Lubricant Degradation, Transport and the effect of extended oil drain intervals on Piston Assembly Tribology.

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SYNOPSIS

There are ever increasing demands on lubricant manufacturers to meet governmental legislation and customer needs by improving fuel economy, engine durability and exhaust system compatibility as shown by the introduction of GF4 and move towards GF5 specification oils. This has created an ever increasing need to understand how oil degrades in an engine and how this degraded oil affects piston assembly tribology. This review conference paper will give an overview of a collaborative project that has been undertaken to further enhance the understanding of how lubricant degrades in an operating engine, its transport through the engine and effect upon piston assembly tribology.

1 INTRODUCTION

The tightening of emissions regulations is impacting upon base oil choice, with a move from higher sulphur content Base I oils to Base III oils. However it is this sulphur that provides the oil with a higher natural resistance to oxidation and therefore Base III oils require an increase in oxidation resistance to be provided by the additive package. This is at the same time as the additive package is expected to perform for longer in order to meet the demands for longer drain intervals. There is additionally a drive towards improved fuel economy which is resulting in the use of lower viscosity oils. However, as oils become degraded they increase in viscosity, thereby reducing the fuel economy benefits. Another problem caused by the lower viscosity lubricants is the potential for increased engine wear, which is clearly undesirable. There is therefore an increasing need to understand how oil degrades in a fired engine and, of equal importance, understand the effect this degraded lubricant has on the tribological operation of the engine, in particular its overall friction and component wear.

This paper gives an overview of the work undertaken to date and still in progress to look at the effect of oil degradation on piston assembly tribology, and to try and elucidate the chemical mechanisms by which oil degrades. It does not cover each area of the work in detail as references to published papers and conference proceedings are given. The engine used for all the research areas discussed is a single cylinder Ricardo Hydra gasoline engine, an in depth description of this engine and the underlying theory behind this work can be found in [1].

2 PROJECT AREAS

2.1 Lubricant degradation

One of the most important lubricant properties is its viscosity and this has been shown to increase during its working life in an engine due to oxidative degradation. This viscosity increase causes increased friction and, hence, in automotive engines, decreased fuel economy. However the chemical mechanisms underlying lubricant degradation are not well understood [2-5]. As fully formulated oil is complex to analyse, resulting in highly convoluted chemical analysis, this work has been undertaken using simplified oil blends based on Shell XHVI™ 8.2 with minimal additives, namely a dispersant and a detergent. Long term degradation tests (41–80 hrs) have been undertaken to investigate the effect of these oil blends on the chemical composition of the oil as it degrades and the end of test engine component condition [1, 6].

To assist this study a system has been designed to allow the extraction of oil from the rear of the top piston ring of the engine while firing [20,1]. In order to further enhance understanding of degradation mechanisms a bench top reactor has been developed that allows samples of oils to be degraded in the lab in a similar environment to that found in the top ring zone (TRZ) area of the firing engine [17]. Both oil samples from the long term degradation tests and model compounds, such as Pristane and Squalane, have been degraded in this reactor. Model compounds and easier to study as they are not a mix of molecules as found in base oil.[7-9]

The TRZ sampling system has allowed the levels of degradation in the ring pack to be compared to those in the sump and this has confirmed the reactor theory suggested by Yatsutomi in 1981 [10]. In order to further the study of bulk lubricant degradation and its effect on the engine a high temperature, high load, accelerated degradation test procedure, the Leeds University Hydra Engine bulk oil degradation sequence 1A (LUHE 1A) has been designed. This has been based on the Sequence IIIG and is work in progress.

2.2 Flow rates and residence times

By comparing the increasing levels of degradation in the sump over time with that in the TRZ samples it is possible to calculate the flow rate of oil through the ring pack of an operating engine. This has been undertaken on the Hydra engine and the effect of lubricant composition and engine speed and load investigated [11-13, 20]. Using this same TRZ sampling system combined with a switching valve to allow the oil supply to the engine to be changed while the engine is running, the residence time of the oil in the ring pack has also been measured [20]. Initially the engine is run on lubricant supplied from Sump A until it reaches thermal equilibrium, the valve is then changed while the engine is running and lubricant in Sump B supplied to the engine. The lubricant in sump B is identical to that in Sump A with the exception that it contains

a marker at 5% concentration. When the TRZ sample concentration is measured to be equal to that in the sump (5%) the oil is deemed to have been replaced, and this time period is taken as the residence time.

Work has also been undertaken to investigate the effect of viscosity on the flow rates through the ring pack and preliminary evidence indicates that more viscous oil flows through ring pack more slowly. This would suggest that as oil degrades and its viscosity increases it will have a longer residence time in the ring pack. The implication is that it will have longer to become more highly degraded and could result in increased sludge and deposits being formed in the ring pack as the oil nears the end of its extended drain interval. This has implications on the friction and hence fuel economy of the engine.

2.3 Numerical modelling

Using the information obtained regarding the flow rates and residence time, and earlier work undertaken in the project, it is possible to develop a detailed analysis of oil transport in the piston assembly and a mathematical model can be generated [14-16]. Work is now underway to try and develop a combined tribological, rheological and chemical model for lubricant degradation in the piston ring pack [17]. This model will go someway towards allowing the prediction of fuel economy with respect to time since fresh fill, allowing the effects of extended oil drain intervals to be investigated.

2.4 Tribological investigation of TRZ oils

In order to start to elucidate the effect of oil degradation on the tribological interaction between the ring and liner relatively large (40ml) quantities of TRZ oil has been extracted from the engine at a range of loads. These oil samples have then been subjected to a range of tribological, rheological and chemical tests in order to characterise them. Changes were required to some of the tribometers used in order to allow for the small quantities of oil available. This is the first time that such a comprehensive range of tests have been carried out on TRZ oils. Initial results have been presented [18, 19] and further analysis is being undertaken.

3 CONCLUSIONS

Work has been and is being undertaken:

- into lubricant degradation mechanisms
- to develop a simple oil formulation for chemical analysis that behaves in a similar manner to fully formulated oil
- to develop a repeatable sequence test for the accelerated degradation of lubricating oil
- to investigate flow rates and residence times with respect to engine load and speed, lubricant composition and viscosity
- to develop a combined tribological, rheological and chemical model for lubricant degradation in the piston ring pack
- to investigate the effect of lubricant degradation on piston assembly tribology with consideration to its degraded composition and rheology using a range of tribometers.

4 REFERENCES

1. Lee, P.M., et al. *The Degradation of Lubricants in Gasoline Engines: Development of a Test Procedure to Evaluate Engine Oil Degradation and its Consequences for Rheology*. in *31st Leeds-Lyon Symposium on Tribology. Life Cycle Tribology*. 2004. Leeds: Elsevier.
2. Mortier, R.M. and S.T. Orszulik, *Chemistry and Technology of Lubricants*. 1997: Blackie Academic and Professional.
3. Van Sickle, D.E., Journal of Organic Chemistry, 1972. **37**: p. 755.
4. Jensen, R.K., et al., Journal of American Chemistry Society, 1981. **103**: p. 1742.
5. Adhvaryu, A., Y.K. Sharmab, and I.D. Singhb, Fuel Volume 78, 2003(11): p. 1293-1302.
6. Lee, P.M., et al. *The Degradation of Lubricants in Gasoline Engines: Part 2: A Study of the Link Between Base Oil Degradation and its Changing Rheological Properties*. in *STLE Annual conference*. 2003. Toronto.
7. Wilkinson, J.J., et al. *Understanding Piston Assembly Lubricant Degradation in Gasoline Engines*. in *IMechE Mission of Tribology 13*. 2004. Birdcage Walk, London: IMechE.
8. Wilkinson, J.J., et al. *The Degradation of Lubricants in Gasoline Engines: Part 3: Chemical Mechanism for the Oxidation of Branched Alkanes*. in *STLE annual conference*. 2003. Toronto.
9. Wilkinson, J.J., et al. *Understanding Piston Ring Pack Degradation in Gasoline Engines*. in *Additives 2005*. 2005. Dublin.
10. Yatsutomi, S., Y. Maeda, and T. Maeda, *Kinetic Approach to Engine Oil: 1 - Analysis of Lubricant Transport and Degradation in Engine System.* Ind. Eng. Chem. Prod. Res. Dev., 1981. **20**: p. 530.
11. Stark, M.S., et al. *The Degradation of Lubricants in Gasoline Engines: Lubricant Flow and Degradation in the Piston Assembly*. in *31st Leeds-Lyon. Life Cycle Tribology*. 2004. Leeds, UK: Elsevier.
12. Lee, P.M., et al. *The Study of the Residence Time and Flow Rate of Lubricating Oil through a Piston Ring Pack*. in *IMechE Mission of Tribology 13*. 2004. Birdcage Walk, London: IMechE.
13. Lee, P.M., et al. *Lubricant Degradation Studies using a Single Cylinder Research Engine*. in *World Tribology Congress III*. 2005. Washington DC.
14. Gamble, R.J., et al., *Preliminary Study of the Influence of Piston Secondary Motion on Piston Ring Tribology*, in *Thinning Films and Tribological Interfaces*, D. Dowson, Editor. 2000, Elsevier Science. p. 679-693.
15. Gamble, R.J., M. Priest, and C.M. Taylor, *Detailed analysis of oil transport in the piston assembly of a gasoline engine.* Tribology Letters, 2003. **14**(2): p. 147-156.
16. Gamble, R., *The Influence of Lubricant Degradation on Piston Assembly Tribology*, in *School of Mechanical Engineering*. 2002, The University of Leeds: Leeds.
17. Stark, M.S., et al. *The Degradation of Lubricants in Gasoline Engines: Part 1: A Combined Tribological, Rheological and Chemical Model for Lubrication Degradation in the Piston Ring Pack*. in *STLE annual conference*. 2003. Toronto.
18. Lee, P.M., et al., *The extraction and tribological investigation of top ring zone oil from a gasoline engine.* IMechE J Special issue, 2005. Leeds-Lyon Symposium on Triblogy.
19. Lee, P.M., et al. *The tribological and chemical analysis of top ring zone samples of fully formulated oil taken from a four stroke gasoline engine*. in *World Tribology Congress III*. 2005. Washington DC.
20. M. S. Stark,* et al., *Measurement of Lubricant Flow in a Gasoline Engine,* Tribology Letters, **19,** 3, *163-168* (2005).