

Assessment of electric-field-induced lubricant film activation in electrorheological biolubricants by optical interferometry

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Abstract

This study investigates the activation of lubricant films in electrorheological (ER) biolubricants under an applied electric field. ER biolubricants based on castor oil and Cloisite 15A nanoclay were analyzed using a colorimetric interferometry on a modified PCS EHD 1 tribometer–interferometer. Results show a rapid increase in film thickness upon electric activation, followed by stabilization. Film enhancement was more pronounced at low entrainment speeds, where dielectrophoretic forces dominate hydrodynamic ones. These findings demonstrate the feasibility of electrically controlled lubrication, contributing to sustainable and adaptive tribotronic systems.

1. Introduction

The growing demand for sustainable and high-performance lubrication has driven the development of smart tribological systems capable of active control [1]. In this context, electrorheological (ER) fluids have emerged as a promising solution due to their ability to reversibly modify their rheological properties under an electric field. This capability opens new possibilities within tribotronics for real-time adaptation of lubrication conditions [2].

Previous advances identified two main mechanisms governing friction behaviour under external electric field: the electroviscous effect, involving changes in viscosity and shear modulus under an electric field, and the electrodeposition of polarized nanoparticles onto charged surfaces [3, 4]. Both mechanisms may affect lubricant film thickness in elastohydrodynamic contacts. However, the lubricant film formation under electric stimulation remains insufficiently understood, particularly for sustainable biolubricants.

This work introduces an innovative experimental approach based on a colorimetric interferometry on a modified PCS EHD 1 tribometer–interferometer, enabling in situ measurement of film thickness in electrified contacts.

2. Materials and Methods

A model ER biolubricant consisting of 6 wt.% Cloisite 15A nanoclay (supplied by Southern Clay Products, USA), dispersed in castor oil (from Guinama, Spain), was used. The dispersion was prepared through mechanical stirring followed by ultrasonic homogenization using an UP400St device (Hielscher, Germany). A total energy input of 0.23 Wh per gram (0.83 kJ/g) in the ultrasonication step was used to ensure a stable and homogeneous dispersion. To prevent thermal degradation, the temperature was maintained below 75 °C by placing the containers in an ice bath throughout the process.

Lubricant film thickness was evaluated using a modified PCS EHD 1 tribometer-interferometer from PCS Instruments (UK). The system was adapted to apply a controlled DC electric field directly within the contact, enabling real-time monitoring of film thickness evolution under the influence of the external electric field. Measurements on a ball-on-disc configuration were conducted at different entrainment speeds under pure rolling conditions.

Film thickness was determined using both Ultra-Thin Film Interferometry (UTFI) and the Spacer Layer Imaging Method (SLIM), with the latter enabling full-field mapping of the contact. A silica spacer layer was preferred to ensure electrical insulation while maintaining measurement accuracy. A dedicated calibration procedure was developed by correlating RGB (Red, Green, Blue) intensity from SLIM interferograms with central film thickness values obtained via UTFI. This approach extended the measurable thickness range up to 800 nm with errors below 3%, allowing accurate and reliable quantification of electrically induced changes in lubricant film thickness.

3. Results and discussion

The results showed that the application of an electric field of 30 V produces a rapid increase in lubricant film thickness within approximately one second after activation (**Fig.1a**). The electrically activated film thickness showed a gradual decrease until a stable steady-state thickness is reached after several tens of seconds, indicating a dynamic response of the lubricant system to electrical stimulation

Film thickness enhancement was more significant at low entrainment speeds. However, the effect diminishes and becomes negligible beyond a threshold speed, suggesting limitations of the activation mechanisms under more dominant hydrodynamic conditions (**Fig.1b**).

Interferometric film maps revealed a uniform thickness distribution across the contact area, indicating either a global modification of the lubricant's rheological properties or a homogeneous nanoparticle deposition process. Overall, these findings confirm the feasibility of dynamically controlling lubricant film thickness through electrical activation, supporting the development of sustainable and adaptive tribotronic lubrication systems.

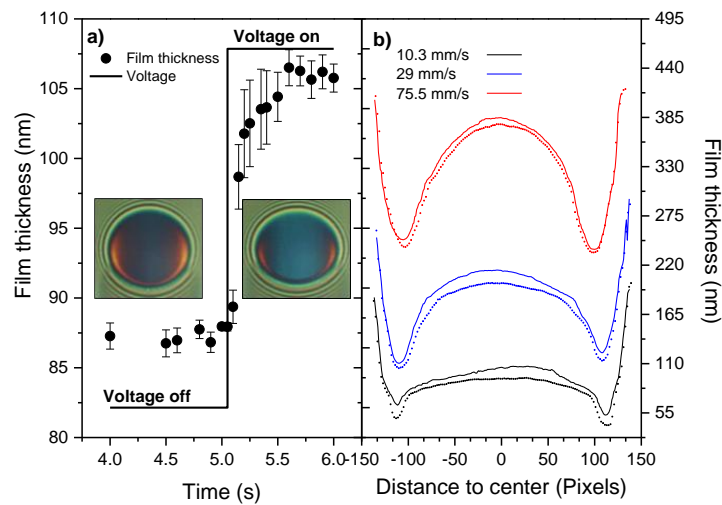


Fig.1 a) Evolution of the central film thickness at 10 mm/s and electric potential of 30 V (interferometric images included) for the nanoclay-based ER biolubricant studied; b) Film thickness profiles in the transversal directions at different entrainment speeds at 0V (dash line) and 30 V (solid line).

4. Conclusions

The modified optical interferometry setup successfully enabled the measurement of lubricant film thickness under an external electric field, confirming active control in nanoclay-based ER biolubricant. The combined UTFI–SLIM calibration ensured accurate measurements up to 800 nm with low error. Application of 30 V increased film thickness and revealed a transient response before reaching steady state. Additional mechanisms beyond the electro-viscous effect, such as particle entrainment within the contact or electro-deposition of particles on the contact surfaces, may also contribute to the overall response. Further studies will be required to clarify their relative influence.

References

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