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High Pressure Viscosity and Tribology of Lubricants with Viscosity Modifiers Additives

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Lubrication Fundamentals I – VII Rheology

Introduction

Previously viscosity of over 30 commercial and laboratory synthesized lubricants were measured up to 1 GPa [1]. We presented the sharp pressure induced viscosity and pressure viscosity coefficient increase for some commercial lubricants and laboratory synthesized lubricants with mineral and synthetic base oils [2]. In this study viscosity modifiers characterization for laboratory synthesized lubricants illustrated that the one set of sharp increase in viscosity is associated to phase change of polymeric viscosity modifiers. EHL film formation and tribological properties were measured, which demonstrated collapse of lubricant film in the contact zone at pressure and temperature consistent with sharp increase in viscosity.

Results

Multiple polyethylene (PE) samples with different densities, structure, and molecular weight were selected for synthesizing laboratory blend specimens. PE was mixed at 5 wt% concentration with polyalphaolefin (PAO) ISO 10 as a base oil. The viscosity of the samples was measured up to 400 MPa at 40, 75 and 100 °C using falling body viscometer [3].

Figure 1 shows pressure-temperature viscosity behavior for the base oil and base oil blend with PE B at 5 wt%. PAO shows classical viscosity behavior with pressure at 40, 75 and 100 °C which follows the power law behavior. However a mixture of PAO and PE B demonstrates unusual viscosity behavior by increasing pressure, where at 75 °C viscosity is greater than 40 °C which is not typical viscosity behavior. Eventually sinker stopped at 400 MPa, 75 °C results in sudden jump in viscosity. Typical viscosity trend observed at 40 and 100 °C. Thorough evaluation of multiple PE with different physical properties it is concluded that, pressure-temperature viscosity dependency is associated to phase transition in polymer additive. Polymer molecular weights, structure and crystallinity can effect the onset of sharp pressure induced viscosity behavior.

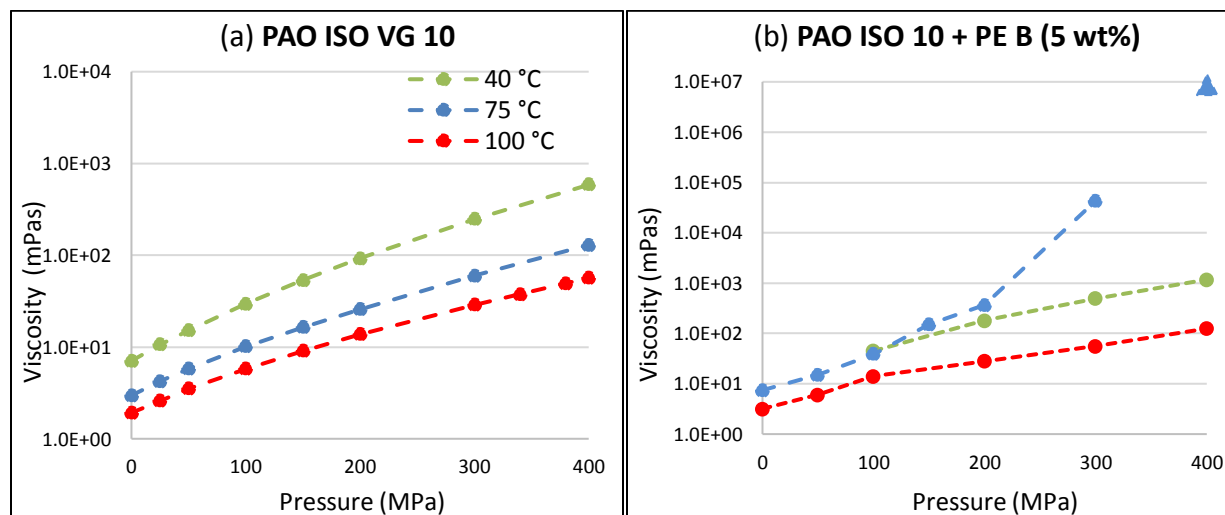


Figure 1. Pressure-temperature-viscosity measurements of (a) base oil, PAO ISO 10 and (b) mixture of PAO ISO 10 and PE B 5wt%.

Since the sharp pressure-driven viscosity increase was not expected, and it is not considered in the EHL film thickness estimation, a series of tribological tests was performed to investigate how friction and

wear behave at contact stresses and temperatures similar to the pressures and temperatures experienced in the viscosity measurements. A WAM6 tribological test rig with a ball on disc contact was used to study the friction, film thickness and wear of specimens.

Table 1 compares the film thickness measurements using the WAM6 at 75 °C for PAO and PAO/PE-B (5 wt%) with film thickness estimation using Hamrock-Dowson equation [4]:

E' : Effective Elastic Modules

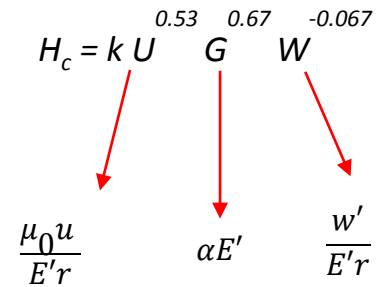
α : Pressure-Viscosity Coefficient

w' : Load per unit width

α : Pressure-Viscosity Coefficient

μ_0 : Absolute viscosity at ambient pressure

k : Constant

$$H_c = k U^{0.53} G^{0.67} W^{-0.067}$$


$$\frac{\mu_0 u}{E' r} \quad \alpha E' \quad \frac{w'}{E' r}$$

Table 1 presents that measured film thickness for PAO base oil is in agreement with estimated film thickness using Hamrock-Dowson equation. However for PAO/PE B blend by increasing contact load film thickness collapsed. This collapse correlates with the pressure-temperature sharp increase in viscosity of the specimens at 75 °C. It is also observed that after the WAM test at 75 °C of the PAO/PE mixture specimen, the fluid transformed to a semi-solid state. It is noteworthy that PAO/PEB blend demonstrated similar film thickness to the PAO and estimated film thickness using H-D equation at 40 and 100 °C.

Table 1. Film thickness measurement for PAO and PAO/PE B at 75 °C.

Film Thickness (nm) @ 75°C			
Load (N)	10	25	40
H-D (Eq.)	69	64	66
PAO	91	79	78
PAO/PE B	95	wear	wear

It is not clear how the lubricants perform in the contact zone after VM phase transitions, or how the solidified VM passes through the contact, or how it functions if it does pass through the contact. However, it is likely that if VMs undergo a liquid-solid phase transition in the inlet region of the contact,

the solidified material will jam or block the flow of lubricant, causing a collapse of the lubricant film. This scenario is consistent with the wear of the glass disc (Cr-coated), used in the EHL measurements. It is concluded that the plate wear arises from a collapse of the films in the contact zone. Furthermore this collapse correlates with the pressure-temperature sharp increase in viscosity of the specimens at 75 °C.

Acknowledgments

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Key words

Lubricant, Viscosity, High Pressure, Polymer Additives, Viscosity Modifier, EHL, Wear.