

Analysis of Deposit Formation Mechanism on TEOST 33C by Engine Oil Containing MoDTC

Satoru Yoshida and Yasushi Naitoh

Japan Energy Corporation

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ABSTRACT

The addition of molybdenum dithiocarbamate (MoDTC) to engine oil improves the fuel consumption of vehicles. However, this is also widely known to cause deposit accretion in the Thermo-Oxidation Engine Oil Simulation Test (TEOST 33C). Thus the effects of additives on TEOST 33C and elemental analysis of the deposits were evaluated to analyze the deposit formation mechanism in TEOST 33C by engine oil containing MoDTC. An elemental analysis of deposits revealed that most consisted of carbide and contained small amounts of molybdenum compounds. Deposit accretion was not caused due to the remarkable increase of compounds derived from MoDTC. It was assumed that they acted as a decomposition catalyst under high temperature and induced carbide to be deposited.

INTRODUCTION

In recent years, the reduction of CO₂ emissions from automobiles has been strongly demanded according to the prevention of global warming. The efficiency of an engine is helpful in improving the fuel consumption of vehicles and many advanced engine technologies such as variable valve timing, direct injection, turbochargers and so forth, have been evaluated. While the turbocharger can increase the power and performance of vehicles without significantly increasing the size or weight, there is a problem whereby the engine oil which lubricates the turbocharger bearing is exposed to relatively high temperatures, especially in air-cooled turbochargers.^{1, 2)} Excessive oil degradation under high temperatures can cause deposit formation and lead to bearing failure in some turbochargers.³⁾

The Thermo-Oxidation Engine Oil Simulation Test (TEOST 33C) was developed as a lubricant test for the evaluation of turbocharger-coking properties.^{4, 5)} This test was required for the International Lubricant Standardization and Approval Committee (ILSAC) GF-2 specification and is assumed to apply to ILSAC GF-5, the next gasoline engine oil specification.⁶⁾ In this test, a mass of deposits occurring on the test piece, called a depositor rod, when the test lubricant passes the depositor rod heated at 200 to 480°C, is evaluated.

The engine oil also plays an important role in improving the fuel consumption of vehicles. There are two methods which are widely accepted for improving the fuel efficiency performance of engine oil. One is lowering the viscosity of the lubricant and the other is an addition of friction modifiers. The addition of friction modifiers helps the engine oil to reduce engine friction under boundary lubrication. Among friction modifiers, molybdenum dithiocarbamates (MoDTC) is reported to be the most effective additive in decreasing engine friction and engine oil containing MoDTC shows high fuel efficiency properties.^{7, 8)} On the other hand, we examined the effects of MoDTC concentration on TEOST 33C and reported that the mass of deposits in TEOST 33C was significantly increased when accompanied with the addition of MoDTC.⁹⁾ Thus, there was a problem with fulfilling both fuel economy and TEOST 33C performance for engine oil containing MoDTC.

In this report, the analysis of the deposit formation mechanism on TEOST 33C by engine oil containing MoDTC was evaluated to estimate the possibility of having both fuel efficiency and acceptable turbocharger-coking properties.

EXPERIMENTAL

TEST OILS

Table 1 summarizes the properties of the test oils used in this study. The oil coded "HMO" was an American Petroleum Institute (API) SM/ILSAC GF-4 0W-20 oil containing MoDTC (Mo=700 ppm). It was prepared from a combination of Group III and Group IV base oil stocks and had ZnDTP with 800 ppm of phosphorus content. Other test oils were arranged by changing additive formulations of HMO. The MoDTC and zinc dithiophosphate (ZnDTP) treatment levels of LMO1 to LMO3 and LPO1 to LPO4 were adjusted respectively. TMO1 to TMO3 were formulated by replacing the MoDTC of HMO with other molybdenum compounds to the level of 500 ppm molybdenum content. These test oils were subjected to TEOST 33C.

Table 1 Test oil matrix

Name	Mo Content (ppm)	P Content (ppm)	Mo Type	TEOST 33C (mg)
HMO	700	800	MoDTC	73.5
LMO1	0	800	MoDTC	24.5
LMO2	350	800	MoDTC	33.5
LMO3	500	800	MoDTC	44.6
TMO1	500	800	Mo Amine	49.6
TMO2	500	800	MoDTP	45.2
TMO3	500	800	MoP	42.6
LPO1	700	0	MoDTC	25.2
LPO2	700	100	MoDTC	41.1
LPO3	700	200	MoDTC	57.3
LPO4	700	500	MoDTC	57.1

TEOST 33C

TEOST 33C was based on ASTM 6335.⁴⁾ The test conditions are summarized in Table 2. This test was repeated for 12 cycles, from a depositor rod temperature of 200°C to 480°C. (Figure 1) In this report, two modified tests were carried out in addition to the standard TEOST 33C. One was set to change the number of test cycles to evaluate the effect of test duration. The other was set to stabilize the temperature of the depositor rod for 24 minutes to estimate the effect of the depositor rod temperature as shown in Table 2.

Table 2 Test conditions for TEOST 33C

	TEOST 33C	Mod. 1	Mod. 2
Sample Volume mL	116	116	116
Catalyst (Fe) ppm	100	100	100
Reactor Temp. °C	100	100	100
Depositor Rod Temp. °C	200–480	200–480	400, 440, 480
Test Cycle	12	3, 6	1
Test Duration min	114	28.5, 57	24
Pump Rate g/min	0.4	0.4	0.4
Wet Air Flow mL/min	3.5	3.5	3.5
N2O mL/min	3.5	3.5	3.5

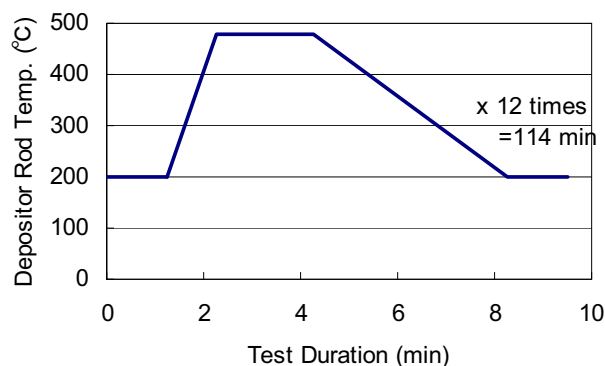


Figure 1 Depositor rod temperature cycle for TEOST 33C

RESULTS AND DISCUSSION

ANALYSIS OF DEPOSIT FORMATION FACTORS

Effects of engine oil additives

The test results for HMO and LMO1 to LMO3 showed the relationship between MoDTC concentration and the mass of deposits in TEOST 33C.⁹⁾ (Figure 2) The mass of deposits increased along with increases in the addition of MoDTC. In particular, with more than 350 ppm of molybdenum content, the addition of MoDTC permitted a significant increase in deposit formation.

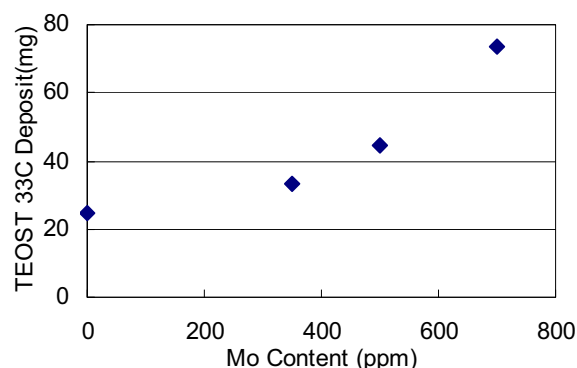


Figure 2 Effects of MoDTC content on TEOST 33C

The effects of molybdenum type on TEOST 33C is detailed in Figure 3. In Figure 3, all test oils contained 500 ppm of molybdenum content. The type of molybdenum compounds for LMO3, TMO1, TMO2 and TMO3 were MoDTC, molybdenum amine complex, molybdenum dithiophosphate (MoDTP) and molybdenum phosphorus complex, respectively. All of these provided the same level of deposit formation regardless of the molybdenum compound type. This revealed that high concentrations of molybdenum compounds induced deposit accretion in TEOST 33C in spite of their complex structure.

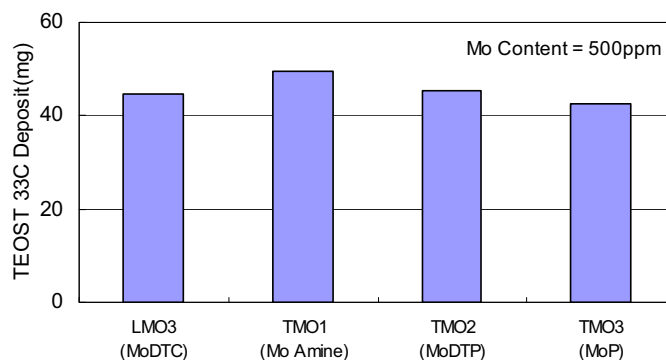


Figure 3 Effects of Mo type on TEOST 33C

The relationship between ZnDTP content and the mass of deposits in TEOST 33C was determined through the test results for HMO and LPO1 to LPO4. (Figure 4) A reduction of ZnDTP caused the suppression of deposit