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Friction and Wear Reduction via Sustainable Fluids: Towards Better Energy Efficiency and Lower CO_2 Emissions

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Extended Abstract
Introduction

Over the years, the global rise in energy consumption has been driven by the expanding world population, alongside a dramatic surge in demand for energy-efficient and environmentally friendly transportation and industrial machinery [1], [2]. Nearly a quarter (23%) of the global energy consumption is used to overcome friction and wear in tribological contacts, resulting in substantial energy losses, increased CO_2 emissions and higher costs [3]. Adopting effective measures to reduce friction and wear on a global scale could potentially minimize energy losses by 18%, reduce CO_2 emission to as much as 1,460 $MtCO_2$ and save 450 billion Euros in cost just within less than a decade [3]. While various approaches and technologies are being developed to achieve this, advanced lubricant formulations are still regarded as one of the most cost-effective solutions for both existing and new mechanical systems [3], [4]. Meanwhile, the demand for using sustainable components as lubricants, such bio-based lubricant base oils and additives is on the rise to further mitigate environmental impact [2], [5].

Scope

In this work, a range of renewable-based, biodegradable trimethylolpropane (TMP) complex esters as lubricant base fluids at various viscosities designed to match the several ISO viscosity grades were developed [6]. The complex ester base fluids with target kinematic viscosity values of 25, 46 and 68 centistokes (cSt) at 40 °C (within the range of ± 10%) were synthesised from the same starting materials at different ratios, yielding multiple viscosity grades. The lubricity properties of the lowest viscosity oils, LB 25, was further investigated by adding 1 wt% of novel ionic liquid friction modifier additive, developed to reduce friction especially for boundary lubrication conditions. The design and the selected synthetic route for making the renewable-based lubricant additives were crafted to adhere as much as possible to the "12 principles of green chemistry" and are devoid of phosphorous, metal, sulfur, and halides [7], [8]. A high frequency reciprocating rig (HFRR) tribometer was used to measure the friction and wear profiles of the mixtures, comparing them against non-additized base oils and mixtures containing conventional commercial additives.

Results

The TMP complex esters demonstrated excellent physicochemical properties across all three viscosity grades, including high viscosity indexes between 154 to 160, excellent pour point values between -48 °C to -63 °C, and outstanding oxidative stability. When combined with the novel friction modifier additives, a remarkable synergistic lubrication behavior was observed, with a significant reduction of the coefficient of friction (CoF) by up to 67% against the non-additized oils. Surprisingly, despite the absence of traditional anti-wear elements such as phosphorous and sulfur, excellent anti-wear properties were also detected, with up to 57% lower wear scar average. A more profound discovery is that the ester blends outperformed conventional friction and wear additives, glycerol monooleate (GMO) and zinc dialkyl dithiophosphate (ZDDP) by 65% and 68% in friction, respectively, and further reduced wear scar diameters by 66% and 50% at equivalent additive concentrations in oil. These findings present a promising outlook and potential sustainable alternative solution to achieve energy efficiency and reduced CO_2 emissions through superior machinery lubrication in metal-to-metal contacts.

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