ABSTRACT

Enhancement in the performance of lubricants and energy efficiency of the system continues to be a major challenge to the transportation and lubricant industries. The reduction of carbon emissions is a key to meeting sustainable development goals, especially for the transportation and industrial sectors. Lubricants play a vital role in efficiently keeping the crucial machine/equipment parts healthy running. However, the drive towards employing lower viscosity oils with low SAPS (Sulphated Ash, Phosphorous, and Sulphur) to enhance the fuel economy impacts the wear and durability of critical tribo-pairs operating under boundary lubrication (BL) regime. Thus, to comply with stringent norms, novel lubricants, especially nano oils (oils with nanoparticles), are currently the focus of research attention. In the past decade, nanoparticles (NPs) of several solid lubricants of various categories (polymeric, metallic, inorganic, and carbonaceous) have been explored as additives in oils and greases. Based on an extensive literature survey in this thesis work, research gaps were identified, which led to the objectives of the work. It was based on the NPs that were either not explored at all, such as Talc and Titanium, or inadequately researched. The concept of the shape of NPs of carbonaceous materials such as multi-wall carbon nanotubes (MWCNTs), multi-layer graphene (MLG), and graphite in oils on the tribo-performance was not addressed.

Moreover, the literature is silent on investigations on the suitability of base oil types such as Group I, II, II and IV for developing the most efficient nano-oils using selected NPs such as PTFE. Furthermore, in the case of NPs of PTFE (Polytetrafluoroethylene), some issues such as stability of oils, in-depth wear mechanisms, exploration of commercially available suspensions, etc., were not addressed.

Keeping all these in view, the objectives of the thesis work were defined. In the present work, NPs from four different categories viz. polymeric (PTFE), carbonaceous (multi-wall carbon nanotubes (MWCNTs, multi-layer graphene -MLG, and graphite-G), inorganic (Talc), and metallic (Titanium) were selected for the tribo-performance enhancement of API group III base-stock oil. Various series of nano-oils containing dispersant (PIBSI+PIBSA)-1 %) and theme NPs in increasing concentrations (0.5, 1, 1.5, 2, 3, and 4 wt.%) were developed, and the stability of formulated oils for the shelf life was studied using multiple techniques, i.e., dynamic light scattering (DLS), ultraviolet-visible spctroscopy, and visual photographs. They were also evaluated for performance (physical- density, viscosity, viscosity index, and tribological-extreme pressure-EP, anti-wear-AW, and anti-friction-AF). The tribo-performance evaluation, such as EP and AW, was carried on a Four-ball tester as per IP 239 and ASTM D4172 standard.

AF performance was evaluated on the Optimal SRV III under a reciprocating condition as per modified ASTM D5707 standard. The worn surface analysis was done by various techniques such as SEM (scanning electron microscopy), EDAX (energy dispersive X-ray analysis), AFM (atomic force microscope), XPS (X-ray photoelectron spectroscopy), and MRS (micro-Raman spectroscopy).

The thesis comprises eight chapters where each chapter mentions its theme, followed by a pertinent literature survey, materials, evaluation of oils, and study outcome.

Chapter 1 briefly explains the key aspects of tribology, lubrication, with a particular reference to mineral oil lubrication, additives, and their functions. Moreover, it addresses the need for novel additives. Nano lubricants, especially based on NPs of solid lubricants, (SLs) were discussed. Finally, it identifies the research gaps, objectives, and execution strategy.

Chapter 2 reveals the particulars of selected materials chosen for the investigations. Various techniques employed for the characterization, development of nano-oils, and performance evaluation and instruments/apparatus utilized) are discussed.

Chapters 3, 4, 5, 6, and 7 comprise the experimental investigations on nano-oils. Chapters 3-6 are on studies on solo oils, while chapter 7 is on combo-oils where combinations of NPs are used in oils.

Chapter 3 reveals the outcome of studies on investigating the most suitable oil among various API basestock oils (Group I, II, III, and IV) to develop nano-lubricant containing PTFE NPs in a fixed amount (3 %) as a tribo-additive in the oil. Furthermore, the amount optimization of PTFE for best tribo-performance as EPA and AWA is explored. Also, the plausible interfacial working mechanism of PTFE NPs is discussed. PTFE NPs in the form of nano-suspension (NanoFlon) proved to have significant potential as an EPA when used in group III oil. 6 wt. % of NPs proved to be the optimum concentration for the highest (392 %) improvement.

Chapter 4 investigates the influence of nano-oils containing Talc nanoparticles (NPs) (≈50 nm size) in varying amounts (0.5, 1, 2, 3, and 4 wt.%) in the presence of dispersant (1 %). Addition of 3 wt. % Talc NPs led to ~ 40%, 122 % improvement in AW and EP properties of oil.

Chapter 5 investigates the effect of various shapes of carbonaceous NPs viz. (MLG, NG, MWCNTs) in dispersant with varying concentrations (0.5- 4 wt.%) on the performance of oils. MLG proved best as AWA (48%), EPA (89%), and AFA (27 %), followed by nano graphite. MWCNTs performed worst among carbonaceous NPs.

Chapter 6 deals with the study of Titanium metallic NPs in various amounts (0.1-2 wt.%) and their effect on the tribological performance of oils. Addition of just 0.5 wt. % of Ti NPs showed the nearly highest reduction in wear and friction compared to other metallic NPs in literature.

Chapter 7 explores the possible synergism while using various combinations of different NPs with PTFE in fixed amounts (3 wt.%) as a primary player. Other NPs (1 %) such as Talc, MLG, G, MWCNTs and Ti were used in each oil with PTFE, the total % being 4 always. The combination of MoDTC (1wt.%) and PTFE (3 wt.%) showed complete synergism in all tribological properties (AW, EP, AF).

Chapter 8 summarizes the salient conclusions of the research work in this thesis and recommends future work to be taken forward.

The major takeaway from the thesis work was as follows.

- The proper selection of base oils for preparing nano-oil with selected NPs is essential since it affects the performance significantly. Group III oil proved to be the most suitable for selected PTFE NPs as EPA.
- The comparative study on different NPs in Group III oil indicated that MLG proved to be the best AWA among the solo particles, followed by NPs of Talc and Titanium, while PTFE performed best as EPA. MWCNTs did not show promising results. The inclusion of a combination of NPs, keeping PTFE as primary NPs proved very beneficial in the case of MoDTC (a commercial lubricant) and NPs of Ti and MLG. A record increase (455 %) in EP property was observed using combination of 1 wt.% MoDTC with 3 wt.% PTFE NPs and 1 wt.% nanographite with 3 wt.% PTFE NPs.