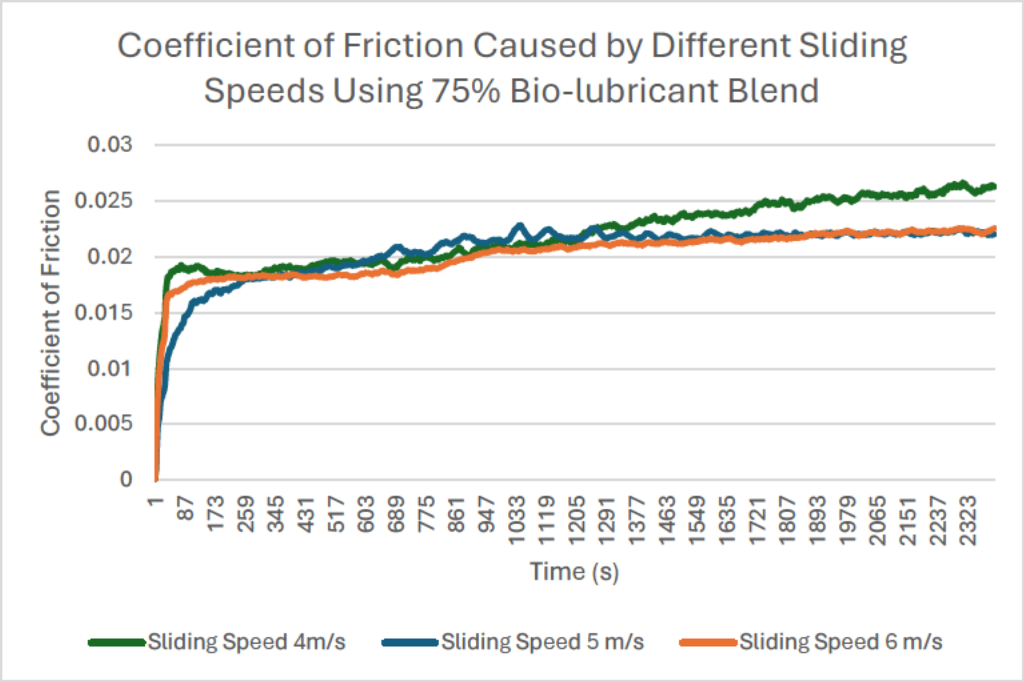


Figure 22:The mean COF reading at each sliding speed for 75% bio-lubricant blend (75% Neem Seed Oil, 25% SAE-30 Oil blend)

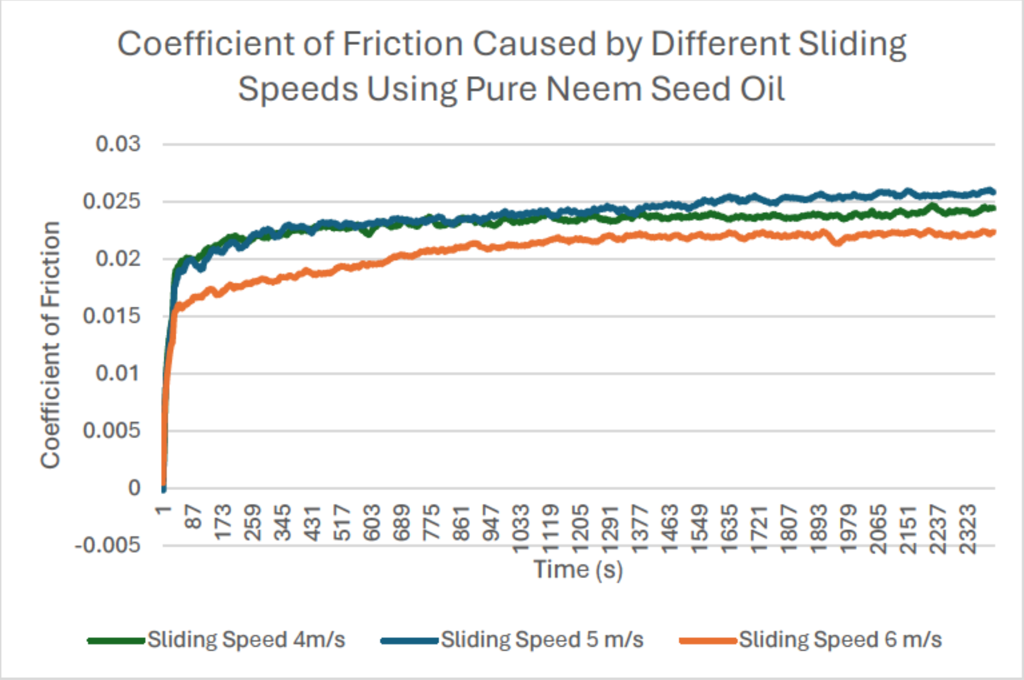


Figure 23: The mean COF reading at each sliding speed for pure Neem seed oil (100% bio-lubricant, 0% SAE-30 blend)

As can be seen from the results, there is a clear relationship between the sliding speed and the coefficient of friction. For each bio-lubricant blend, the increase of sliding speed decreases the coefficient of friction between the two surfaces. This phenomenon can be explained by Stribeck's diagram. It appears that at these rates of sliding speed, this oil blend is in a 'mixed' lubrication state, rather than boundary or hydrodynamic. During this lubrication regime, the coefficient of friction is reduced from the boundary regime as the load becomes supported by an oil film between the two surfaces, as well as the contact between the asperities of the surfaces. A drop in the coefficient of friction is often seen during this period, as seen in Figure 4 and Figure 10. Additionally, in the case of a 'mixed' lubrication regime, viscosity of the lubricant is an important factor in fluid film thickness, explaining the difference in values for each lubricant blend. The coefficient of friction can be seen to have a clear relationship with the sliding speed of the counterface, with Xia et al. reporting similar results. In their study, it was stated that when submitting 6060 grade aluminium to tribological wear conditions, a rise in the coefficient of friction was observed when sliding speeds were increased (Xia et al., 2018). These results are also similar to the specific wear rate decreasing at higher sliding speeds.

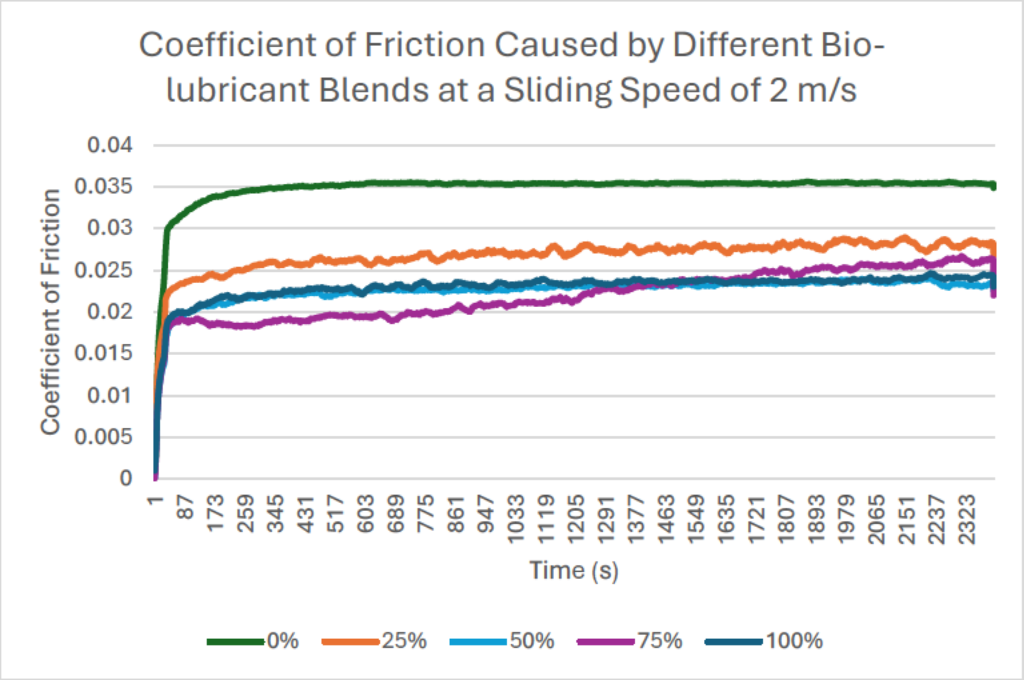


Figure 24:The mean COF reading for each bio-lubricant blend at a sliding speed of 2 m/s

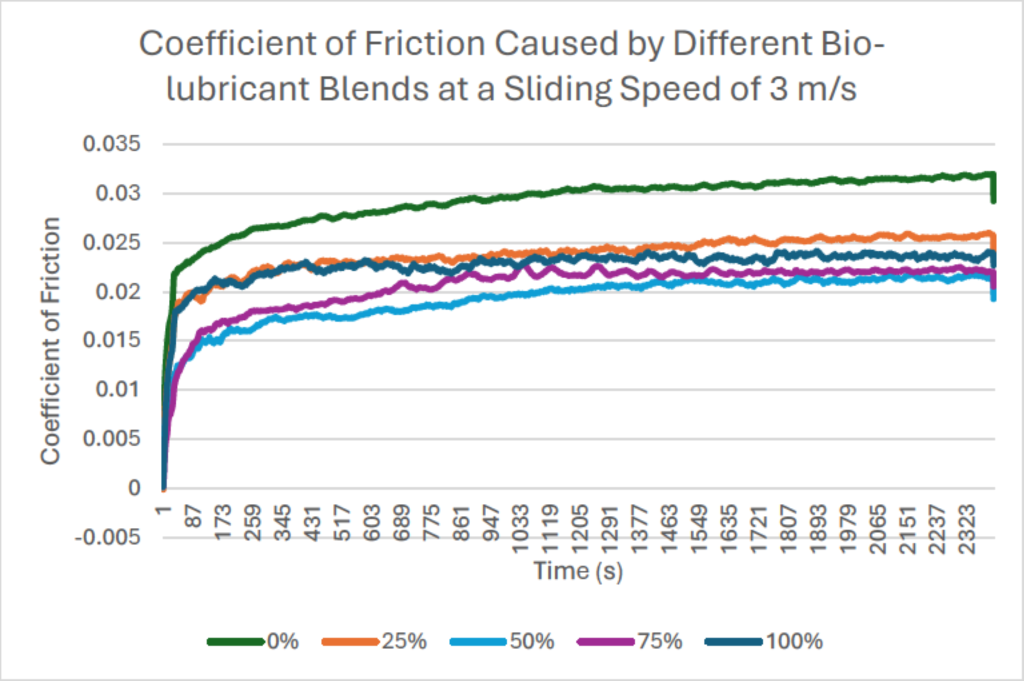


Figure 25:The mean COF reading for each bio-lubricant blend at a sliding speed of 3 m/s

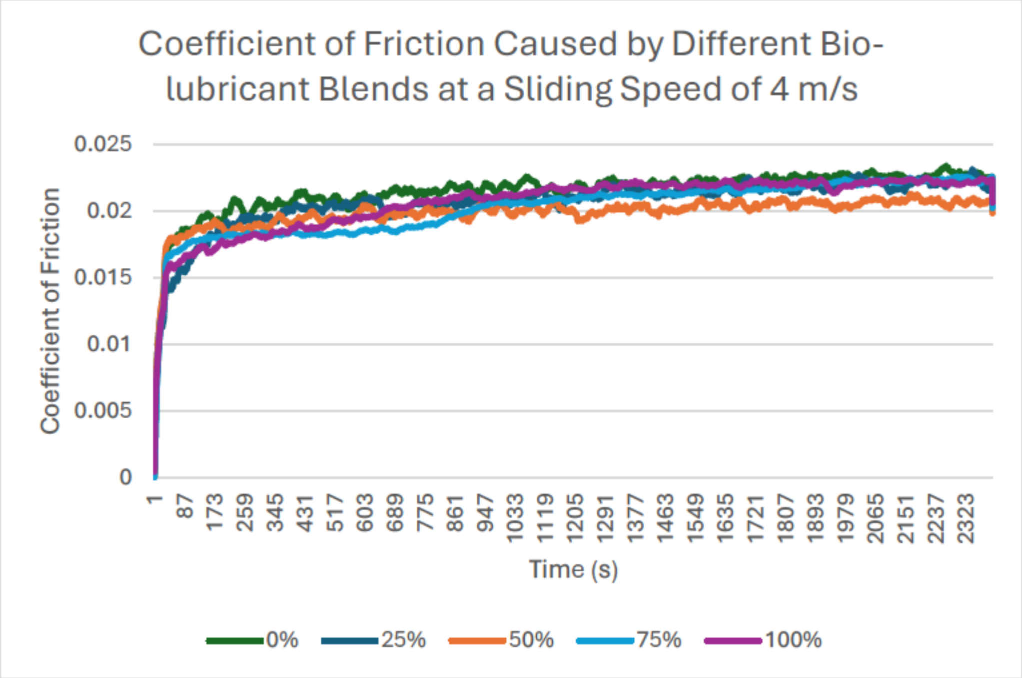


Figure 26:The mean COF reading for each bio-lubricant blend at a sliding speed of 2 m/s

As can be seen from each of the three previous figures, the 0% bio-lubricant blend, or the pure mineral oil has the highest coefficient of friction at each sliding speed. While this means that this bio-lubricant blend has the least frictional losses, this can be attributed to the lower viscosity of the bio-lubricant blends that contain Neem Seed Oil. As the Neem Seed Oil has a viscosity that is much lower than the SAE-30 oil, it is assumed that the viscosity of each bio-lubricant blend increases with the percentage of Neem Seed Oil. So, it is assumed that the 0% bio-lubricant blend has the highest viscosity followed by the 25% bio-lubricant blend, then the 50%, the 75% and finally, the 100% bio-lubricant blend. It is therefore determined that the high viscosity of the 0% bio-lubricant blend is the reason for it having the highest coefficient of friction. This is further reinforced by the literature with Bovington et al. also finding that a reduction in lubricant viscosity is one way to reduce friction between two surfaces. However, it is also noted in this study that a reduction in lubricant velocity also often leads to a reduced material durability as a consequence of lower oil film thicknesses. A lower oil film thickness between the two materials means that the surface asperities are often in tight contact, leading to further wear of the material surfaces (Bovington et al., 1999).

4.4 SCANNING ELECTRON MICROSCOPE IMAGES

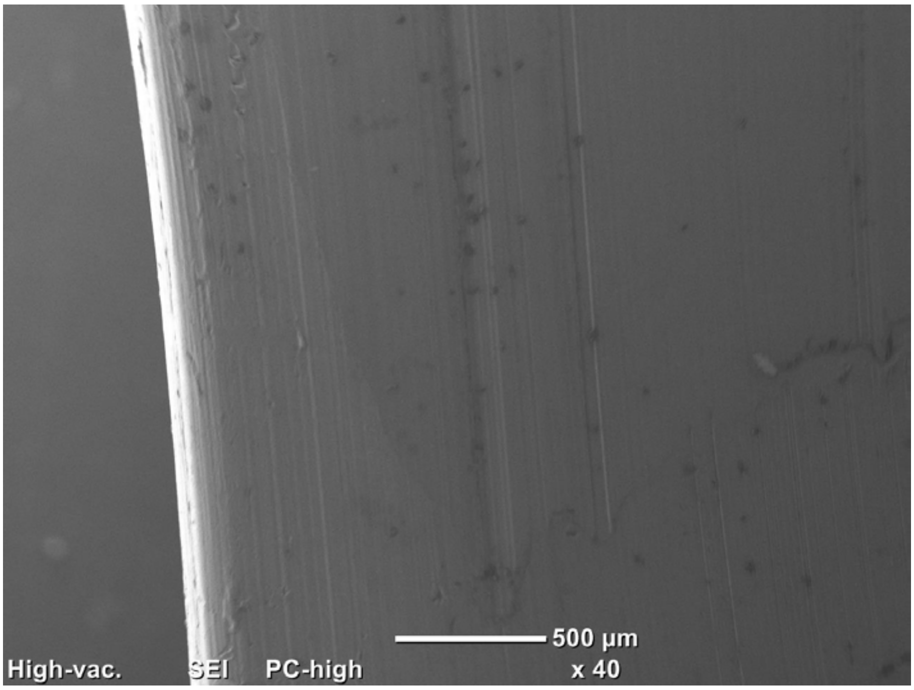


Figure 27:A 40x micrograph of a sample piece used under 100% bio-lubricant blend, 2 m/s sliding speed conditions

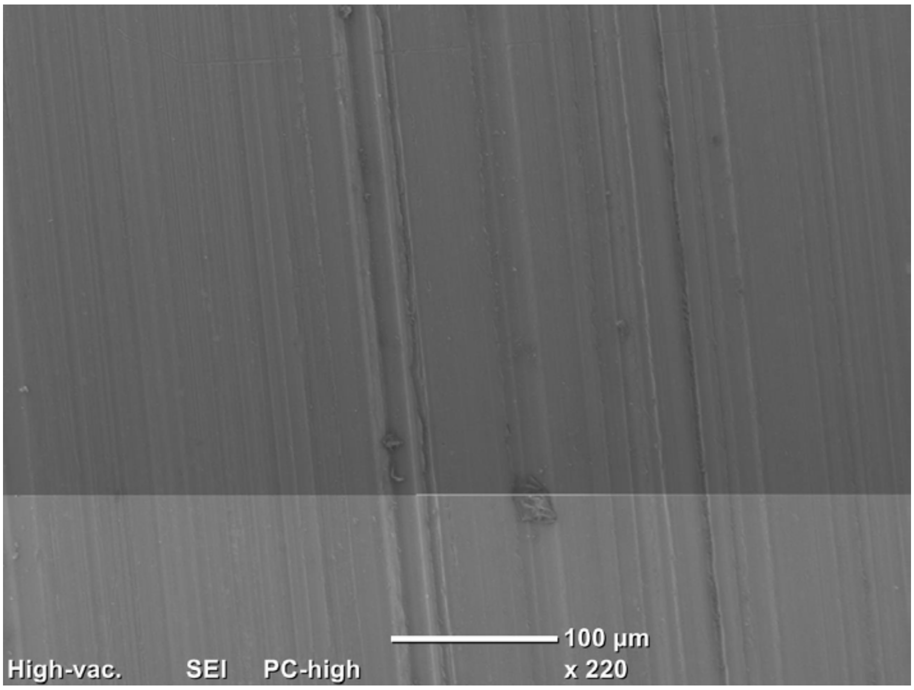


Figure 28: A 220x micrograph of a sample piece used under 100% bio-lubricant blend, 2 m/s sliding speed conditions

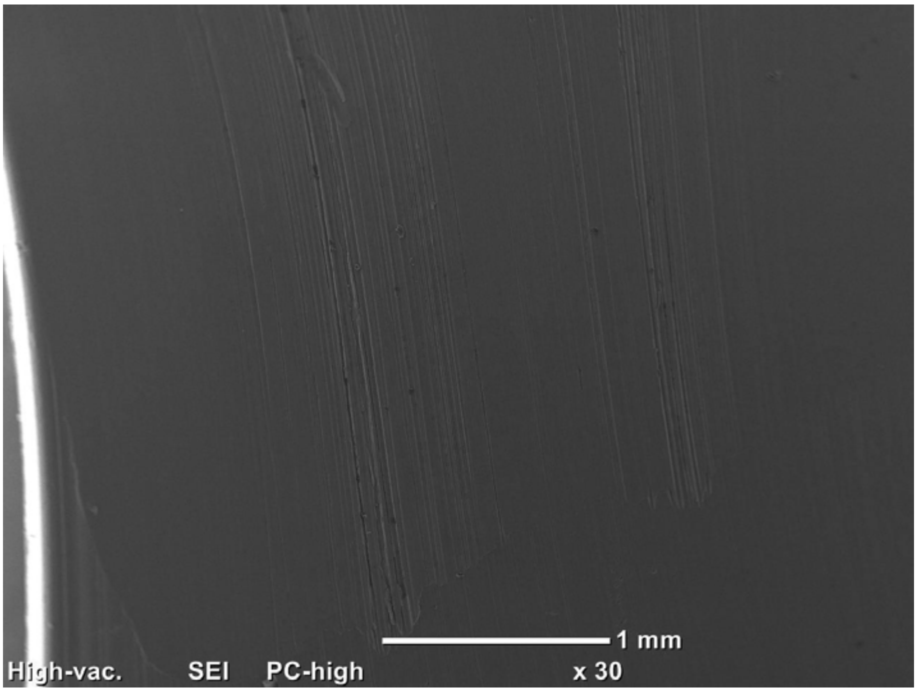


Figure 29: A 30x micrograph of a sample piece used under 100% bio-lubricant blend, 3 m/s sliding speed conditions

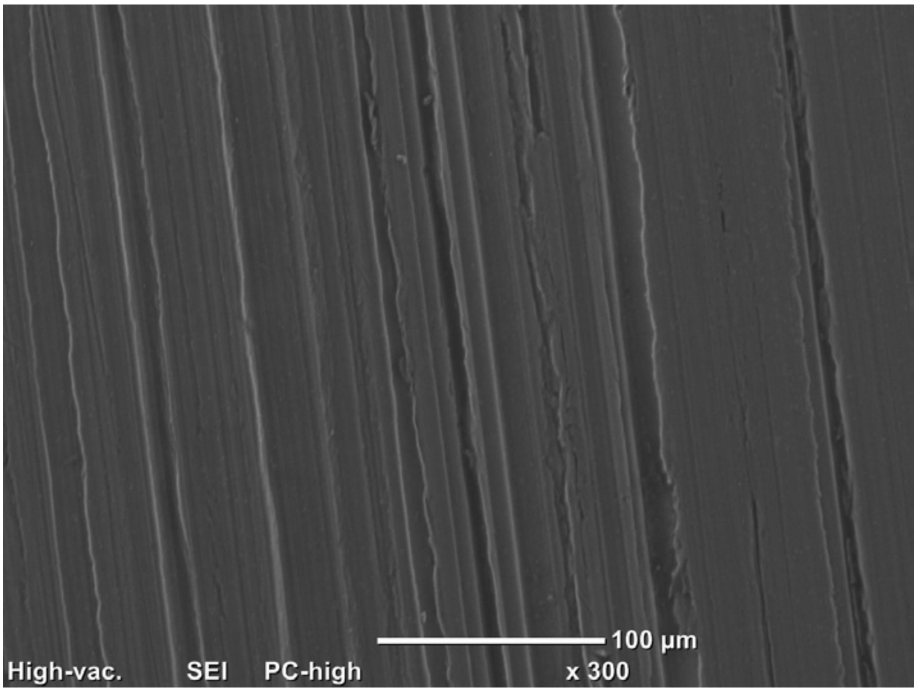


Figure 30: A 300x micrograph of a sample piece used under 100% bio-lubricant blend, 3 m/s sliding speed conditions

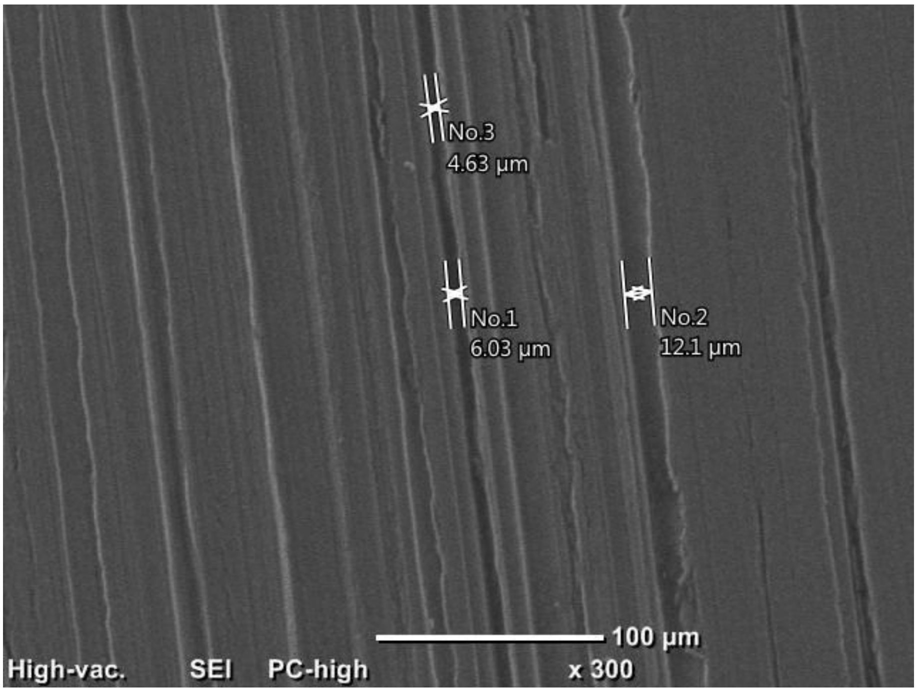


Figure 31: Diameter of abrasive grooves on the sample piece, caused by poor fluid film formulation

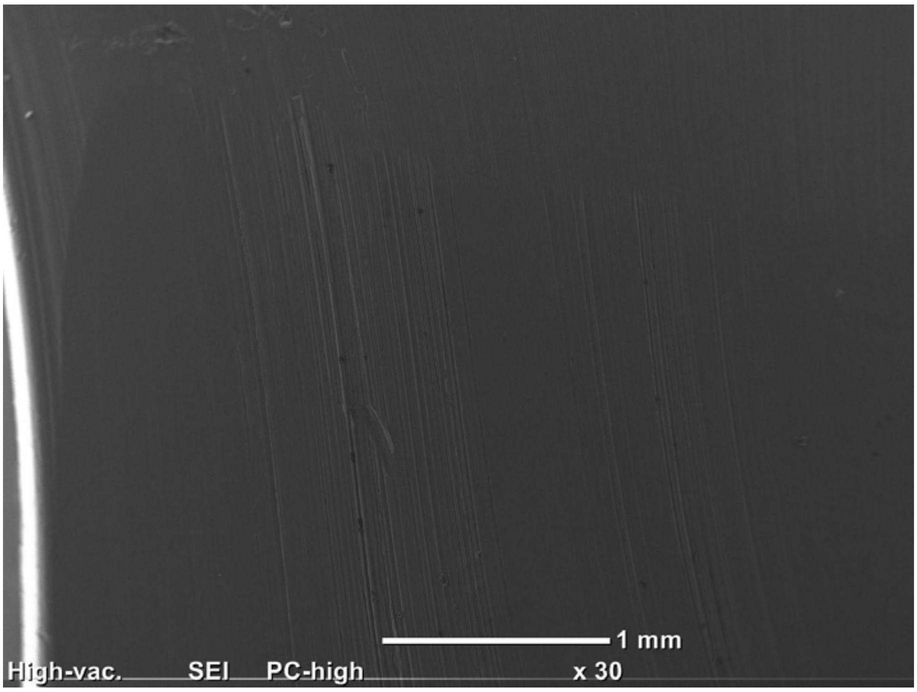


Figure 32:A 30x micrograph of a sample piece used under 100% bio-lubricant blend, 4 m/s sliding speed conditions

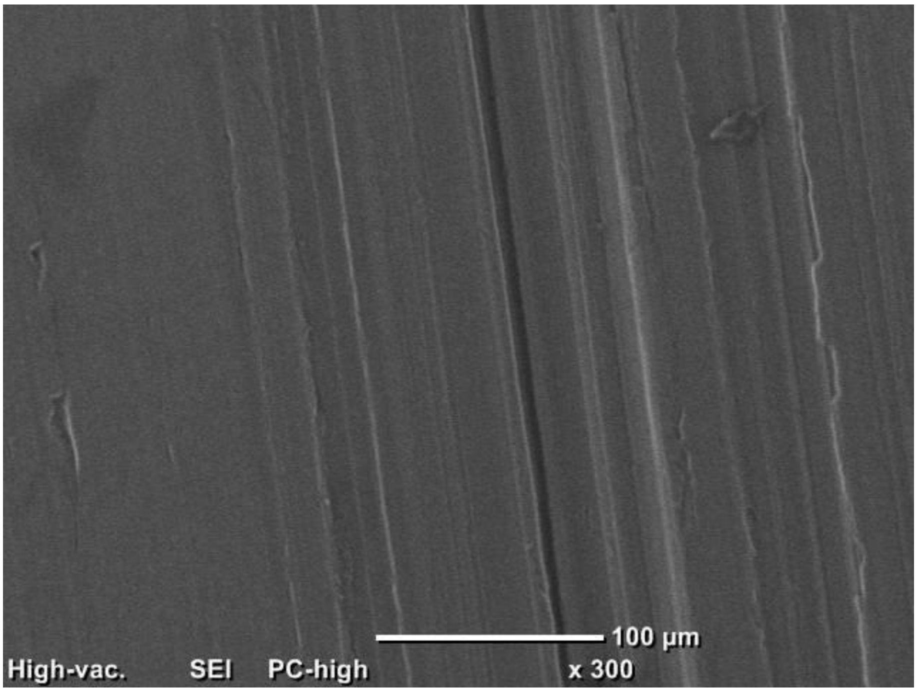


Figure 33: A 300x micrograph of a sample piece used under 100% bio-lubricant blend, 4 m/s sliding speed conditions

In each of the SEM images that have been captured, there is a lack of adhesion wear present, which is referenced in Figure 2. It is assumed that this is due to the aggressive load that is in this testing configuration with a normal load of 50N between the sample piece and the counterface. This load is rather high for tribological testing and leads to a majority of abrasion wear rather than adhesion wear. This abrasion wear can be seen to be extremely prevalent in each of the sample pieces that has been analysed by the SEM images, with large grooves being visible. Another reason for the large amount of abrasion wear present in this form of tribological testing is suggested to be the material selection. In tribological testing, abrasion wear is generally present between two materials that are uneven in their hardness, with one material being much softer than the other and therefore exhibiting large amounts of abrasion wear. Adhesive wear is more commonly seen between two hard materials that are in contact and moving against one another (Nirmal et al., 2018). In the SEM images, there is also a large amount of debris visible, another clear indication of abrasion wear. The presence of debris, assumed to be from the aluminium surface, leads to further scratching and grooves in the surface of the sample. This allows for further classification of this wear type to be three-body abrasion (Gates, 1997). Each of the figures in this sub-chapter display evidence of debris being embedded into the surface of the sample, and grooves made by debris can also be viewed. For the slowest sliding speed, a larger amount of embedded debris is visible, most likely due to the larger wear rate that is present at lower sliding speeds. It is important that these wear types are analysed, to ensure that there is a sufficient understanding of the wear that may be caused in engine components when using bio-lubricants.

4.5 OVERALL PERFORMANCE OF BIO-LUBRICANT BLENDS

This chapter aims to evaluate the overall performance of each of the bio-lubricants that were tested during this project. To do this, both the coefficient of friction and specific wear rate of each bio-lubricant blend will be reviewed and compared. This will allow for a better comparison between each of the bio-lubricant blends. This chapter will then select the best performing bio-lubricant blend when compared to the pure mineral oil. This bio-lubricant blend will be identified as a potential substitute for SAE-30 in automotive engines and will be recommended for further research.

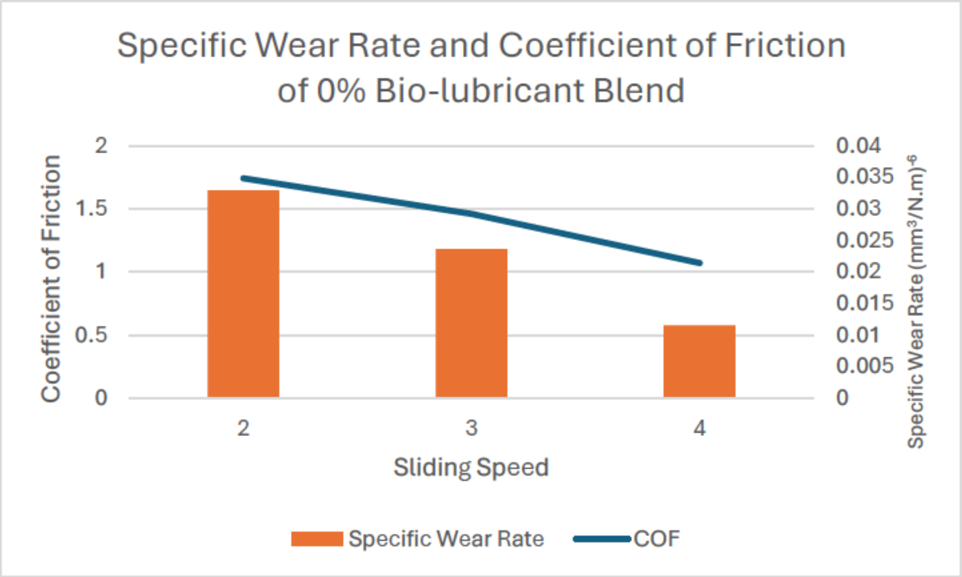


Figure 34:The specific wear rate and coefficient of friction for 0% bio-lubricant blend at different sliding speeds

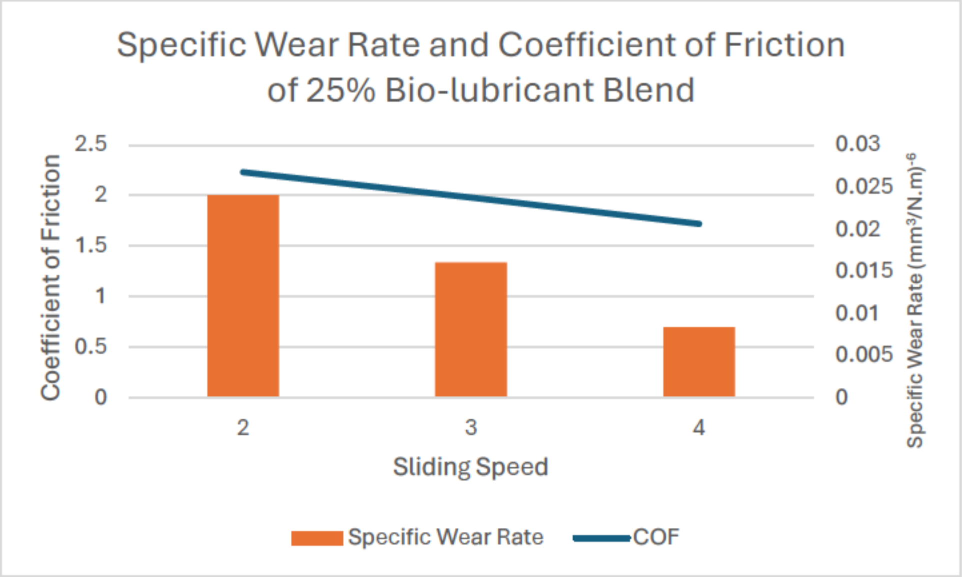


Figure 35: The specific wear rate and coefficient of friction for 25% bio-lubricant blend at different sliding speeds

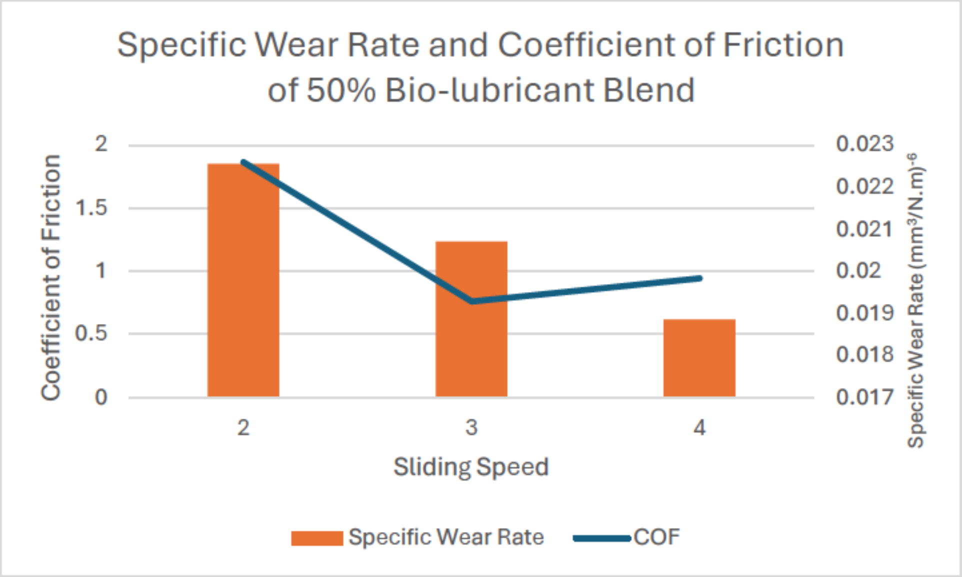


Figure 36: The specific wear rate and coefficient of friction for 50% bio-lubricant blend at different sliding speeds

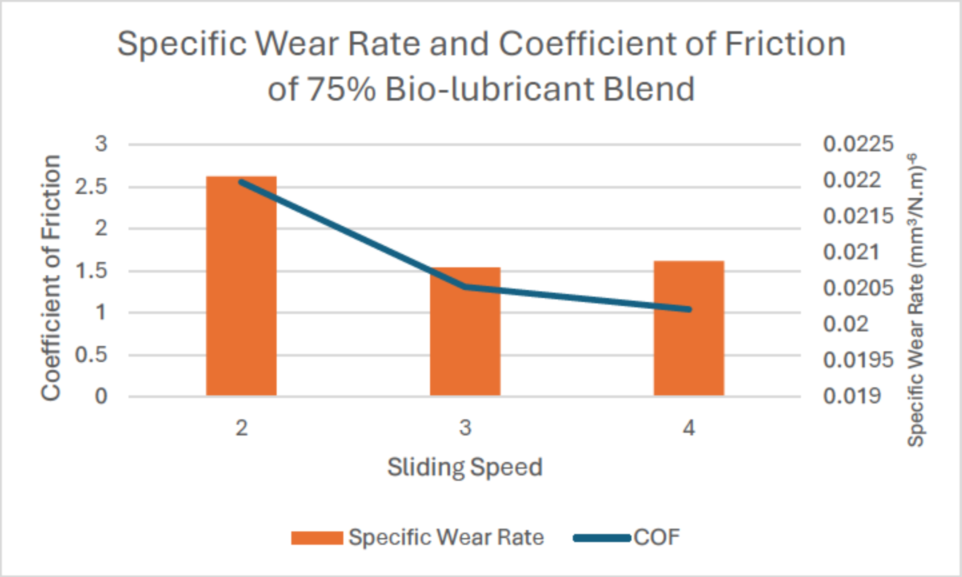


Figure 37: The specific wear rate and coefficient of friction for 75% bio-lubricant blend at different sliding speeds

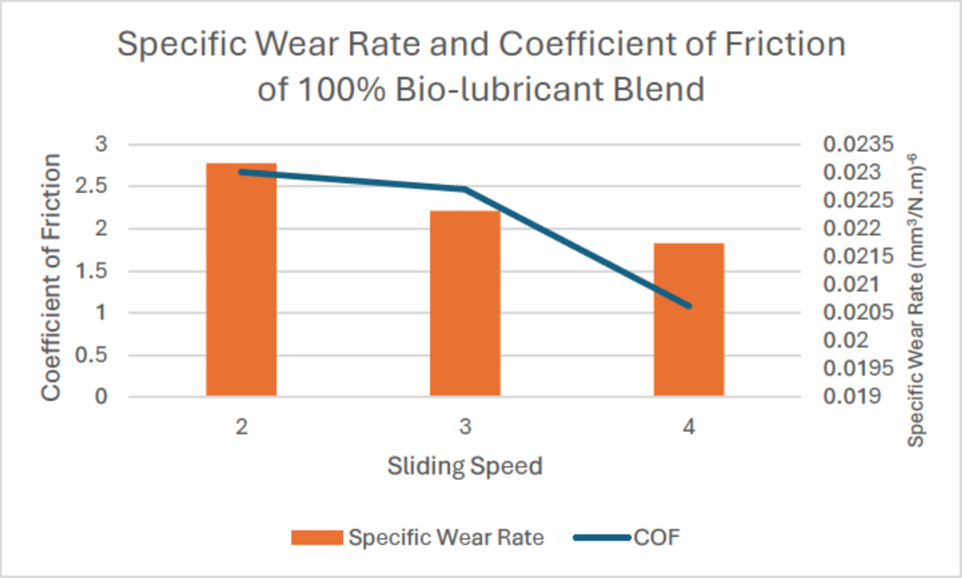


Figure 38:The specific wear rate and coefficient of friction for 100% bio-lubricant blend at different sliding speeds

From each of the five previous figures, there are some clear trends that have been identified. With an increase in sliding speed, a linear decrease in specific wear rate can be observed. The only outlier of this is for the 75% bio-lubricant blend, with a sliding speed of 6 m/s exhibiting a higher specific wear rate than the 5 m/s sliding speed. Additionally, the increase of sliding speed brings about a decrease in the coefficient of friction between the two surfaces. This decrease is mostly linear, or at least extremely close to linear, with the only exception being the 50% bio-lubricant blend, having a lower coefficient of friction at a sliding speed of 3 m/s than it did at 4 m/s. While the previous five figures are extremely useful when comparing the effect of the sliding speed on both the coefficient of friction and on the specific wear rate, the following figures will allow for a direct comparison between the five bio-lubricant blends that were used.

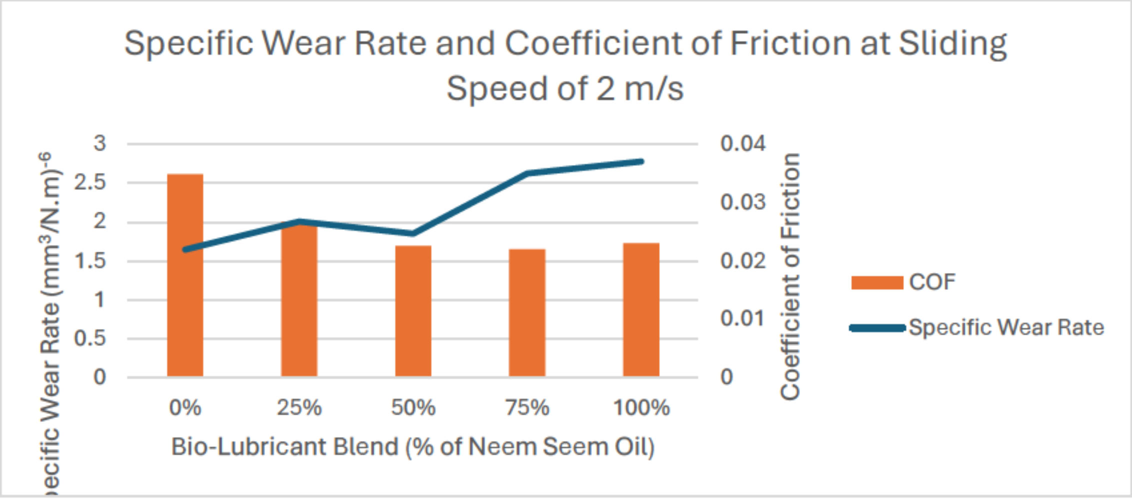


Figure 39: The specific wear rate and coefficient of friction for different bio-lubricant blends at a sliding speed of 2 m/s

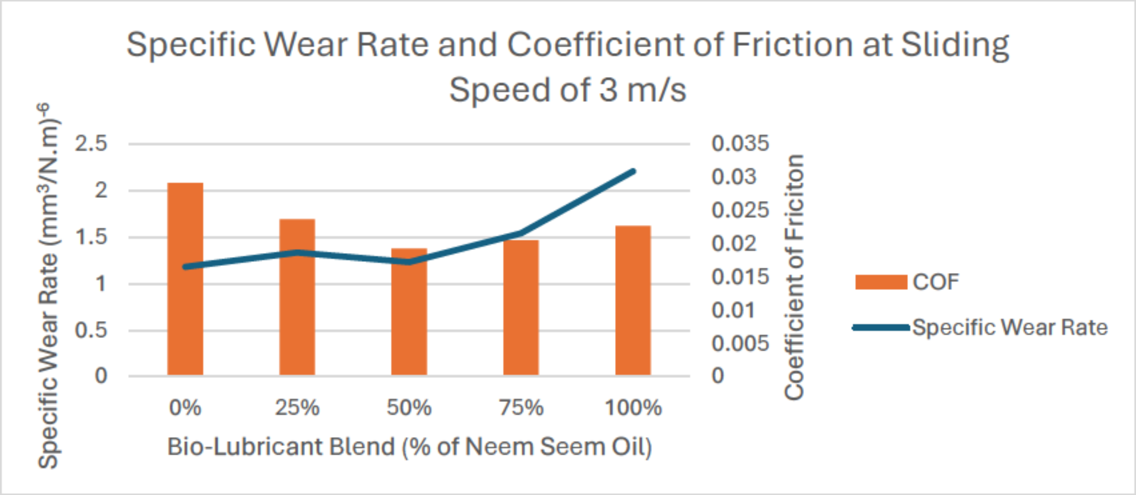


Figure 40: The specific wear rate and coefficient of friction for different bio-lubricant blends at a sliding speed of 3 m/s

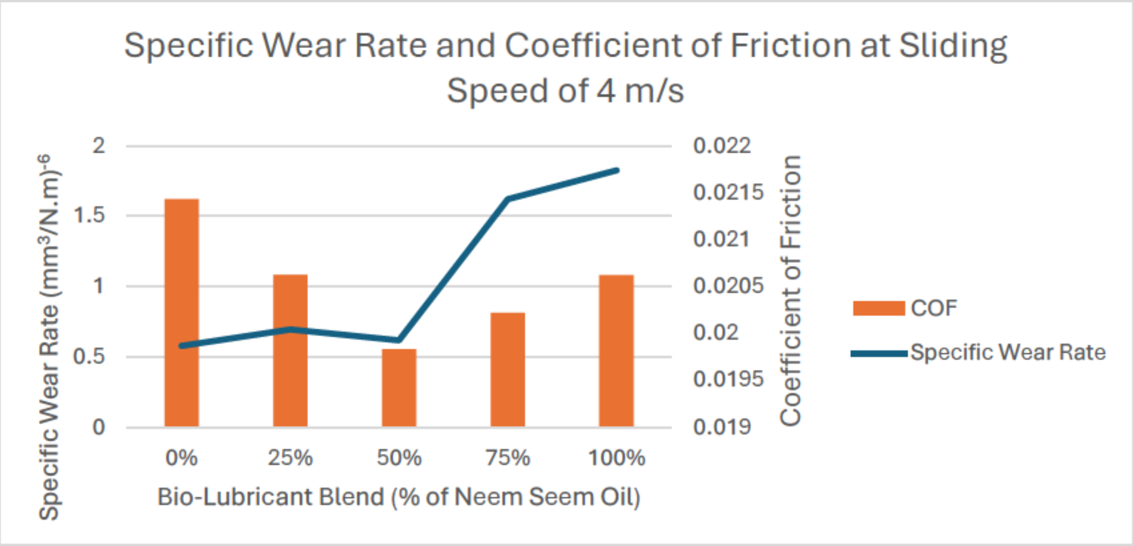


Figure 41:The specific wear rate and coefficient of friction for different bio-lubricant blends at a sliding speed of 4 m/s

The three previous figures show a clear trend in the difference between the bio-lubricant blends. The 0% bio-lubricant blend consistently exhibits the lowest specific wear rate, but also the highest coefficient of friction, showing that these sample pieces were the most resistant to wear. Both the 75% and 100% bio-lubricant blends displayed extremely high specific wear rates, and coincidentally, the lowest coefficients of friction. These bio-lubricants were expected to perform at a lower level due to their low viscosity and low percentage of SAE-30 oil. The 25% bio-lubricant blend shows a slightly improved coefficient of friction compared to the pure SAE-30 bio-lubricant blend (0%), however, this was also accompanied by a considerably higher specific wear rate. For the bio-lubricant blends that contain Neem Seed Oil, the 50% bio-lubricant blend appears to be the most promising. This bio-lubricant was able to defy the trend that was present in each of the other bio-lubricant blends, by displaying a similar specific wear rate to the 0% bio-lubricant blend. In addition to this, it also displayed a coefficient of friction that was much lower than the 0% bio-lubricant blend, suggesting that this bio-lubricant blend may be able to maintain acceptable wear rates while reducing losses due to frictional forces. For further comparison of the two bio-lubricant blends, the direct results are further compared below in Figure 42. While these results are promising, it is key that there is further research in this area to determine where this bio-lubricant could improve and whether it would be suitable for use in industry. Further improvements to the bio-lubricant could be made in slight alterations to the ratio of SAE-30 oil and Neem Seed Oil, as well as additives, to ensure that performance of the lubricant is optimised.

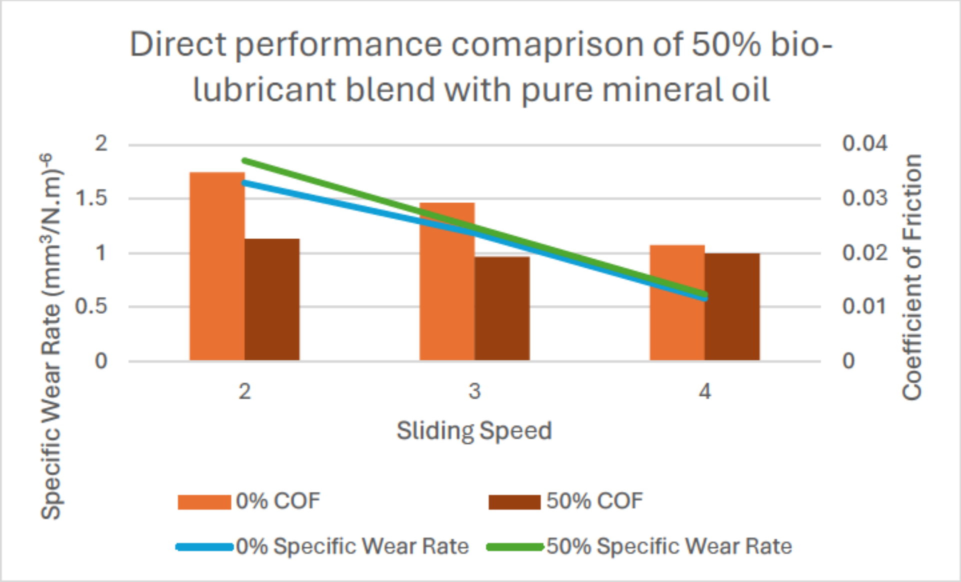


Figure 42: Comparison of 50% bio-lubricant blend with 0% blend

Figure 43 shows the key differences between the 0% and 50% bio-lubricant blend. While the pure SAE-30 oil (0% blend) displays a superior wear performance due to its lower specific wear rate, the 50% bio-lubricant blend is able to maintain a consistently lower coefficient of friction between the two surfaces. The difference between each of the values is broken down further in Table 4.

Table 4: Key Differences in Performance of pure mineral oil and 50% bio-lubricant blend

		Lubricant Type			
Performance	Sliding Speed (m/s)	Pure Mineral Oil	50% bio-lubricant blend)	Percentage Difference	Overall % Difference
COF	2	0.034859	0.022592	-54.2956	-38.0047
	3	0.029239	0.01928	-51.6491	
	4	0.021432	0.019832	-8.06937	
SWR	2	1.646090535	1.851852	11.11111	7.175926
	3	1.183127572	1.234568	4.166667	
	4	0.578703704	0.617284	6.25	

From Table 4, it can be seen that the 50% bio-lubricant blend has an average coefficient of friction that is ~38% lower than the coefficient of friction for the mineral oil. Compared to the mineral oil, the 50% bio-lubricant has a 7% average increase in specific wear rate. While this is a slight disadvantage as it is evidence of a poorer wear performance, it is a very slight drawback and is still extremely impressive.

This is a significant finding, as it provides evidence that a bio-lubricant derived from Neem Seed oil has the potential to perform similarly to a traditional mineral oil that is commonly used in the automotive industry. With further research and testing of this bio-lubricant, it is possible that a valid and effective bio-lubricant could be formulated to be used in automotive engines. While this bio-lubricant does display a higher wear rate, it is within range of the mineral oil and has the potential improve in this area if additives are used. Additionally, the advantage of maintaining a lower coefficient of friction means that this bio-lubricant could possibly reduce mechanical losses commonly seen in engine components.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will discuss how the results relate to the original project objectives. It also reviews the accuracy and validity of results, and lists ways that this project could have been improved, or how it could be improved in the future.

5.2 OVERALL CONCLUSION OF THE PROJECT

Overall, this project met the objectives that were set out in the early stages of this report. This project set out to meet the following specific objectives:

- Conduct wear and fatigue analysis of sample pieces and relating this to engine components.
- Obtain a co-efficient of friction for each lubricant that is used and compare.
- Perform wear testing of sample pieces used during testing to determine the effectiveness of the lubricant
- Compare the results with real-world data and data collected from similar projects.

This project was in fact able to produce clear results on the analysis of wear and fatigue of sample pieces. This was a significant achievement, as the 6060 grade aluminium that was used represents engine components of the same material. By completing the tribological testing in this project, the results that were produced form an understanding of the effectiveness of the formulated bio-lubricants. With the 50% bio-lubricant blend exhibiting similar results to that of the pure mineral oil, it is proposed that this bio-lubricant is tested further, to determine whether this bio-lubricant could be realistically used in industry.

Throughout testing, accurate and replicable results were produced for both the coefficient of friction and specific wear rate for each lubricant that was submitted to tribological testing. As can be seen in the previous chapter these results were compared between the two changes in variables: the sliding speed and the bio-lubricant blend. The results gained were able to be compared to a control variable of the pure mineral oil, which allowed for a direct comparison with a lubricant that is already established within the automotive industry.

The use of the SEM in this project allowed for an analysis of the wear type present in the sample pieces after tribological testing. The use of this technology was important in the scheme of the project, as different wear types will influence other results such as the coefficient of friction and wear rates. While this project only encompassed one type of wear, analysing other wear types would allow for a direct comparison of the influence of wear type.

It was important that this project was completed, as it provided further results in the field of bio-lubricants. While the field of Neem Seed bio-lubricants is popular, it is only with continuous research in this area that technological solutions will be found. By adding to the research of Neem Oil bio-lubricants, a better understanding of tribological processes, benefits and weaknesses of Neem Oil is now developed. The results from this project were able to be compared to results from other studies that already exist in this area. This allows for the results of this project to be related to real-world application, and determines a level of accuracy for the project.

5.3 RECOMMENDATIONS FOR FURTHER WORK

While this project produces intriguing results, it is recommended that further work is to be undertaken in this area. There are a number of recommendations that will be made as to how this project could be further improved upon, or how this project may be related to further work.

While outside of the scope for this project, further work in this area could involve characterising the selected bio-lubricant blends. Doing this would allow for identification of key properties of the oil and would allow for further comparison to current traditional lubricants. Especially for the best performing bio-lubricant blend, characterising the bio-lubricant would allow for a more direct comparison with the SAE-30 oil, to see where the bio-lubricant could be improved, or to observe conditions where the bio-lubricant may not be suitable for industry use. The viscosity of the oil is an extremely important property that must be identified. The viscosity of the bio-lubricant would need to be identified at two different temperatures: ambient or standing temperature, and operating temperature. These are typically at around 25°C and 80-100°C. As previously known, the viscosity of the bio-lubricant will change as the temperature of the oil is altered. However, it has been previously listed that the Neem Seed Oil has a higher viscosity index than the SAE-30 oil, meaning that it has a better viscosity stability when undergoing changes in temperature. To ensure that the true frictional performance of the lubricant can be recorded, it is important that the viscosity is known at both a standing temperature and an operating temperature. This may be a weakness of the bio-lubricant, as it already displays a lower viscosity than the SAE-30 oil. When the operating conditions increase the temperature of the bio-lubricant, it is likely that the further decrease in viscosity may cause further problems, especially in fluid film formation and therefore wear resistance. It would also be desirable for the bio-lubricant to be tested at ‘operating temperature’ (roughly 80-100ºC) in a tribological setting to determine how this change in lubricant viscosity affects it’s performance regarding wear and friction. Other important properties of lubricants are the flash point, pour point and thermal stability. To ensure smooth functioning throughout the testing process, it is required that all of these properties for all lubricant mixtures are known. These properties will also allow for an early comparison of the bio-lubricant with a traditional pure synthetic oil. Flash point and pour point are important factors to consider when selecting a bio-lubricant as they determine the extreme temperatures (high and low) that the lubricant may still be able to effectively perform in. These properties will no doubt affect the final recommendations made in this project, as they will determine whether bio-lubricants are a valid alternative to synthetic oils within automotive engines.

Another recommendation for further work on this project is the use of additiives to improve the performance of the bio-lubricant blend. As the 50% bio-lubricant blend was selected as the most ideal candidate to be compared with the SAE-30 oil, this bio-lubricant could be further analysed. While the other bio-lubricant blends were able to produce results that seemingly appeared to be accurate, they were not comparable to the performance of the SAE-30 oil. Therefore, it is suggested that this selected bio-lubricant blend of 50% is focused upon heavily in further research. With further additives, the bio-lubricant may be able to perform at a higher rate than it currently does and address the concerned weaknesses that it possesses (low viscosity at high temperatures, ability to generate a sufficient fluid film thickness at high temperatures). As shown in the study completed by Menon & Rajasekaran, the use of additives such as Zinc diakyl dithiophosphates (ZDPP) can improve the ability of Neem Seed Oil to form a protective oil film on the surface of materials, leading to reduced surface abrasion wear. ZDPP additives were also found to improve the stability of vegetable-oil based lubricants, especially under extreme conditions such as high pressure and high temperatures.

Further research in this area could also include the alteration of other variables in this project. Load and sample material are both variables that were kept constant throughout this project, however further work could include altering these factors. While the 50% bio-lubricant blend performed well in the specific testing and environment that it was exposed to, further testing is required to determine whether this bio-lubricant could be implemented into industry. This bio-lubricant could be exposed to a larger range of sliding speeds, to determine its performance outside of the range used int his project as well. Altering the load and sample material used in this experiment could also lead to different wear types present in the sample pieces, such as adhesive wear. As previously discussed in this report, adhesive wear was generally not observed when using the SEM, as the load used during testing was rather aggressive, and the 6060 sample piece of aluminium was much softer than the stainless steel counterface. The presence of other wear types in this project would have allowed for a deeper understanding of the tribology involved in such processes, and would have exposed the bio-lubricant blend to a different form of wear. With the current results, it is difficult to determine how the 50% bio-lubricant blend would perform under such conditions, and so, it is recommended that further work is completed in this area. This will ensure that this bio-lubricant can perform in such conditions, and therefore it may then be able to be recommended for use within industry.

Additionally, a field test of the prosed bio-lubricant would allow for direct results to be monitored and observed. Similar to the study completed by Menon & Rajasekaran, submitting the 50% bio-lubricant to testing within an engine would be a further improvement on this project, and would allow for direct recommendations as to whether this bio-lubricant would be able to perform within the automotive industry. Overall, while there are several possible improvements on this project, the results gained have set a firm foundation for further work, and more testing in this area can only improve the technology of bio-lubricants. The future of this field is bright, with popularity and interest for bio-lubricants on the rise.

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APPENDIX A: PHOTOS OF METHODOLOGY

Figure 43: High precision scale used to weigh samples before and after testing

Figure 44: The countersurface, load cell and sample holder inside the tribology machine

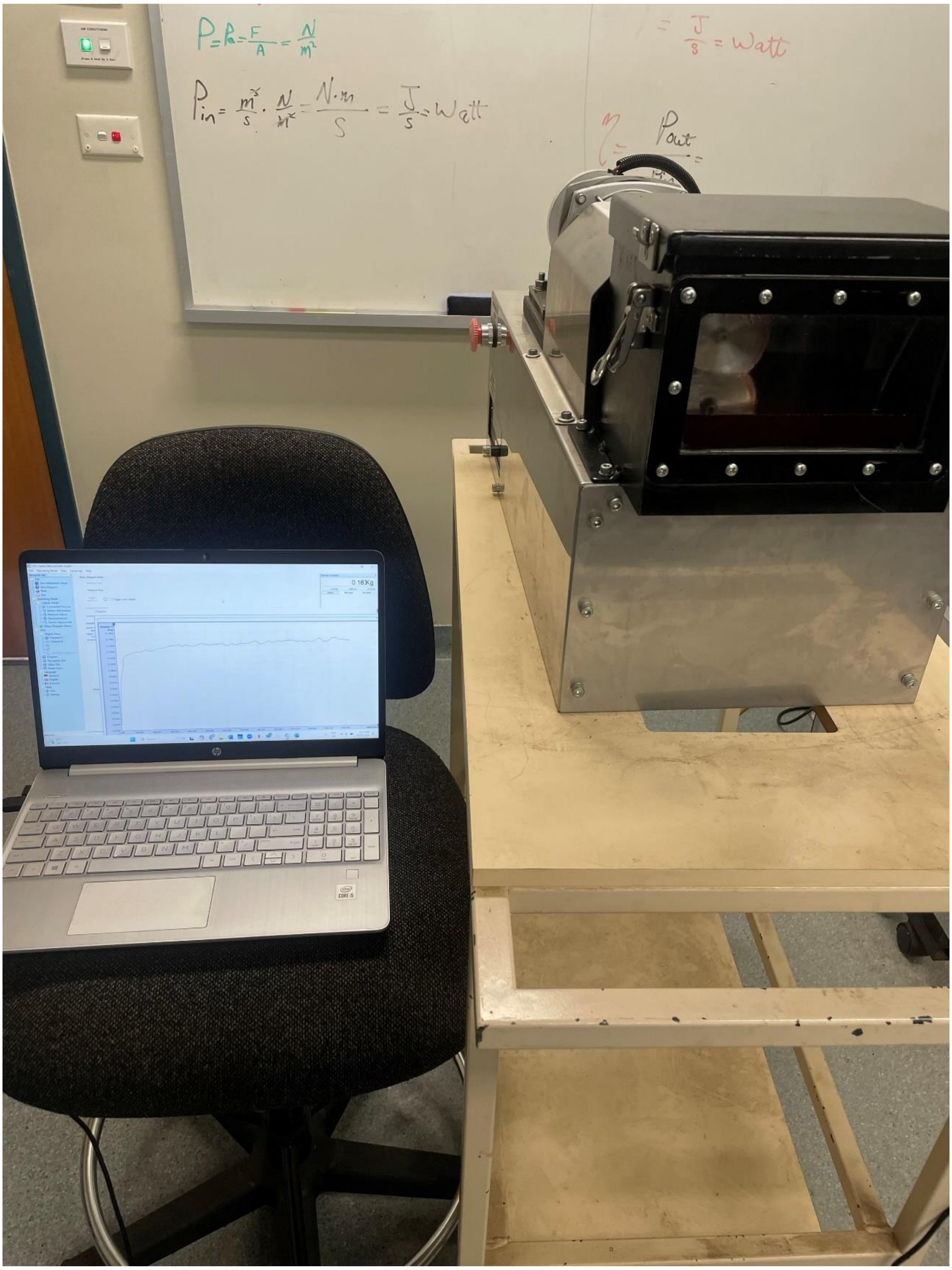

Figure 45: The tribology machine under operation with live data being recorded

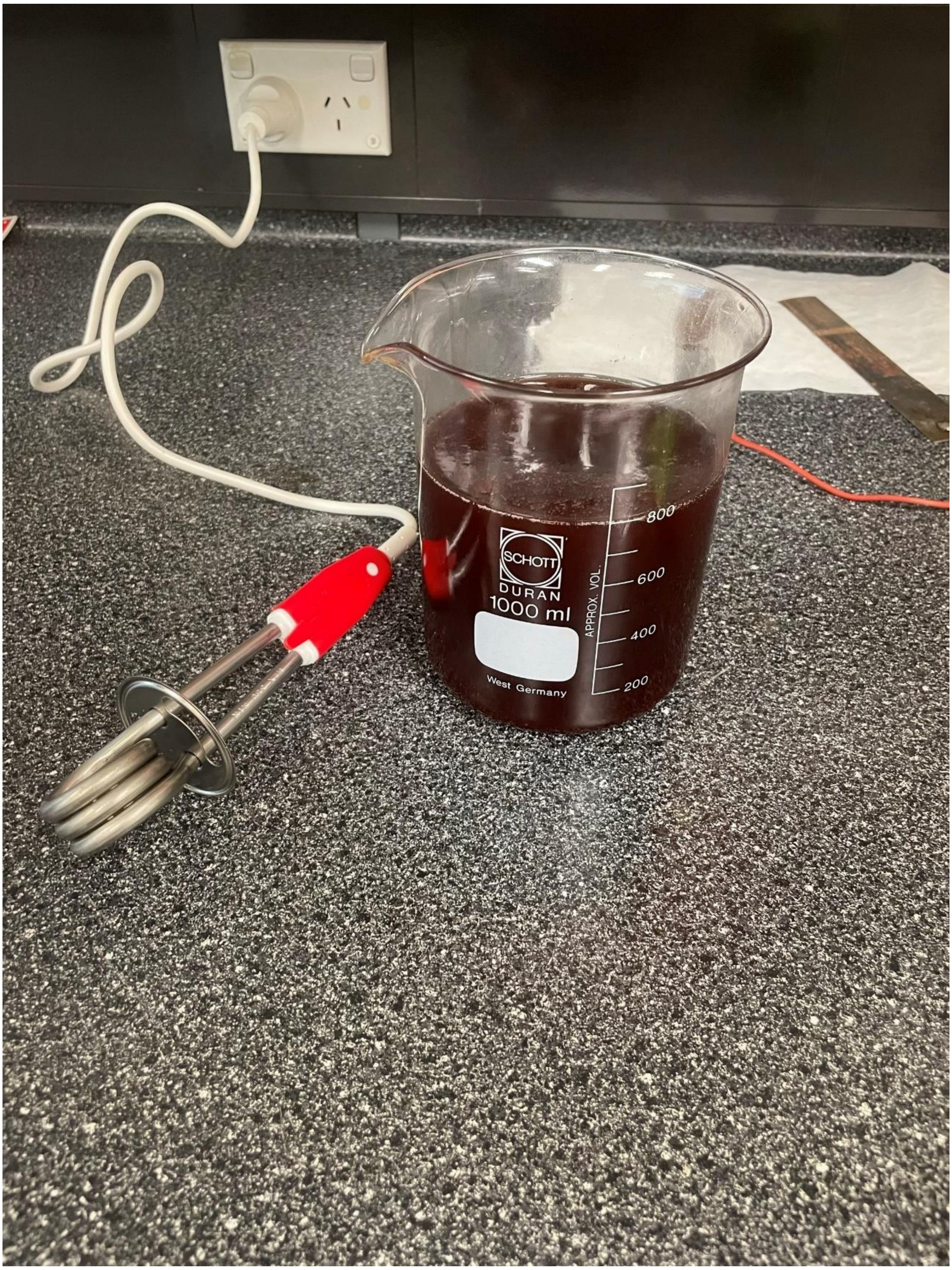

Figure 46: 75% bio-lubricant blend after using the heater (pictured) and being blended

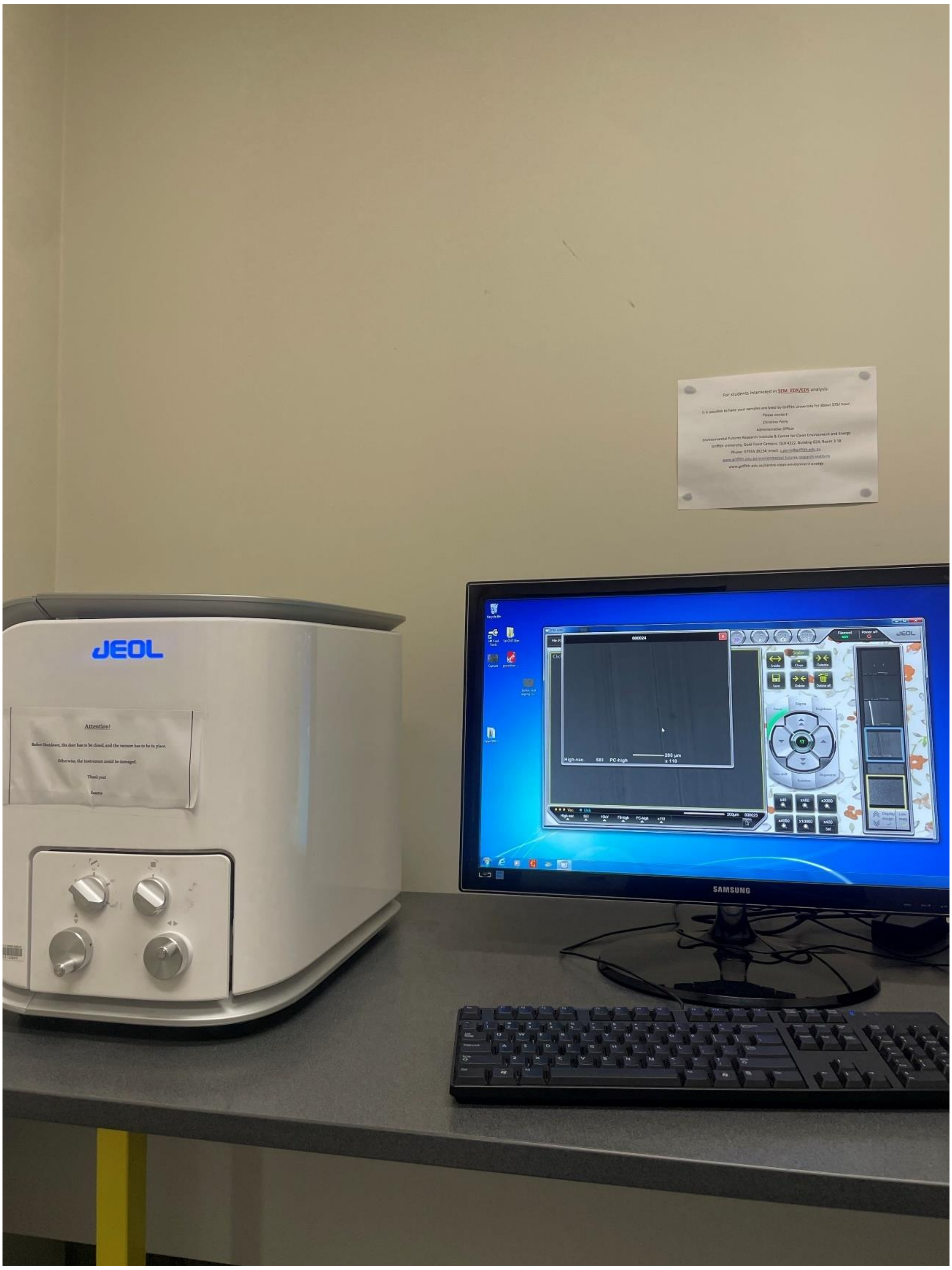

Figure 47: Using the scanning electron microscope for further analysis of wear

Figure 48: A typical wear scar left after testing in the tribology machine

APPENDIX B: SAFETY CONSIDERATIONS

plantneeds

MATERIAL SAFETY DATA SHEET

1. MATERIAL AND SUPPLY COMPANY IDENTIFICATION

Product name: PLANO

Synonyms (N/A) **Product Code (N/A)** **Bar Code (N/A)**

Brand description: PLANT NEEDS NEEM OIL **Product Description:** Neem Seed Oil

This product is a brown colour liquid of neem seed oil used as fertiliser and soil conditioner. This product poses no health concerns through normal use in accordance with label directions.

Supplier: Plant Needs Pty Ltd Australia.
ABN: 74130532375
Street Address: 21A Nathan Dr
Campbellfield VIC 3061
Australia
Telephone: 613 90058578

Emergency Telephone number: Australia – 613 90058578 / 613 456314888

2. HAZARDS IDENTIFICATION

Potential health effects Routes of entry: Eyes, skin, oral, inhalation.Human effects and Symptoms of overexposure: None noted. Acute eye contact : May cause mild reversible eye irritation .chronic eye contact:Chronic exposure is not likely from normal use. Acute Skin Contact: None noted. Acute Inhalation :None noted .Chronic skin Contact : None noted .Chronic inhalation: None noted

STATEMENT OF HAZARDS NATUTRE

Not a Dangerous Good according to Australian Dangerous Goods (ADG) Code, IATA or IMDG/IMSBC criteria.
Risk Phrases: R36, R51, R38/38. Irritating to eyes. Toxic to aquatic organisms. Irritating to eyes and skin.
Safety Phrases: S61, S24/25, S36/39. Avoid release to the environment. Refer to special instructions/Safety Data Sheets. Avoid contact with skin and eyes. Wear suitable protective clothing and eye/face protection.
SUSMP Classification: None allocated.
ADG Classification: None allocated. Not a Dangerous Good according to Australian Dangerous Goods (ADG) Code, IATA or IMDG/IMSBC criteria.
UN Number: None allocated

3.COMPOSITION INFORMATION

Description: cold pressed neem oil 100%

4. FIRST AID MEASURES

For eyes: Wash with plenty of water. Seek medical advice if irritation persists.

For skin: Remove contaminated clothing. Wash with soap and water. Seek medical attention if irritation persists.

For inhalation: Remove to fresh air. Seek medical advice if irritation persists.

For ingestion: Do not induce vomiting. Never give anything by mouth to a victim who is unconscious or is having convulsions. Get medical advice/ attention if you feel unwell.

5. FIRE FIGHTING MEASURES

NONE NOTED

Extinguishing media Natural oil: Carbon dioxide or Halon extinguisher

Unusual fire and explosion hazards: None

Special fire fighting procedures: None

6. ACCIDENTAL RELEASE MEASURES

SPILL: Sweep up and place in an appropriate container, hold for disposal, wash spilled surfaces to remove any residues.

7. HANDLING AND STORAGE

Handling: Wash hands thoroughly with soap and water after handling and before eating, drinking, chewing gum, using tobacco, or using the toilet.

Storage: Store in a cool dry place, keep tightly closed container.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure limit: No exposure limit established.

Respiratory protection: Adequate ventilation recommended. Respirators are not necessary.

Protective clothing: Normal clothing with chemical resistant gloves.

General hygiene: Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Natural Brown color organic neem oil
Melting point: 55°F / 13 °C
Boiling point: 310°F / 154°C
Specific gravity: 0.9228 at 27°C
Vapor Pressure: Not applicable

Vapor Density: Not applicable
Solubility in water: Not soluble
Odor: Characteristic Odor
Evaporation rate: Not applicable
Molecular weight: Not applicable

10. STABILITY AND REACTIVITY

General: Stable and non-reactive under normal conditions of use/storage

Incompatible materials: Incompatible with oxidizing agents, reducing metals, alkalis and acids

Condition to avoid: Exposure to direct sunlight Hazardous

Decomposition: Will not occur

Hazardous decomposition: Will not occur

11. TOXICOLOGY INFORMATION

Oral (Rat): >5000 mg /kg
Inhalation: >5.3 mg/l air
Eye irritation: Non-irritant
Dermal (Rat): >2000 mg/kg
Skin irritation: Non-irritant
Ingestion: None known
Chronic effects: None known
Other Toxicity: Not applicable

12. ECOLOGICAL INFORMATION

Ecotoxicity: Not classified as environmentally hazardous, but avoid contaminating surface water or other water sources.

Degradability: Readily biodegradable in soil and water

13. DISPOSAL CONSIDERATION

Do not put into sewer lines. Dispose in accordance with local, state and federal regulations.

14. TRANSPORTATION INFORMATION

ADG Code: This product is not classified as a Dangerous Good by ADG, IATA or IMDG/IMSBC criteria.
No special transport conditions are necessary unless required by other regulations.

15. REGULATORY INFORMATION

OSHA: None

TSCA: None

CERCLA: None

RCRA: None

SARA Title III

Section 302: None

Section 311/312: None

Section 313: None

CA Prop 65: None

US State Right to Know: None

16. OTHER INFORMATION

Date of issues:16/08/2014

Declaration: The above information is believed to be correct on the date it is published. However, information in PLANO MSDS, may not be valid if used in combination with any other material or in any process. The information in the Safety Data Sheet is offered for your consideration and guidance when exposed to this product. Plant Needs Pty Ltd, disclaims all expressed or implied warranties and assume no responsibilities for the accuracy or completeness of the data contained with this document. It is the user's responsibility to satisfy themselves as to the suitability and completeness of this information for their specific use and application. The information contains in PLANO MSDS does not apply to use with any other product or in any other process information is the rights of Plant needs Pty ltd and should not be changed or copied.

NON-Hazardous, NON-Dangerous Goods

1. MATERIAL AND SUPPLY COMPANY IDENTIFICATION

Product name: Small Engine Mono 30

Synonyms	Product Code	Bar Code
Small Engine Mono 30	SEFS30	
HS Code: 2710.19.92	-	
HS Code: 2710.91.92	-	
HS Code: 2710.99.92	-	

Recommended use: Petrol engine oil.

Supplier: Penrite Oil Company Pty Ltd

ABN: 25 005 001 525

Street Address:
Australia:
110-116 Greens Road
Dandenong South VIC 3175

New Zealand:
75 Lady Ruby Drive
East Tamaki Auckland 2013

Telephone: Australia: 1300 736 748; New Zealand: 0800 533 698

Facsimile: Australia: 1800 736 748; New Zealand: 0800 533 698

Emergency Telephone number: Australia: 1300 736 748; New Zealand: 0800 533 698

2. HAZARDS IDENTIFICATION

Classification

Based on available information, this material is not classified as hazardous according to criteria of Safe Work Australia GHS 7.

Hazard Classification

Not allocated

Label Elements

Hazard Pictograms

Not allocated

Signal Word

Not allocated

Hazard Statement

Not allocated

Prevention Precautionary Statements

Not allocated

Response Precautionary Statements

Not allocated

Storage Precautionary Statement

Not allocated

Disposal Precautionary Statement

Not allocated

Poison Schedule: Not Applicable

Child-resistant fastening: Not Applicable

Tactile warning: Not Applicable

DANGEROUS GOOD CLASSIFICATION

Not classified as Dangerous Goods by the criteria of the "Australian Code for the Transport of Dangerous Goods by Road & Rail" and the "New Zealand NZS5433: Transport of Dangerous Goods on Land".

Classified as a C2 (COMBUSTIBLE LIQUID) for the purpose of storage and handling, in accordance with the requirements of AS 1940. Refer to State Regulations for storage and transport requirements.

3. COMPOSITION INFORMATION

CHEMICAL ENTITY	CAS NO	PROPORTION
Distillates, petroleum, hydrotreated heavy paraffinic	64742-54-7	>60 %

Ingredients determined to be Non-Hazardous	-	Balance
		100%

4. FIRST AID MEASURES

If poisoning occurs, contact a doctor or Poisons Information Centre (Phone Australia 131 126, New Zealand 0800 764 766).

Inhalation: Remove victim from exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered. Seek medical advice if effects persist.

Skin Contact: If skin or hair contact occurs, remove contaminated clothing and flush skin and hair with running water. If swelling, redness, blistering or irritation occurs seek medical assistance.

Eye contact: If in eyes wash out immediately with water. In all cases of eye contamination it is a sensible precaution to seek medical advice.

Ingestion: Rinse mouth with water. If swallowed, do NOT induce vomiting. Give a glass of water to drink. Never give anything by the mouth to an unconscious patient. If vomiting occurs give further water. Seek medical advice.

PPE for First Aiders: Wear safety shoes, overalls, gloves, safety glasses. Available information suggests that gloves made from nitrile rubber should be suitable for intermittent contact. However, due to variations in glove construction and local conditions, the user should make a final assessment. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storing or re-using.

Notes to physician: Treat symptomatically.

FIRE FIGHTING MEASURES

Hazchem Code: Not applicable.

Suitable extinguishing media: If material is involved in a fire use water fog (or if unavailable fine water spray), alcohol resistant foam, standard foam, dry agent (carbon dioxide, dry chemical powder).

Specific hazards: Combustible liquid.

Fire fighting further advice: On burning or decomposing may emit toxic fumes. Fire fighters to wear selfcontained breathing apparatus and suitable protective clothing if risk of exposure to vapour or products of combustion or decomposition.

ACCIDENTAL RELEASE MEASURES

SMALL SPILLS

Wear protective equipment to prevent skin and eye contamination. Avoid inhalation of vapours or dust. Wipe up with absorbent (clean rag or paper towels). Collect and seal in properly labelled containers or drums for disposal.

LARGE SPILLS

Clear area of all unprotected personnel. Slippery when spilt. Avoid accidents, clean up immediately. Wear protective equipment to prevent skin and eye contamination and the inhalation of vapours. Work up wind or increase ventilation. Contain - prevent run off into drains and waterways. Use absorbent (soil, sand or other inert material). Collect and seal in properly labelled containers or drums for disposal. If contamination of crops, sewers or waterways has occurred advise local emergency services.

Dangerous Goods - Initial Emergency Response Guide No: Not applicable

HANDLING AND STORAGE

Handling: Avoid eye contact and repeated or prolonged skin contact. Avoid inhalation of vapour, mist or aerosols.

Storage: Store in a cool, dry, well-ventilated place and out of direct sunlight. Store away from foodstuffs. Store away from incompatible materials described in Section 10. Store away from sources of heat and/or ignition. Keep container standing upright. Keep containers closed when not in use - check regularly for leaks.

Classified as a C2 (COMBUSTIBLE LIQUID) for the purpose of storage and handling, in accordance with the requirements of AS 1940. Refer to State Regulations for storage and transport requirements.

EXPOSURE CONTROLS / PERSONAL PROTECTION

National occupational exposure limits:

	TWA		STEL		NOTICES
	ppm	mg/m3	ppm	mg/m3	
Oil mist, refined mineral	-	5	-	-	-

As published by Safe Work Australia.

TWA - The time-weighted average airborne concentration over an eight-hour working day, for a five-day working week over an entire working life.

STEL (Short Term Exposure Limit) - the average airborne concentration over a 15 minute period which should not be exceeded at any time during a normal eight-hour workday.

These Exposure Standards are guides to be used in the control of occupational health hazards. All atmospheric contamination should be kept to as low a level as is workable. These exposure standards should not be used as fine dividing lines between safe and dangerous concentrations of chemicals. They are not a measure of relative toxicity.

If the directions for use on the product label are followed, exposure of individuals using the product should not exceed the above standard. The standard was created for workers who are routinely, potentially exposed during product manufacture.

Biological Limit Values: As per the "National Model Regulations for the Control of Workplace Hazardous Substances (Safe Work Australia)" the ingredients in this material do not have a Biological Limit Allocated.

Engineering Measures: Ensure ventilation is adequate to maintain air concentrations below Exposure Standards. Use only in well ventilated areas. Use with local exhaust ventilation or while wearing appropriate respirator.

Personal Protection Equipment: SAFETY SHOES, OVERALLS, GLOVES, SAFETY GLASSES.

Personal protective equipment (PPE) must be suitable for the nature of the work and any hazard associated with the work as identified by the risk assessment conducted.

When handling individual retail packs no personal protection equipment is required.

Wear safety shoes, overalls, gloves, safety glasses. Available information suggests that gloves made from nitrile rubber should be suitable for intermittent contact. However, due to variations in glove construction and local conditions, the user should make a final assessment. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storing or re-using.

Hygiene measures: Keep away from food, drink and animal feeding stuffs. When using do not eat, drink or smoke. Wash hands prior to eating, drinking or smoking. Avoid contact with clothing. Avoid eye contact and repeated or prolonged skin contact. Avoid inhalation of vapour, mist or aerosols. Ensure that eyewash stations and safety showers are close to the workstation location.

PHYSICAL AND CHEMICAL PROPERTIES

Form:	Liquid
Colour:	Red
Odour:	Petroleum

Solubility:	Immiscible in water
Density:	0.881 g/cm^3 @ 15°C
Relative Vapour Density (air=1):	>1
Vapour Pressure (20 °C):	<0.001 kPa
Flash Point (°C):	225
Flammability Limits (%):	N Av
Autoignition Temperature (°C):	N Av
Melting Point/Range (°C):	N Av
Boiling Point/Range (°C):	N Av
pH:	N App
Viscosity:	93 cSt @ 40°C
Total VOC (g/Litre):	N Av

(Typical values only - consult specification sheet) N Av = Not available, N App = Not applicable

STABILITY AND REACTIVITY

Chemical stability: This material is thermally stable when stored and used as directed.

Conditions to avoid: Elevated temperatures and sources of ignition.

Incompatible materials: Oxidising agents.

Hazardous decomposition products: Oxides of carbon and nitrogen, smoke and other toxic fumes.

Hazardous reactions: No known hazardous reactions.

TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Acute Effects

Inhalation: Material may be an irritant to mucous membranes and respiratory tract.

Skin contact: Contact with skin may result in irritation.

Ingestion: Swallowing can result in nausea, vomiting and irritation of the gastrointestinal tract.

Eye contact: May be an eye irritant.

Acute toxicity

Inhalation: This material has been classified as not hazardous for acute inhalation exposure. Acute toxicity estimate (based on ingredients): $LC_{50} > 20.0$ mg/L for vapours or $LC_{50} > 5.0$ mg/L for dust and mist.

Skin contact: This material has been classified as not hazardous for acute dermal exposure. Acute toxicity estimate (based on ingredients): LD_{50} > 2,000 mg/Kg bw

Ingestion: This material has been classified as not hazardous for acute ingestion exposure. Acute toxicity estimate (based on ingredients): LD_{50} > 2,000 mg/Kg bw

Corrosion/Irritancy: Eye: this material has been classified as not corrosive or irritating to eyes. Skin: this material has been classified as not corrosive or irritating to skin.

Sensitisation: Inhalation: this material has been classified as not a respiratory sensitiser. Skin: this material has been classified as not a skin sensitiser.

Aspiration hazard: This material has been classified as not an aspiration hazard.

Specific target organ toxicity (single exposure): This material has been classified as not a specific hazard to target organs by a single exposure.

Chronic Toxicity

Mutagenicity: This material has been classified as not a mutagen.

Carcinogenicity: This material has been classified as not a carcinogen.

Reproductive toxicity (including via lactation): This material has been classified as not a reproductive toxicant.

Specific target organ toxicity (repeat exposure): This material has been classified as not a specific hazard to target organs by repeat exposure.

ECOLOGICAL INFORMATION

Avoid contaminating waterways.

Acute aquatic hazard: This material has been classified as not hazardous for acute aquatic exposure. Acute toxicity estimate (based on ingredients): > 100 mg/L

Long-term aquatic hazard: This material has been classified as not hazardous for chronic aquatic exposure. Non-rapidly or rapidly degradable substance for which there are adequate chronic toxicity data available OR in the absence of chronic toxicity data, Acute toxicity estimate (based on ingredients): >100 mg/L, where the substance is not rapidly degradable and/or BCF < 500 and/or log K_{ow} < 4.

Ecotoxicity: No information available.

Persistence and degradability: No information available.

Bioaccumulative potential: No information available.

Mobility: No information available.

DISPOSAL CONSIDERATIONS

Persons conducting disposal, recycling or reclamation activities should ensure that appropriate personal protection equipment is used, see "Section 8. Exposure Controls and Personal Protection" of this SDS.

If possible material and its container should be recycled. If material or container cannot be recycled, dispose in accordance with local, regional, national and international Regulations.

TRANSPORT INFORMATION

ROAD AND RAIL TRANSPORT

Not classified as Dangerous Goods by the criteria of the "Australian Code for the Transport of Dangerous Goods by Road & Rail" and the "New Zealand NZS5433: Transport of Dangerous Goods on Land".

MARINE TRANSPORT

Not classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea.

AIR TRANSPORT

Not classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air.

REGULATORY INFORMATION

This material is not subject to the following international agreements:

Montreal Protocol (Ozone depleting substances)

The Stockholm Convention (Persistent Organic Pollutants)

The Rotterdam Convention (Prior Informed Consent)

Basel Convention (Hazardous Waste)

This material is subject to the following international agreements:

International Convention for the Prevention of Pollution from Ships (MARPOL)

- Annex I - Oil

This material/constituent(s) is covered by the following requirements:

The Standard for the Uniform Scheduling of Medicines and Poisons (SUSMP) established under the Therapeutic Goods Act (Commonwealth): Not Applicable.

AICIS Status: All components of this product are listed on or exempt from the Australian Inventory of Industrial Chemicals (AIIC).

All components of this product are listed on or exempt from the New Zealand Inventory of Chemical (NZIoC).

OTHER INFORMATION

Reason for issue: Revised. Updated to GHS 7.

This Safety Data Sheet has been prepared by Chemical Data Services Pty Ltd on behalf of its client.

Safety Data Sheets are updated frequently. Please ensure that you have a current copy.

This information was prepared in good faith from the best information available at the time of issue. It is based on the present level of research and to this extent we believe it is accurate. However, no guarantee of accuracy is made or implied and since conditions of use are beyond our control, all information relevant to usage is offered without warranty. The manufacturer will not be held responsible for any unauthorised use of this information or for any modified or altered versions.

If clarification or further information is needed to ensure that an appropriate assessment can be made, the user should contact this company.

Our responsibility for product as sold is subject to our standard terms and conditions, a copy of which is sent to our customers and is also available upon request.

FoHES Induction for Engineering Laboratories

University of Southern Q[redacted]
West St. Toowoomba4350

This Induction form outlines the process of entry into the Engineering Laboratory Spaces

Introduce relevant staff

- Senior Coordinating Technical Officer – Adrian Blokland, Toowoomba (Ext: 1719)........ ☑
- Technical Officer –.......BRIAN LOUSKE.. ☑
- Security.. Call 46312871 or 0412716838 ☑

➢ Room Entry Requirements

- Have you completed a general USQ health and safety induction? .... NO / [✓ YES]
- Risk Management Plan Completed if required? ....TBC................................ NO / YES
- PPE MUST be worn as outlined in the Risk Assessment Form or as requested......... ☑
- Covered footwear MUST be worn at all times in these laboratories.......................... ☑
- Safety shoes/boots may be compulsory in some areas or during some tasks .... ☐ NA
- NO food or drink to be consumed in these laboratories.. ☑
- Competency assessed by Tech staff before using equipment or undertaking task.......... ☑

➢ Explain Emergency Procedures

- All Emergencies .... Call 2222 (07 4631 2222) ☑
- Life Threatening Events.................................... Call (0) 000 ☑
- Fire Exits... ☑
- Assembly point: space west of Z block.. ☑
- Alarm system (Automatic / Manual Evacuation in some cases)............................ ☑
- Fire Extinguishers are located in the hallway on each floor .... ☑
- Spill kit is located in the Z115 .... ☑

➢ Show First Aid Details

- The First Aid Kit is located in the hallway on each floor .... ☑
- Safety shower/eyewash station is in Z110.. ☑
- Sink is located in each lab .... ☑

➢ Room Details

- Access to laboratories through technical staff.. ☑
- SWP and any relevant SDS are stored in folder in each area.................................. ☑

➢ House Keeping

- Toilets are located on each floor.. ☑
- Telephone is located in each lab (also in foyer on each level)................................ ☑
- All bags must be off the floor... ☑
- Make sure area is thoroughly tidied after each activity... ☑
- Close all doors (including storage areas) before leaving the lab............................... ☑

Name (Print): Matthew Cuskelly
Signature: [redacted]

Staff/Student No: ....
Date (dd/mm/yyyy): 5/11/24

Technical Staff: ADRIAN BLOKLAND
Signature: [redacted]

Employee No: ....
Date (dd/mm/yyyy): 5/11/24

Supervisor: ....
Signature: ....

Employee No: ....
Date (dd/mm/yyyy): ....

6131	RISK DESCRIPTION	STATUS	TREND	CURRENT	RESIDUAL
	elly [redacted] ENP4111- Use of the Tribology Machine for Testing Purposes	Live	🟨	Medium	Low

RISK FACTOR(S)	EXISTING CONTROL(S)	CURRENT	PROPOSED CONTROL(S)	TREATMENT OWNER	DUE DATE	RESIDUAL
Use of lubricants and oils at high temperatures due to friction may cause burns, blistering, scalding, potential for explosion or fire if oils reach flash point	Control: Oils/lubricants are covered when operating. Oils will be monitored to ensure they don't reach high temperatures.	Medium	Use of appropriate PPE to ensure safety.		08/11/2024	Low
Potential for oil spills/leaks to lead to slipping/falling injuries.	Control: Oils/lubricants will be handled as little as possible, and will be handled as careful as possible when needed.	Low				Low
Rotating of parts within the machine is a risk for personal injury.	Control: Machine will be used with safety covers in place to ensure that rotating parts are not exposed to operators.	Low				Low
The use of the tribology machine may lead to electrocution, electrical shock or tripping hazards from cords/leads	Control: Clearing of any unnecessary cords, organisation of any electrical cords to lower risk. Tribology machine will be tagged and tested by professionals prior to use. Walk with care. Use of ground mat.	Low			commercial i	Low
Working with potentially environmentally harmful contaminants, leading to environmental contamination/pollution	Control: Handling all lubricants/oils with care. Any spills will be cleaned up accordingly and appropriately disposed of. Use of appropriate chemicals during testing	Low				Low
Working with lubricants/chemicals, leading to potential inhalation/ingestion of toxic substances	Control: Appropriate PPE. Limit handling of chemicals. Check SDS of all chemicals	Low				Low

ATTACHMENTS