Fuel, Lubricant and Grease

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1 Introduction

Safety and security are the most important concerns for fuel, or in broader terms, for energy in general. More specifically, the key requirements for fuel are the so-called 3E items: environmental protection, energy security, and economic efficiency. In the past, the discussion about energy often focused on environmental protection, but in the wake of concerns related to nuclear power generation following the Great East Japan Earthquake, the discussion has shifted and greater emphasis is now being placed on the topic of energy security.

Fig. 1 shows the changes in fuel oil sales in Japan [(1)]. In 2012 a total of 199,850,000 kL of fuel oil was sold in Japan, including 57,100,000 kL of automotive gasoline and 33,400,000 kL of automotive diesel.

The target amount of bioethanol that petroleum refiners must use is defined in a law (the Energy Supply Structure Sophistication Act) that concerns the usage of non-fossil fuel energy sources and promotes the effective use of fossil fuels by energy supply companies [(2)]. After conversion into a crude oil equivalent, the target amount of bioethanol is 210,000 kL in 2011, 210,000 kL in 2012, 260,000 kL in 2013, 320,000 kL in 2014, 380,000 kL in 2015, 440,000 kL in 2016, and 500,000 kL in 2017.

The Energy Supply Structure Sophistication Act also established a target for increasing the installation ratio of heavy oil cracking facilities (the ratio of the processing capacity of heavy oil cracking facilities compared to the processing capacity of crude oil atmospheric distillation facilities).

2 Fuels

2. 1. Fuel standard trends

Recent trends in automotive gasoline standards include the amendment on March 30, 2012 of a part of the enforcement regulations for the law (Act on the Quality Control of Gasoline and Other Fuels) that deals with ensuring the quality of volatile oils and other substances (the amendment went into force on April 1, 2012) [(3)]. In addition to this, the JIS standard for motor gasoline (JIS K 2202) was also amended [(4)]. These amendments stipulated standards for E10 fuel (gasoline fuel blended with up to 10% bio-ethanol). This created the legal environment that will enable the use of E10 fuel, but only in appropriate gasoline-powered vehicles designed to handle E10 fuel, from the standpoints of ensuring the safety of E10 fuel use and preventing air pollution.

The old JIS standard for motor gasoline differentiated between two types of gasoline by octane number: No. 1 (high octane) and No. 2 (regular). The amendment added two new types of fuel to bring the total up to four types. The No. 1 (E) fuel has an oxygen content of between 1.3% and 3.7% of the mass (for ethanol this is up to 10% of the total volume) and an octane number of 96.0 or higher. The No. 2 (E) fuel has an oxygen content of between 1.3% and 3.7% of the mass and an octane number of 89.0 or lower.

The 50% distillation temperature of the No. 1 and No. 2 fuels is between 75°C and 110°C, which is the same as it was previously. However, in the case of the No. 1 (E) and No. 2 (E) fuels, when ethanol makes up over 3% of the volume, the 50% distillation temperature is between 70°C (65°C in the winter) and 105°C. However, when ethanol makes up 3% or less of the volume in the No. 1 (E)

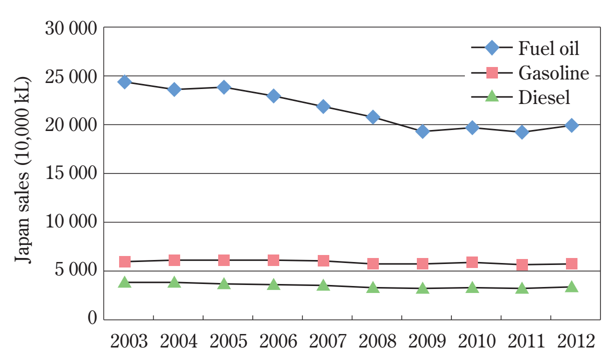

Fig. 1 Changes in fuel oil sales in Japan.

Table 1 Summary of investigation results from JATOP Biofuel/Gasoline Vehicle Research WG.

Fuel quality	Effect on fuel quality of 10 % ethanol blend	Research items	Investigation results
Distillation characteristics 50 % distillation temperature	Decreases by approximately 10°C	(1) Investigate the effect on emissions, fuel efficiency, and CO_2 (2) Investigate the effect on driving performance - Identify effect of T50 (high-temperature side) - Identify effect of T50 (low-temperature side)	The effects of E10 on the vehicle were seen at the JIS upper limit region (110°C) of T50. No other effects of E10 on T50 were seen in other temperature ranges, including the T50 lower limit region.
Vapor pressure (RVP)	Increases by approximately 7 kPa (Amount of evaporation increases at high temperatures)	(3) Investigate the effect on vehicle evaporative emissions - Identify effect of permeation (when vehicle is parked/stopped) - Identify effect of increase in amount of evaporation at high temperatures (when driving)	No significant effects of E10 were seen in the test vehicle used by this WG. (The effects of E10 on HSL+DBL were seen in the test vehicle used by the previous research WG.)
Material compatibility (rubber)	Permeation of rubber		
Preservation stability (metal, rubber, plastic)	Corrosion of metal	(4) Investigate the effect that materials have on the fuel properties	A larger increase in the gum value in the E10 fuel was seen in accordance with the rubber. No difference was seen in the effect of metal on fuel quality between the E0 and E10 fuels.
	Swelling of rubber and plastic		

and No. 2 (E) fuels, the 50% distillation temperature stays at between 75°C and 110°C.

In terms of the JIS standard value for vapor pressure, the lower limit value for the No. 1 (E) and No. 2 (E) fuels is 55 kPa, when ethanol makes up over 3% of the volume and the fuel is intended for use in winter. The lower limit value for the No. 1 (E) and No. 2 (E) fuels is 60 kPa, when ethanol makes up over 3% of the volume, the fuel is intended for use in winter, and the fuel is applicable for use in regions where the outside air temperature reaches −10°C or lower.

The partial amendment of the enforcement regulations for the Act on the Quality Control of Gasoline and Other Fuels on March 30, 2012 also made changes to the standard quality of diesel that contains fatty acid methyl ester (FAME) of over 0.1% but less than 5% of its mass (so-called B5 diesel). The previous standard stipulated a maximum increase in the acid value of 0.12. This was amended to an oxidative stability of 65 minutes or more. The PetroOXY method was adopted as the test method for oxidative stability. For the time being, B5 diesel in which the acid value increases by 0.12 or less is considered to meet the requirement for an oxidative stability of 65 minutes or more.

2. 2. Fuel technology trends

One technological trend in fuels is the Japan Auto-Oil Program (JATOP) that was carried out for 5 years beginning in 2007. The results of this program were published in March 2012 [5]. JATOP was a joint research program between the automotive and petroleum industries that was carried out by the Japan Petroleum Energy Center with the support of the Japanese Ministry of Economy, Trade and Industry. The goals of this program were to develop and utilize a highly precise air quality estimation model, and also to develop the most suitable automotive and fuel technologies to simultaneously solve the following three issues: CO_2 reduction, fuel diversification, and emissions reduction.

The JATOP Biofuel/Gasoline Vehicle Research WG conducted research on gasoline blended with 10% ethanol (E10) and a summary of the results of this research is shown in Table 1. Based on these results, the WG reported that some vehicles currently on sale in the Japanese market were affected by E10 fuel. It will be necessary to pay attention to these effects when E10 fuel is introduced.

The purpose of the JATOP Biofuel/Diesel Vehicle Research WG was to clarify the technical issues when a high-concentration (over 5%) biomass fuel is blended with a diesel fuel and then used in a diesel vehicle. This WG carried out analytical investigations, including of both vehicle- and fuel-based countermeasures, and technical knowledge was obtained to help examine a possible introduction of this fuel into the market, including stan-

Table 2 Issues and countermeasures for use of fuel blended with a high concentration of FAME.

Items				FAME blend	
				10 % blend, 20 % blend	50 % blend, 100 % (neat)
(1) Effect on fuel properties	Ignitability		Issues	- There is a large difference between the cetane index and the cetane number. - The IQT cetane number (DCI) is 2 to 3 higher than the cetane number in diesels blended with 10 % and 20 % FAME.	
			Counter-measures	- The cetane index is not applicable. - If the IQT cetane number is used, control in consideration of the shift width due to FAME blending.	
(2) Effect on stability	Oxidative stability		Issues	- The oxidative stability deteriorates when FAME is blended in. - Deterioration is large particularly in the case of SME, which has many C18 : 2 and C18 : 3 with multiple double bonds. - In the case of SME, there was a poor response to the addition of an anti-oxidizing agent. - When the anti-oxidizing agent was added to SME after long-term storage, the improvement in stability was small compared to when it was added immediately after the SME was obtained.	
			Counter-measures	- The addition of an anti-oxidizing agent was an effective means of improving the oxidative stability of diesel blended with FAME. (The effects of the BASE diesel stability, FAME composition, and natural antioxidants on the oxidative stability were taken into consideration.) - In the case of SME, a large amount of anti-oxidizing agent is necessary. - It is necessary to add the anti-oxidizing agent to the SME immediately after it is obtained.	
	Effect on components	Rubber	Issues	- The effect on rubber was small according to the results of the immersion test.	- Rubber was affected in some cases. (Also effects related to the stability of FAME.)
			Counter-measures	—	- Extra attention to the components that are used is necessary.
		Plastic	Issues	- The effect on plastic was small according to the results of the immersion test.	←
			Counter-measures	—	—
		Metal	Issues	- Caution is advised for terne-coated carbon steel sheets.	- Metal was affected in some cases. (Caution is advised for tough pitch copper, bonderized steel plate, and terne-coated carbon steel sheets.)
			Counter-measures	- Use fuel tanks that do not contain any terne-coated carbon steel sheets.	- Extra attention to the components that are used is necessary.
	Room temperature storage stability		Issues	- Check for any precipitates in PME, RME, and SME when the temperature is higher than the cloud point. PME: Fuels with a lot of saturated fatty acid monoglycerides have a large precipitate weight. SME, RME: The generation of large crystals was seen. In addition, these crystals clogged the filter and the ability of the oil to pass through the filter deteriorated. - Malfunctions, such as engine stalling, occurred due to the fuel filter becoming clogged with precipitates.	
			Counter-measures	- Countermeasures are necessary to address the deterioration in ability to pass through the filter due to precipitates. PME: Control the amount of saturated fatty acid monoglycerides. SME, RME: There is a possibility of improving this issue through the use of additives. - Increase the frequency of fuel filter replacement. - Increase the size of the fuel filter. - Replace the fuel element with one for use in winter (heating type).	
(3) Effect on emissions			Issues	- The effect on emissions is small.	- NOx increased.
			Counter-measures	—	
(4) Effect on aftertreatment			Issues	- Manual forced regeneration failed when using fuel blended with 20 % FAME.	- Manual forced regeneration and automatic forced regeneration failed.
			Counter-measures	- An examination of how to optimize the regeneration operation that suits the operating conditions is necessary.	

(5) Effect on low-temperature operability		Issues	- The operating temperature limit rose with PME, RME, and SME and the low-temperature operability deteriorated (the effect was especially large for PME).	
		Counter-measures	- Do not use PME in cold regions or in the winter. - Increase the frequency of fuel filter replacement. - Increase the size of the fuel filter. - Replace the fuel element with one for use in winter (heating type).	
(6) Effect on engine oil		Issues	- The engine oil pressure decreased and there was oxidative degradation of the engine oil due to FAME mixing into the oil.	
		Counter-measures	- Increase the frequency of engine oil replacement. - Use high-performance engine oil.	
(7) Effect on reliability	Injector deposits	Issues	- The amount of fuel injection decreased due to the formation of injector deposits when metal became mixed in the fuel.	
		Counter-measures	- Manage the fuel so that the amount of metal contaminants in the FAME are reduced. - Use the appropriate components for the fuel system parts.	
	Stability during long-term parking	Issues	- Malfunctions, such as poor starting, occur when the vehicle is started after being parked for a long time.	
		Counter-measures	- Replace the fuel with diesel that does not contain FAME before parking.	

Serious point of concern　Point of concern　Review of fuel index is necessary

dardization. Table 2 shows a summary of the results of this research and the issues and countermeasures that were identified when a high concentration of FAME (the mainstream biofuel for use in diesel vehicles) is blended with the diesel fuel. The WG identified many points of concern when a fuel blended with 10% or 20% FAME was used. These concerns include the effect on components, the room temperature storage stability, and the fuel stability when the vehicle is parked for a long time. If such a biofuel is widely utilized as a fuel for diesel vehicles under the assumption that the amount of supply can be ensured, then it will be necessary to consider many of these points of concern if FAME-blended fuel is to be used. However, maintaining a uniform fuel quality is difficult because the characteristics of FAME differ depending on the composition of the raw materials. Particularly, it will be difficult to implement any countermeasures on existing vehicles. From the standpoint of quality, it is desirable to use hydrogenation or another means to convert this fuel into a hydrocarbon fuel that possesses the same quality as diesel. Furthermore, even when a fuel blended with a high concentration of FAME is used in a limited range through local production and local consumption, the points of concern must still be considered and the necessary countermeasures must be implemented.

The JATOP Future Fuel/Diesel Vehicle Research WG conducted research to examine the effects of fuels using various diesel base materials on the performance of a diesel vehicle. The practical issues were identified and technical knowledge was obtained to help examine a possible introduction of these fuels into the market. In particular, as the future configuration of oil refineries is considered (i.e., what increases in the capacity of secondary cracking devices is necessary), the effect of cracked light distillates will become a main focus since the importance of these distillates will only increase in the future as a base material for diesel. An increase in these cracked light distillates is predicted to cause changes in fuel quality, such as a decrease in the cetane number. Therefore, the WG summarized the effects of these distillates on emissions, fuel efficiency, low-temperature starting ability, and low-temperature operability by cetane number, focusing on vehicles that comply with the new Japanese short- and long-term emissions regulations. Future activities include an investigation into the effects of these light distillates on the performance of vehicles that comply with the post-new long-term emissions regulations, which will be the main vehicles in the market in 2020, and an evaluation of the effect of these distillates on components and injector deposits as well as on emissions, fuel efficiency, low-temperature starting ability, low-temperature operability, and the like. The investigations into these issues have been taken up by JATOP II, which began in 2012.

It is well known that the chemical structure of the fuel and the elementary reaction mechanism have a large effect on spark ignition engine knocking and HCCI combustion. There are also many research reports that concern the detailed reaction mechanism for selfignition and combustion of the structural components of gasoline [6–9]. There have been remarkable advances in this field in recent years and the reaction model for alkane fuels has reached the level where it can be put into practical use.

Various reports have been published that examine the countermeasures implemented to address the issues that occur when a biodiesel fuel blended with FAME is used. These include reports into the issues mentioned in the JATOP reports described previously.

One report described an investigation into the effects of adding cold flow improver (CFI) and an anti-oxidizing agent (AO) to a fuel blended with FAME [10]. This report also examines the emissions characteristics when CFI and AO are added.

Another report discussed the results from an examination of FAME-compatible components (NBR and FKM) that were subjected to oxidation degradation [11]. This report performed analysis using the Hansen solubility parameter.

A further report investigated FAME made from Jatropha, as a biofuel resource that does not compete with food sources [12]. This report examined the combustion characteristics of this FAME when pilot fuel injection, high-pressure fuel injection, EGR, and PCCI combustion were used.

A single-cylinder diesel engine test has been carried out to examine how to suppress the increase in NOx emissions produced by FAME [13]. The test results found that, under medium load operating conditions, lowering the fuel injection pressure and increasing the diameter of the injector nozzle hole were effective means of reducing NOx emissions.

The changes in the composition of demand for fuel oil in Japan and the increase in the installation ratio of heavy oil cracking facilities due to the Energy Supply Structure Sophistication Act mean that the cracking of heavy oil into diesel will become even more important in the future. The use of cracked light oil as the base material for diesel fuel should result in fuels with better oxidative stability. This is reportedly due to a likely increase in the polycyclic aromatic content of these fuels, which possess better oxidative stability [14].

3 Lubricants

3. 1. Trends for automotive lubricant standards and technologies

3. 1. 1. Gasoline engine oil

The next gasoline engine oil standard, ILSAC GF-6, will go into effect in September 2016. Consequently, discussions between the oil side (lubricating oil and additive manufacturers) and the automotive side (automakers) are being promoted in preparation for the new standard. The following points have been reported as indicators of the direction that GF-6 [15].

- Improved fuel efficiency and sustainability: Further improvement of fuel efficiency through the use of Sequence VI D
- Improved robustness and wear resistance: Improvement in the performance of Sequence III G, IV A, and V G and also improvement in evaporation performance
- Solutions and countermeasures for low-speed pre-ignition (LSPI)
- Determination of the required viscosity values that reflect the revisions in SAE J300

The viscosity grades are also being examined because it is assumed that GF-6A will be a multi-grade oil based on SAE20 and SAE30, which are the summer grades in the conventional SAE J300 viscosity standard. It is also assumed that GF-6B will be based on the newly established SAE16 (viscosity of 2.3 mPa/s or more at 150°C HTHS). The state of development of the engine test method is also being examined and a Toyota engine is being used for Sequence IV B, a Ford engine (2-liter turbocharged) is being used for VH, and the engine for VI D is being changed to a latest 2012 MY model [16].

Good fuel efficiency will also be the key for the GF-6 standard. Therefore, an attempt to improve the oil viscosity temperature characteristics (i.e., increasing the viscosity index) through the incorporation of a conventional high-performance viscosity index improver is being examined. In addition, lowering the friction in the boundary lubrication region through the addition of a friction modifier (FM) that mainly consists of molybdenum dithiocarbamate (MoDTC) is also being examined. Currently, the search for and research into new high-performance viscosity index improvers and friction modifiers is ongoing. In particular, the research and development of new additive technologies, which will compensate for the reduced oil film that accompanies the lower oil viscosities, and surface treatment technologies for engine components are likely to become key fuel saving technologies of the future.

3. 1. 2. Diesel engine oil

The next heavy duty (HD) diesel engine oil standard from API will be the PC-11. The examinations and discussions surrounding this standard are ongoing and its target introduction date is January 2016 [15][17]. Two key points for this standard are as follows.

- Diesel engine oils must be compatible with new engine technologies that are being developed to conform to fuel economy regulations for lowering exhaust emissions, encouraging the use of renewable fuels (biodiesels), and reducing CO_2 emissions
- Problems with the supply of test engines (and parts) used for the CJ-4 standard, which was introduced into the market 6 years ago

Two types of standards with different HTHS viscosities are being examined for PC-11. One standard stipulates a HTHS viscosity of 3.5 mPa/s or more, the same as for CJ-4. This standard can also be applied to conventional engine models. The other standard is for fuel-efficient engine oils and stipulates a HTHS viscosity of 2.9 mPa/s or more. The oils that conform to this standard will be used on the recommendation of each automaker [18]. The PC-11 standard will continue to use the same engines for the engine test as in the CJ-4 standard, namely the Cummins ISB and ISM, the Caterpillar C-13, and the Mack T-11. The new engine tests that are still being examined are the Cat C-13 engine test for the oil aeration evaluation and the adoption of the Mack T-13 engine for the oxidation, ring, liner, and bearing wear evaluation tests. The use of the Daimler DD-13 engine is also being examined in the evaluation method for the low-viscosity oil scuffing prevention test. The necessity of reviewing the other bench tests, such as the biofuels impact assessment test method, and the shear stability and oxidative stability evaluation tests, is also being examined [18].

In Japan an alternative engine test method for the cleanliness evaluation engine test (TD-25) that is carried out as stipulated in the JASO DH-2 standard is also being examined. This examination is proceeding under the cooperation of automakers, construction equipment manufacturers, additive manufacturers, and petroleum manufacturers.

3. 1. 3. Changes to SAE J300

The SAE J300 standard stipulates engine oil viscosity grades. The changes made to this standard established the new SAE16 grade and made a modification to the lower limit value of the kinetic viscosity at 100°C of SAE20 [19]. In the SAE16 grade, the HTHS viscosity (150°C) is 2.3 mPa/s or more, which made it possible to place an SAE label on engine oils that fall below the viscosity of 0W-20. In the future it is likely that many 0W-16 engine oils will emerge on the market because of the good fuel efficiency performance of these oils. It has been reported that the number 16 was selected for SAE16 to avoid numbers that are used on the W grade, such as 15 and 10 [20].

4 Grease

4. 1. Automotive grease [21]

It is well known that initiatives to improve vehicle fuel efficiency are being promoted by growing customer awareness about the importance of reducing CO_2 emissions and conserving natural resources. Consequently, there are demands that automotive parts that use grease also help to improve fuel efficiency through decreased size and weight and the use of lower torques. Since reducing the size and weight of parts can lead to a decrease in the part's strength, improvements in the greases used are expected to improve the part's performance as well as to ensure a stable, lubricated state. Automotive parts with longer service lives are also required to help extend the period between vehicle inspections and to promote more maintenance-free operation. Therefore, greases must be developed with a better heat resistance and longer service life for these parts as well.

Hybrid and electric vehicles are being introduced into the market to achieve even greater reductions in CO_2 emissions. Numerous electronic parts and electric components are used in these vehicles, and greases are used on the contact portions of these parts. The greases used on the contact portions must be capable of performing two conflicting functions: providing electrical insulation to prevent short circuits, and ensuring electrical conductivity through contact between metals during operation. These greases are also required to form an oil film to help suppress wear on the parts.

4. 2. Biodegradable grease [22]

In recent years, grease technology to reduce environmental impact has been receiving more attention as a part of environmental protection policies. The development of biodegradable grease is being promoted as one way to address this issue. In the same way as biodegradable lubricating oils, biodegradable grease is mainly composed of substances that can be easily decomposed by microorganisms. A biodegradable grease is defined as having a biodegradability ratio of 60% or higher according to the OECD or ATSM methods. Biodegradable grease is largely divided into two types according to the kind of base oil that is used, either vegetable oil or synthetic ester. The degree of biodegradability of the base oils starts with canola and other vegetable oils at the top, and then proceeds down in the following sequence: synthetic ester, mineral oil, polyglycol, poly-alpha-olefins (PAO), and alkyl diphenyl ether. However, biodegradability and lubricating properties do not always correspond to thermal and oxidative stability. Vegetable oils have excellent lubricity and biodegradability, but low thermal and oxidative stability. In contrast, synthetic ester has excellent heat resistance, but is expensive. In the case of thickening agents, lithium 12-hydroxystearate has a high level of biodegradability, but urea has a low level. The development of a superior biodegradable grease is ongoing and will have to take all of the following points into consideration: the biodegradability of the grease components, lubricity, thermal and oxidative stability, cost, and so on.

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