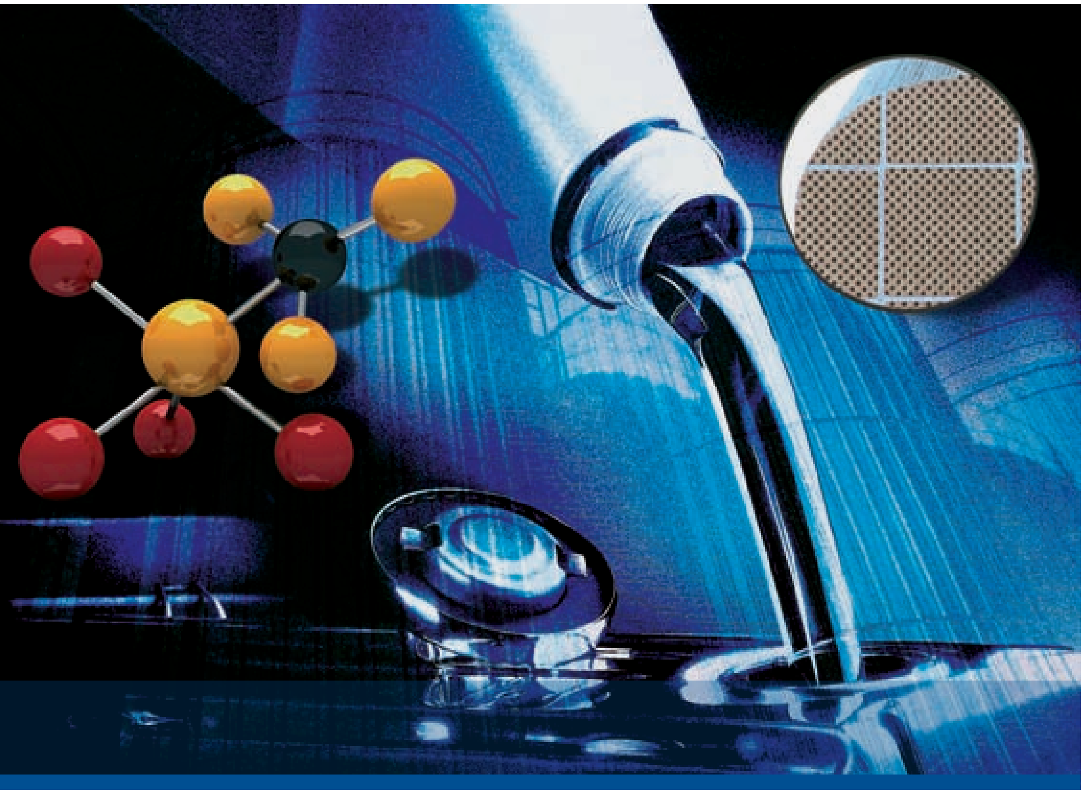

Particulate filters are capable of significantly reducing soot and particulate emissions from a diesel engine. Regeneration of the filter through oxidation of the filtered soot is assisted, among other means, by postinjection. IAV has examined the results of experiments relating to functionality and field of application for two typical lubricant formulations under the aspect of lube-oil dilution. Attention focuses on the influence of physico-chemical properties as well as their effects on function.

Effects of Diesel Particulate Filter Regeneration on Lubricant Quality

1 Introduction

Regeneration measures are necessary for meeting future regulations on particulate and nitrogen-oxide emissions from diesel engines. These processes employ regenerating systems that work on a continuous or intermittent basis. Although these are mainly active systems requiring an additional heat supply, use is, in some cases, also made of passive processes that in general utilize catalytic effects [1].

In addition to the challenge of achieving an adequate regeneration temperature in all operating ranges, a particular problem is shown to lie in the dilution of lubricant resulting from fuel entrainment. **Figure 1** presents a multiple-injection strategy up to the point at which the filtered soot if completely oxidized. The HC fractions condensed before soot burn-off through post-injection dilute the lubricant in the oil sump through the piston ring liner group. Acceptable for the most part, lubricant is known to be diluted by as much as 10 % with the regeneration mode in hand [2].

The following article reports on investigations carried out at IAV GmbH into the regeneration of diesel particulate filters for different lubricant qualities and examines the results obtained.

2 Laboratory Analyses

Regeneration is primarily shown to result in a change in kinematic or dynamic viscosity behavior. In addition, however, particle composition and lubricant surface tension are also affected.

Examination covered two lubricant qualities currently in use from the SAE 10W-40 (hydrocrack oil) and SAE 5W-30 (polyalphaolefin / PAO) viscosity ranges. Both qualities are low-ash oils. **Figure 2** shows the percentage dynamic change in viscosity taking place in both base-oil formulations as a result of contamination from fuel, water and soot. Behavior tends to be similar both for the petroleum-based formulation as well as for the synthetic type. Responses of this type are, for example, also documented in [3] and [4]. Depending on diesel-fuel composition, viscosity changes of up to 20 % occur in the temperature range relevant to operation.

In this context, the highly volatile fractions from conventional diesel fuel, Figure 2a, have a stronger influence than diesel fuel exposed to thermal loads, Figure 2b. A similar situation also occurs when using oxygen-containing fuel components as a result, for example, of adding vegetable oils, Figure 2c. However, as soot and, under specific boundary conditions, water components also contaminate the lubricant Figures 2d, 2e, higher viscosities are the long-term behavior produced in most cases during engine operation. The typical overall engine profile shows operation at low temperatures and with increased water contents to play a more significant part than operation at high load, Figure 2f. Accounting for up to 25 %, petroleum-based formulations exhibit higher changes in viscosity than synthetic base-oil formulations.

3 Test-Bench and Vehicle Investigations

Depending on regeneration strategy, the effects resulting from fuel entrainment differ. By way of example, **Figure 3** demonstrates the change in viscosity that occurs in response to single postinjection as compared with multiple postinjection. Here, as a result of the lower temperature level in the combustion chamber, the fuel entrained with multiple postinjection is greater than with a single postinjection of equal mass [2].

The analyses described below present results obtained for the regeneration strategy with single postinjection for two different qualities of lubricant equal in volume. The fuel quality used is conventional diesel oil. In this context, **Figure 4** documents the results from a driving profile reproduced on an engine test bench. It shows viscosity at a near-real operating temperature of 100 °C, the residual alcaline lubricant component, characteristic wear elements with the oil-volume related limit values as well as an assessment of lubricant state. Irrespective of regeneration behavior, the lubricant shows an increase in viscosity that correlates with oil aging. In particular, the higher thermal load brought about on the test bench sheds a critical light on the aspect of defining oil-change intervals. As their thermal resistance is better than petroleum-based formulations, synthetic oils can, for a similar load profile, tolerate oil-change intervals that are as much as 25 % longer. Here, soot entrainment increasingly superimposes the effects of fuel dilution within an oil-change interval. Wear behavior is shown to follow the same pattern.

In general, lubricant undergoes polymerization or coagulation during the

The Author

Dipl.-Ing.
Klaus Herrmann
is team leader in the Base Engines/Transmissions division, Business Area Development Powertrain at IAV GmbH in Chemnitz (Germany).

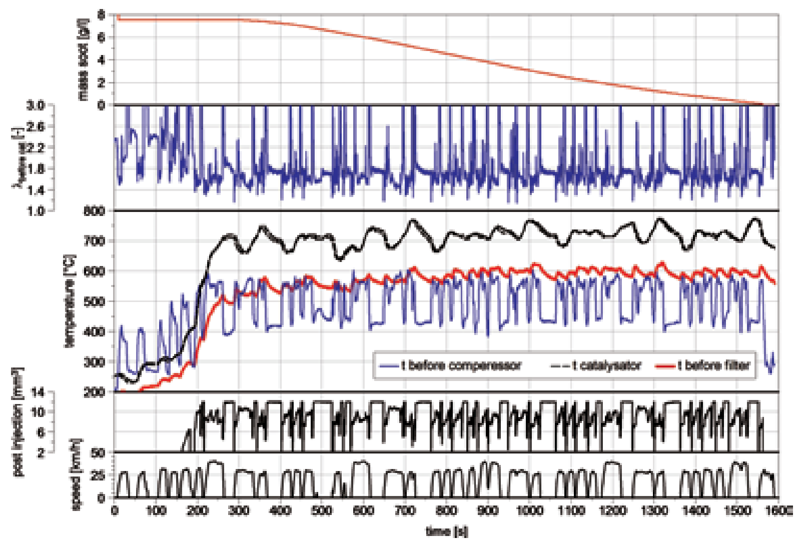

Figure 1: Regeneration by means of multiple-postinjection mode

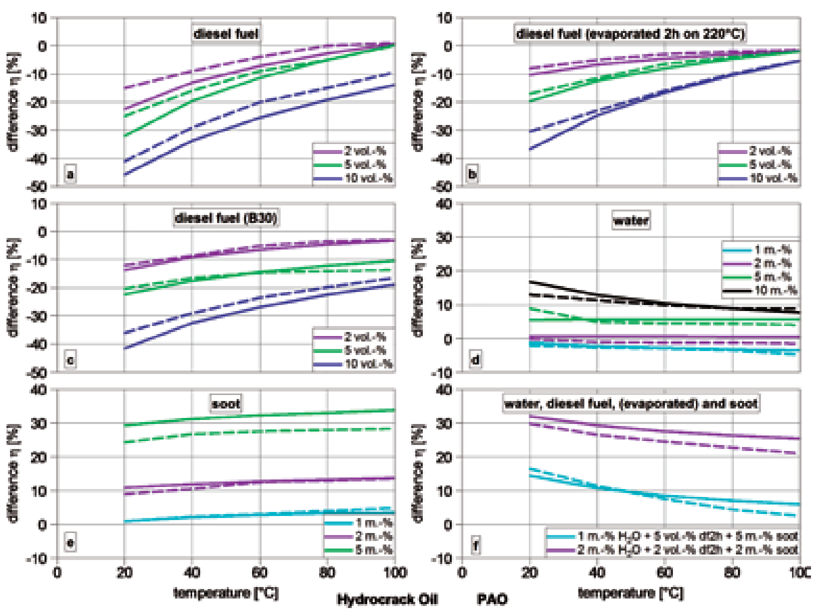

Figure 2: Influence of contamination on viscosity behavior for two base oil formulations

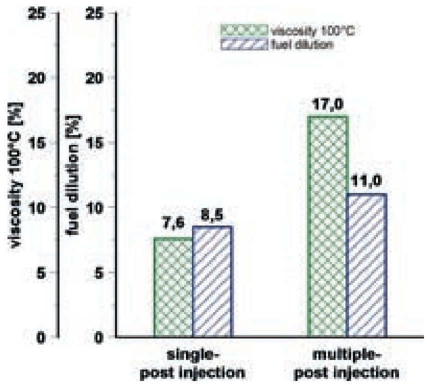

Figure 3: Lubricant dilution in different regeneration strategies

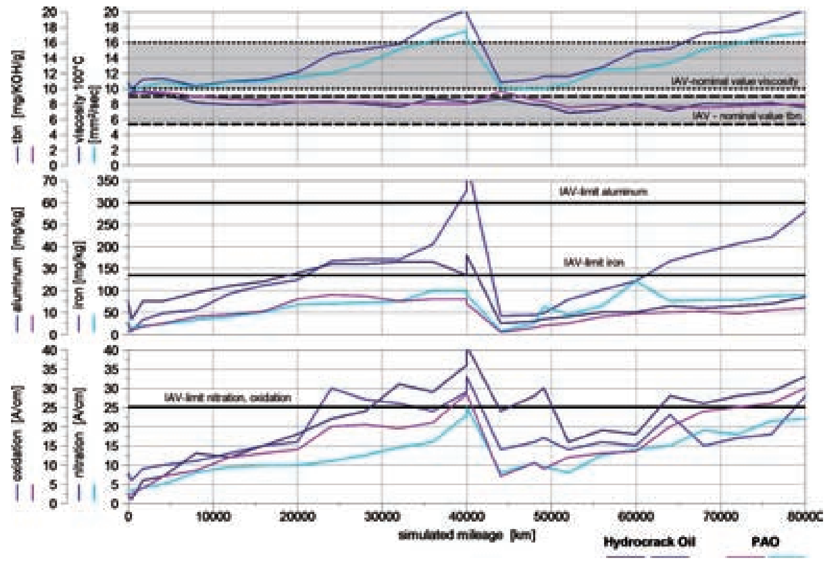

Figure 4: Influence on lubricant parameters in engine testing during a driving profile simulated on the engine test bench

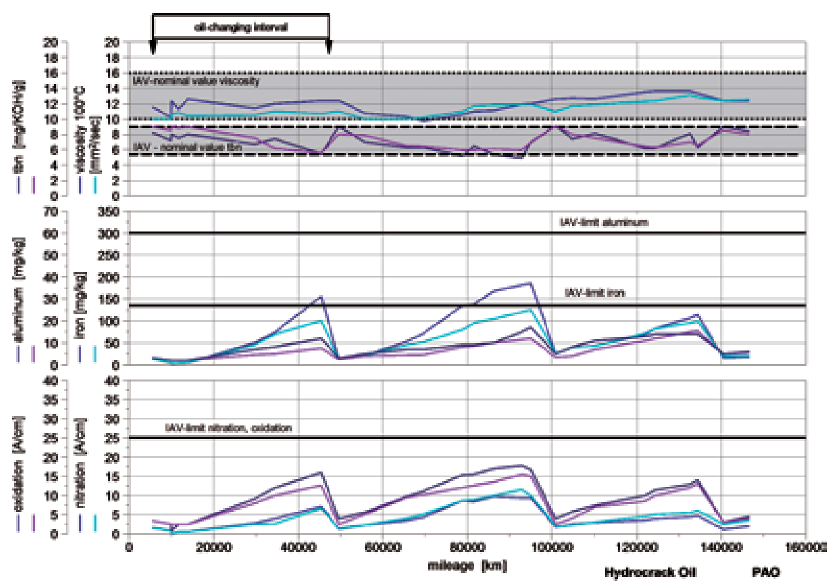

Figure 5: Influencing lubricant parameters in vehicle testing

regenerative phase. Significantly larger particles are formed through the fuel's HC fractions as well as high-molecular lubricant compounds. These have, for example, also been identified by [1] in particulate filters and confirmed on the basis of transmission-electron microscope images as well as thermogravimetric analyses. As a result of their structure, petroleum-based compounds, and particularly the aromatic compounds, tend to coagulate more intensely than synthetic formulations do.

Whereas fuel entrainment at low and medium engine loads can amount to as much as 10 % with the engine running on the best bench as a result of the thermal boundary conditions involved, levels are in most cases significantly lower in the vehicle. This can largely be explained by operation taking place in a combination of adsorption and regeneration cycles [2]. By way of example, **Figure 5** shows the change in lubricant properties over a total distance of 140000 km. The lubricant-specific parameters as well as resultant wear are shown to behave in linear fashion over the lubricant-change intervals and, as a long-term effect, reveal a slightly degressive tendency. Both in terms of the way characteristic parameters change as well the effects this has, the synthetic formulation is seen to behave more favorably than the petroleum-based option. The influence of viscosity on engine-specific behavior is shown to weigh more heavily than the fuel component. Urban driving cycles are more critical in this context than long-distance and expressway driving cycles, Figure 2f.

4 Effects

During the regenerative phases, the fuel's HC fractions increasingly attach themselves to the carbon or soot. Together with the wear particles and lubricant compounds, this leads to coagulations that affect the characteristic values produced, in particular viscosity. This indicates effects specific to the engine. Using the example of connecting-rod bearing appearance on the bearing-cover side and applying the same load profile, **Figure 6** clearly illustrates an indication, for both lubricant qualities, of a higher mixed-friction component as a result of the change in viscosity. Here, the traces of wear are more pronounced when using hydrocrack oil. Resulting from this, the **Table** presents the limit values predicted by IAV for defining extended oil-change intervals with current regeneration strategies. These demand design measures for reducing wear particles as well as an improved lubricant formulation – in particular with a reduction in ash-forming additives. To achieve fault-free engine behavior, existing viscosity

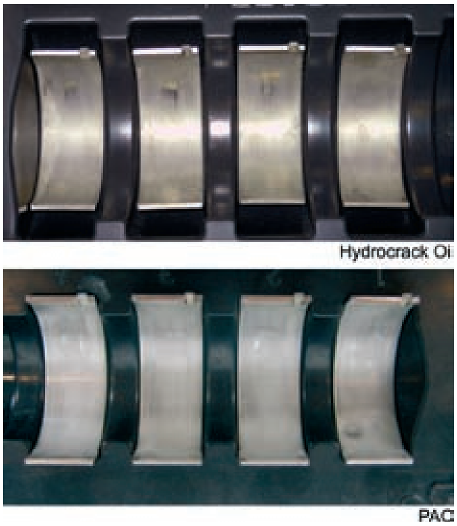

Figure 6: Visual appearance of connecting-rod bearing on the bearing-cover side

behavior must be maintained while at the same time reducing oil aging and soot entrainment. Hydrocrack oils no longer satisfy these demands.

5 Conclusions and Outlook

In developing diesel engines, it will become increasingly important to reduce the dilution of oil in the process employed for regenerating diesel particulate filters with a view to lessening the negative after-effects associated with adsorption on the tribological contacts. Temporary levels of dilution of up to 8 % through a single or multiple-postinjection mode permit acceptable engine operation. Lubrication dilution can be reduced with complex ventilation concepts as well as efficient warm-up strategies. The increase in viscosity through soot and water entrainment over running time, however, is still shown to have a major influence. In future, the desired requirement profile will only be met by synthetic formulations. To verify the requisite oil quality, engine oil identification in the way described in [5] will also gain significance.

Table: Lubricant-specific setpoint value ranges predicted by IAV and forecast for the engine size under review

inspection parameter	limit values		prognosis for future oil intervals
wear elements	**unit**	**limit values**	
iron	mg/kg	90-135	<100
chromium	mg/kg	12-18	
tin	mg/kg	10-25	
aluminum	mg/kg	15-60	<40
nickel	mg/kg	2-4	
copper	mg/kg	30-60	40
lead	mg/kg	20-30	15
molybdenum	mg/kg	4-16	
contamination			
silicium / dust	mg/kg	25-40	
sodium	mg/kg	fresh oil +25	
potassium	mg/kg	25	
fuel	m %	10	10
soot	m %	5,0 (2,0)	2
water	m %	0,2	
glycol	ppm	500 (positive)	
total fouling	m %	6	4
oil quality			
viscosity 100 °C	mm^2/s	10-16 increase max. 3	12
oxidation	A/cm	25	20
nitration	A/cm	25	20
additive elements			
calcium	mg/kg	2000-4000	2500
magnesium	mg/kg	100-1500	1000
boron	mg/kg	20-500	
zinc	mg/kg	800-1800	800
phosphor	mg/kg	750-1900	750
barium	mg/kg	0-80	
other			
tbn	mgKOH/g	>60% fresh oil, but >7,0 (for 10W-40)	>5

References

[1] Pischinger, S.; et. al.: Konzeptansätze für einen integrierten Regenerationsbetrieb mit Dieselpartikelfilter und NO_x-Speicherkatalysator (Concepts for an Integrated Regeneration Mode with Diesel Particulate Filter and NO_x Adsorption Catalysts), 27th International Vienna Engine Symposium 2006, Vienna, p. 286 ff

[2] Krüger, M.; et. al.: Regenerationsbetrieb und motorische Langzeiteffekte beim Dieselmotor (Regeneration Process and Long-Term Effects in the Diesel Engine), 13th Aachen Colloquium on Vehicle And Engine Technology 2004, Aachen, p. 1179 ff

[3] Bleimschein, G.: Lubricant Base Oil Effects on Regulated EURO II Heavy-Duty Diesel Engine Emissions and Fuel Economy, Mineralöltechnik, 5/2003

[4] Luther, R.: Alternative Kraftstoffe aus der Sicht der Motorenschmierung (Alternative Fuels from the Aspect of Engine Lubrication), p. 167 ff. In: Kraft- und Schmierstoffe (Fuels and Lubricants) – ATZ/MTZ Engine Conference 2007, Hamburg

[5] Luther, R.: Identifikation von Schmierstoffen (Identification of Lubricants). In: MTZ 69 (2008), Nr. 1, S. 34 ff