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Research Article

Effect Of Waste Plastic Pyro-Wax as A Thickener on the Properties of Lubricant Grease

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ABSTRACT

The formulation of a lubricant from polyethylene waste is an outstanding development in conversion of waste to wealth and control of the environmental pollution, this is important in science as non-biodegradable materials on pyrolysis produced pyro-wax. This is used as thickener in the production of lubricant grease by transformation of the properties of polyethylene waste to a useful raw-material in a thermal process. The work aimed to identify the effect of the waste plastic pyro-wax as a thickener on the properties of lubricant grease. These was made by varying amount of the pyro-wax from 15 to 30% at 3% interval and the pyro-wax grease properties results for consistency from 38.0 – 15.6 mm, dropping point from 113 to 124 °C, oil separation from 0.33 to 0.06%, water wash-off from 1.67 to 0.26%, and load carrying capacity from 200 to 1200N respectively were obtained. The result of the analysis shows increases in concentration of the thickener decease in the oil separation and water wash-off but increase consistency, dropping point and load carrying capacity. This is significant in that the application principles of the grease dependent on the outcome from the adherence of the product on the surface which result from the structural density of the pyro-wax. This provides knowledge on how plastic waste can be up-cycled for a useful lubricant product and the outcomes contribute to effective environmental management and pollution control.

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1.0 INTRODUCTION

Grease is a semi-solid lubricant consisting primarily of base oil and a thickening agent, with additives sometimes incorporated to enhance its performance characteristic (Mohd Najib Razali et al., 2017). Structurally, grease may be regarded as a porous system in which thickener fibers are dispersed throughout the lubricating oil. Conventional lubricants have commonly been produced using base oils, thickeners, and various additives, some of which may contain or degrade into substances that are harmful to human health and the environment (Uhryn, 2024). The application of locally sourced polyethylene waste as a feedstock for producing pyro-wax, which can serve as a thickening agent in grease formulation, represents an emerging area of research. This approach has the potential to produce grease without the need for conventional additives. Variations in the amount of thickener used can significantly influence the physical and performance characteristics of the resulting grease. Grease can be manufactured using different formulation techniques, with properties dependent on factors such as thickener concentration, base-oil composition, and processing conditions (Suetsugu et al., 2013).

The increasing accumulation of polyethylene and other plastic wastes presents a serious environmental challenge. Improper disposal and inadequate waste-management practices contribute significantly to environmental degradation. Plastic waste constitutes a substantial proportion of solid waste because of its durability and resistance to natural decomposition. Global plastic production doubled, 234 million tonns in 2000 to 460 million tonns in 2019 (OECD, 2022), further intensifying concerns associated with plastic pollution. Converting polyethylene waste into pyro-wax through pyrolysis and subsequently using the wax as a thickener in grease production offers a potential solution to two interconnected challenges: plastic-waste management and the development of alternative lubricant materials. This process can reduce the volume of persistent plastic waste entering the environment while transforming an otherwise unwanted material into a useful and potentially valuable product. In this way, the conversion of waste polymers into lubricant components supports the concept of waste valorization and may contribute to both environmental protection and economic value creation.

Previous studies have indicated that variations in thickener structure can alter its specific surface area, which plays an important role in enhancing thickening efficiency and minimizing the rate of oil separation from the grease (Jia *et al.,* 2025). Grease formulated with pyro-wax can exhibit good mechanical and storage stability, with limited oil leakage and separation when the base oil and thickener are properly homogenized. The formulation ratio is particularly important because it influences key grease properties, including consistency, oil bleeding, and oil separation. Many of these characteristics are strongly dependent on the concentration and nature of the thickener, especially with regard to grease consistency. However, the fundamental lubrication mechanisms associated with pyro-wax-based grease remain insufficiently investigated, as relatively few studies have focused on this type of lubricant system (Yeong et al., 2004). The development of pyro-wax-based grease also offers potential environmental and socioeconomic benefits. Using waste-derived materials as lubricant feed stocks may provide an alternative to conventional metal-salt-based formulations and could support efforts to meet biodegradability and bioaccumulation requirements. Furthermore, the approach creates opportunities to develop alternative raw materials for industrial applications, reduce dependence on conventional resources, generate economic value from plastic waste, and potentially create employment opportunities within local communities.

MATERIALS

Pyrolysis reactor, weighing balance, cone penetrometer, pressure control tank, Engine oil, polyethylene waste, Beakers, Buckner funnel, stirrer, sample bottles, measuring cylinder, waste polyethylene (WPE), Petri dish.

METHODS

A batch-type locally built reactor with a large heating pot was used for the pyrolysis experiments. This reactor designed comprises of the reactor shield where the tank was wrapped with glass wool for insulation, the system include condenser, heating source described by Abdul Aziz et al., (2017)



Plate 1: 1. Polyethylene (PE) waste. 2. Pyro-wax

Optimized Grease formulation

The preparation of the waste engine oil and pyro-wax was initially carried out to eliminate coarse particles and other impurities present in the materials. Molten pyro-wax and the liquid oil were separately passed through a sieve to remove any relatively large particles. The waste engine oil was also filtered to eliminate fine suspended contaminants. Following filtration, the treated oil was heated to approximately 120 °C for one hour to facilitate the removal of residual moisture through evaporation. The processed engine oil and solidified pyro-wax were subsequently collected and stored in suitable containers until required for grease formulation. A modified procedure based on the methods reported by Mohd Najib Razali 2017; Abdulbari et'al., (2008) were employed for the preparation of the pyro-wax grease. A predetermined mass of pyro-wax was measured and combined with a specified quantity of unused engine oil (QUARTZ 5000 20W-50) with kinematic viscosity of 176.4 and 19.1mm^2/s at 40 and 100 °C respectively, which served as the base oil. The two components were heated together at a controlled temperature of approximately 110 °C to melt the pyro-wax and promote its incorporation into the oil. Continuous mixing was maintained while the mixture remained hot to ensure uniform dispersion of the thickener throughout the base oil. Agitation was continued during the cooling stage until a homogeneous, smooth, and semi-solid pyro-wax grease was obtained. The general procedure for grease preparation was maintained while the proportions of the pyro-wax thickener and engine-oil base were systematically varied to investigate the influence of thickener concentration on the properties of the resulting grease. The quantities of thickener and base oil used in grease formulations generally depend on the intended application and the desired performance characteristics. Consequently, rather than relying on a single fixed composition; a range of concentrations is commonly evaluated to identify an optimum formulation. For this study, pyro-wax concentrations of 15, 18, 21, 24, 27, and 30 g were combined with corresponding base-oil quantities of 85, 82, 79, 76, 73, and 70 g, respectively. These formulations represented different thickener-to-base-oil ratios within the selected experimental range. The formulations were evaluated with particular attention to grease retention and adhesion characteristics in order to identify a suitable composition. The corresponding thickener mass fractions were 0.15, 0.18, 0.21, 0.24, 0.27, and 0.30, respectively.

Grease Analysis

Consistency Test

Grease consistency was evaluated in accordance with the standard procedure established by the American Society for Testing and Materials (ASTM D-217). The consistency of the formulated grease was

assessed using a Seta Universal Cone Penetrometer, Model 17000-2 (Stanhope-Seta, UK). During the test, a prepared grease sample was placed beneath the penetrometer cone, which was allowed to penetrate the sample under its own weight for a period of five seconds. Following sthe specified penetration time, the depth reached by the cone was recorded and expressed in tenths of a millimetre. The penetration value obtained from the instrument was used as an indication of the consistency of the grease (Nadkarni 2007).

Oil Separation test

Oil separation from the formulated grease was evaluated according to the standard procedure specified by the American Society for Testing and Materials (ASTM D-1742). The test was conducted to determine the tendency of the grease to release oil during storage. A clean pressure-bleeding apparatus was first prepared, and the sieve was weighed to the nearest 0.05 g before being filled completely with the grease sample. Care was taken during filling to prevent the entrapment of air within the sample. The surface of the grease was leveled, and its initial mass was recorded. The assembled test setup was maintained at 25 ºC for 24 hours. During the test, the grease sample was supported on a 74 μm (200-mesh) sieve and subjected to an air pressure of 1.72 kPa. Any oil released from the grease passed through the sieve and was collected in a clean, pre-weighed beaker positioned beneath the apparatus. At the end of the test period, the separated oil was recovered and weighed. The percentage of oil separation by mass was then calculated and used to assess the storage stability of the formulated grease with respect to oil bleeding (Mohd Najib Razali *et al.,* 2017).

Dropping Point Test

The dropping point of the formulated grease was determined in accordance with the standard method specified by the American Society for Testing and Materials (ASTM D-2265). A small quantity of grease was carefully introduced into the test cup and placed in a heating apparatus under controlled temperature conditions. A thermometer was positioned within the test assembly such that it measured the temperature of the grease sample without making direct contact with the grease. The temperature was gradually increased while the sample was continuously monitored. The dropping point was identified as the temperature at which the first portion of the grease flowed through the opening at the bottom of the test cup and fell into the lower section of the test-tube jacket. At this stage, the temperature indicated by the sample thermometer was recorded to the nearest degree Celsius. Simultaneously, the temperature of the surrounding heating block was also measured and recorded.

A correction factor, corresponding to one-third of the temperature difference between the heating block and sample thermometer readings, was applied to the observed temperature. The corrected value was reported as the dropping point of the grease. This measurement is particularly important because the type and characteristics of the thickening agent can have a significant influence on the dropping point of the formulated grease (Mohd Najib Razali *et al.,* 2017).

Water resistance

The water wash-off test was performed according to the standard procedure specified by the American Society for Testing and Materials (ASTM D4049). A measured quantity of 30 mL of the grease sample was uniformly applied to a metal panel and positioned horizontally. Water was sprayed onto the coated surface at a temperature of 38 °C and a flow rate of 5 cm^3/s for a duration of five minutes. After exposure, the test assembly was removed from the water-spray system and allowed to dry completely before being weighed. The change in mass was then determined, and the percentage weight loss was calculated to evaluate the water wash-off resistance of the grease.

Load carrying capacity

The load-carrying and extreme-pressure performance of the formulated grease was evaluated using a four-ball test in accordance with the standard procedure specified by the American Society for Testing and Materials [ASTM D2596 (2002)]. A four-ball testing apparatus was employed, consisting of three stationary balls supporting a fourth ball that rotates

under an applied vertical load. The upper ball was operated at a constant rotational speed, while the temperature of the test assembly was regulated using a temperature-control system to maintain the required test conditions. The extreme-pressure (EP) test was conducted in accordance with ASTM D2596 to assess the ability of the grease to withstand progressively increasing loads and resist wear under severe pressure conditions ASTM D2596. During each test run, a new set of four balls was used, and the applied load was increased incrementally until seizure occurred. The seizure point represents the condition at which the lubricant film and grease structure can no longer adequately separate and protect the contacting surfaces.

At the final seizure load, the contacting balls may weld or fuse together as a result of the severe pressure and frictional conditions. The load at which this occurs provides an indication of the grease's extreme-pressure and load-carrying capability, allowing the performance of the pyro-wax grease to be assessed under high-load operating conditions (Dave et al., 2025).

RESULTS AND DISCUSION

Polyethylene (PE) pyrolysis

Polyethylene (PE) wax, referred to as pyro-wax in this study, was produced through the thermal decomposition or cracking of waste polyethylene. The pyrolysis process generated two principal product streams, namely pyrolysis oil and pyro-wax. Table 1 presents the results obtained from three repeated PE pyrolysis experiments. The findings indicate that more than 70% of the processed polyethylene remained a solid residue after thermal cracking. This substantial residue fraction presents a challenge to complete waste recovery because the recycling or upcycling process remains incomplete if the dominant product is not effectively utilized. Previous studies have devoted considerable attention to the liquid pyrolysis-oil fraction, while comparatively less emphasis has been placed on the solid residue or wax fraction. Failure to find a beneficial application for this residue may simply shift the pollution problem from plastic waste to another form of waste requiring disposal. In this context, Gaidhani and Mahanwar (2023) suggested that pyro-wax could possess considerable commercial potential and serve as an economically viable alternative to other products obtained from plastic pyrolysis, including fuels and gaseous products. Consequently, further investigation into the properties, applications, and potential industrial value of pyro-wax is warranted.

Table 1: Pyro-wax yield from pyrolysis of polyethylene

S/N	Mass of PE used (g)	Mass of wax obtained (g)	Percentage (%)
1	20	14.5	72.5
2	21	15	71.4
3	20.5	15	73.2
Mean value/Standard deviation	20.50±0.5	14.83±0.3	72.37±0.7

Result of this work is relevant since the residue (pyro-wax) obtained use for this purpose has a multiple benefit and large enough to discredit an objective of recycling and up cycling for mitigating environmental pollution when discarded.

Development of Grease

The formulated grease samples exhibited a dark-brown coloration and ranged in consistency from semi-solid to paste-like

materials. Their texture was characterized by a sticky, viscous, and oily wax-like appearance, with the consistency varying according to the concentration of pyro-wax used as the thickener. The samples demonstrated good adhesion to metallic surfaces as well as to the glass containers used during preparation, indicating favorable characteristics for potential lubricant applications.



Plate 2; Grease Formulation using engine oil and pyro-wax

Characterization of grease

Pyro-wax grease optimization

Optimization of the pyro-wax grease involves evaluating its flow behavior and viscoelastic characteristics in relation to the concentration of the thickening agent. From a scientific perspective, the grease can be considered a colloidal system in which the interaction between the base oil and thickener determines its overall structure and performance. Therefore, optimization requires systematic adjustment of the proportions of pyro-wax and base oil to establish a formulation with desirable lubrication properties.

Table 2: Pyro-wax grease with varying amount of thickener

S/N	Sample	Pyro-wax (g)	Engine Oil (g)	Pyro-wax percentage fraction	Type
1	A	15	85	0.15	Soft and runny
2	B	18	82	0.18	Soft
3	C	21	79	0.21	Soft and pastry
4	D	24	76	0.24	Hard and pastry
5	E	27	73	0.27	Hard
6	F	30	70	0.30	Hard and rigid

Changes in the concentrations of the thickener and base oil can significantly influence the physical and functional characteristics of the resulting grease, both during application and storage. Previous research has shown that the viscosity of the base oil and the micro-structural characteristics and concentration of the thickener are important factors influencing lubricant film thickness, particularly under fully flooded lubrication conditions Cyriac, Lugt and Bosman (2016b).

Pyro-wax grease Consistency test

The consistency of the formulated pyro-wax grease was strongly influenced by the concentration of the thickening agent, with an increase in thickener content producing a corresponding increase in grease firmness. Consistency is an important parameter for determining whether a lubricant possesses the semi-solid

characteristics required of grease. The results showed that the NLGI grade of the pyro-wax grease increased progressively from 0 to 5 as cone penetration decreased from approximately 38.0 mm to 15.6 mm work penetration. This behavior can be attributed to the development of a denser thickener network within the base oil as the pyro-wax concentration increased. As the concentration of pyro-wax increased, the resistance of the grease to cone penetration also increased, resulting in a progressively harder material. At sufficiently high thickener concentrations, the grease may become excessively rigid, limiting cone penetration and potentially producing a solid structure. Such an excessively hard formulation may be susceptible to cracking during handling, application, or storage, as illustrated in Figure 1. Conversely, formulations containing very low concentrations of pyro-wax, particularly below 0.15 mass fractions, exhibit behavior more closely resembling that of the base oil.

Based on these observations, a minimum pyro-wax concentration of approximately mass fraction of 0.15 is suggested for producing grease with suitable semi-solid characteristics. Concentrations below this level may produce an excessively fluid material with inadequate retention and application properties. On the other hand, increasing the thickener concentration beyond approximately 0.30 mass fraction may result in overly hard grease that is more prone to cracking during storage or use. These findings demonstrate the importance of identifying an appropriate thickener concentration range for achieving the desired balance between flow ability, firmness, and structural stability. The concentration of the thickener is therefore a major factor controlling the behavior of grease during service. Overall, the results indicate that grease consistency is closely associated with the relative proportions of its constituent materials, particularly the thickener.

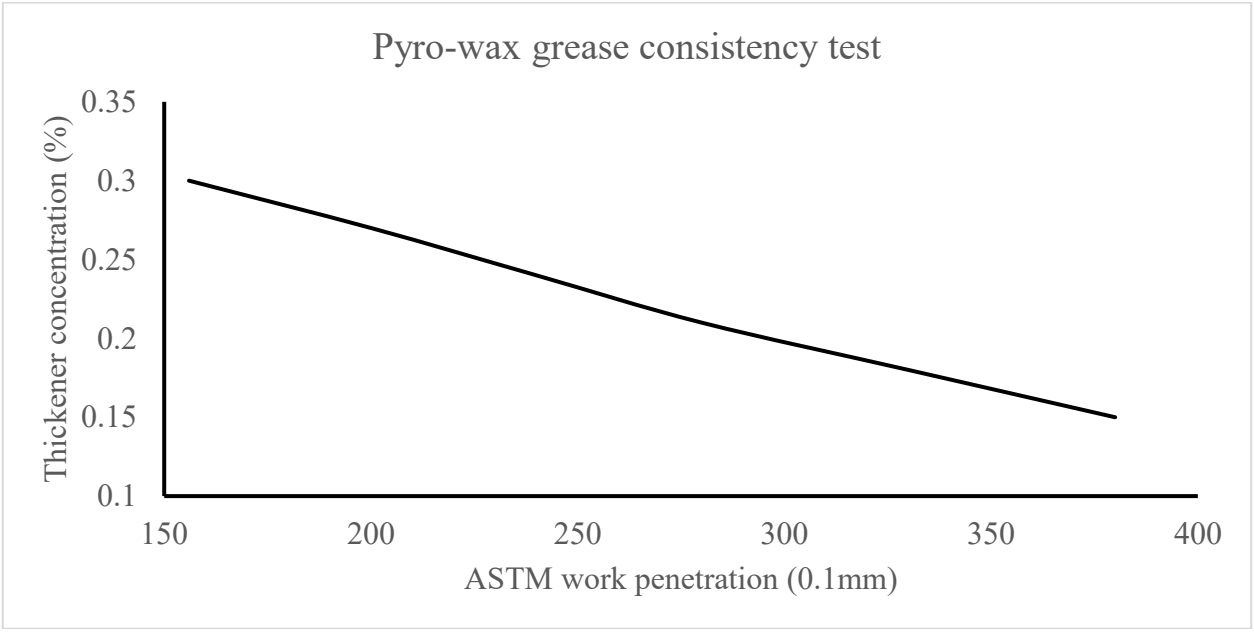


Figure 1. Relationship between the pyro-wax thickener weight percentage and a cone penetrometer work penetration (mm) of a grease Consistency test

Optimization through pyro-wax concentration can therefore be used to tailor the grease from a relatively fluid material to a firmer, load-supporting lubricant. Similar to the role of additives in conventional lubricant formulations, adjustment of the thickener concentration provides a means of modifying and improving the performance characteristics of the resulting grease.

Pyro-wax grease dropping point

The dropping point of grease is associated with the temperature at which the thickener network loses its structural integrity and the semi-solid grease begins to release its liquid phase. In the case of pyro-wax grease, the strength and density of this

network were observed to increase as the concentration of the thickener increased. The experimental results therefore indicate a positive relationship between pyro-wax concentration and dropping point, suggesting that a greater quantity of thickener improves the thermal stability of the formulated grease. Previous studies have similarly reported that increasing the concentration of a given thickener can enhance the dropping point of grease formulations (Jia et al., 2025). From a rheological perspective, the thickener concentration represents the density of the fibrous network formed throughout the base oil. This network contributes to the characteristic semi-solid structure and may also influence the thixotropic behavior of the grease. The thermal response of grease is determined by the interaction between the thickener network and the base oil. Previous research has shown that changes in dropping point can be associated with factors such as thickener-network density, structural breakdown of the network, and the viscosity of the base oil (Suetsugu et al., 2013).

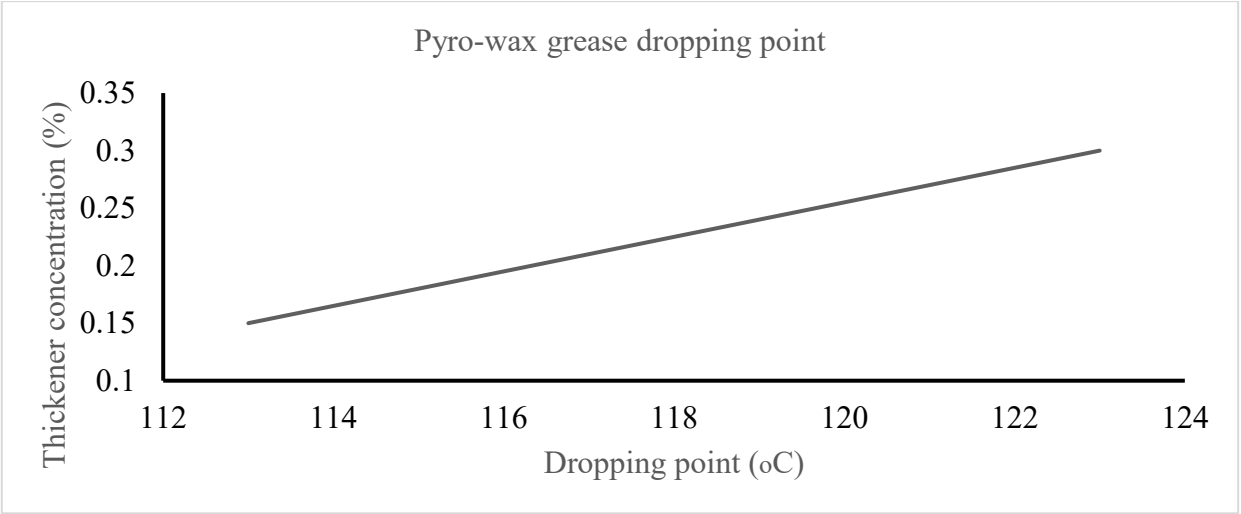


Figure 2. Relationship between the pyro-wax thickener weight percentage and dropping point of a grease

Pyro-wax grease oil separation

The results obtained for oil separation in the pyro-wax grease shows that increasing the concentration of the thickener led to a reduction in the amount of oil released from the grease. This behavior can be attributed to the formation of a denser and more interconnected thickener network, which effectively immobilizes a greater proportion of the base oil within its structure. Consequently, oil separation exhibited an inverse relationship with pyro-wax concentration, as illustrated by the corresponding graph. The structural characteristics of the thickener also influence the resistance of grease to oil separation. A higher aspect ratio of the thickener particles or fibers, together with a greater distance between the retained oil and potential structural openings, can strengthen the ability of the grease network to retain the base oil (Jia et al., 2025). Effective oil retention is important because excessive oil separation can alter grease consistency and accelerate oxidative deterioration, potentially reducing the storage stability and service life of the lubricant.

At very low concentrations of pyro-wax, the graph shows a sharp decline in the oil-separation behavior, indicating the presence of a relatively weak thickener network. At this concentration range, the structure may approach a critical condition at which the grease begins to lose its characteristic semi-solid or paste-like form and increasingly behaves like the liquid base oil.

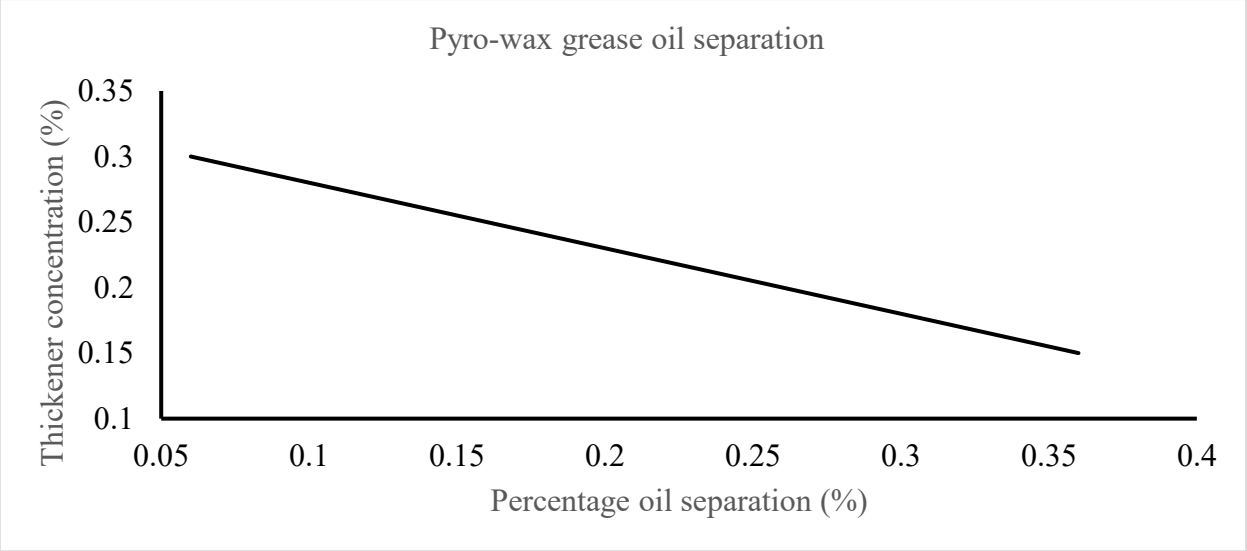


Figure 3. Relationship between the pyro-wax thickener weight percentage and percentage oil separation

This observation suggests that an adequate interaction between the base oil and thickener is necessary to establish sufficient structural strength and restrict excessive flow.

Pyro-wax grease Water Resistance

Water resistance is an important property in determining the ability of grease to maintain its structure and performance when exposed to moisture or water. The results obtained in this study indicate that the formulated pyro-wax grease exhibited a high degree of resistance to water. This behavior can be attributed to the water-resistant characteristics of the materials used in its formulation. The resistance to water was also observed to improve as the concentration of the pyro-wax thickener increased. In comparison, some conventional metal-soap greases, particularly lithium-based formulations, may exhibit limited water resistance because certain soap thickeners have hydrophilic characteristics and may retain small quantities of water originating from the manufacturing process. Consequently, such greases can experience reduced resistance to water unless their formulations are specifically modified to improve water tolerance. The use of pyro-wax as a thickener therefore presents a promising alternative because its polymer-derived structure possesses inherently low affinity for water. Exposure to water can alter several important properties of grease, including surface retention, consistency, adhesion, cohesion, tackiness, and oil-bleeding behavior. These changes can affect the ability of the grease to remain attached to lubricating surface and continuously supply oil to the contact region (Cyriac et al., 2016a). In particular, excessive water interaction may cause the grease to either soften or harden, depending on its formulation, potentially reducing its ability to replenish the lubricating contact through controlled oil release.

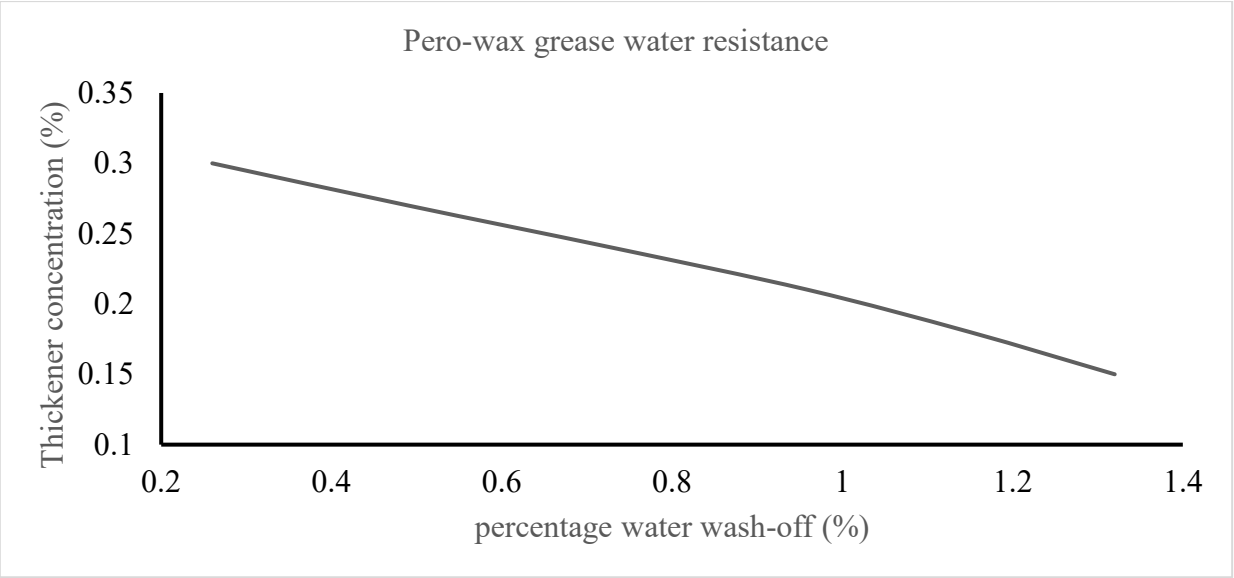


Figure 4. Relationship between the pyro-wax thickener weight percentage and percentage water wash-off

The pyro-wax grease demonstrated excellent resistance to water even at relatively low thickener concentrations. This behavior is attributed to the polymeric origin of the pyro-wax, which exhibits hydrophobic characteristics and consequently contributes significantly to the water-resistant nature of the formulated grease.

Pyro-wax grease Load Carrying capacity

The physical characteristics of lubricating grease can be considered intermediate between those of liquid oils and solid lubricants. Grease combines some of the beneficial features of both types of lubricants, although its structural and rheological behavior differs considerably from that of conventional mineral or synthetic oils and solid lubricants such as graphite and molybdenum disulfide. One notable characteristic of grease is its ability to support loads in a manner similar to a solid material. Under normal loading conditions, properly formulated grease can retain its structure without flowing or creeping, even when applied to inclined or vertical surfaces. However, when the applied load exceeds a critical value known as the yield point, the internal structure of the grease breaks down and the material begins to flow in a manner similar to a liquid lubricant. Once the applied load is removed, the grease gradually recovers its semi-solid structure and returns toward its original state after a period of rest (Yeong et al., 2004).

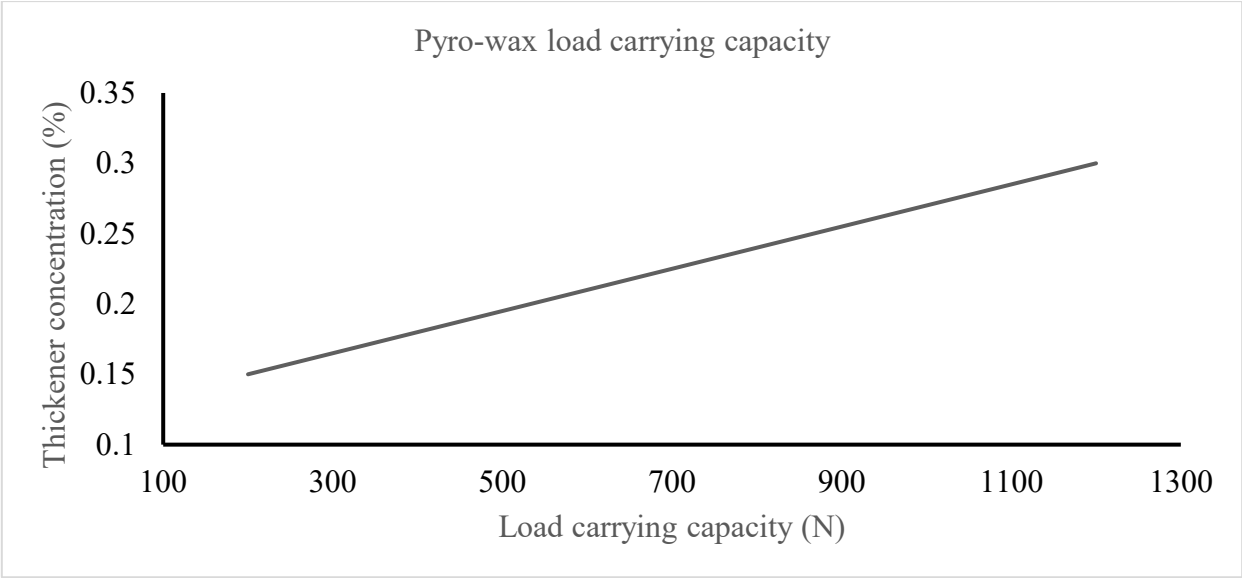


Figure 6. Relationship between the pyro-wax thickener weight percentage and Load carrying capacity.

The microscopic fibers of the pyro-wax thickener are distributed in an irregular arrangement throughout the grease matrix. This random packing creates numerous points of contact between the thickener fibers, resulting in the development of interconnected pores capable of retaining the base oil. This three-dimensional structure is commonly referred to as the gel or thickener network. When an external load is applied, some of the junctions within this network begin to break or rearrange, allowing the grease to deform and eventually flow. The load required to initiate this structural breakdown provides an indication of the load-carrying capacity of the grease. The results show that increasing the amount of pyro-wax thickener improves the load-carrying ability of the formulated grease. Lubricating grease is a multiphase material composed primarily of a thickening or gelling agent dispersed within a liquid lubricant. The concentration of the thickener plays a major role in determining the ability of the grease structure to withstand applied loads. Adequate thickener concentration is essential because it provides the structural framework required for load support while still allowing the grease to release and distribute the base oil effectively during operation.

CONCLUSION

The characterization of the pyro-wax lubricant grease focused on determining how variations in thickener concentration influenced the overall performance of the formulated grease. Six grease formulations were prepared with pyro-wax concentrations ranging from 15% to 30%, using 3% increments. Each formulation was evaluated based on key performance parameters, including consistency, dropping point, oil separation, water resistance, and load-carrying capacity. Consistency, dropping point and load-carrying capacity increased with thickener content, whereas oil separation and water wash-off decreased. Water wash-off decrease indicates increase water resistance. These changes can be attributed to the development of a progressively stronger three-dimensional gel network within the grease. As the concentration of pyro-wax increased, the network became denser and more resistant to deformation and oil migration. Its relatively high thickener fraction and strong affinity for the base oil contribute to the formation of a stable structural network while maintaining sufficient flow characteristics for lubrication. The formulated pyro-wax grease demonstrated favorable performance across a range of evaluated conditions, indicating its potential for practical lubrication applications.

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Author Contributions: The authors participated in the preparation and drafting of the manuscript. One author supervised the practical aspects of the research, while all authors contributed to the review, revision, and correction of the manuscript.

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