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Research on Separation of Waste Lubricating Oil and its Friction Performance

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ABSTRACT

After a period of use, automobiles require lubricant replacement to ensure engine reliability. However, the main components of waste oil(wo) remain unspoiled. Researching their regeneration is crucial for environmental protection and sustainable energy development. This study utilized isopropanol as a flocculant and zeolite as an adsorbent to recycle waste lubricants. A comparison of the tribological, rheological, and compositional properties of the regenerated oil (RO) with fresh oil (FO) revealed that the former exhibits shear thinning, enhancing its friction-reducing effect. The optimal load for the RO is 140N, where the friction coefficient is 0.8833, and wear volume is 21% lower than that of FO.

KEYWORDS

Engine Oil Regeneration; Flocculation; Anti-friction.

1. INTRODUCTION

In recent years, the demand for engine lubricating oil has been continuously increasing, and China has become the country with the largest output of used oil [1]. During the use of engine lubricating oil, due to the invasion of external pollutants such as dust, metal debris, and moisture, as well as its use under high-speed operating conditions, the oil undergoes chemical reactions such as oxidation and polymerization when in contact with air, gradually aging and deteriorating. As a result, it loses its effectiveness in controlling friction and reducing wear, becoming used oil that needs to be replaced. However, the main components of the used oil have not deteriorated, with only 10% of the hydrocarbons actually deteriorating, and the rest are still effective components of the oil [2]. If the used oil can be effectively regenerated and recycled through technology to remove moisture and sediments, it can still be used as fuel oil. Moreover, extracting 1 liter of lubricating oil requires 67 liters of crude oil, while extracting 1 liter of lubricating oil from used oil requires only 1.6 liters of used oil [3]. Therefore, studying the regeneration of used oil can maximize the utilization of resources and is of great significance for environmental protection [4].

Currently, the regeneration processes for used oil include adsorption regeneration, distillation regeneration, flocculation regeneration, and hydrogenation regeneration. Flocculation regeneration involves adding appropriate flocculants to the waste lubricating oil, causing the suspended particles and colloidal substances in the oil to aggregate into larger flocs, which are then separated from the oil using filtration methods. This process has the advantages of low pollution, high efficiency, and low cost [5]. Zhang et al. [6] used a petroleum demulsifier for flocculation and adsorption regeneration of used oil, and the results showed that some of the physical and chemical indicators of the RO met national standards. Guo [7] used a mixture of sodium hydroxide and triethylenetetramine as a compounded flocculant for the regeneration of used oil, achieving a maximum decolorization rate of 50.55%. Yang et al. [8] used butanol as an extractant and monoethanolamine as a flocculant to separate the base oil from used oil, and under the condition of refining for 20 minutes at 30°C, the obtained oil was almost similar to that of the HV150 original oil.

In this experiment, isopropanol was used as the flocculant and white clay as the adsorbent for the regeneration of used oil. Meanwhile, the tribological properties of new oil, used oil, and RO were explored.

2. EXPERIMENTAL SECTION

2.1. Materials and Reagents

FO (Great Wall Motor Special Engine Oil 5w-30), Waste engine oil (from a passenger car after 50,000 kilometers of use), Isopropanol (AR, Shanghai Aladdin Biochemical Technology Co., Ltd.), Zeolite (particle size 1mm)

2.2. Instruments

UMT-5 multifunctional friction and wear testing machine (Bruker, USA), GCr15 Steel Balls (Diameter: 10 mm), Scanning Electron Microscope (SEM, Tescan, USA), Fourier Transform Infrared Spectrometer (FTIR, Thermo Fisher Scientific, USA), three-dimensional white light interferometry (Bruker, USA), Electronic Balance, Buchner Funnel

2.3. WO Regeneration Process

First, 60g of used engine oil was placed in a magnetic stirrer and stirred at 60°C for 30 minutes. Then, 210g of isopropanol was added, and the mixture was stirred at 40°C for 30 minutes. Next, 135g of zeolite was added, and the mixture was stirred at 130°C for 30 minutes to decolorize the waste oil. After decolorization, the mixture was allowed to settle for 3 hours at 70°C before filtration. Finally, the filtered WO was vacuum distilled at 70°C to obtain 20g of RO.

2.4. Testing and Characterization

The composition and structure of the FO, waste oil, and RO were characterized using a Fourier Transform Infrared Spectrometer. The viscosity of the three oil samples was measured using a rotational rheometer. The tribological properties of the three oil samples under different loads were evaluated using a UMT-5 multifunctional friction and wear testing machine. The three-dimensional wear morphology was observed using a white light interferometer, and the micro-morphology of the wear scars was examined using a scanning electron microscope to investigate the wear mechanisms.

3. RESULTS AND DISCUSSION

3.1. FTIR Analysis

Figure 1 presents the infrared spectra of the oil samples. The results indicate that the infrared spectra of the three oil samples are essentially identical, suggesting that the flocculation treatment only induced physical changes and did not affect the internal molecular structure. At a wavelength of 3500 cm-1, there were no absorption peaks observed in the infrared spectra of the three oil samples, confirming the absence of water. Peaks at 2960 cm-1 and 2826 cm-1 corresponded to the C-H stretching vibration absorption peaks of methyl and methylene groups. Peaks at 1460 cm-1 and 1380 cm-1 were attributed to the C-H bending vibrations of methylene and methyl groups, respectively.

The peak at 721 cm-1 represented the in-plane rocking vibration absorption peak of methylene groups in straight-chain alkanes with n≥4.

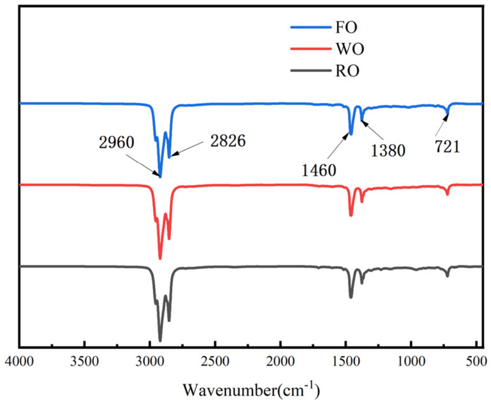

Figure 1. Infrared Spectrum of sample oil

3.2. Viscosity Testing

Figure 2 demonstrates that FO exhibits Newtonian fluid behavior, meaning its viscosity remains nearly constant with changes in shear rate. However, FO is highly sensitive to temperature, with the highest viscosity of approximately 110 mPa·s at 20°C and the lowest viscosity of approximately 8 mPa·s at 100°C. This is primarily due to increased molecular motion and reduced intermolecular forces caused by temperature rise, leading to a decrease in viscosity [9]. WO also shows temperature sensitivity, with a more regular pattern. As the temperature increases from 20°C to 80°C, the viscosity decreases from an initial 100 mPa·s to 8 mPa·s. RO exhibits non-Newtonian fluid behavior, showing minimal temperature dependence. At 20°C, the viscosity is the highest at 100 mPa·s, and it does not change significantly with increasing temperature. Additionally, the RO exhibits shear thinning behavior. Shear thinning occurs because most fluids are composed of molecular chains, and when these chains are subjected to shear stress, they deform, reducing internal flow resistance and lowering viscosity [10]. This phenomenon contributes to a decrease in the COF.

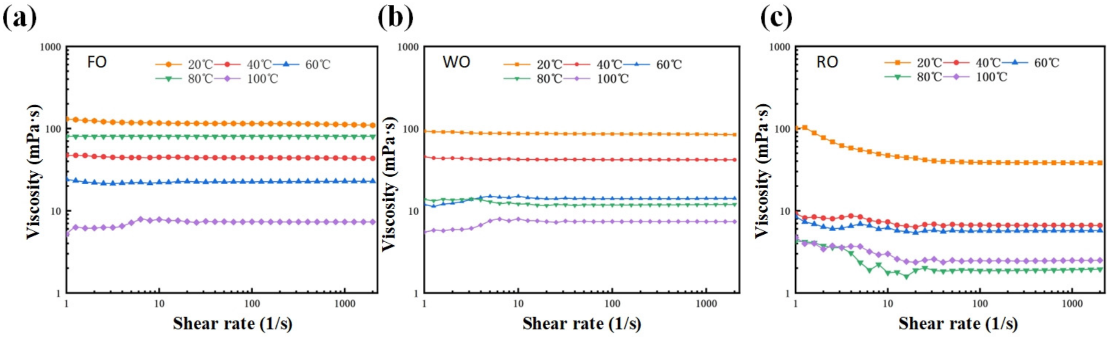

Figure 2. Viscosity Curve Diagram (a)FO (b)WO (c)RO

3.3. Tribological Properties Testing

Tribological properties of FO, waste oil, and RO were initially evaluated using a UMT-5 multifunctional friction and wear testing machine. The test conditions were as follows: at room temperature, different loads were applied, and the friction mode was ball-on-disc (both the ball and disc were made of GCr15, with a ball diameter of 10mm). The friction stroke was 8mm, the frequency was 5Hz, and the friction time was 30 minutes. The friction curves are shown in Figure 3

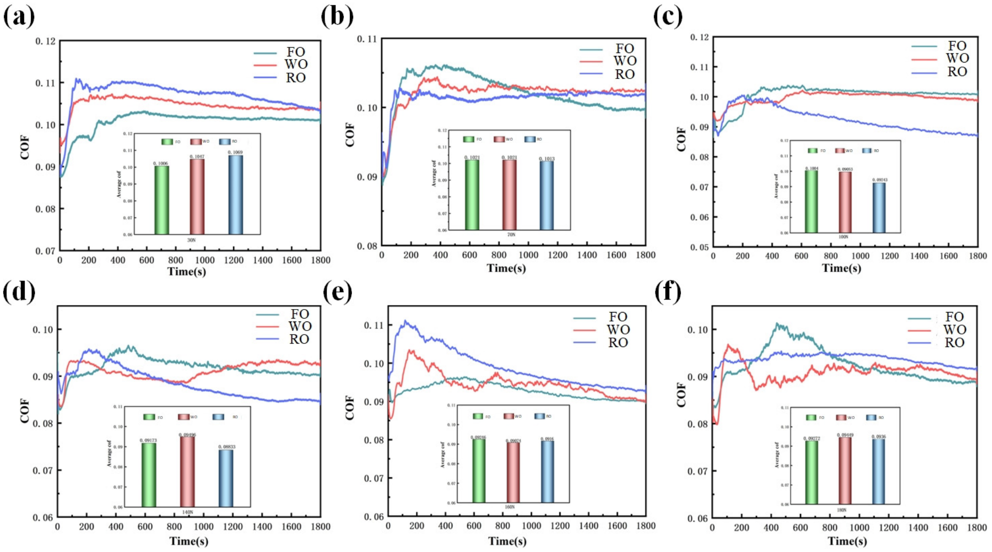

Figure 3. COF curves of three sample oils under different load conditions: (a) 30N (b) 70N (c) 100N (d)140N (e) 160N (f) 180N

Upon examining Figure 3, it is evident that under a 30N load, the friction coefficient of FO remains relatively stable, stabilizing around 0.1 after 400 seconds of friction. Conversely, the friction coefficients of both WO and RO are higher than that of FO, with the RO reaching a maximum of 0.11. Among the three oil samples, only the RO exhibits a decreasing trend in its friction curve over time. When the load reaches 70N, the friction coefficient of FO exhibits notable fluctuations, rapidly increasing from 0.09 to 0.105 within the first 500 seconds. This is attributed to the transition from static friction to dynamic friction at the initial stage of the friction process [11]. As the friction continues beyond 500 seconds, the reciprocating friction promotes the uniform distribution of the oil film on the wear surface [12], reducing the contact between the friction pairs and subsequently lowering the friction coefficient of FO to 0.1. In contrast, the RO maintains a stable friction coefficient around 0.1 under this load, indicating that it facilitates the formation of a stable oil film at 70N. As the load increases to 100N and 140N, the RO demonstrates superior anti-friction performance, with the friction coefficient continuously decreasing to approximately 0.085 after 300 seconds. Meanwhile, the friction coefficient of FO remains relatively stable between 0.1 and 0.09. This is attributed to the shear thinning phenomenon observed in the RO during viscosity analysis. The shear stress generated during friction reduces the viscosity of the lubricating oil, thereby decreasing the resistance at the friction pair surface and contributing to a lower friction coefficient [13]. At loads of 160N and 180N, both the RO and WO experience a sudden increase in friction coefficient at 200 seconds, indicating the rupture of the oil film and the failure of the lubricating oil. At 180N load, the friction coefficients of both FO and WO exhibit varying degrees of fluctuation, primarily due to changes in the roughness of the wear surface during the friction process [14]. In contrast, the RO maintains a stable friction coefficient of 0.095, primarily attributed to the rapid temperature rise of the friction surface under high-speed and heavy load conditions. This leads to the melting of micro-protrusions on the material surface, resulting in a smoother surface and reduced friction [15]. In general, the friction coefficient of FO decreases with increasing load, from an initial 0.1006 to 0.09206. The RO is suitable for heavy-load applications above 100N but fails at 160N.

3.4. Wear Morphology Analysis

The three-dimensional surface topography was observed using a three-dimensional white light interferometry, as shown in figure 4. Figure 4 reveals that the wear scar width of FO increases with the load, reaching a maximum width of 0.4140mm under a 200N load, with a corresponding wear depth of 0.3253μm. Under the same conditions, the wear scar width of the RO is 0.3270mm, representing a 20% reduction compared to the FO. The corresponding wear depth is 0.3721μm, indicating superior wear resistance. The minimum width of the FO is 0.3915mm at a 30N load, with a wear depth of 0.3116μm. At this load, both the width and depth of the wear scar for the RO show varying degrees of increase compared to the FO, with increases of 17% and 28%, respectively. The results from the white light interferometer indicate that the RO demonstrates better wear resistance under heavy-load conditions.

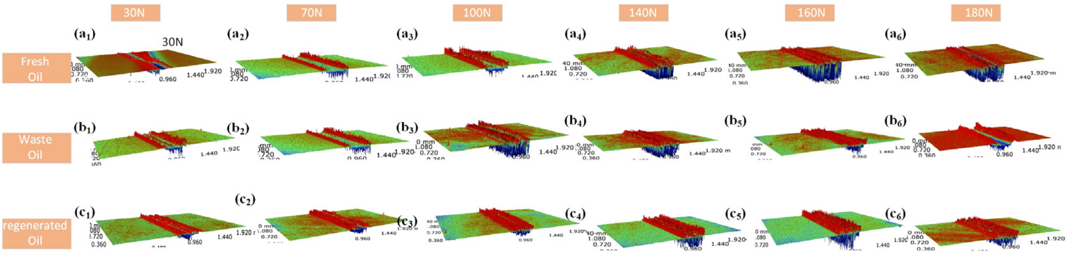

Figure 4. three-dimensional morphology of wear tracks for three sample oils under different load conditions. (a1) -(a6) FO (b1) - (b6) WO (c1) - (c6) RO

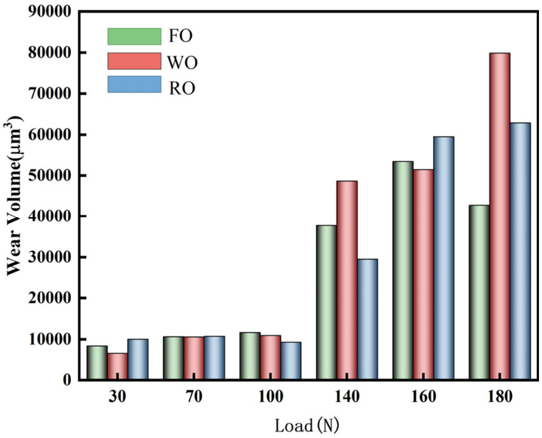

Figure 5. Wear volume graph

Figure 5 shows that the wear volumes of the three oil samples increase with the load to varying degrees. At loads of 30N, 70N, and 100N, the wear volume of the FO is less than that of the RO, with the minimum wear volume of the FO being 8401.186 μm³ at a 30N load and the maximum wear volume being 37713.03 μm³ at a 140N load. The wear volume of the RO at a 140N load is 29535 μm³, which is a 21% reduction compared to the FO under the same conditions, demonstrating superior anti-friction performance. At a 200N load, the wear volume is 22% less than that of the waste oil.

4. CONCLUSION

This paper refines and recovers WO through a flocculation-adsorption regeneration process and tests the composition, viscosity, and tribological properties of the RO. The main conclusions are as follows: (1) The WO is refined and recovered using the flocculation method, with a ratio of agent to oil of 3.5, resulting in a yield of 20% for the RO. (2) The RO exhibits a non-Newtonian fluid state, with shear thinning observed in its rheological curve, which aids in better friction reduction performance. (3)The tribological performance of the RO reaches the lowest friction coefficient of 0.08833 under a 140N load, with a wear volume 21% lower than that of FO under the same conditions.

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