

VISCOUS AND MOLECULAR EFFECTS IN TRIBOCHEMICAL THIN FILM LUBRICANT FLOW

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ABSTRACT

Multiple concentrations of fatty acids in the range of $C_{10} - C_{18}$ atoms in light mineral oil were tested in this study. The experiments were carried out in a high-tech laboratory to predict pressure and flow parameters in the confines of a screw driven positive displacement piston. Theoretical and experimental data were compared for pure light mineral oil and fatty acid mixtures. The viscous forces were found to lead to the full pressure drop whereas a minor pressure drop was caused by molecular forces. With increased temperature, less pressure was required to pump the oil through the extremely thin space between parallel plates. The increase in viscosity as concentration increased, resulted in an increase of experimental strain. Variations in film temperatures showed that fluid friction was higher for the fatty acid mixture than for pure light mineral oil. For the variance of pressure with concentration, a regression analysis was plotted. The study was carried out to promote the use of surfactants in the lubricant and dynamic seal industry.



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1. INTRODUCTION

In almost every dynamic seal design, balancing the conflicting demands of low leakage with low friction and wear of the seals' mating surfaces is a major challenge. The idea was that more tightly bound surfactant additives would provide better lubricant behaviour, resulting in a better dynamic seal. Fundamental experimental knowledge was needed in order to formulate mathematical models and predict the behaviour of thin films. Thin film migration was interpreted as flow through porous media, i.e. Darcy flow. The aim of this experiment was to compare the flow of an oil and surfactant solution to output pressure drop in the confines of a positive displacement piston and a thinly spaced (approximately 0.02mm) end-connected collection of parallel plates. The lubricant used in the study was light mineral oil, and the surfactant additives were fatty acids

in the C_{10} - C_{18} range. Common sources of hydrophobes for the non-ionic surfactant industry have been fatty acid triglycerides from both animal and vegetable sources.

In almost all cases, the main component acids belonged to the above range (Cross, 1987). The results of Palmitic acid dissolved in Polyolefin and confined between smooth surfaces were experimentally analysed (Yamada et al., 2016). The acid was primarily used as an additive friction modifier. The disparity between smooth and rough surfaces in friction behaviour was discussed. This gives insight into the formation of low-friction surfaces in the lubrication of macroscopic tribology dependent on oil. The effect of unsaturated fatty acids on the lubricating properties of a biodiesel consisting of a mixture of methyl ester fatty acids and conventional diesel fuel was studied (Martin et al., 2013).

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The addition of fatty acids to biodiesel as additives increased the lubricating properties of the fuel at higher temperatures. Elevated temperatures and oxygen were required to shape this protective film that reduced friction and limited wear. The normal and friction forces between layers of three fatty acids and rosin acid measured in n-hexadecane with a surface-forced apparatus were studied (Lundgren et al., 2008). When absorbed from dry n-hexadecane, almost all of the fatty acids formed loose packed monolayers on mica surfaces. In all systems, the friction force increased linearly with load, and increasing unsaturation. Friction forces were measured between molecularly smooth mica surfaces confining thin films of various branched hydrocarbons using the surface forces apparatus (Drummond & Israelachvili, 2000). It thoroughly investigated the evolution of systems to steady-state sliding from rest or after a change in sliding velocity, noting the existence of various length and time scales. In order to fully describe the dynamic response of lubricants and complex fluids under shear, it was obvious from these findings that both time and distance of sliding had to be considered (Smith et al., 2006).

It was shown that the manufacturers of lubricants responded by producing low-viscosity lubricants with complex additive packages capable of reducing overall engine friction while preserving the engine's useful life. The friction modifier, whose task was to reduce the sliding friction of components operating in the boundary lubrication regime, was an important component in the lubricant additive package. It was widely agreed that the piston/ring/cylinder wall interface attributed to 40-60 per cent of mechanical friction, much of which was due to the compression ring whose lubrication was kept intentionally minimal to control exhaust emissions. A computer model has been modified and used to further investigate the potential effect of the fuel administration of the friction modifier at the top ring zone. The molecular level role of the model and commercial friction modifier lubricant additives used in automatic transmissions at wet clutch interfaces were researched using surface force equipment adjusted for oscillatory shear (Zhu et al., 2003). In the boundary lubrication regime, the nano rheological properties of tetradecane were investigated with and without a model friction modifier additive and compared to a fully formulated automatic fluid transmission system (ATF). Nano rheological properties comparable to those observed for tetradecane containing 0.1-0.2 wt. percent 1-hexadecylamine were demonstrated by the ATF containing industrial grade friction modifiers. It was shown that significant improvements in the load capacity, wear resistance and friction coefficient of mechanical seals could be achieved by forming a regular microsurface structure on their surfaces in the form of micropores (Etsion,2004).

A feasibility study was performed experimentally to produce the micropores using the laser surface texture technique. Friction and face temperature had been reduced in all the tests, wear resistance had been

increased and life prolonged. The study findings formed the theoretical basis for the prediction of boundary film behaviour between sliding surfaces. A model for optimising the lubricant output as well as the design of dynamic seals provided the calculated effects of various parameters. For designing more enhanced dynamic seals, the information gained from the observed effects of different lubricant constituents on the permeability factor was used. The findings of this research contributed significantly to improving the design and functioning of dynamic seals.

2. POSITIVE DISPLACEMENT PISTON TEST RIG

In order to analyse the flow behaviour characteristics of certain chemical fluids with and without additives such as fatty acids, the test apparatus specifically built for this project was used. Basically, this system was a long positive displacement piston operated by a digital oscilloscope and instrumentation. A cross-section of the screw-driven piston that housed the testing unit and enclosed in a chrome-steel case is shown in Fig.1. The exterior diameter and thickness of the case were 70mm and 6mm respectively. The lengths of the case and interior screw were 580mm and 190mm. There was a socket at the right end of the piston into which a steel threaded plug was inserted. An annular space was formed through which a liquid was squeezed. Accurate measurements of the predetermined film thickness setting were made with two sizes of plugs.

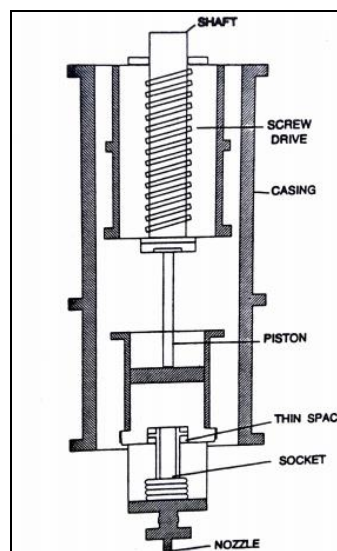


Figure 1. Cross-section of a positive displacement piston and end connected set of thin spaced parallel plates

The thin space was created by the distance between the inner surface of the socket and the outer surface of the plug (Duriseti, 1993). Between the screw drive and the piston, there was a socket inserted into which an LVDT (load cell) was inserted. After each cycle, lubricant was poured into the piston by unscrewing the right end of the

$$P = (12\mu l/b h^3)Q \tag{1}$$

where the flow rate is Q, P is the pressure change, μ is the viscosity, b is the face width, h is the thickness of the film, and l is the socket length. A straight-line variation in the plot was expected for a certain pressure and flow rate.

3. RESULTS AND DISCUSSIONS

Data obtained from the above theoretical and experimental models were compared for pure light mineral oil and fatty acid oil solutions. A composite collection of results was plotted taking all the experiments performed into account. An additional statistical regression analysis was done taking into account the variance of concentration. The measurements of the fluid film pressure for each of the 0, 0.1 and 1 percent concentrated solutions of both the well-polished plugs were done using C10, C14, C16 and C18 acids. The broad variations of the experimental and the theoretical pressures were attributed to the viscous forces and molecular forces. The findings showed satisfactory agreement between experimental and theoretical measurements for pure light mineral oil as shown in Fig.5.

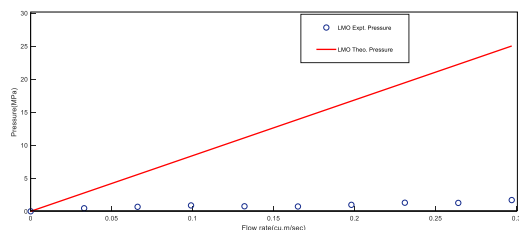


Figure 5. Comparison between the experimental and theoretical pressure profiles pure light mineral oil at 0.2mm plug.

In the case of the 0.2mm plug, the difference between the experimental and theoretical pressures was greater. The liquid's rise in temperature as it flowed through the annular space was high enough to see that the viscosity decreased to pump the fluid through. The data obtained for pure light mineral oil was lower than the theoretical projections for the same piston speed and film thickness, but in good agreement. Results were taken into consideration after the recalibration of the load cell was done after testing. The calibration curves prior to and after testing as shown in Fig. 6 were found to correlate well which served as validation of the results.

Fig.7 shows the theoretical pressure profiles for 0, 0.1 and 1 % concentrated Palmitic acid using the 0.1mm plug. It was observed that the peak pressure and the slope of the pressure profile increased with increase in concentration. This was explained by the equation

$$P_2 - P_1 = \text{loss} = \frac{flv^2}{2gD} \tag{2}$$

where

$$f = 16/Re = 16\mu/\rho V l$$

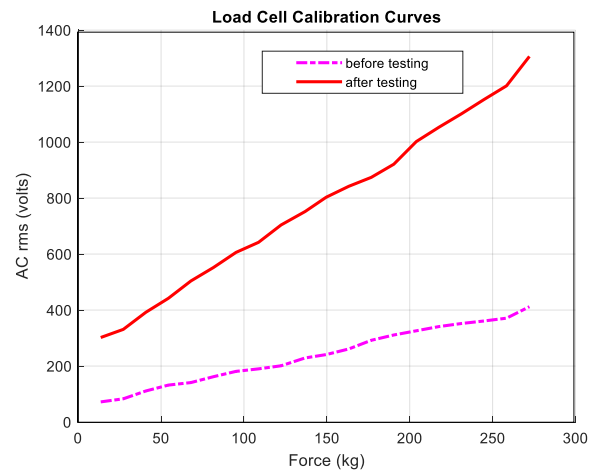


Figure 6. Validation of the calibration curves of the load cell prior to and after testing

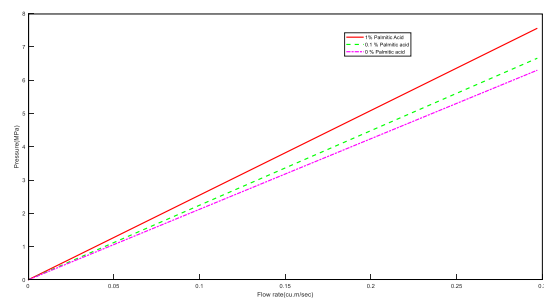


Figure 7. Comparison of the 0, 0.1 and 1% theoretical pressure profile of Palmitic acid in 0.1mm plug.

With increase in concentration viz. viscosity the more friction force was generated and velocity being constant greater pressure was required to pump the fluid. Fig.8 showed the experimental and theoretical pressures for all acid mixtures of 0.1% concentration using the 0.2mm plug.

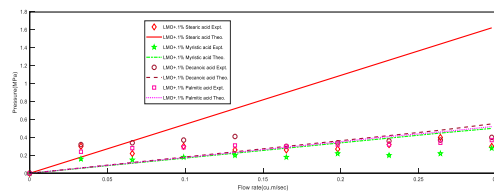


Figure 8. Combined comparison of experimental and theoretical pressures of 0.1% C₁₀-C₁₈ acids in light mineral oil using the 0.2mm plug

Similarly, Fig. 9 showed the combined experimental and theoretical pressure findings for all acid mixtures of 1% percent concentration with the 0.1mm plug. The peak pressures and slopes of the pressure profiles were noted to be significant with the stearic acid blend having the highest peak pressure and pressure profile slope.

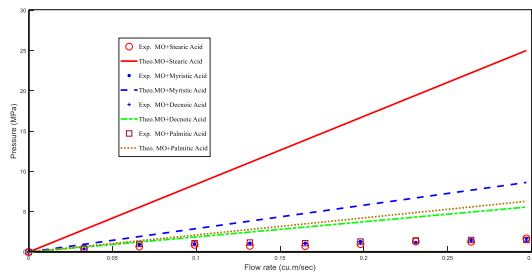


Figure 9. Combined comparison of 1% C₁₀-C₁₈ acids with light mineral oil at 0.1mm plug

Fig.10 demonstrated the concentration against pressure profiles at 0.2m³/sec flow rate using the 0.2mm size plug. The pressure vs concentration results showed that the maximum peak pressure for the said acids C₁₀-C₁₈ was justified. In the oil medium, the over emulsification of stearic acid was unique. In order to clarify the graphs, the essential micelle concentration of a surfactant decreased as the number of carbon atoms increased in the hydrophobic group to 16 (Wasan et al., 1988). Appropriate charge ions lowering the critical micelle formation was correctly attributed to the impact of lowering surface tension.

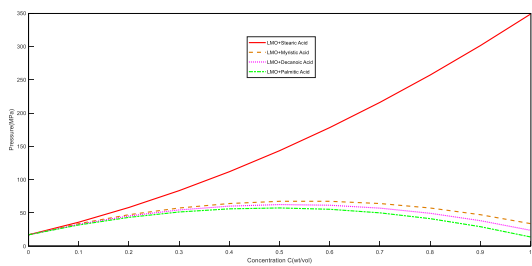


Figure 10. Pressure vs concentration curve at 0.2m³/sec flow rate using 0.2 mm plug

4. CONCLUSION

The fluid's effective viscosity and pressure were increased with the addition of a fatty acid. The fluid friction was found to be higher with increase in fatty acid concentration. The main focus of this research was explained as the temperature of the fluid increased as it was pushed through the very thin space between parallel plates. It resulted in a decrease in viscosity-cum-pressure. In comparison to the pressure drop caused by viscous forces, the molecular forces made a minor contribution with the addition of fatty acids. Based on preliminary experimental and theoretical findings, it was determined that the given fixed geometry was useful for comparing various fluids. Under severe conditions, several phases will be encountered as the carrier lubricant begins to evaporate, complicating the linear issue. When pressure profiles of the same acid in various concentrations were grouped together, the 1% was the highest, followed by 0.1 and 0%. In the presence of inorganic salts, surface and interfacial stresses decreased. The lowering of surface tension was correctly attributed to the presence of ions with the appropriate charge. These reduced the critical concentration for micelle formation. The concentration versus pressure plots indicated a justified minimum peak pressure for C₁₀-C₁₆ acids. C₁₈ had a unique proclivity due to its excessive emulsification in the oil.

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