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Assessment and comparison of dispersancy properties in fresh lube oils

Lubricants

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ABSTRACT

Soot particles, which often result from incomplete combustion, frequently enter the lubricating oil system via gas blowby. When lubricating oils become contaminated with soot, they can lead to issues such as increased wear and the fouling of critical machine components like injectors and exhaust lines.

To combat this problem, lubricating oils are formulated with dispersant additives. These additives are specifically designed to keep contaminants, including soot, suspended in the oil. This prevents them from aggregating into larger particles that can clog filters and minimizes their deposition on machinery. Traditional methods exist to assess the dispersant properties of oils already in service.

A new approach focuses on evaluating the dispersancy properties of lubricating oils during the selection process, prior to their use. By creating control samples containing various levels of particulate contaminants and assessing them using advanced blotter spot techniques, this method allows for a direct comparison of the dispersant effectiveness of fresh oils. This approach supports more informed decision-making regarding lubricant selection and application.

1 INTRODUCTION

Dispersancy is a key performance characteristic of lubricants, especially in heavy-duty diesel engine oils. It facilitates the effective suspension of contaminants, including soot, sludge, and wear particles, thereby preventing their accumulation on engine components. Dispersants represent the most extensively used additive in crankcase lubricants, with treat rates ranging from 2% to 10% in heavy-duty diesel engine oils. To meet the global demand in these applications, over one million kilotons of dispersants are produced annually [5].

Dispersants function by adsorbing onto particle surfaces, providing steric or electrostatic stabilization to inhibit particle agglomeration. Typically, these dispersants are formulated using polymeric or ashless chemistry, such as polyisobutylene succinimides [6]. Their interaction with other lubricant additives, including detergents, anti-wear agents, and viscosity modifiers, significantly influences overall lubricant performance through competition, incompatibility, or unintended interactions. They may compete with anti-wear agents, friction modifiers, or extreme pressure additives for surface adsorption, reducing the effectiveness of protective films. Dispersants can also chemically interact with detergents or antioxidants, forming less effective complexes or deactivating the latter. High concentrations of dispersants might overload the oil's solvency, leading to the precipitation of other additives or altering the formulation's rheological properties, which affects the performance of viscosity modifiers. Research underlines the importance of optimizing additive synergies to preserve effective dispersancy while maintaining other critical lubricant properties [4][6].

The design of dispersants requires a deep understanding of molecular architecture to fulfill specific functions in targeted applications and environments [5]. Oxidative degradation of lubricants generate a variety of undesirable by-products, primarily derived from the base oil, additives, and, if present, the polymeric viscosity modifiers. In engine oils, oxidative degradation is initiated by the combustion of fuel. Fuel components most susceptible to generating these reactive species include highly branched aliphatic hydrocarbons, unsaturated compounds such as olefins, and aromatic structures like alkylbenzenes.

Traditionally, dispersancy performance is evaluated through tests conducted on in-service oils. When an asset owner seeks to purchase new lubricants for their machinery to ensure optimal performance and maximum return on investment, the dispersancy performance of the oils is not available prior to their application. This results in uncertainty for the buyer in selection of the most suitable new lubricant for their assets. Hence, this study introduces a novel methodology designed to assess the dispersancy performance of fresh oils prior to their use by dosing the fresh oils with Carbon Black (CB) particles. This innovative approach enables purchasers to obtain a baseline assessment of the dispersancy properties of the new lubricant and make well-informed decisions regarding their purchase by providing critical performance insights upfront. This study investigates the performance trends of fresh lubricants across varying concentrations of carbon particles, providing a basis for evaluating their dispersancy potential.

2 MATERIALS & METHODS

The in-depth evaluation of fresh lubricant dispersancy performance requires a well-defined approach encompassing material selection, test methodologies, and analytical techniques. This section outlines the materials used in the study, including the type of lubricants, particles used to simulate fouling of lubricant alongside the specific methods employed to assess dispersancy. The methodologies were designed to simulate real-world conditions while ensuring reproducibility and reliability.

2.1 Diesel Engine Oils

For this study, four different heavy-duty diesel engine oils from various formulators were selected to assess for their dispersancy performance. Heavy-duty diesel engine oils are normally formulated with advanced additives to handle the generation of harmful byproducts of combustion and oxidation of the lubricant.

Soot consists of hydrocarbon fragments with partial hydrogen depletion, leading to the formation of charged particles. Due to their charged nature, soot particles exhibit a propensity to aggregate. Aggregation on surfaces, such as those within the combustion chamber, results in the formation of soot deposits, which are characterized by a soft and flaky texture. In lubricating oils, the presence of soot can lead to an increase in viscosity. This viscosity increase is typically influenced by the presence of polar materials within the oil, which can interact with and associate with the soot particles, thereby exacerbating the aggregation effect.

As diesel engine oils are more exposed to contaminants and particles than hydraulic or gear oils, they require excellent dispersancy properties. To prevent particle agglomeration and ensure system cleanliness, dispersants are added. The concentration and molecular composition of these additives can differ among manufacturers. Therefore, for this study, four different engine oils from various suppliers were selected.

2.2 Carbon Black (CB)

To investigate the dispersibility of soot particles in lubricants, laboratory tests have been designed using model particles. Carbon Black (CB) has been selected as a representative model for soot due to its similar characteristics. CB is produced through the incomplete combustion of petroleum hydrocarbons under controlled conditions, resulting in fine particles with a high surface area-to-volume ratio. A comparison of diesel soot and carbon black using Transmission Electron Microscopy (TEM) images reveals that both types of particles possess a fractal structure and exhibit similar aggregate sizes [3].

Due to the similarity between CB and soot, the oils A through D (refer Table 1), selected for this study have been dosed with CB at varying levels to replicate different stages of soot contamination, effectively simulating onboard fouling conditions.

2.3 Heated Sonicator

A heated sonicator integrates temperature control with ultrasonic waves induced by the energetic collapse of microbubbles—enhancing the mixing, and sample preparation by increasing molecular mobility and promoting efficient dispersion. They are instrumental in producing stable emulsions and dispersions by reducing particle size and achieving uniform distribution. Furthermore, this technique accelerates chemical reactions by enhancing molecular interactions and reaction kinetics. In material science and nanotechnology, heated sonicators enable deagglomeration and homogenization of particles, ensuring consistent suspensions and dispersions.

Figure 1 shows a typical lab heated sonicator with dial adjustments for temperature and time.

2.4 Oxidation Vessel Bomb

The oxidation vessel bomb (similar to one used in ASTM D2272) is designed to test the oxidation stability of lubricants, specifically under high temperature and pressure conditions [2]. In this study, this vessel is used to expose the lubricant to oxygen at a controlled temperature and pressure, to simulate the operating conditions of machinery.

The bomb consists of a robust metal chamber that can withstand the pressure buildup that occurs when the lubricant is heated and oxidized.

Figure 2 shows a typical oxidation vessel bomb used in ASTM D2272.

2.5 Standard Test Method for Measuring the Merit of Dispersancy of In-Service Engine Oils with Blotter Spot Method (ASTM D7899)

This test evaluates an engine oil's capacity to suspend and disperse soot and other insoluble by-products generated during combustion. Ineffective dispersancy can result in sludge formation, deposits, and accelerated engine wear. The method involves placing a drop of in-service oil onto a specialized filter paper.

As the oil spreads across the paper, it carries dispersed soot and insolubles, forming a characteristic "halo" pattern. The uniformity of soot or insoluble distribution within the halo serves as an indicator of the oil’s dispersancy performance. A high-definition image analysis system quantifies the dispersancy, assigning a Merit of Dispersancy (MOD) rating that ranges from excellent to poor.

Higher MOD values reflect effective dispersancy, ensuring even suspension of contaminants, while lower MOD values indicate diminished dispersancy capabilities, often attributable to oil degradation or contamination. This technique provides critical insights into oil health and its ability to prevent deposit formation in engines [1].

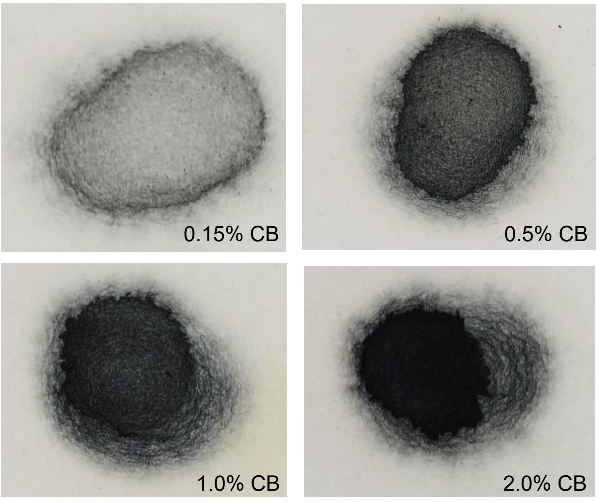

Figure 3 shows the spot of the oil drop dosed at various CB levels

3 EXPERIMENTAL PROCEDURE

The testing procedure for this study involves the selection of similar grade of oils from different suppliers and dosing the sample oils with CB under two conditions. The first by directly dosing the fresh oils and the second by aging the samples for a predetermined duration prior to the addition of CB.

3.1 Dosing samples with CB before aging

Sample preparation for dosing involves measuring a specified weight of each sample and transferring it into appropriately labeled volumetric flasks. A precise quantity of CB is then weighed, and the samples are added to achieve the desired dosing rates of 0.15 %wt., 0.25 %wt., 0.50 %wt., 1 %wt., and 2 %wt. The prepared samples are subsequently subjected to sonication at 60°C for 10 minutes to ensure uniform mixing and dispersion. Experimental trials revealed that shorter sonication durations (<10 minutes) were inadequate for effectively dispersing the CB particles in the oil, while extending sonication beyond 10 minutes offered no additional improvement in dispersion quality.

3.2 Dosing samples with CB after aging

The second set of samples is prepared by weighing a specified amount of each sample. These samples are then aged in the oxidation vessel bomb, where they are pressurized with oxygen to 620 kPa ± 1.4 kPa (90 psi, 6.2 bar) and placed in a bath maintained at 150°C. The samples are subjected to these conditions for approximately 90 minutes. After the aging period, the vessel is carefully depressurized, and the samples are allowed to cool to room temperature. Following this, the samples are dosed with CB at the same rates specified in section 3.1.

The dosed samples are subsequently assessed for their Merit of Dispersancy (MOD) values as per the guidelines in ASTM D7899.

4 RESULTS & DISCUSSION

The results of the study, obtained by following the outlined procedure, indicate consistent trends in the behavior of fresh and aged samples treated with CB at varying dosages. As anticipated, the ability to disperse the insoluble particles, measured as MOD, decreases as the concentration of CB increases.

For fresh oils dosed with CB, at lower concentrations (<1 %wt.), Oil D consistently demonstrates better dispersancy through its higher MOD values in comparison to the other three brands across all CB concentrations. At 1 %wt., Oils A, B, and D exhibit comparable dispersancy levels, with the exception of Oil C. At the maximum concentration (2 %wt.), Oil D continues to retain its dispersancy efficiency, evidenced by a slower decline in MOD values relative to the other samples. Thus, at higher concentrations (≥1 %wt.), Oil D maintains its dispersancy more effectively than the other samples.

Table 1 presents the MOD results for fresh oil samples dosed with CB across the four selected engine oils before they are oxidized.

	Oil A	Oil B	Oil C	Oil D
0.15%	61	59	62	67
0.25%	45	55	45	58
0.50%	43	44	44	55
1.00%	39	39	35	38
2.00%	26	31	28	37

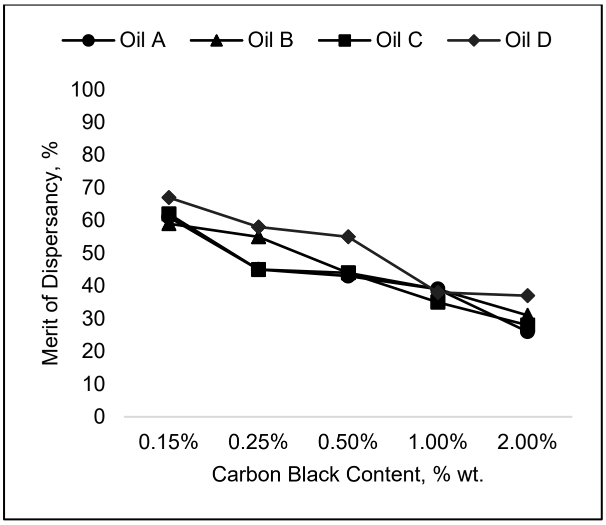

Figure 4 illustrates the trend of fresh oil MOD values at different CB concentrations for the four selected oils.

Oxidation adversely affects dispersancy molecules in lubricants by degrading their chemical structure, thereby diminishing their functional efficiency. Consequently, when the same oils are subjected to oxidation prior to dosing with CB, the MOD values at identical CB concentrations are consistently lower compared to those observed in fresh oil except oil C at 0.15 % wt. At concentrations >0.15% wt., oil D again consistently outperforms the other three oil samples by exhibiting higher MOD values at the relative concentrations. This performance by the oil D at both, the fresh state and the oxidized state establishes it as the oil displaying the best dispersancy performance amongst all the oils.

These findings highlight the critical role of dispersancy additives in oil formulations and their varying efficacy under different CB dosages and oxidation states.

Table 2 presents the MOD values of CB-dosed oil samples after undergoing oxidation.

	Oil A	Oil B	Oil C	Oil D
0.15%	58	46	62	56
0.25%	37	40	42	48
0.50%	36	39	38	44
1.00%	33	30	28	41
2.00%	27	26	27	35

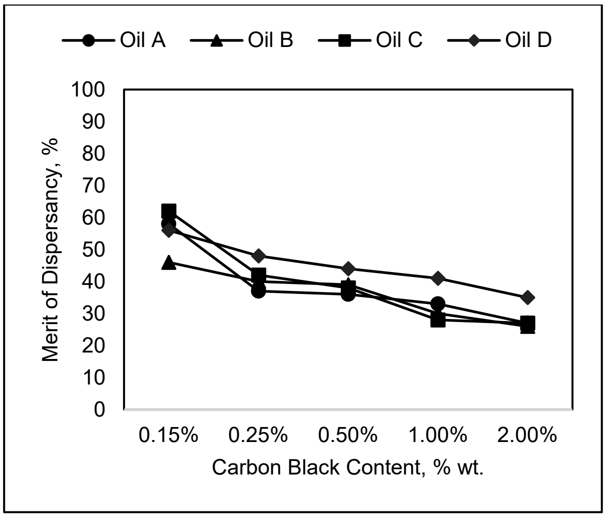

Figure 5 illustrates the trend of fresh oil MOD values at varying CB concentrations for the four selected oils after oxidation.

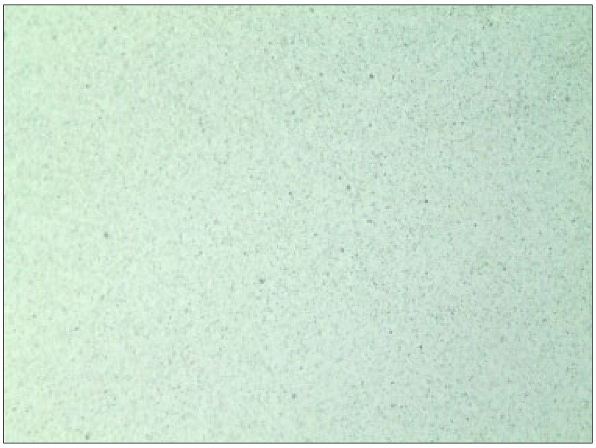

Figure 6 shows the 100x magnification image of the oil D sample at 2 %wt. concentration of CB

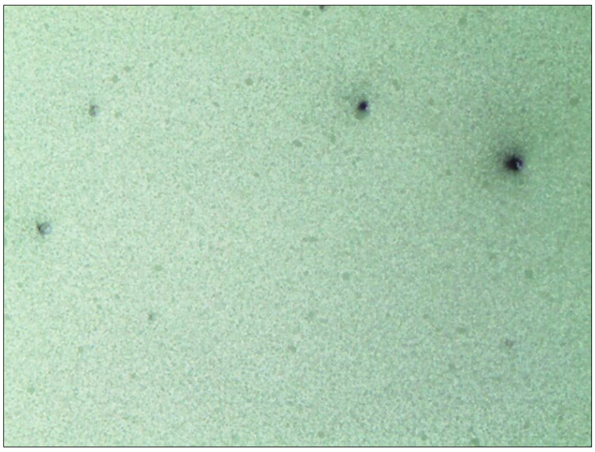

Figure 7 shows the 100x magnification image of the oil A sample at 2 %wt. concentration of CB

The microscopic images from figure 6 and figure 7 show the performance of oil D which demonstrates higher MOD at 2 %wt. when compared with oil A which demonstrates a lower MOD at 2 %wt. concentration of CB in the fresh oils.

According to the sole OEM of the MOD instrument [7] used in ASTM D7899, in-service oils with MOD values above 90 are considered to have good dispersancy, while those between 80 and 90 indicate average dispersancy. Oils with MOD values of 80 or lower are classified as having poor dispersancy. However, the ASTM D7899 standard itself does not define these ratings.

Moreover, these ratings are not applicable to this research study, as the proposed test method focuses primarily on evaluating oils (using CB to simulate soot contamination) before they go into service.

The next phase of this research will focus on testing the selected oils in actual engine bench tests to evaluate their dispersancy performance under real operating conditions. This will involve running controlled engine tests where oils will be exposed to soot and contaminants over time. At set intervals, the engine will be stopped, and the pistons will be removed for detailed inspection. The level of fouling, deposit formation, and wear on the piston surfaces, cylinder liner and other components will be analyzed to assess the effectiveness of the oil's dispersancy properties. By correlating these findings with the MOD values from the initial fresh oil testing, this phase will provide a more comprehensive understanding of how well the dispersancy characteristics hold up in actual engine operation.

5. CONCLUSIONS

This study emphasizes the significance of dispersancy performance and its crucial role in heavy-duty diesel engine oil formulations.

While standard methods exist to evaluate the remaining dispersancy performance of in-service oils, there is a lack of established procedures to assess the dispersancy of fresh oils, which is essential for informed decision-making. This research study contributes to understanding the dispersancy performance of fresh oils, before they go into service by simulating near real-world conditions and evaluating their effectiveness.

6. REFERENCES

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