Individual Project Report

(7CCEMPRJ)

Hydrogen Fuelled Internal Combustion Engines

Fundamental Challenges of Hydrogen Direct Injection

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Abstract

The goal towards using cleaner alternatives to fossil fuels, hydrogen can be presented as a promising alternative in the mobility space which contributes significantly to climate change. However, using hydrogen as a fuel which can be directly injected into the combustion chamber comes with a set of challenges. This project delves into one of the main concerns of water as a combustion byproduct. This water has the potential to seep through the piston rings leading to contamination of lubricant. This study aims to understand the effects of water contamination on lubricant performance. This project also taps into the use of Fusion 360 to design a component required for the experiment and subsequently manufactured by a vendor. The experiment starts off by testing pure oil samples along with oil samples contaminated with different water concentrations under varying loads and speed using a Universal Mechanical Tester by Bruker. The results obtained were analyzed by comparing the plots obtained from different concentrations of water in oil, to provide a fine line comparison between the three sample mixtures, the results are represented using a Stribek Curve which sheds light on the different lubrication regimes for each of the oil samples tested. The findings provide valuable insight into the effects of water contamination on lubricants and provide a broader vision into the future work related to the effects of water contamination at different temperatures of oil and hydrogen internal combustion engine.

Nomenclature

ICE	Internal Combustion Engine
HICE	Hydrogen Internal Combustion Engine
H2DDI	Hydrogen Diesel Direct Injection
UMT	Universal Mechanical Tester
A/F	Air to Fuel Ratio
TDC	Top Dead Center
BDC	Bottom Dead Center
Al	Aluminum
Si	Silicon
Mg	Magnesium
ISO	Internal Organization for Standardization
N	Newton
RPM	Revolutions Per Minute

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1 Introduction

1.1 Project Context

Sustainability, in recent times, has been the focus across the globe. This project addresses problems that occur while using sustainable energy sources such as Hydrogen. Hydrogen as a sustainable fuel mainly due to its free availability in the atmosphere and its combustion characteristics that are very similar to that of conventional fossil fuels. The increase in greenhouse gas emissions has contributed to the change in climate and weather patterns. The main contributing factors are the increase in the dependence on fossil fuel as a source of energy. The main contributors to climate change are the emissions from Industries, Power Thermal Plants and Vehicles. This study mainly focuses on the mobility space where the contribution of passenger vehicles alone in carbon dioxide emissions is approximately three billion metric tons across the world. [1]

Hydrogen can be used in different energy forms, the recent development of energy discharge systems using hydrogen as the source of energy are:

1. Hydrogen Fuel Cells
2. Hydrogen Internal Combustion Engines

The use of Hydrogen Fuel Cells as an alternate form of energy involves storage of hydrogen in fuel cells which can be prone to leakages. Hydrogen being exothermic in nature can lead to catastrophic disasters. Usage of hydrogen fuel cells can lead to the need for production of new components for fuel delivery systems as well as establishing a new supply chain network. The above factors can lead to an increase in the total cost of the product. This report shares insights by which Hydrogen Internal Combustion Engines can serve as a better alternative in comparison to hydrogen fuel cells.

The primal focus in this experiment is on Hydrogen Internal Combustion Engines, the grounds on which Hydrogen Internal Combustion Engines can be a better alternative compared to Hydrogen Fuel Cells as well as Lithium Ion batteries is mainly in terms of the supply chain stability in the availability of components of an internal combustion engine, thereby reducing the dependency on manufacturing new components using new materials thereby reducing the cost accounted for manufacturing components and establishing a new supply chain network leading to reduction in greenhouse gas emissions.

The byproduct of combustion of hydrogen with air is water making it not harmful for the environment. Since the molecular size of water is small. The water which is a byproduct of combustion can have a higher probability of seeping through the oil rings of the piston and interacting with the lubricants. This interaction can cause the contamination of the lubricant. The contamination can occur at different concentrations leading to different wear rates and coefficients of friction between the oil rings of a piston and the cylinder.

The drawbacks of using hydrogen for directly injection into the combustion chamber can be accounted to the exothermic nature of hydrogen because of which the manufacturer should ensure fail safe fueling systems to prevent fire hazards which can endanger humans. The storage of hydrogen can also be concerning mainly due to the embrittlement of the storage systems which can promote localized cracks which can propagate through the metal [2] [3]. Since fossil fuels are self-lubricating, the injection systems do not require lubrication, which is not like the case of hydrogen, which can lead to embrittlement in injector nozzles.

This study narrows down to tribological study of materials and their behavior in relative motion of materials and artificial systems. In this study a stainless-steel disc is subjected to different loads while creating an environment which simulates a rotary hydrogen internal combustion engine and the effects of water and oil mixture at different concentration on the coefficient of friction between two rotary components, the oil and water film is subjected to different loads using a Universal Mechanical Test Machine.

1.2 Project Motivation

The motivation for this project kicks off from the drive towards a carbon neutral environment. The recent evolution in the mobility space where we have witnessed a paradigm shift from Gasoline internal combustion engines to electric vehicles, electric vehicles have taken the recent spotlight, but they do have their downsides as well, the process of obtaining lithium by mining has been proven hazardous and so is the disposal of lithium into the environment can cause greater harm to the living beings [4]. The use of hydrogen as a source of energy can be taken into light since the availability of hydrogen in the atmosphere is free and the combustion characteristics are very similar to that of conventional gasoline. We have focused very specifically on the problems that can be caused by directly injecting it into combustion chamber. The byproduct water encounters the lubricant which can degrade the lubricating property of the lubricant.

1.3 Project Methodology

The outline of methodology of this experiment involves testing effects of dilution of water in lubricant under varying loads and speeds. This test can be conducted on UMT test rig with a specially designed component explained in the later stages of this report. A similar experiment conducted by [5], which involves testing of friction and wear, at different concentrations of water in lubricant under different loads. It is also to note that [5] has conducted this experiment with the same grade of oil. The table below shows the stages at which the experiment was conducted. In this experiment all the lubricant samples are tested at different speeds for a duration of 60 seconds.

Test Number	Type of Lubricant Used	Load (N)	Speed (RPM)
1	Pure Oil	10	0,5,10,50,100,150
2	Pure Oil	20	0,5,10,50,100,150
3	Pure Oil (Repeat)	20	0,5,10,50,100,150
4	Pure Oil + 5% Dilution of water	10	0,5,10,50,100,150
5	Pure Oil + 5% Dilution of water	20	0,5,10,50,100,150
6	Pure Oil + 20% Dilution of water	10	0,5,10,50,100,150
7	Pure Oil + 20% Dilution of water	20	0,5,10,50,100,150

Table 1: Tests Conducted

The experiment involves seven tests with varying Loads and Speed, a test with Pure Oil with 20N load is repeated to show the good repeatability of the test equipment.

The flow chart below gives a pictorial representation of the experiment conducted.

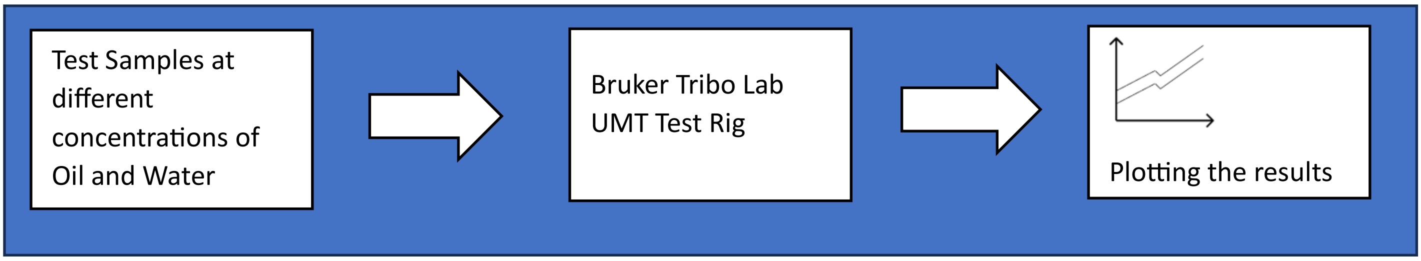

Figure 1: Flow Chart of Experiment

1.4 Report Structure

Chapter One: The first chapter outlines the introduction to the topic including the definition, motivation of the problem and provides an outline of methodology in the report.

Chapter Two: The aims and objectives of this project are presented.

Chapter Three: This chapter mainly focuses on the background knowledge to conduct the experiment.

Chapter Four: This chapter consists of information regarding the requirement of additional components.

Chapter Five: This chapter focuses on the methodology of the experiment conducted.

Chapter Six: This chapter discusses the results obtained from the experiment performed.

Chapter Seven: This chapter discusses the managerial aspects of the project.

Chapter Eight: This chapter discusses the various industries that can benefit from this project.

Chapter Nine: This chapter provides a conclusion to the entire project and includes the prospects can provide help us understand the impact of contamination of water on lubricant performance.

2 Aims and Objectives

This experiment aims to contribute to the global shift towards sustainable energy solutions by exploring the viability of hydrogen as an alternative fuel source. Given the environmental concerns associated with fossil fuels, understanding the intricacies of hydrogen combustion and its byproducts is crucial for its broader adoption in the mobility space.

The primary aim of this experiment is to investigate the interaction between the lubricant with varying concentrations of water at different speeds and its effect on lubricating performance. The experiment further aims to simulate the phenomena where the oil interacts with water between the oil rings of a piston using a Universal Mechanical Test rig from TriboLab. The experiment further evaluates the contamination of water in lubricants affects the integrity of the lubricants which plays a crucial role in ensuring that engines remain well-lubricated and operate smoothly even with contamination of water in the system.

In a broader engineering context, this experiment endeavors to facilitate the advancement of lubrication formulations for hydrogen internal combustion engines and to pioneer the research into alternative materials for fabrication of piston rings.

The objectives to cover over the course of this project include:

1. To systematically study how varying concentrations of water, a byproduct of hydrogen combustion, interact with a given lubricant.

2. Assessing the patterns of the resistive force between the circular specimen or ball at varying speed and concentrations of water in lubricating oil.

3. Plotting the frictional behavior (Coefficient of friction) of a liquid lubricant across the Stribek Curve at Boundary lubrication, Mixed lubrication, and Hydrodynamic lubrication.

3 Background and Literature Review

The signpost serves as a comprehensive guide, clearly explaining the step-by-step workflow of the literature review process.

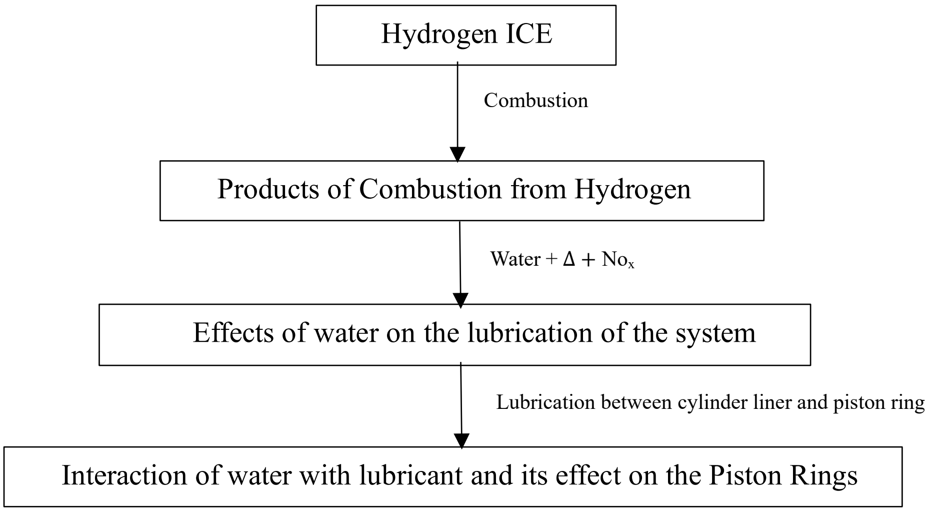

Figure 2: Flow Chart of literature review

3.1 Direct Injection of Hydrogen

A comprehensive review of Hydrogen Direct Injection reveals the distinct characteristics of hydrogen when utilized as a fuel in internal combustion engines. Notably, the primary harmful byproduct of hydrogen combustion is NOx, which has the potential to trigger pre-ignition of the fuel. Which can be mitigated through direct injection techniques and exhaust gas recirculation systems. The key advantage of hydrogen as a fuel is its ability to operate efficiently under lean mixture conditions, which is attributed to its high flame speed. Furthermore, despite low volumetric density, hydrogen presents a compelling alternative to traditional fuels such as gasoline or diesel due to its clean combustion characteristics. [6]

Hydrogen internal combustion engines follow diesel combustion cycle. The methods of injecting hydrogen into the combustion chamber in a hydrogen internal combustion engine are:

1. Port Injection: Majority of Hydrogen ICEs use port injection, port injection is a method of injecting hydrogen in proportions with air from the intake manifold into the combustion chamber.
2. Direct Injection: Direct injection of hydrogen into the combustion chamber is very similar to injection of diesel into the combustion chamber. The use of small quantities of diesel jet to auto ignite the hydrogen direct injection jet is proposed and is also known as Hydrogen Direct Injection(H2DDI) mode.
3. BMW developed a hydrogen direct injection system with up to 300 bar injections and integrated a spark ignition, achieving a maximum efficiency of 42%. [6]

A pivotal exploration into hydrogen fuelled internal combustion engines presented by BorgWarner sheds light onto Hydrogen Internal Combustion Engines offer an efficient and cost-effective route to achieve carbon net zero in the mobility space. The report also states that around 11% of global energy related CO_2 emissions come from passenger vehicles and 7% from commercial vehicles. The report provides an overview about the advantages of offered by directly injecting hydrogen into the combustion chamber over port injection, such as not affecting the volumetric efficiency and eliminating backfire. [7]

3.2 Products of Combustion

Hydrogen is a colorless, odorless gas which is readily available and constitutes 75% of the universe's mass. The other sources of hydrogen are from biological organisms which naturally produce hydrogen from their metabolic processes. The production of hydrogen mainly involves electrolysis of water.

When hydrogen is directly injected into the combustion chamber of an internal combustion engine, the products of hydrogen and air are water, heat and NO_x emissions. This can be demonstrated with the chemical reaction shown below:

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \Delta Heat$$

Equation 1: Combustion of Hydrogen

The technical review about the use of hydrogen in internal combustion engines, the stoichiometric Air Fuel Ratio of Hydrogen Internal Combustion engine is 34:1, that is its takes 34 units of air by mass to combust 1 unit of hydrogen by mass. [8] The stoichiometric value obtained is much greater than conventional internal combustion engines at 14.7:1. The volume occupied by air is comparatively smaller and in ideal conditions hydrogen displaces the combustion chamber more than that of conventional liquid fossil fuels.

A technical review highlights the emission and clean combustion characteristics of hydrogen to potentially operate with near net zero emissions mainly due to two unique characteristics of hydrogen's flow flammability limit allows for stable combustion under highly dilute conditions. This can result in low combustion temperatures, which can relatively reduce the rate at which NO_x emissions are formed. [9]

3.3 Effect of Water on Lubricants

The above section helped us understand the characteristics of hydrogen as a fuel and the products of combustion, in this section we move our focus more towards the effect of water on the lubricant. The test conducted by [5] helps in understanding the effect of simultaneous dilution of water in the lubricant and its effect on the viscosity of the lubricant, the test conducted is very similar in terms of the samples used that is pure 0W20 oil and 0W20 oil+5% dilution of water. The mini traction machine test Stribek curves is essential to understand the transition of lubrication regions. It is observed from the Anti Film Thickness test with pure 0W20 oil sample was found to be thicker and rougher in comparison to diluted counterpart which signifies that 0W20 oil samples are prone to provide better protection in comparison to diluted counterpart.

From a study conducted by [10] it is observed that there is significant decrease in lubricity of the lubricant and the esters present in the oil is almost disappeared entirely. Due to the high flame speed of hydrogen fuel and the resultant rapid pressure rise, the piston rings fail to provide a total seal as the molecules of hydrogen are very small and very likely to seep between the cylinder wall and the piston rings to interact with the lubricants.

The other harmful effects of water mixing with lubricants is that it can react with some additives not only making them chemically unavailable but can also transform them into harmful sludge or acids. A sulfurized additive can interact with water to form hydrides of sulphide which have proven to be harmful to the environment. [11]

Tests related to the effects of lubricant contamination with water, the wear of ferrous materials in hydrogen environment mainly focuses on the wear of parts such as bearings, seals, and valves in a hydrogen environment. Ferrous metal components are used in hydrogen internal combustion engines mainly due to the mechanical properties and effectiveness; these metals are also prone degradation. The experimental setup in [12] comes close to the experimental methodology conducted in this report. Additionally, the experimental setup [12] is designed to study of effects of water and oxygen impurities in hydrogen on the tribological properties of ferrous materials. The results obtained from [12] states that the coefficient of friction of ferrous metals varied with different concentrations of water.

3.4 Tribology of Piston Rings

Piston rings provide a seal between the crown on the piston and the cylinder. They prevent blow by of products of combustion into the oil sump which leads to the contamination of the lubricant oil. Piston rings can be classified into two categories Oil rings and Compression rings. Oil rings allow the lubrication of the cylinder wall against the piston during its translating motion. Compression rings help in providing a tight seal between the piston and cylinder wall to prevent harmful gases entering the oil sump. The ideal properties of piston ring include its resistance to corrosion and elasticity under all working conditions. Due to the smaller atomic size of hydrogen can lead to hydrogen entering the lubricant in the oil sump. The heat produced in the combustion chamber leads to the formation of micro welds onto the cylinder walls, thereby scratching the surface of the cylinder leading to ovality of the piston. Understanding the tribology of a piston becomes crucial in this study.

Understanding the friction between the piston ring and the cylinder liner helps us gain a better understanding of the sliding contact between the piston ring and the liner under various loads. According to a review by [13] the ring friction depends on various factors such as load on the piston ring, the surface properties, and the lubricating conditions. The frictional properties of a lubricant and different speeds are commonly expressed in terms of Stribek's Curve, which consists of three regions Boundary, Mixed and Hydrodynamic region [14]. From [15] observed boundary and mixed layer lubrication at the top and bottom dead centers of the pistons, a hydrodynamic layer is found during the mid stroke of the piston. The increase in coefficient of friction can lead to scuffing caused by micro welds formed on the surface of the liner.

The table below illustrates the literature review conducted across various aspects of the project addressing the research gaps and relevance.

3.5 Literature Review Table

Title	Objective	Methodology	Key Findings	Relevance to Study
A Review of Hydrogen Direct Injection for Internal Combustion Engines: Towards Carbon-Free Combustion [6]	This paper aims to review the use of hydrogen as an alternative to fossil fuels and its recent development. It discusses properties of hydrogen and different injections methods, evaluating potential of direct injection.	Systematic review of existing literature, studies, and research on hydrogen in ICEs	Hydrogen is a promising alternative due to its carbon-zero content. Hydrogen can be used in two energy forms: Direct Injection as fuel and Fuel Cells	Helps in understanding the current state of development of HICEs.
Direct Injection systems for Hydrogen Engines [7]	BorgWarner has developed a hydrogen direct injection.	A 1.5L, four-cylinder gasoline engine with DI was converted to support hydrogen.	Lean operation of Hydrogen reduces combustion rate and noise, improving efficiency. Reduces NOx emissions.	Practical implementation of Direct injection of hydrogen into the combustion chamber.
Hydrogen use in Internal Combustion Engine: A review [8]	Explores the use of hydrogen as a fuel	A review of methods of injecting hydrogen, design, and efficiency of the engines	Stoichiometric A/F of HICEs is 34:1, higher compared to conventional gasoline engines. Hydrogen can be used dual-fuel mode configuration.	Thermal efficiency of hydrogen and stoichiometric A/F ratio of HICEs.
Characterising the effects of simultaneous water and gasoline dilution on lubricant performance [5]	Different operating conditions in hybrid electric vehicles can increase water and fuel dilution of engine oil.	Testing samples of pure oil(0W20) and 0W20 + water dilution	The anti-wear film from pure oil is significantly thicker and rougher. Water dilution increase low shear viscosity	Similar grade of oil used, and the lubricating property of pure oil is similar to the experiment conducted.

The trouble with water [11]	Effects of water contamination in lubricants and methods to address the issue.	Methods to evaluate water content in oil by Visual Inspection and testing for moisture.	Water contamination can cause problems such as fluid breakdown, reduce lubricating film thickness and corrosion. Mixing with sulphides which can be harmful for the environment	Understanding the effects of water in lubricants on the lubricant performance and the environment.
Friction and Wear of Ferrous Materials in a Hydrogen Gas Environment [12]	Influence of traces of water on ferrous materials	Material Used: Austenitic Stainless steel, A sliding contact for different concentrations of water	Variation in coefficient of friction of Austenitic Steel at different concentrations of water.	Understanding the effects of water on stainless steel in the absence of lubricant.
Piston ring tribology [13]	Study focuses on the tribology of piston rings used in ICEs	Uses Oil Film model	Study of oil film thickness under different engine speed and load.	The review helps in understanding the functioning of a piston ring and different speeds and loads with varying oil film thickness.
Automotive Engine Tribology [14]	Design considerations for improving efficiency and durability	Various modes of lubrication. Design considerations for piston rings.	A fluid exhibits boundary layer regime at the TDC and BDC. It exhibits mixed layer regime during mid stroke.	Phase transitions of regime during the translating motion of the piston.
Automotive Tribology overview of current advances and challenges for the future [16]	Importance of tribology for automotive components Lubrication regimes of different components of an engine.	Test methods to correlate to real world conditions.	Lubrication regimes of engine components. Journal bearing are required to work in hydrodynamic region to ensure proper lubrication.	The journal bearing is similar to an apparatus setup. Understanding the speeds at which contact between surfaces is in hydrodynamic regime

Table 2: Summary of literature review

4 Components and equipment

4.1 Component Drafts

The holder consists of two components, these components have been machined and customized for this experiment. The entire procedure involved in designing the component and outsourcing the manufactured component from Xometry, who is a vendor in this current project. The funding for this project has been approved by the Department of Natural, Mathematical and Engineering Sciences, King's College London.

Note: All the drawings shown below follow 1st angle of Projection.

4.1.1 Part Name: Holder Lock/ Part 1

The holder lock is an engineered component designed specifically for this experiment to stabilize the holder which houses the ball that encounters the rotating disc. It features a shaft that can be attached to the suspension of Universal Testing Machine.

Technical specifications:

Material Used: Aluminum alloy, identified as 6082/3.2315/ Al-Si 1Mg.

Tightness Tolerance: ISO 2768 Medium/ Standard Grade

Maximum roughness: 3.2μm Ra (Roughness average)

Number of threads: 1

Thread Dimension: M26x1.56g

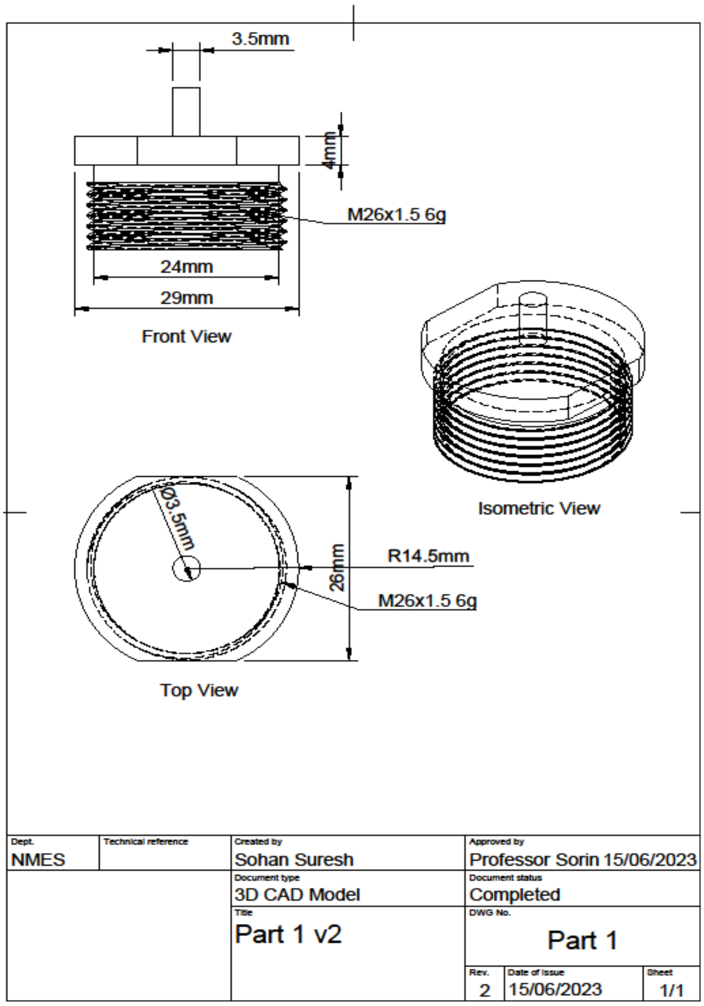

Figure 3: 2D Draft of Holder Lock/ Part 1

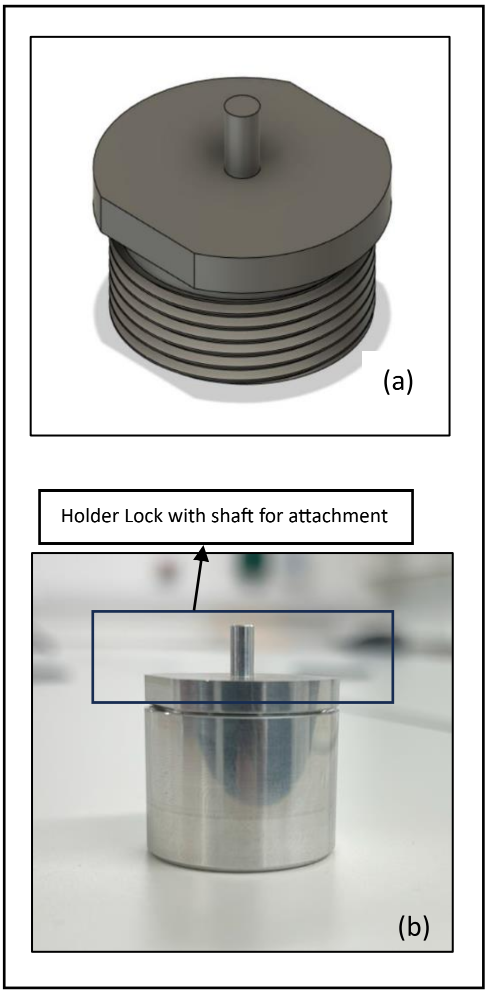

Figure 4: 3D Model of Holder Lock (a) and component (b)

4.1.2 Part Name: Ball Holder / Part 2

The ball holder is a specifically designed component used in this experiment. The ball holder accommodates the ball which is used to apply load of the rotating disc. The holder ensures that there is minimal motion of ball within the cavity ensuring the ball is in a secured position while the load is applied.

Technical specifications:

Material Used: Aluminum alloy, identified as 6082/3.2315/ Al-Si 1Mg

Tightness Tolerance: ISO 2768 Medium/ Standard Grade

Maximum roughness: 3.2μm Ra (Roughness average)

Number of threads: 1

Thread Dimension: M26x1.56H

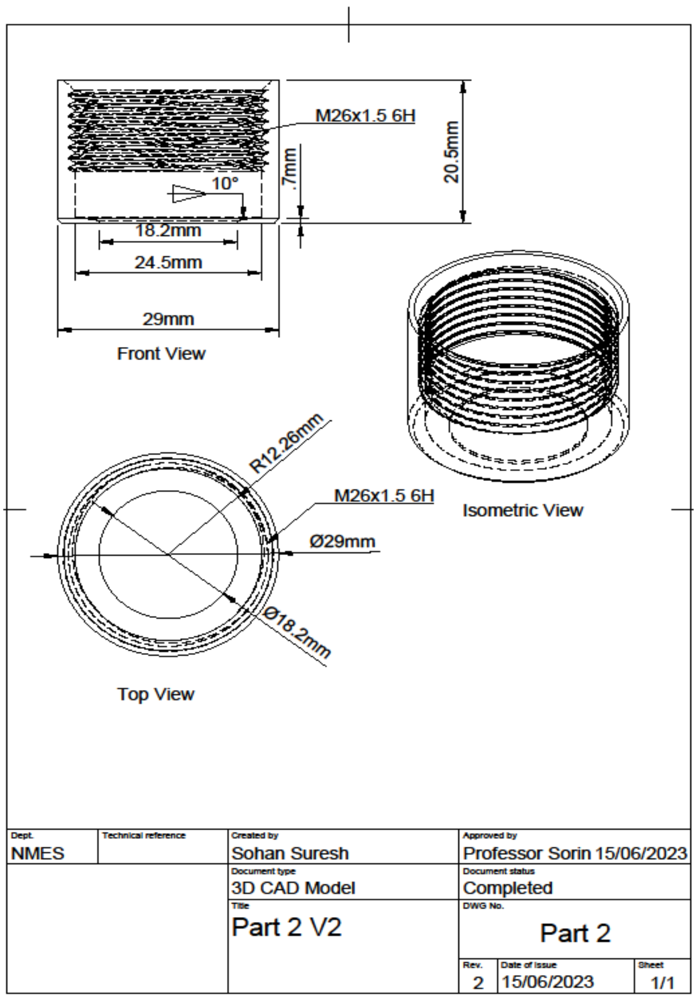

Figure 5: 2D Model of Ball Holder /Part 2

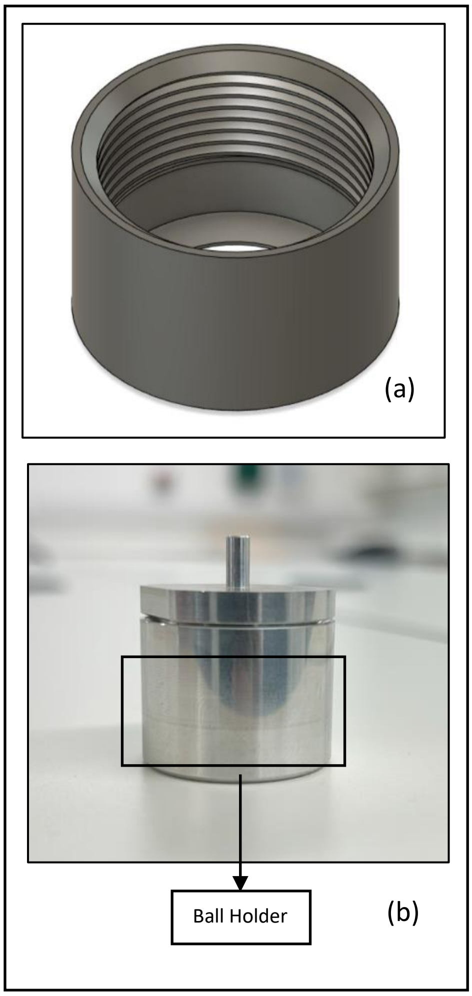

Figure 6: 3D Model of Ball Holder (a) and component (b)

4.1.3 Part Name: Ball /Part 3

The rotating ball plays a major role in this experiment. The main function of the ball is to ensure that it applied load on the rotating disc uniformly and always remains in contact with the disc and at varying speeds. The ball holder and the lock help in securing them in a firm position.

Technical Specifications:

Ball Diameter: 19.18mm

Material: Stainless steel

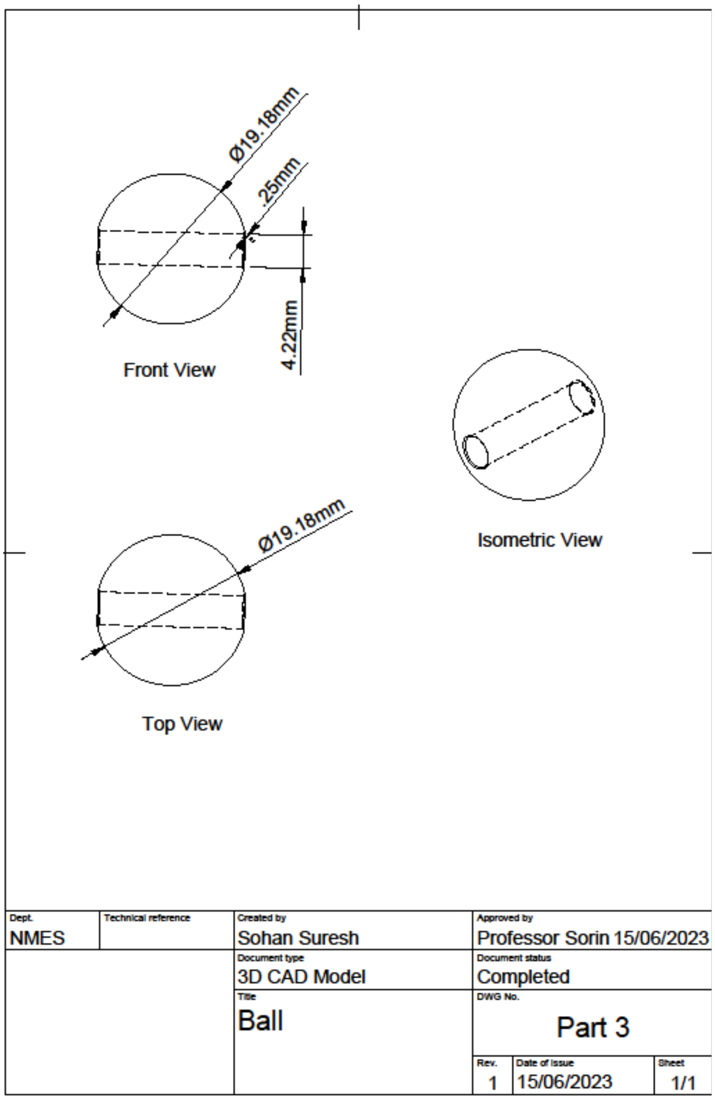

Figure 7:2D Draft of Ball

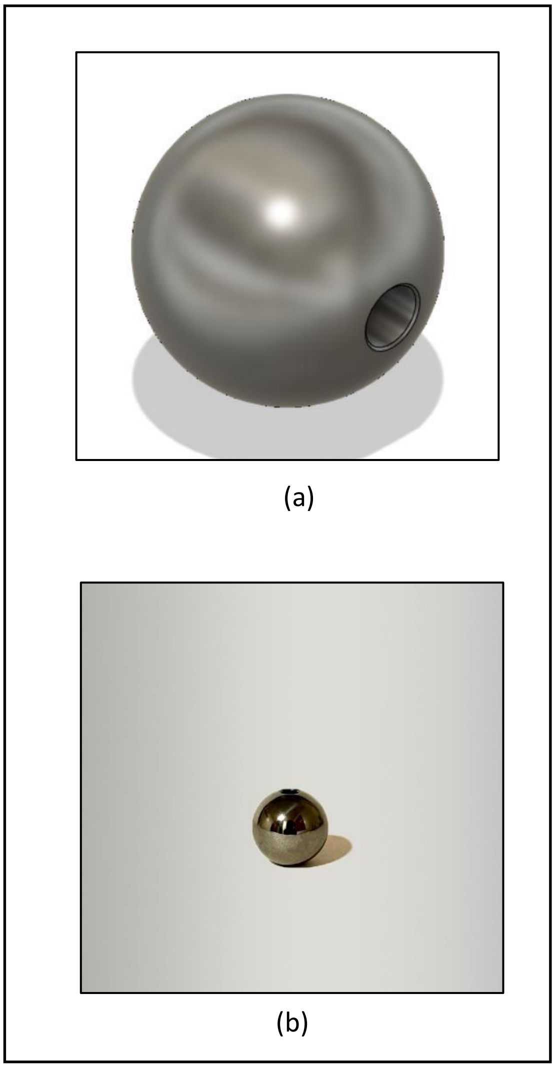

Figure 8: 3D Model of Ball(a) and component(b)

4.1.4 Part Name: Rotating Disc

The rotating disc plays a pivotal role in this experiment, it is bolted onto the lower assembly of the UTM machine and is submerged in an oil bath, the rotating disc rotates at variable speed by a motor drive in the lower assembly while it is subjected to a constant load applied by the boil. The outer diameter of the disc is a polished region which encounters the ball during the experiment.

Technical Specifications:

Disc Diameter: 45mm

Material: Stainless steel

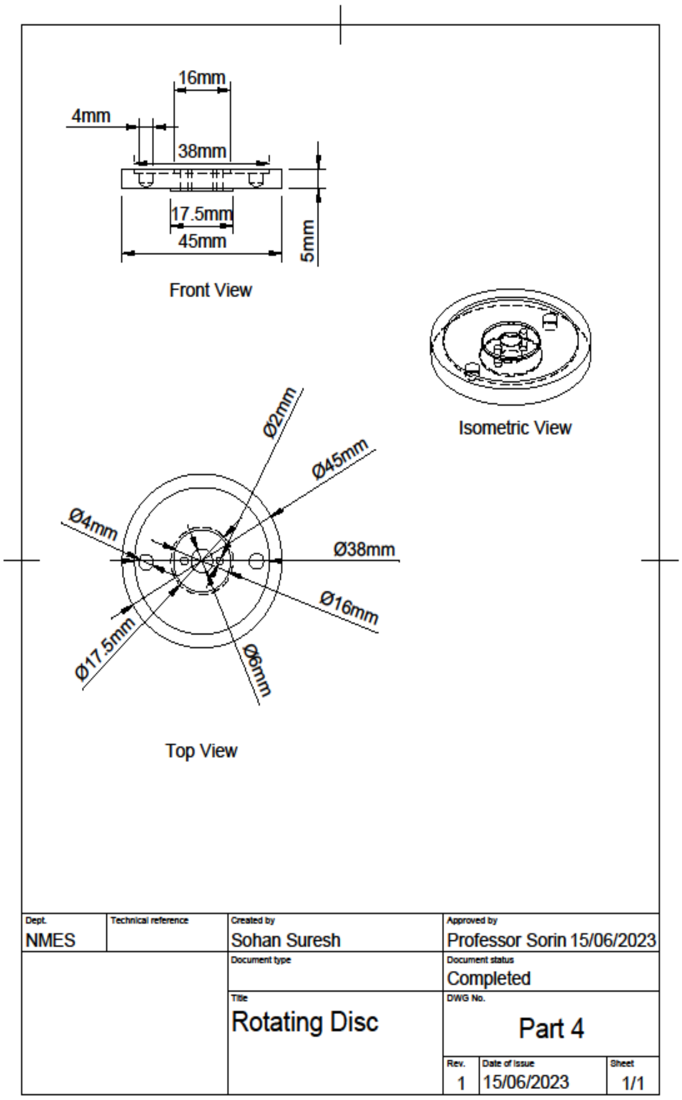

Figure 9: 2D Draft of Rotating Disc

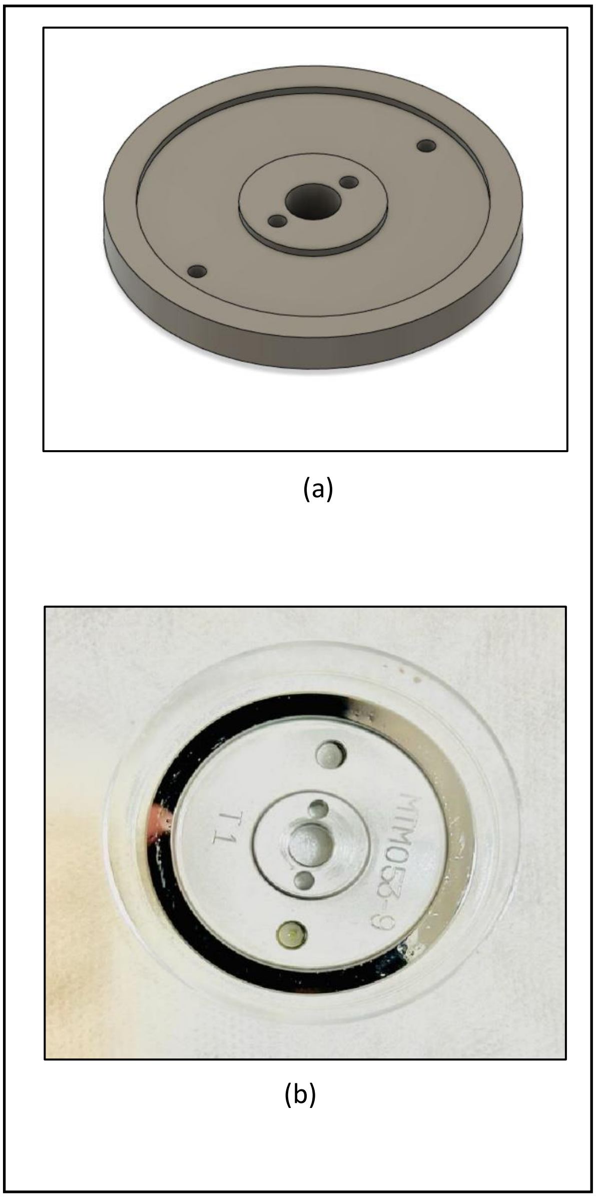

Figure 10: 3D model of Rotating Disc (a) and Component (b)

4.2 Bruker TriboLab UMT Test Rig

The experiment is conducted using a TriboLab Universal Mechanical Tester rig. The applications of a Bruker TriboLab UMT Machine can be from Brake Material Screening, Lubricant Testing and Wet clutch material Screening. This test rig can be used for testing Lubricant and additives which is the primal focus in this experiment. The types of lubricants that can be tested using Bruker TriboLab UMT Test Rig varies from a broad range of Diesel Oil, Coolants, Synthetics, Lubricating Oils, Lubricating Greases, Automotive Lubricants, and Industrial Lubricants. [17]

Figure 11: Universal Mechanical Tester by Bruker [18]

The test rig caters to experiment and simulates a rotary internal combustion engine by rotating the disc at different speeds. This experiment can be successfully conducted using the above components mentioned in the report above and the test rig. [17]

The other components that are used in this experiment are the software component from Bruker which enables us to vary the loading and determine the results of our experiment. The UMT software is a proprietary tool provided by Bruker. This tool enables us to load the rotating disc with static or dynamic loads by varying the RMPs. The test rig offers various sensors such as Load Sensor, Torque Sensor, Contact Acoustic Emission sensor, Electrical Contact resistance sensor, DC voltage sensor and a digital camera. [17]

The test rig is supported by a high-density cast-iron vibration damped frame. The test rig also accommodates additional components. It also consists of a lower assembly which can be used to mount the rotating disc to simulate a rotary motion. The methodology of conducting this experiment is discussed later in this report. The load sensor used in the test rig is Gold Series sensors, which provide noise levels, measuring at just 0.02% of their maximum capacity. Additionally, the sensor range has expanded significantly, now encompassing eleven different sensors capable of detecting forces ranging from 1 millinewton to 2 Kilonewtons. [17]

4.3 Lubricant Used

The lubricant used in this experiment depends on the type of vehicle that is going to be running hydrogen internal combustion engines. The focus on the type of vehicle used are earth moving equipment and long-haul vehicles like trucks. The engines used in trucks require a torque band at a very low RPM. [19] This is mainly because the trucks require a greater initial torque to move from a stationary position with greater loads. The engines are designed with a smaller bore and a longer stroke to generate greater torque. These engines can be categorized as heavy-duty engines. The dependency on fossil fuels for long haul vehicles can be reduced by using hydrogen as an alternate source of energy. [19]

The lubricant used in this experiment is Mobil 1 0W-20, this lubricant is a fully synthetic engine oil certified by API SN Plus/SP. The experiment comes close to simulating a long-haul vehicle which uses grades of 0W-20 or 5W-40. The main reason to go for a lubricant with such lower viscosity is mainly due to the cold start conditions. The lubricant used for testing in this experiment is 0W-20, which can be used to simulate a heavy-duty engine performance at certain RPMs. [20] The blend of the lubricant used is a fully synthetic oil. The main reason to use this as a synthetic lubricant is mainly because the additives and blend of esters help us simulate the working of an engine better. [20]

The tests conducted by [5] shows various concentrations of water mixed with lubricating oil. The study mainly focuses on understanding the viscosity of the mixture and emulsion of water in oil at different concentrations and temperatures.

The purpose of using ultra-low viscosity oil is to achieve ultra-low viscosity and improving thermal efficiency based on numerical simulation and theoretical analysis, the research methodology proposes a multi-dynamics model under mixed lubrication regimes with the loading being calculated numerically and verified experimentally using SAE 0W20 lubricant. The tests concluded that ultra-low viscosity oil can be used in internal combustion engines considering the various design parameters. [21]

5 Methodology

The experiment was carried out in a well-equipped laboratory setting, ensuring a controlled and secure environment. All necessary safety protocols were strictly adhered to, and appropriate personal protective equipment, including gloves, lab coats, and safety glasses, were used throughout the process. It is important to highlight that the experiment was not a solitary endeavor; rather, it was conducted under the watchful and expert supervision of my project supervisor. His supervision ensured not only the accuracy and reliability of the experimental procedures and data collected, but also the safety and wellbeing of all individuals involved.

The methodology of this experiment can be explained using the signpost show below:

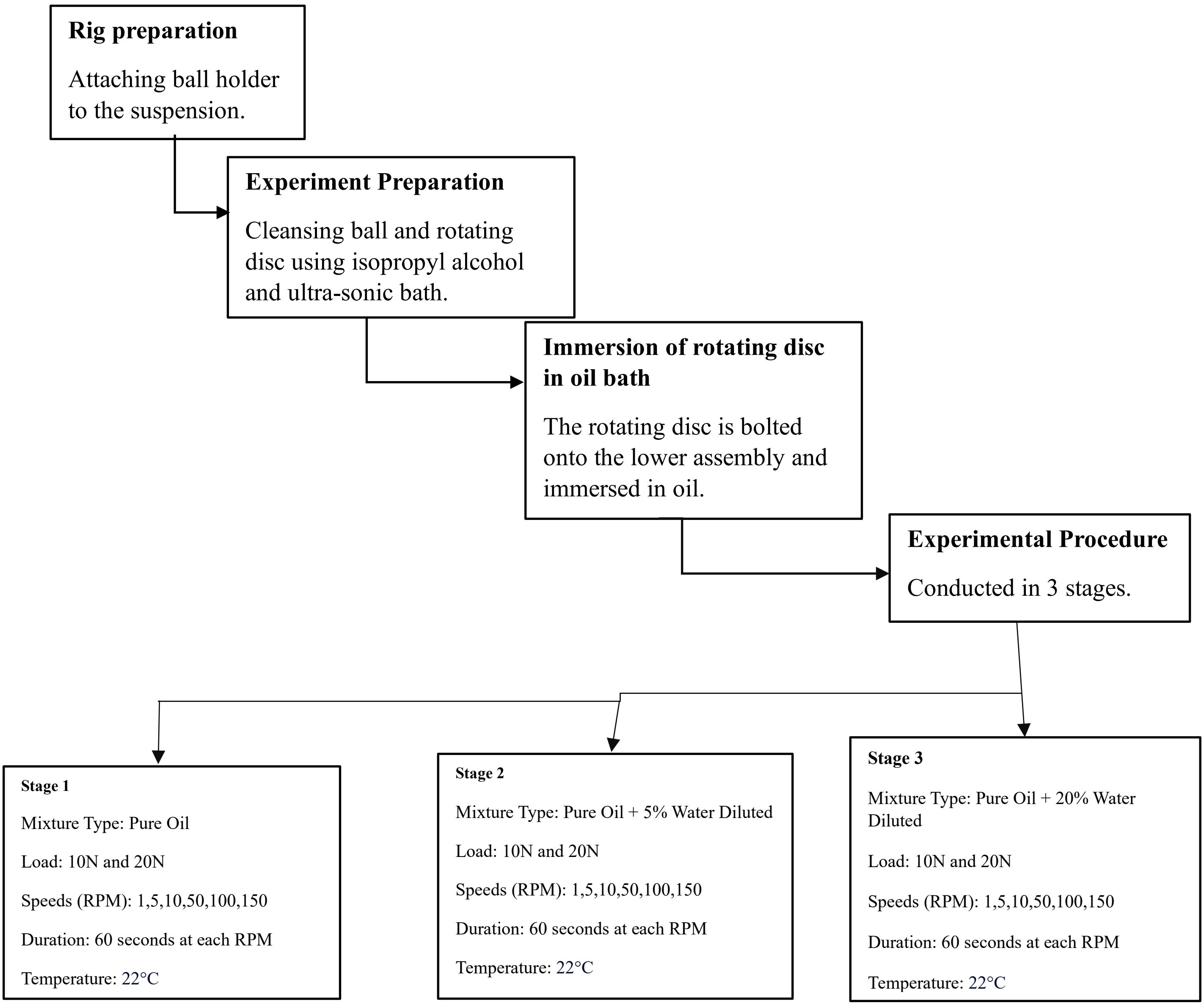

Figure 12: Flow Chart of experiment procedure

5.1 Rig Preparation

The test rig is provided with additional support which enables us to mount the holder. Additional support was utilized to securely mount the holder onto the load sensor on the test rig, ensuring accurate and reliable measurements. The mount is secured to the load sensor firmly using four screws across the edges of the mount. While the holder is held in place with a with a attachment secured using a bolt. The load sensor is calibrated according to the position of ball holder to ensure correct loading is applied on the ball which translates to applying force on the rotating disc.

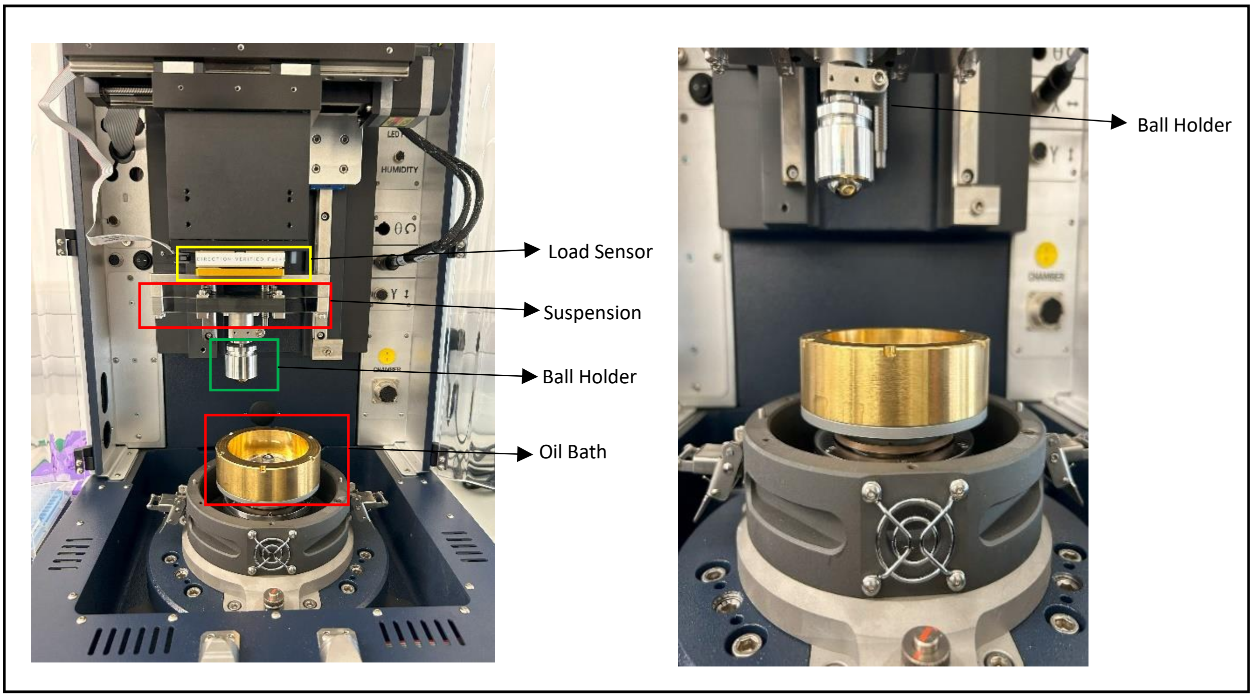

Figure 13: Holder mounted to load sensor.

5.2 Experiment Preparation

The rotating disc and the ball are cleaned using Isopropyl alcohol. This is done to make sure that the ball and disc are free of any contaminants, following which the ball and the disc are immersed into an ultra-sonic bath before conducting the experiment. An ultrasonic bath is used for cleaning because of the ultrasonic cavitation bubbles collapse, leading to cleansing action that can remove dirt, grease, or other deposits on the metal surface.

Figure 14: Ultra-sonic bath used in the experiment.

5.3 Experimentation Procedure

The experiment is carried out in three different stages and the duration of application of load at a given speed is limited to 60 seconds for the entire experiment. The different stages of the experiment are explained below:

Stage 1: The disc is bolted on to the lower assembly of the test rig. The disc is immersed in pure oil bath. A consistent force of 10N is exerted onto the rotating disc by the ball at an initial rotational speed of 0RPM. This step is sequentially replicated at rotational velocities of 1,5,10,50,100 and 150 RPM. Data is acquired from the load sensor.

Stage 2: The disc is submerged in the lubricant with 5% dilution of water, the oil is mixed with water using a stirrer, the submerged disc is now subjected to 10N of load starting from 0rpm to 150rpm, while repeating the same steps for a load of 20N.

Stage 3: The disc is submerged in the lubricant with 20% dilution of water, the oil is mixed with water, a similar type of experiment procedure is followed from stage 2 where the disc is subjected to a load of 10N and 20N with varying rpms from 0rpm to 150rpm.

5.4 Immersion of Rotating Disc in oil bath

The rotating disc is bolted on to the bottom of lower assembly of the test rig and the disc is submerged in the oil bath. The first stage involves immersing 200ml of pure oil in the bath chamber, subsequently a similar method is repeated for pure oil+5% water diluted and pure oil+20% water diluted mixture. Prior to introducing a subsequent lubricant mixture, the reservoir is purged of the previous mixture and thoroughly cleaned.

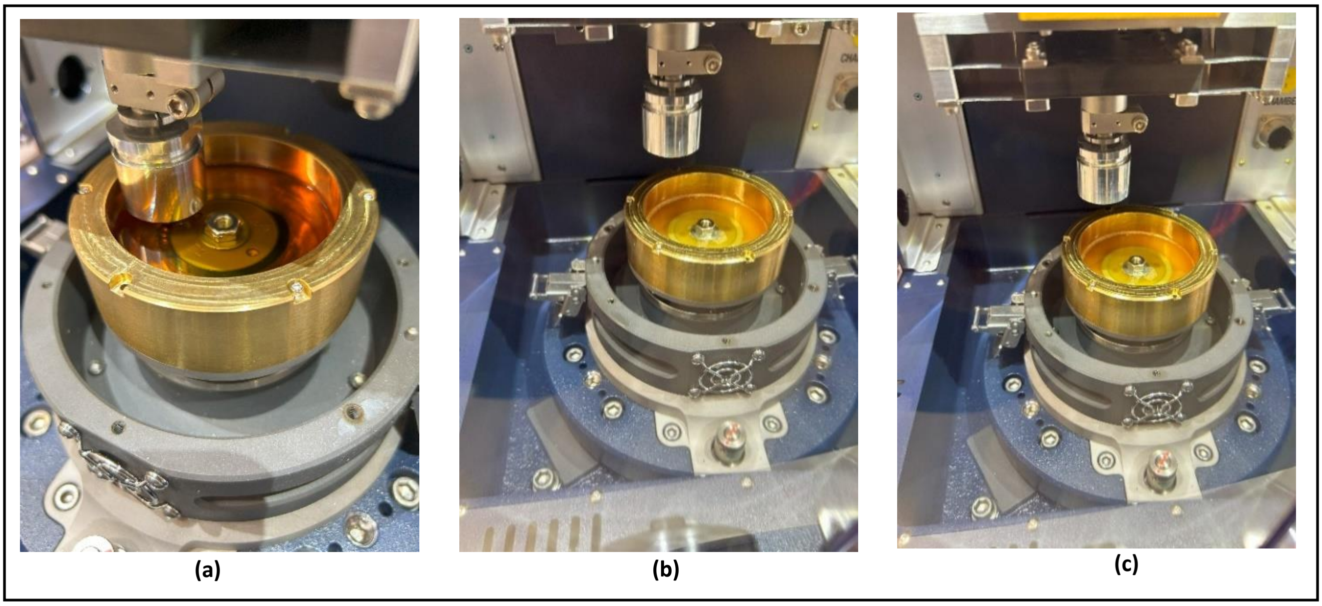

Figure 15: Rotating disc and ball immersed in Pure Oil(a), 5% Water in Oil(b), 20% Water in Oil(c)

The mixing of pure oil and water is performed using a stirrer.

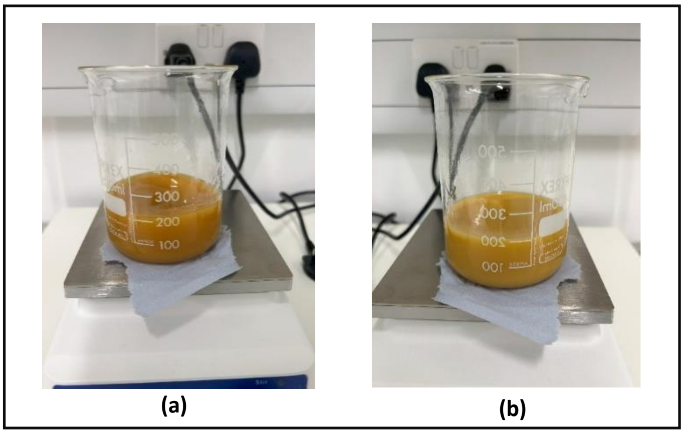

Figure 16: Mixtures of 5% Water in Oil (a), 20% Water in Oil (b)

5.5 Data from sensor

The output derived from the equipment's load sensor is presented as tabulated data, delineating parameters such as Time (in seconds), Force along X direction Fx (in newton), Force along Z direction Fz (in newton), Speed (in RPM), Force resultant to X direction Ff (in newton) and the coefficient of friction between the two surfaces. The representation of the output from the test rig is shown below:

	A	B	C	D	E	F
7						
8	Run # 1					
9	Script file C:\Users\PC\Desktop\Sohan\Sohan.ctsx					
10	Run date 10 Jul 2023 20:00:30					
11	Step No. 1					
12						
13	Step Type Code: 0					
14	Radius = 23.1608					
15	Velocity = 0					
16	Set Force = -10					
17	Duration = 20.00					
18	Data Count = 201					
19	Started at: 20:01:02.765 10 Jul 2023					
20						
21	T	Fx	Fz	V2	Ff	COF
22	sec	N	N	RPM	N	
23						
24	0	-0.09876	-9.93249	0	0.098758	0.009943
25	0.1	-0.09876	-9.95699	0	0.098758	0.009918
26	0.2	-0.09876	-9.98714	0	0.098758	0.009888
27	0.3	-0.09876	-9.99091	0	0.098758	0.009885
28	0.4	-0.10062	-9.99845	0	0.100621	0.010064
29	0.5	-0.09876	-10.0003	0	0.098758	0.009875
30	0.6	-0.10248	-10.0003	0	0.102484	0.010248
31	0.7	-0.10062	-9.99845	0	0.100621	0.010064
32	0.8	-0.10248	-9.99468	0	0.102484	0.010254
33	0.9	-0.10248	-9.99279	0	0.102484	0.010256
34	1	-0.10248	-9.99279	0	0.102484	0.010256
35	1.1	-0.10248	-9.99468	0	0.102484	0.010254

Figure 17: The output obtained from sensor.

6 Results and Discussion

The data procured from the sensor can be delineated across various parameters. The resultant data is segmented into distinct categories, each accompanied by its pertinent analysis as illustrated subsequently.

6.1 Pure Oil

6.1.1 Pure Oil with applied load of 10N

The plot below represents Coefficient of Friction vs Time at varying speeds:

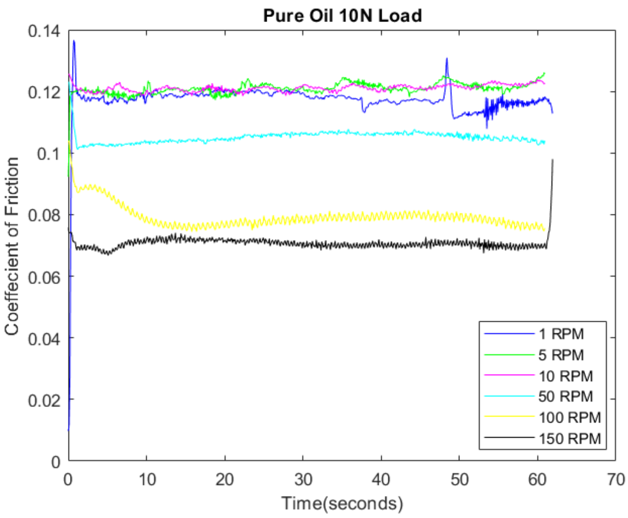

Figure 18: COF vs Time Plot for Pure Oil under 10N load

We can categorise the speeds (in RPM) to different lubrication regimes:

- **At speed: 1RPM, 5RPM and 10PRM**
  At these lower speeds, the lubricant exhibits characteristics of boundary lubrication. In this regime, the lubricant film thickness is minimal, leading to asperity contact between the interacting surfaces. This is indicative of the high coefficient of friction observed.
- **At Speed: 50 RPM**
  As the speed increases to 50 RPM, there's a notable decrease in coefficient of friction. This suggests an increase in lubricant film thickness, transitioning the system into the mixed lubrication regime.

At this speed both asperities contact, and the fluid film lubrication coexist, with latter becoming more dominant as speed increases.

- **At speed: 100RPM and 150RPM**
  At 100RPM, the coefficient of friction diminishes further, signifying a shift to the hydrodynamic lubrication regime. In this domain, a full film lubrication is established, effectively separating the surfaces with a substantial lubrication layer. This behaviour, characterized by increased film thickness and reduced friction, persists, and is similarly observed at 150 RPM.

6.1.2 Pure Oil with applied load of 20N

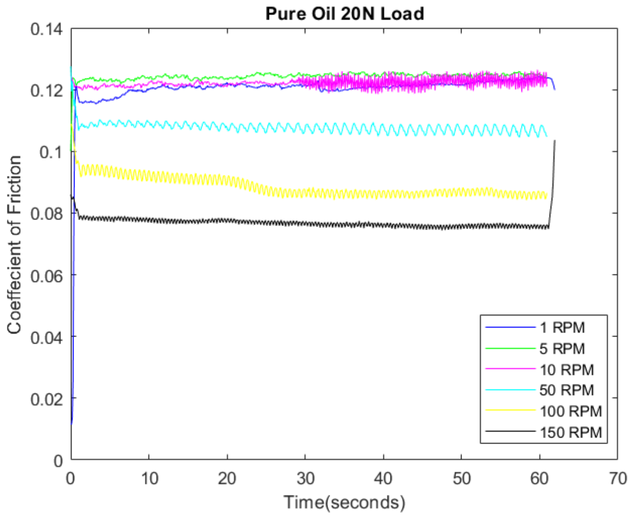

Figure 19: COF vs Time Plot for Pure Oil under 20N load

We can categorise the speeds to different lubrication regimes:

- **At Speed: 1 RPM, 5 RPM and 10 RPM**
  At speeds of 1 RPM, 5 RPM and 10 RPM it is observed that the lubricant film thickness is very thin, the asperity contact between the two interacting surfaces, which is observed with a higher coefficient of friction.
- **At Speed: 50 RPM**
  With an increase in rotational speeds, a discernible reduction in the coefficient of friction is evident, as illustrated in the preceding plot. This behaviour is indicative of an enhanced lubricant film thickness and asperity contact between the two interacting surfaces tend to exist.
- **At Speed: 100 RPM and 150 RPM**
  At rotational velocities of 100 RPM and 150 RPM, there is a marked reduction in the coefficient of friction. This trend strongly suggests an enhancement in the hydrodynamic lubrication, characterized by an increased lubrication film thickness separating the interacting surfaces. Notably, the data from the plot indicates a more pronounced reduction in the coefficient of friction at 150 RPM compared to 100 RPM.

Comparison between 10N and 20N plot

Analysing the data from both the figures, it is evident that as the applied load increases from 10N to 20N, there's a corresponding rise in the coefficient of friction. This behaviour underscores the principle that the increase in loading tends to compress the lubricant film, resulting in decrease in film thickness. Consequently, the interacting surfaces are more prone to asperity contact, leading to an increase in coefficient of friction across the entire speed spectrum tested.

6.2 Pure Oil + 5% Water Dilution

6.2.1 Pure Oil + 5% Water Dilution with applied load of 10N

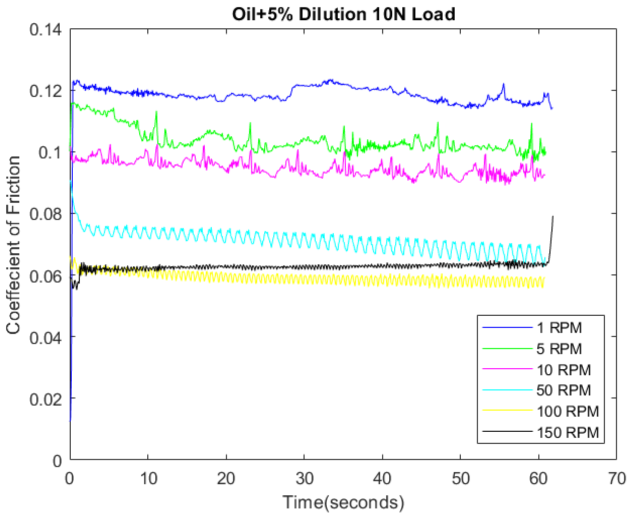

Figure 20: COF vs Time Plot for Oil + 5% Water Diluted under 10N load.

- **At Speed: 1 RPM, 5 RPM and 10 RPM**
  At rotational speed of 1 RPM, the frictional coefficient for both 10N and 20N load appears consistent with that of undiluted oil. As the rotational speed increases, there's a discriminable reduction in the coefficient of friction, a similar trend is observed in the previous plots. Notably, when utilizing a lubricant mixture of pure oil with 5% water dilution, the frictional coefficient at 5 RPM and at 10RPM it is notably lower compared to the undiluted oil under 10N load. This behaviour can be predominantly attributed to the change in viscosity of the lubricant due to dilution.
- **At Speed: 50 RPM**
  At a rotational velocity of 50 RPM, there is a marked reduction in the coefficient of friction when contrasted with the value at 1RPM, 10RPM and 15 RPM. This trend, which mirrors observations from the previous plots, can be attributed to the increase in the lubricant film thickness with an increase in speed which leads to a reduction in friction between the two contact surfaces.
- **At Speed: 100 and 150 RPM**
  At rotational speeds of 100 and 150 RPM, there's a discernible decline in the coefficient of friction, consistent with the characteristics of the hydrodynamic lubrication regime. In this regime, a substantial lubricant film is established, minimising direct asperity contact between the interacting surfaces. Notably, when compared to the undiluted oil under a 10N load, the frictional coefficient is observed to be lower, underscoring the influence of lubricant composition and load on tribological performance.

6.2.2 Pure Oil + 5% Water Dilution with applied load of 20 N

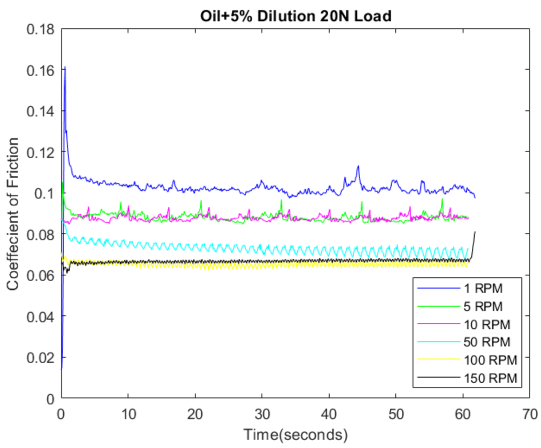

Figure 21: COF vs Time Plot for Oil + 5% Water Diluted under 20N load.

- **At Speeds: 1 RPM, 5RPM and 10 RPM**
  At rotational velocities of 1RPM, the lubricant mixture's behaviour aligns with the observation from the previous plot. As the speed increases to 5RPM and 10RPM, the coefficient of friction remains consistent with previous data trends. This suggests that, at lower rotational velocities, variations in lubricant dilution and applied load have a negligible impact on the coefficient of friction.
- **At Speed: 50 RPM**
  At a rotational speed of 50RPM, the coefficient of friction exhibits minimal variation when compared to the previous plot. This indicates a stable lubrication film thickness, suggesting that, in this regime, alterations in lubricant viscosity have a minimal influence on the coefficient of friction.
- **At Speeds: 100RPM and 150RPM**
  At rotational speeds of 100RPM and 150RPM, the coefficient of friction mirrors the trends observed at 150RPM, showcasing minimal fluctuations. This consistent behaviour across these speeds suggests a stable lubricant film thickness, indicating that the system predominantly operates within a consistent lubrication regime over this speed range.

Comparison between the Pure Oil Mixture and Pure Oil +5% Water Dilution mixture:

When contrasting the pure oil with pure oil augmented by a 5% water dilution under both 10N and 20N loads, there a discernible reduction in coefficient of friction with the later. This behaviour can be attributed to the enhanced hydrodynamic action, a phenomenon where there is a pressure build up in the lubricant film due to the decrease in viscosity and the relative motion between the surfaces and the modified viscosity characteristics introduced by the addition of water into pure oil.

6.3 Pure Oil + 20% Water Dilution

6.3.1 Pure Oil + 20% Water Dilution with applied load of 10N

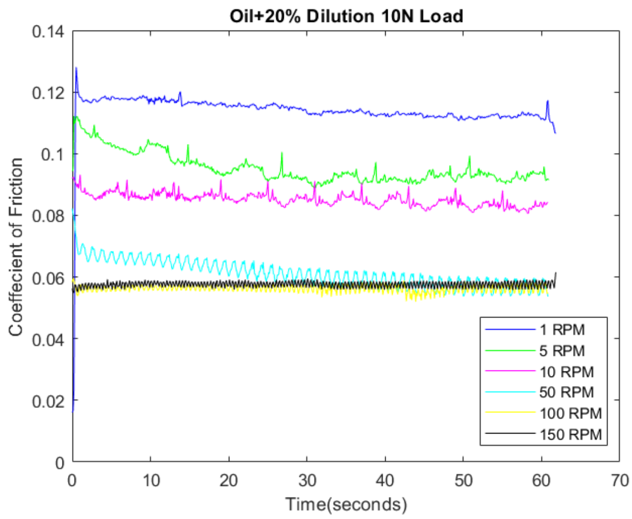

Figure 22: COF vs Time Plot for Oil + 20% Water Diluted under 10N load.

- **At speeds: 1RPM, 5RPM and 10RPM**
  At a rotational velocity of 1RPM, there is notable difference in the coefficient of friction in comparison to the previous plot of Pure Oil +20% Water dilution at 10N load. However, as the speeds increase to 5RPM and 10RPM, the lubricant mixture's behaviour aligns closely with that of the Pure Oil +5% water dilution. This suggests that, within the speed range, the lubricant composition imparts similar behaviour to the other mixtures.
- **At speed: 50RPM**
  Upon analysis, it is evident that at rotational velocities of 50RPM, 100RPM and 150RPM, the coefficient of friction exhibits a consistent behaviour. This trend indicates that within the speed range, variations in rotational speeds have a negligible impact on the coefficient of friction.

- **At speeds: 100RPM and 150RPM**
  At rotational speeds of 100RPM and 150 RPM, the coefficient of friction demonstrates consistent behaviour. This indicates that, within this velocity range, the coefficient of friction remains invariant.

6.3.2 Pure Oil + 20% Water Dilution with applied loading of 20N

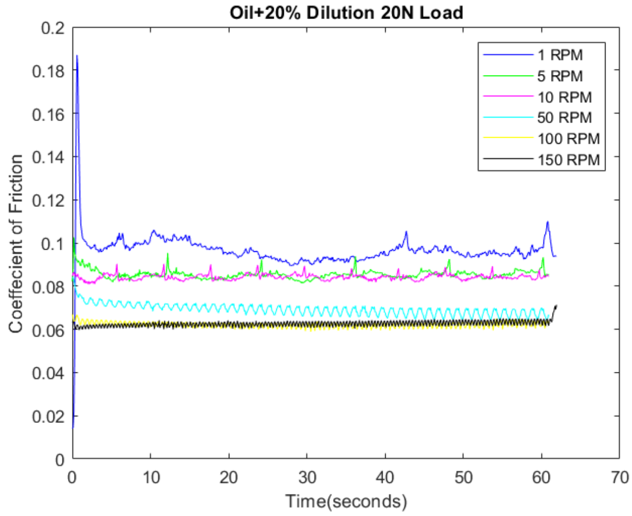

Figure 23: COF vs Time Plot for Oil + 20% Water Diluted under 20N load.

- **At Speeds: 1RPM, 5RPM and 10RPM**
  At rotational velocity 1RPM, there's a noticeable decrease in coefficient of friction. However, when the speed is increased to 5RPM and 10RPM, the coefficient of friction remains constant, both between these speeds and in relation to data from other plots. This suggests that variations in load and alterations in lubricant viscosity have minimal impact on the coefficient of friction within the speed range.
- **At Speed: 50RPM**
  At a rotational speed of 50RPM, the coefficient of friction aligns closely with the values observed at 100RPM and 150RPM. This indicates that the introduction of water dilution doesn't introduce any significant variations in the coefficient of frictional behaviour between the interacting surfaces with this speed range.
- **At Speeds: 100RPM and 150RPM**
  At rotational velocities of 100RPM and 150RPM, the coefficient of friction exhibits consistent values across both speeds. This suggests that beyond specific rotational thresholds, the influence of dilution on the coefficient of friction becomes negligible.

Comparison between mixtures of Pure Oil, Pure Oil +5% Water dilution and Pure Oil +20% Water Dilution

Based on the data sets across both the applied loads, several key trends emerge. Compared to the pure oil mixture, the coefficient of friction between the interacting surfaces is observed to decrease. Furthermore, an escalation in the applied load trends to amplify the coefficient of friction across the tested speed range, as the rotational speed increases, their influence on the coefficient of friction diminishes, indicating a stable lubrication regime at higher speeds.

6.4 Stribek Curve for applied loading of 10N

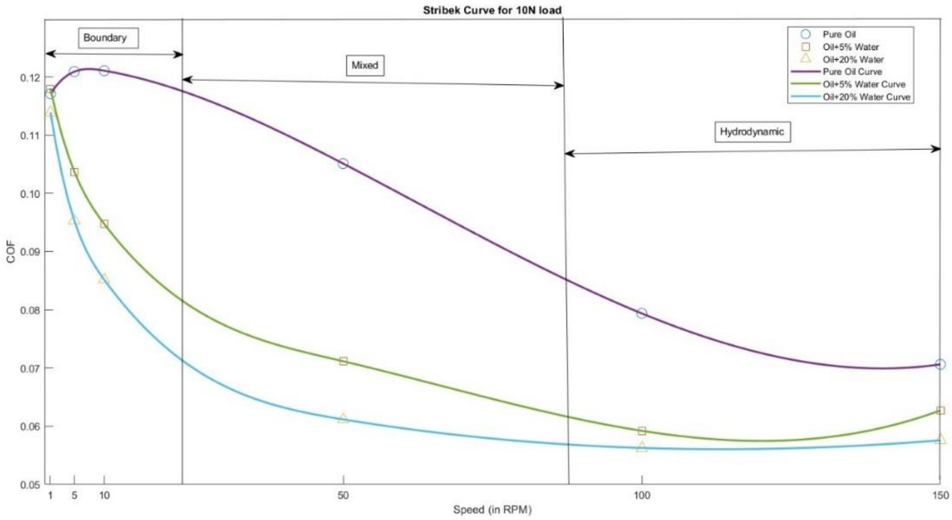

Figure 24: Stribek Curve for 10N load

The average value of coefficient of friction across all the speeds and mixtures is given in the table below:

Composition/ Speed (RPM)	1	5	10	50	100	150
Pure Oil	0.1172	0.1209	0.1210	0.1051	0.0794	0.0706
Pure Oil +5% Water Diluted	0.1180	0.1037	0.0947	0.0712	0.0592	0.0627
Pure Oil +20% Water Diluted	0.1139	0.0953	0.0852	0.0612	0.0563	0.0576

Table 3: Average COF values for Different Oil Mixtures and Speeds for 10N load

The plot represents a Stribek curve which can be segmented into three regimes,

Boundary Regime: Within this regime, characterized by rotational speeds of 1RPM, 5RPM and 10RPM, the lubricant film is notably thin, resulting in elevated friction due to increased surface interactions. It is observed that introducing dilution to the lubricant leads to a reduction in the coefficient of friction. This behaviour can be attributed to viscosity alterations stemming from varying water concentrations in the lubricant mixtures. Additionally, a trend is evident where the coefficient of friction reduces as rotational speeds escalate.

Mixed Regime: Within this regime, a further reduction in the coefficient of friction is evident for all mixtures. Here, both asperities contact, and a coexisting lubrication film are present. Notably, the mixture of pure oil with 20% water dilution exhibits the lowest coefficient of friction compared to the other two mixtures. The reduction in viscosity, particularly in the 20% water diluted and 5% water diluted samples, likely contributes to the reduction in friction.

Hydrodynamic Regime: Within this regime, characterized by elevated rotational speeds, there's discernible decline in the coefficient of friction for all mixtures, indicative of a robust lubricant film separating the interacting surfaces. The hydrodynamic regime is existent at speeds greater than 100RPM. The mixture of pure oil +20% water diluted, owing to the altered viscosity from contamination, exhibits a particularly pronounced reduction in friction compared to the other two mixtures.

6.5 Stribek Curve for applied loading of 20N

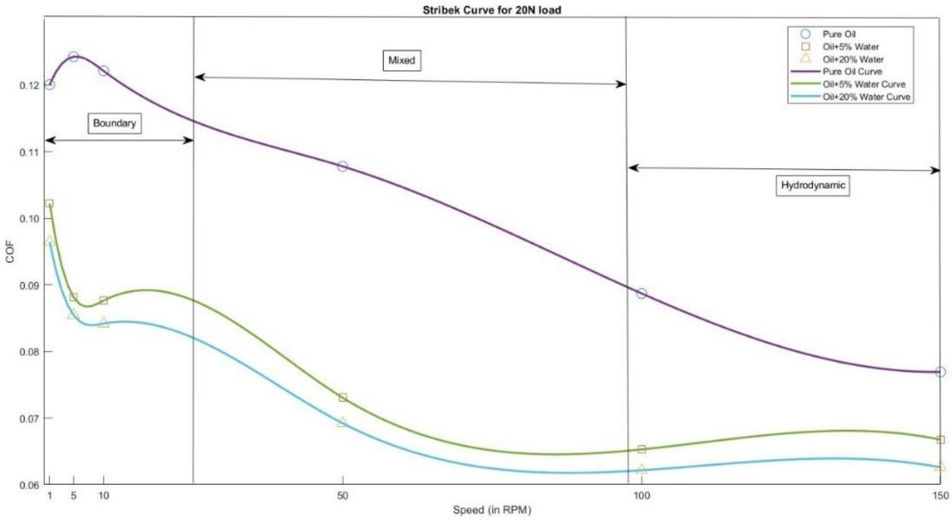

Figure 25: Stribek Curve for 20N load

The average value of coefficient of friction across all the speeds and mixtures is given in the table below:

Composition/ Speed (RPM)	1	5	10	50	100	150
Pure Oil	0.1201	0.1243	0.1221	0.1078	0.0887	0.0769
Pure Oil +5% Water Diluted	0.1022	0.0881	0.0876	0.0731	0.0653	0.0668
Pure Oil +20% Water Diluted	0.0964	0.0854	0.0842	0.0692	0.0622	0.0626

Table 4: Average COF values for Different Oil Mixtures and Speeds for 20N load

The plot represents a Stribek Curve which can be segmented into three regimes,

Boundary Regime: In this regime, mirroring the behaviour observed under 10N load, the coefficient of friction of pure oil at 1RPM under 20N load is notably higher than its counterpart at the same speed under 10N load. This increase can be attributed to the increase in loading. As rotational speeds increase to 5RPM and 10RPM, the lubrication remains with the boundary regime, though a rise in speed correlates with a diminishing coefficient of friction. Notably, the mixtures containing water contaminants exhibit a reduced coefficient of friction when compared to the undiluted pure oil.

Mixed Regime: Within this regime, a decrease in coefficient of friction is observed, as shown in the plot for all the three mixtures at 50RPM. Notably, the mixture with the highest level of contamination demonstrated the lowest coefficient of friction. This behaviour can be attributed to the decrease in viscosity of the mixture.

Hydrodynamic Regime: Within this regime, a marked reduction in the coefficient of friction is observed across all the mixtures. The mixtures of pure oil +20% water dilution consistently display the lowest coefficient of friction values, a trend evident at both 100RPM and 150RPM. This regime is characterized by the most substantial lubricant film thickness among the three lubrication regimes. It can infer that an increase in lubricant film can decrease the coefficient of friction between the two contact surfaces.

6.6 Comparison between Stribek Curves of 10N and 20N load

Comparing the plots of Stribek curves of 10N and 20N with respect to each lubrication regime,

1. **At Boundary Lubrication Regime:** For the pure oil mixture, the coefficient of friction under a 10N load is lower compared to that under 20N load. This increased load likely compresses the lubrication film, resulting in a reduced film thickness. A noteworthy observation is that the introduction of water contamination into

the oil results in a reduced coefficient of friction between the interacting surfaces, even under increased load. From the data, it is evident that introducing water contamination into the pure oil, across varying concentrations, leads to a decreased coefficient of friction at a rotational speed of 1RPM, 5RPM and 10RPM for both the data sets. This behaviour is likely attributed to a reduction in the fluid's viscosity.

2. **At Mixed Lubrication Regime:** In both the data sets, a shift from boundary to the mixed regime is discernible, likely driven by increasing rotational speeds that enhance lubricant film thickness. The rate of at which the coefficient of friction reduces is more pronounced for the mixtures of pure oil with water contamination compared to the undiluted pure oil. This behaviour can be caused by the decrease in viscosity in water contaminated mixtures.
3. **At Hydrodynamic Regime:** Within this lubrication regime, a shift towards hydrodynamic phase is evident, predominantly influenced by rising rotational speeds. In this phase, a pronounced lubricant film forms, effectively separating the interacting surfaces. Such hydrodynamic lubricant plays a key role in efficient in the working of journal bearing in an internal combustion engine. Notably, as water contamination levels increase, there is a reduction in the coefficient of friction. This behaviour can be linked to the decrease in viscosity and the operational speeds, observed under both 10N and 20N loads.

7 Managerial Aspects

The managerial aspects involved in this project can be structured and categorized as shown below:

7.1 Project Scope Definition:

Understanding the effects of water contamination on lubricant performance in hydrogen internal combustion engines.

7.2 Deliverables:

1. Project Proposal
2. Project Report
3. Data from sensor
4. Project Presentation

7.3 Project Costs:

The costs associated with this project are given in the table below:

Resource	Vendor Name	Purpose	Cost
Outsourcing ball holder from vendor	Xometry UK, Chelmsford, CM 1HF	Ball holder is used to conduct the experiment	£209.84
Mobil 1 0W20 Engine Oil	Halfords, Old Kent Road, London	Oil specimen required to conduct the experiment	£14.29
		Total	£224.13

Table 5: Project Costs

All the costs pertaining to the project have been approved by the Department of Engineering and have been processed by King's College London Business Support Team.

7.4 Stakeholder Analysis:

Project Stakeholders: The stakeholders for this project can be categorized by using The Salience Model based on the three attributes: Power, Legitimacy and Urgency [22]

Stakeholder	Power	Legitimacy	Urgency	Category
Researcher	No	Yes	Yes	Dependent Stakeholder
Project Supervisor	Yes	Yes	No	Dominant Stakeholder
King's College London	Yes	Yes	No	Dominant Stakeholder
Department of Engineering	Yes	Yes	Yes	Definitive Stakeholder

Table 6: Stakeholder Salience Model

7.5 Project Schedule:

The project schedule is represented by a Gantt Chart

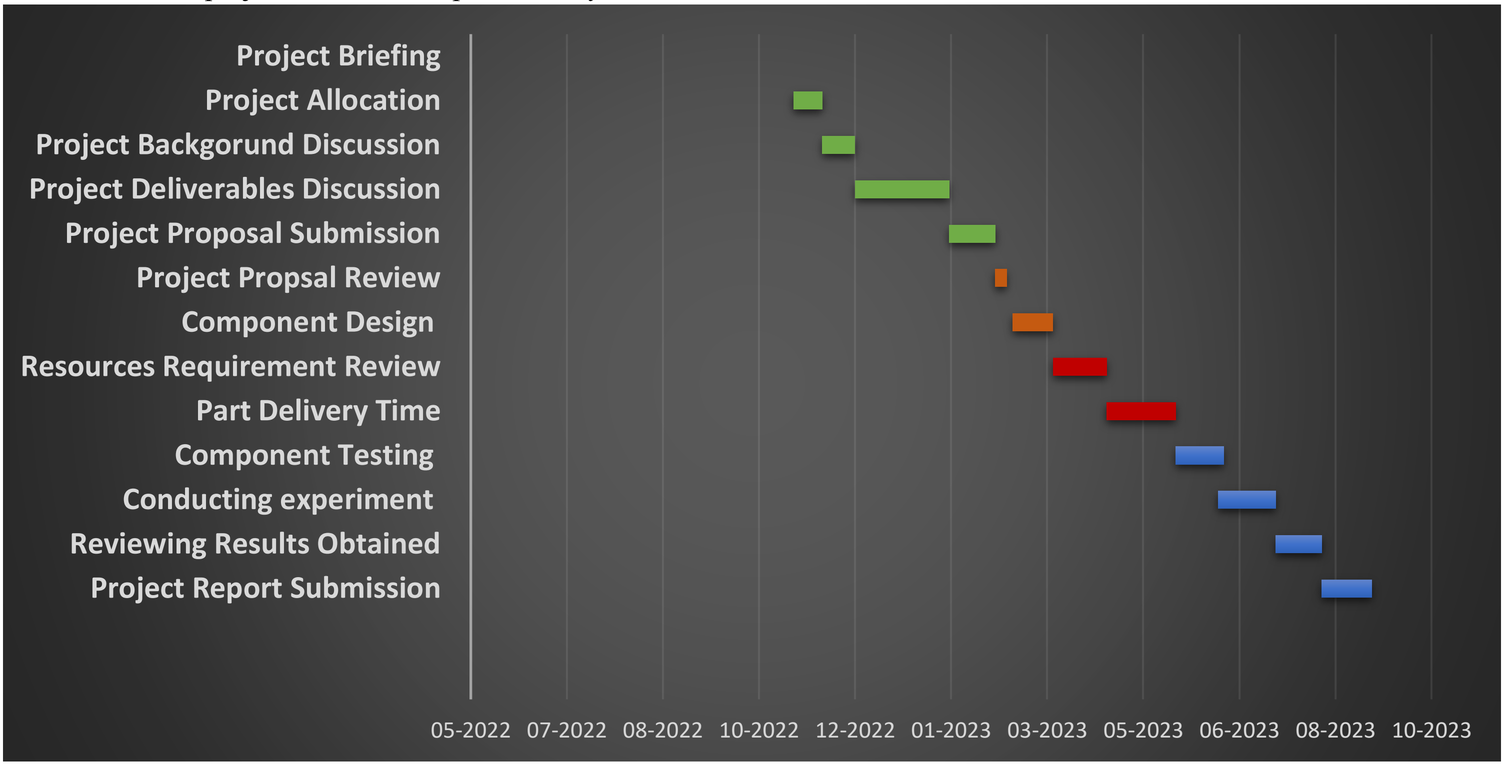

Figure 26: Gantt Chart

7.6 Resource Management:

In this table we can list down the set of resources required for the entire project:

Task	Resource Name	Quantity	Start Date	End Date
Project Proposal	1. Academic Journals 2. Online Database	-	5/12/2022	16/02/2023
Oil Sample	Mobil 1 0W20 Engine Oil	1 Liter	12/07/2023	12/07/2023
Experimentation	1.Testing Equipment 2.Lab Space	Tribology Lab	12/07/2023	12/07/2023
Ball Holder	Ball Holder outsourced from Xometry	1	15/04/2023	12/06/2023
Ball	Available In Tribology Lab	1	12/07/2023	12/07/2023
Deionized Water	Available in Tribology Lab	1 Liter	12/07/2023	12/07/2023
Rotating Disc	Available in Tribology Lab	1	12/06/2023	12/06/2023
Report Writing	1. Academic Journal 2. Plotting Tools	-	22/06/2023	31/08/2023

Table 7: Project Resources

7.7 Risk Management:

The occurrence of the risks associated with this project are defined in the table below with the risk matrix:

From the risk matrix and the probability vs impact grid, we can establish that the risk associated with this project is considerable and preventive measures must be taken to mitigate the risks.

RISK MATRIX					
RISK	Probability	Severity	Risk	Level of Risk	Mitigation Plan
Breakdown of UTM Test Rig	1	5	5	Apreciable	Contact the equipment manufacturer to draw a feasible outcome and time of repair.
Breakdown of Ball Holder	3	4	12	Important	Ordering a new ball holder from vendor/ 3D printing a new ball holder
Delay in delivery of Ball Holder from vendor	4	4	16	Critical	3D printing new ball holder
Excessive Oil Consumption	2	2	4	Apreciable	Additional supply of oil sample
External Risk	1	1	1	Marginal	Following protocols according to the severity of the risk and conducting the experiment

Table 8: Risk Matrix

			SEVERITY (IMPACT)				
			VERY LOW **1**	LOW **2**	MEDIUM **3**	HIGH **4**	VERY HIGH **5**
PROBABILITY	VERY HIGH	**5**	5	10	15	20	25
	HIGH	**4**	4	8	12	16	20
	MEDIUM	**3**	3	6	9	12	15
	LOW	**2**	2	4	6	8	12
	VERY LOW	**1**	1	2	3	4	5

	Critical risk. Requires urgent preventive actions. Service must not be provided without taking urgent preventive actions for these risks.
	Important risk. Mandatory preventive measurements. The variables of the process/service must be tightly controlled during the operation.
	Considerable risk. Analyze the economical viability of introducing preventive actions to reduce the level of risk. If not viable, keep variables controlled.
	Marginal risk.It should be controlled but requires no initial preventive actions.

Table 9: Probability vs Impact Grid

7.8 Communication Plan:

The communication plan below provides a structured approach to keeping the project supervisor informed and engaged in the project.

Monthly Project Updates:

a. Monthly Project Updates: Once a month
b. Medium: Face to Face
c. Purpose:
    1. Provide comprehensive update on the project's progress.
    2. Discuss challenges faced and potential solutions.
    3. Review and adjust project timelines and milestones.
    4. Seek Feedback and guidance.
d. Preparation:
    1. Prepare a brief report outlining the progress, challenges and future steps.
    2. Include any data, findings, or preliminary results.

7.9 Documentation:

1. All the test result files are stored in secured cloud storage.
2. Documents pertaining to the project are allocated separate repository one One Drive cloud storage.
3. Changes to the initial plan and the reason for the changes are documented.

8 Professional Matters

The transition to sustainable energy sources is a global imperative and hydrogen stands out as a promising alternative fuel. As research delves into hydrogen internal combustion engine, understanding the challenges and intricacies becomes crucial. One such challenge is the direct injection of hydrogen into the combustion chamber, which results in water as a byproduct. This water, when interacting with engine lubricants, can lead to contamination potentially affecting engine performance and longevity. The professional matters involved in this project are:

8.1 Scientific Knowledge:

a. Combustion of hydrogen: Understanding the combustion of hydrogen and its byproducts is fundamental. This requires knowledge of thermodynamics, combustion kinematics and fluid mechanics.
b. Lubrication Science: Understanding the effects of contamination of water on lubricant used plays a crucial role.

8.2 Engineering Design:

a. Fusion 360: This project involves using Fusion 360 to design parts required for this experiment.
b. Prototyping and Manufacturing: This project involves outsourcing design prototypes from vendors and ensuring they meet the required specifications and standards.

8.3 Environmental and Safety Concerns:

a. Emissions: Combustion of hydrogen produces water as a byproduct. The formation of NOx emissions is of a greater environmental concern, methods to mitigate and reduce NOx emissions is discussed in this report in the previous sections.
b. Safety: Hydrogen is flammable, and its storage, handling and delivery plays a crucial role in ensuring the safety of the user.

8.4 Ethical Considerations:

a. Integrity in reporting: The experiment procedure, results and findings are reported with honesty and does not involve any mishandling of results or data.

8.5 Economics and Logistics:

a. Cost Analysis: During the procurement of the required components, the process involved comparing the cost of manufacturing the components quoted by multiple vendors.
b. Logistics: The vendor who could provide the manufactured component with the shortest delivery and lowest cost is chosen. This process involved building and maintaining relationships with vendors and ensuring the quality of the components are met and negotiating the prices to obtain a value for money component.

9 Conclusion

The core aim of this study was to analyze the influence of water contamination on the efficacy of lubricants. Lubricant performance was evaluated under varying water concentrations, rotational speeds and applied loads. Through rigorous testing and analysis, this investigation yielded critical insights that serve as foundational data in comprehending the detrimental effects of water contamination on lubrication efficiency.

The observations from the experiment can be categorized into two sections with the Effect of Lubricant contamination on coefficient of friction and sudden decrease in frictional response when the lubricant is contaminated.

9.1 Effect of Lubricant Contamination on the coefficient of friction:

Upon executing tribological tests on pure oil, a 5% water in oil emulsion, and 20% water in oil emulsion, a decreasing coefficient of friction was observed. Specifically, as the contamination of water increased, there was a marked reduction in the coefficient of friction. The 20% water in oil mixture exhibited the lowest coefficient of friction among the test samples.

This phenomenon can be attributed to the decrease in viscosity of the contaminated oil samples, which facilitated enhanced lubrication between the interacting surfaces. While the immediate effects of increased water contamination appear to enhance lubricity, prolonged exposure could potentially degrade the lubricant's tribological properties.

9.2 Sudden decrease in frictional response when the lubricant is contaminated:

Based on the observed reduction in frictional response upon lubricant contamination, this phenomenon can be monitored using a friction sensor. This will serve as an indicator of potential lubricant contamination, which may subsequently impact the lubricant's performance characteristics.

The real-world tests can be very similar to that performed by [23] where newly designed sensors were installed in three vehicles. The road test included operations for short trip, cold start and city driving conditions, with periodic collection of oil samples while measuring key parameters such as viscosity, total acid number, total base number, oxidation induction time, and the contents of possible contamination such as fuel and water were measured in the samples. The oil sensor was tested for its ability to detect water condensation in engine oil, especially during cold start and short trip scenarios. An oil condition sensor was used in this experiment.

9.3 Future work:

a. To corroborate this hypothesis, further experimental investigations are required. Utilizing the contaminated oil samples over extended durations and introducing elongated intervals, spanning weeks or even months between successive tests is imperative.

b. Additionally, subjecting the lubricant to elevated mechanical loads might throw light up on immediate adversarial effects of contamination. By intensifying the load conditions, a more comprehensive insight into the potential degradation of the lubricant's tribological properties due to the contamination can be ascertained.

c. To evaluate the viscosity variations among the three oil samples, it is essential to analyse the extent of viscosity reduction in the oil samples contaminated with water. To emulate the motion of an actual internal combustion engine, we can adopt a test configuration like [24] , which utilizes a reciprocating pad and an electric motor driven mechanism to mimic the stroke action inherent in engine operation.

d. Given the experiment was carried out at ambient temperature and pressure, it is recognised that fluid viscosity typically decreases as temperatures increase. By subjecting both pure oil and water contaminated oil to controlled heating can help gain better insights into the thermos-viscous behaviour of the mixtures across different temperatures.

Concluding this project, there are several key takeaways that standout and has helped me leverage my engineering and management skills. Primarily the design of ball holder according to the required specification using Fusion 360 which has helped me expand my capabilities in engineering design. To complement this, project management skills has helped me in keeping my work structured and organized. With a foundation in Automotive Engineering, this project has facilitated a profound opportunity into the combustion of hydrogen and understand the tribological properties of piston rings. In summation this project underscored the potential of hydrogen as a promising alternative to the available energy systems. Upon reflecting this journey, the project has been an instrumental in refining my critical thinking and enhanced my ability to interpret data. Beyond the immediate technical skills, it has fostered me with qualities essential for an engineer, such as innovation, honesty, equity, integrity, protection of public health, safety welfare and honesty. This project has instilled a vision of engineering for a brighter and more sustainable tomorrow.

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APPENDIX

APPENDIX A

Data Relevant to Project

Please click on the link above to access the Drawings, Plots, Images, Videos and Data received from the sensor of the equipment.

APPENDIX B

Automotive Engine-Oil Condition Monitoring by Donald J. Smolenski and Shirley E. Schwatz

Bruker UMT Manual