Fuel, Lubricant and Grease

1 Introduction

In 2013, the government of Japan promoted the discussion over the energy supply in Japan and drew up its Basic Energy Plan, which was then approved by the cabinet in April of 2014. Within this debate, the role of oil was defined as follows: "Even though the demand for oil in Japan has been decreasing, it currently accounts for over 40% of our primary energy. It is a fuel with a wide range of applications for transportation, people's livelihoods, and generating electricity, as well as having the advantage of being useful for material applications, such as chemical products. The transportation industry is especially dependent on oil as a fuel and oil also plays a critical role in the manufacturing industry as a raw material. Compared to those applications, the amount of oil that is used to generate electricity is not all that large, but it does serve a specific function as an energy source for generating electricity during peak demand and when the power supply is regulated. Oil is the energy source with the greatest geopolitical risk related to its procurement, but it is also highly portable and the supply network in Japan is already in place. The current Japanese stockpiles of oil are abundant and it can serve as a substitute fuel in the case where other electricity generating sources are lost. It is a vital energy source that will continue to be used in the future." Clearly, factors such as the effective use of crude oil, the diversification of the fuels used for transportation, and the utilization of oil-fired power plants for a regulated power supply have made oil an essential energy source for Japan.

In July of 2009 the "Energy Supply Structure Sophistication Act" was established and this law stipulated various initiatives, such as the promotion of more sophisticated and efficient applications of fossil fuel resources. Within this law is a target for increasing the installation ratio of heavy oil cracking facilities in Japan up to around 13% by 2013 (this is the ratio of the processing capacity of heavy oil cracking facilities compared to the processing capacity of crude oil atmospheric distillation facilities, which was approximately 10% in 2010). This law also makes it mandatory for all the petroleum refiners to achieve this target installation ratio. Consequently, the oil wholesale companies in Japan undertook efforts to raise crude oil processing capacities to increase the installation ratio of heavy oil cracking facilities. At its peak the crude oil processing capacity in Japan was 5,940,000 barrels/day (capacity of crude oil atmospheric distillation facilities), but as of April 2014 it is has decreased to approximately 3,980,000 barrels/day (Fig. 1).

Next, if attention is turned to the estimated sales of fuel oil in Japan, the sales volume of each type of oil compared to the previous year changes by −0.4% for gasoline, −3.6% for kerosene, +1.4% for diesel, and −14.6% for heavy oil. The total fuel oil sales volume decreased by −1.7%, even when sales of naphtha and jet fuel were added (Table 1). A downward trend in the demand for fuel oil has continued since 2009, when the total demand for fuel oil was less than 200 million kL. Some of the possible structural factors causing this trend are the development of oil-free policies, changes in the structure of society, and global warming countermeasures. Other contributing factors include the tremendous increase in the number of fuel-efficient vehicles, including mini-vehicles, that were introduced into the market, and a shift in lifestyle from the use of kerosene heaters in homes to air conditioners and floor heating systems. It is assumed that this downward trend in fuel oil usage will continue in the future based on these factors.

2 Fuels

2. 1. Fuel standard trends

In December 2013, JIS K 2280 "Petroleum products -- Determination of octane number, cetane number and calculation of cetane index" was amended. This revision was made to facilitate the development of Japanese

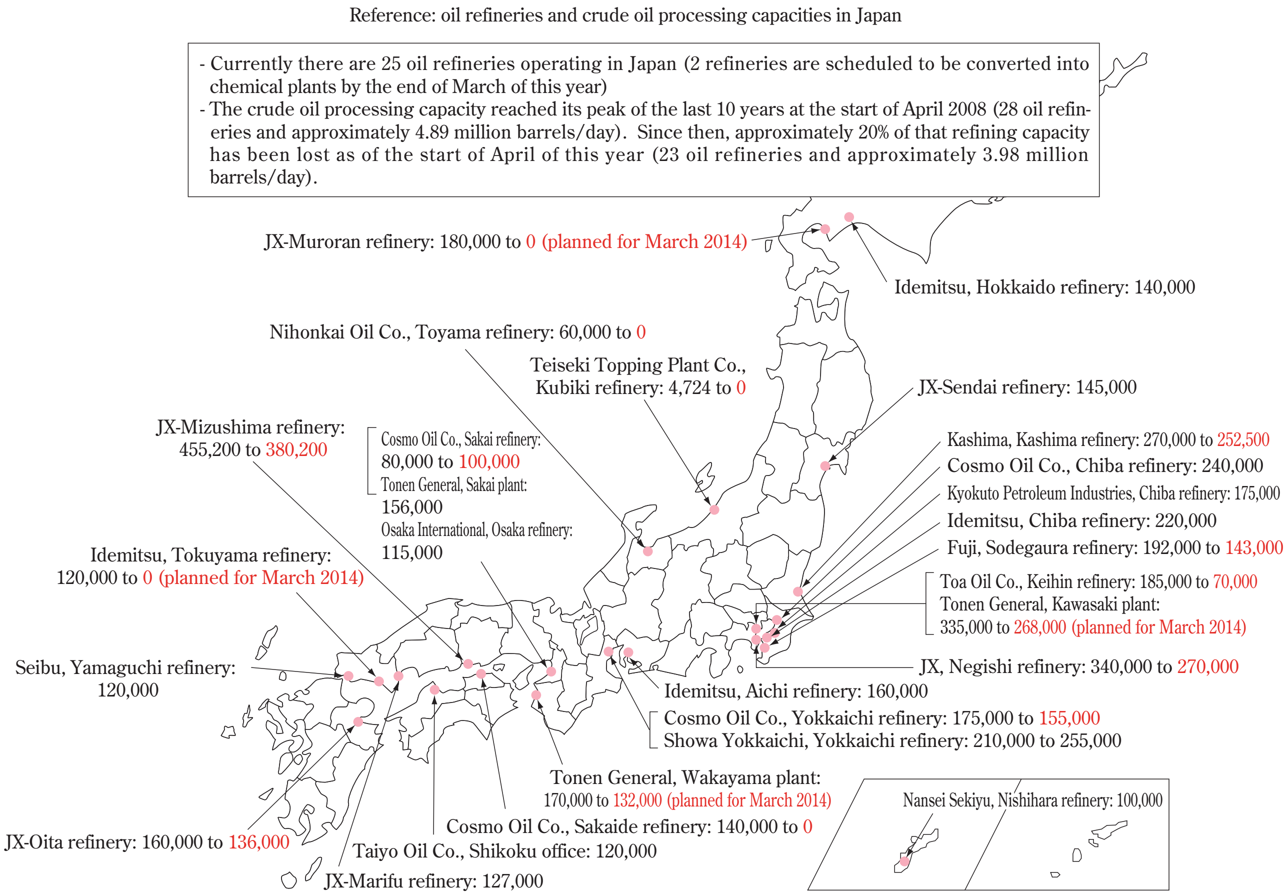

Fig. 1 Refinery locations and crude oil processing capacities (as planned for April 2014).

Table 1 Fuel Oil Sales Volume Totals[3].

Units: kL

	2012	2013	Compared to previous year
Gasoline	56 447 408	56 249 117	−0.4 %
Kerosene	18 991 302	18 301 060	−3.6 %
Diesel	33 442 999	33 910 475	1.4 %
Heavy oil	41 500 957	35 430 855	−14.6 %
Fuel oil total	197 519 545	194 075 294	−1.7 %

Industrial Standards that corresponded to the establishment and revision of international standards. It was also done in light of the fact that individual test method standards were being stipulated for items such as the octane number and cetane number in international standards stipulated by the International Organization of Standardization (ISO). The revision divided up the former JIS K 2280 according to each test method and reorganized it into the following 5 parts.

Part 1: Research octane number (JIS K 2280-1)

Part 2: Motor octane number (JIS K 2280-2)

Part 3: Octane number -- Supercharge method (JIS K 2280-3)

Part 4: Cetane number (JIS K 2280-4)

Part 5: Cetane index (JIS K 2280-5)

The main changes to the test methods were the change in the calibration value of the toluene system inspection fuel, which is used to measure the octane number (research method and motor method), and the method used to adjust this calibration value. Particularly in the case of this latter change, the range of the measurement value after the intake air temperature has been adjusted is stricter than it was previously.

2. 2. Fuel technology trends

Some examples of gasoline-related research include studies into the combustion emissions of fuel-efficient direct-injection (DI) engines and the impact of using biofuels, as well as studies into the impact on engine deposits. Research was also carried out using DI engines of vehicles from inside and outside Japan to evaluate particulate matter (PM) emissions characteristics. It was found that in both cases the engines emitted PM with a maximum diameter of approximately 70 nm, and that the main component of the PM was elemental carbon produced by incomplete combustion and not organic carbon.

Another investigation examined the impact that ethanol blended gasoline had on the emissions of a DI engine. The results showed that the amount of CO in the emissions tended to decrease as the ethanol mixture ratio increased, but the caloric value per volume of ethanol is low compared to gasoline, so the results also indicated that the fuel consumption increased at the same time.

Since the deposits that form within the injectors of a DI engine inhibit the optimum fuel spray, research examined whether the deposits could be removed using detergents. Commercially available gasoline that contains detergents does help remove these injector deposits, but it was confirmed that the use of specially designed additives removed the deposits more quickly.

The Japan Auto-Oil Program II (JATOP II, fiscal year 2012 to 2014) project is a joint research program between the automotive and petroleum industries that aims to solve technical problems in the fields of vehicles and fuels. In broad terms, this program consists of vehicle and fuel research and also atmospheric research. The vehicle and fuel research is focusing on cracked light distillates, which have mainly come to be used as a base material of A fuel oil. However, there has been a significant decrease in demand for these as the base material for A fuel oil and due to the increase in the cracking facility ratio to improve the crude oil processing volume based on the Energy Supply Structure Sophistication Act, it is expected that there will be a surplus of cracked materials. As a result, the expanded use of these distillates for vehicle fuel (diesel) has become unavoidable. Consequently, tests are now being conducted using actual vehicles and engines to determine the effects that fuels using these cracked light distillates will have 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. The fuels used in these tests utilize the current JIS No. 2 diesel fuel as a base and then cracked materials are mixed in to change the cetane number. Figure 2 shows a list of these test fuels. Seven different types of test fuel were selected: the cetane-number changed series, which is mainly used to evaluate the impact of changing the cetane number of the fuel, and the composition-changed series, which assumed the use of additives and other various base materials, such as cetane number improvers, gas to liquid

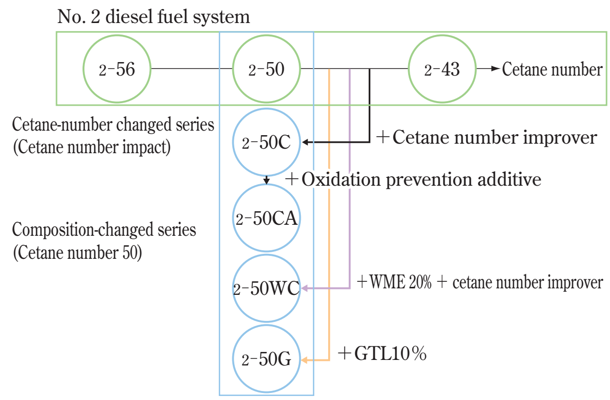

Fig. 2 Test fuels for JATOP II future fuel/diesel vehicle research.

(GTL) and wasted oil methyl ester (WME).

A report from Haji et al. described the need to construct a new cetane index to address diesel fuel derived from unconventional oil sources that are expected to increase in the future and also diesel fuel that includes diesel fractions produced from heavy oil cracking facilities. As the conventional cetane index was proposed in 1986, its precision is not necessarily that high for the diesel fuel derived from unconventional oil sources and diesel fuel that includes diesel fractions from heavy oil cracking facilities. Therefore, Haji et al. carried out an examination that focused on the relationship between the molecular structure and the cetane number. As a result, a new cetane index was constructed that is capable of estimating the cetane number with a higher degree of precision than the current cetane index. This new index adds kinetic viscosity as another factor in addition to the density and distillation characteristics that are used to calculate the conventional cetane index.

There have also been many reports written on the results of research into biodiesel fuels. Biodiesel fuel has attracted attention from the standpoints of energy security and limiting the rise of the CO_2 concentration in the atmosphere due to the fact that it is carbon neutral. However, its main component is fatty acid methyl ester (FAME), which has a double bond in its molecular structure and distillation characteristics that are also comparatively heavy, so it has slightly different properties and quality than conventional diesel fuel.

Matsuura et al. conducted bench tests using a post-new long-term emissions regulations compliant diesel engine that was equipped with a urea selective catalyst reduction (SCR) system, and examined the emissions characteristics when a high-concentration FAME blended fuel was used. The tests confirmed that when a B20 fuel (i.e., fuel containing a 20% FAME blend) was used, the amount of NOx emissions from the tailpipe increased by a maximum of 43% compared to B0 fuel.

In addition, another characteristic of FAME compared to general diesel oil is its low oxidation stability due to the presence of the double bond. The oxidation of fuel may cause problems, such as corrosion of metal and injector clogging, due to the generation of acid and polymers. Kondo et al. have reported the results of an investigation into the impact that oxidation degraded FAME has on fuel injection using a rig tester equipped with a common rail high-pressure fuel injection system. In this test, no impact from FAME oxidation was seen on the amount of fuel injection.

3 Lubricants

3. 1. Gasoline engine oil

The introduction of the next gasoline engine oil standard, ILSAC GF-6, has been postponed because the development of the new test method was delayed and the new goal is to have it ready by January 2017. There have been no major changes in the direction of GF-6 and the following shows the main differences between this standard and GF-5.

- Sustainability and improvement of fuel efficiency
- Improved robustness in regard to the engine
- Coping with low speed pre-ignition (LSPI)
- Improved maintenance of wear resistance, including the timing chain

In the case of the sustainability and improvement of fuel efficiency, the fuel efficiency test method was changed from Sequence VID to Sequence VIE. In this new VIE test method, the same 3.6-liter engine from GM as in the conventional VID test is used, but the engine body was changed to the latest 2012 model and the standard concerning the sustainability, in other words the fuel efficiency improvement rate after degradation, was strengthened.

In the case of improved robustness, high-temperature durability was strengthened through the adoption of Sequence IIIH. This Sequence IIIH is currently under development, and higher required values for the high-temperature detergency and upper limit of the viscosity increase will be set.

No concrete test methods for LSPI and timing chain wear have been established yet. In the case of LSPI, there were obvious problems caused by the engine downsizing technologies in the DI turbocharged engines from European automakers. Consequently, a test to evaluate the ability to prevent premature ignition at low speed is being examined as a countermeasure. In the case of the timing chain wear, the test will evaluate the ability to prevent wear on the timing chain when soot becomes mixed in the oil due to DI.

3. 2. Diesel engine oil

The development of PC-11, which is the next heavy duty (HD) diesel engine oil standard from API, is making progress. The following shows the main objectives of this standard.

- Measures for biodiesel fuels
- Contributing to reduced amount of CO_2 emissions
- Solving the problem of the supply of API CJ-4 test engines

Discussions are making progress on the possibility of introducing PC-11B as a fuel-efficient engine oil standard to help reduce CO_2 emissions. It was decided to stipulate the 150℃ high temperature high shear (HTHS) viscosity at 2.9 mPa･s or more, but debate is continuing on whether to set the upper limit value to 3.2 or 3.3 mPa･s.

On the other hand, in regard to coping with biodiesel fuels, it is expected that this will be removed from the PC-11 standard because priority was given to finalizing the rules for HTHS viscosity in the fuel-efficient engine oil standard.

The original date for this standard to be introduced was January 2016, but this has been changed to April 2016 as a result of a proposal from the Engine Manufacturers Association (EMA).

In December 2012 the European Automobile Manufacturers' Association (ACEA) standard was amended and ACEA 2012 was issued. Consequently, it is no longer possible to register under the old standard as of December 14, 2013. There are no major changes to the E category, which is the HD diesel engine oil standard. However, the seal test material was stipulated as the conventional VAMAC material and the acceptance criteria were "As per Daimler". After the new revisions, the material was stipulated as "DBL-AEM" and the acceptance criteria were also published as an ACEA standard. Against the background of widespread biodiesel fuel use in the European market, a low-temperature viscosity test (MRV) after the oxidation test with biodiesel fuel mixed in was newly added (CEC L-105).

In Japan, the revision of JASO M355:2008, which is an automotive diesel engine oil standard, is making progress. The main revisions are to the test engines used for JASO M336 (piston detergency test) and M354 (valve train wear test) due to the adoption of engines that comply with the post-new long-term emissions regulations. Consequently, engine oils are also being developed for engines that comply with the latest emissions regulations. In 2013 the piston detergency test was revised and the valve train wear test is planned to be revised next. Heavy vehicle fuel efficiency standards were stipulated in 2006 and these are to be achieved by the end of fiscal year 2015. Therefore, there are now active efforts to establish a fuel efficiency evaluation method for diesel engine oil and there are plans to advance the discussions over turning it into a JASO standard.

3. 3. Revision of SAE J300

The SAE J300 standard stipulates engine oil viscosity grades and it was revised in April 2013 when the SAE 16 viscosity grades were added. In SAE 16 the high-temperature high-shear viscosity is 2.3 mPa･s or more, and the 100C kinetic viscosity is 6.1 mm^2/s or more, but less than 8.2 mm^2/s. At the current time these are the lowest viscosity standards, even below SAE 20. At the same time, the lower limit of the 100℃ kinetic viscosity in SAE 20 was raised from 5.6 to 6.9 mm^2/s or more.

The addition of SAE 16 to SAE J300 demonstrates the increasing demand to improve fuel efficiency performance by further lowering the viscosity of the oils used in gasoline engines. The results of evaluations conducted under international fuel efficiency mode conditions, including those of the EU, were reported as verification that the use of ultra-low viscosity gasoline engine oils did lead to better fuel efficiency.

It is well known that when a base oil with low viscosity is used to create an engine oil, this lower viscosity oil reduces the engine friction in the region where this fluid lubrication is present. This is why base oils from group III or group IV, which have a high viscosity index and low evaporation loss at high temperatures, are used and are an effective way of establishing the technology for ultra-low viscosity engine oils. It is thought that the demand for group III base oils will increase in the future and that the production capacity for every group III base oil will also be increased as a result.

3. 4. Gear oil

The American Society for Testing and Materials (ASTM) D7450 standard that corresponds to API service classification GL-5 was revised in 2013 and ASTM L42, which evaluates the load carrying capacity of the final reduction gear unit, was replaced by ASTM D7452.

JASO M315, which is a standard that covers automatic transmission oil, was revised in March 2013 as a trend in automatic transmission fluid (ATF) standards. The following are the two main points that were changed.

- A low-viscosity automatic transmission oil (1-A-LV$_{13}$) was added and the 100℃ kinetic viscosity reference values were reviewed in conjunction with this
- RTF1 was newly added to the reference oils and the reference values for each classification of oil were set based on this RTF1

In this latest revision, the oil types 1-A$_{13}$ and 2-A$_{13}$ were set as having a 100℃ kinetic viscosity of 6.5 mm^2/s or more, while the 1-A-L V$_{13}$ oil was set as having a viscosity of less than 6.5 mm^2/s. JASO M347 stipulates that the 100℃ kinetic viscosity after shearing for the 1-A$_{13}$ and 2-A$_{13}$ oils shall be 5.7 mm^2/s or more and the 1-A-L V$_{13}$ oil shall maintain a viscosity of 5.2 mm^2/s or more. The new reference oil (RTF1) was added to JASO M348, M349, and M357. In conjunction with this, the standard value based on RTF1 was also included in addition to the standard value based on the former reference oil (T-III). Even after the revisions to this standard, a review of the shear stability test by the ATF is continuing to be examined, and another revision of the M315 standard is planned.

There was a report concerning the fuel efficiency of CVT oil, an examination of how to optimize the formulation of dual clutch transmission (DCT) oil, and research and development of oil for electric (hybrid vehicle) transmissions. Various studies and examinations are now being conducted into the properties of oil and improving transmission efficiency using lubricant technology oil with an eye on the future trends in each type of transmission.

4 Grease

In accordance with growing demands for improved fuel efficiency and environmental friendliness, vehicle parts have increasingly been getting smaller, lighter in weight, and given higher performance. As a result, the demand for high-performance, multi-functional grease suitable for use with these parts is also increasing. For example, front-wheel drive (FWD) vehicles have been increasing in number and decreasing in weight since the mid-1980s. The trend to turn the wheel bearings of passenger cars into a single unit has rapidly advanced. Consequently, these units are now positioned close to the disc brakes and must be resistant to the radiant heat from the brakes. Furthermore, the issue of fretting, which is caused by micro-vibrations when a vehicle is transported over long distance, has also emerged. Currently, urea grease is typically used as the grease that is most suitable for these types of conditions, but as the demands for better fuel efficiency and lower torque have accelerated in recent years, a further improvement of the grease performance is very desirable. In the future, it is predicted that wheel bearings of large-sized passenger vehicles, such as trucks and buses, will also increasingly be turned into single units. Therefore, it is likely that demand will continue increasing for high performance grease with good load resistance, shearing stability, heat resistance, and a long bearing life to cope with those harsh conditions.

The electrification of vehicle power steering systems is advancing to help improve fuel efficiency. Unlike conventional hydraulic power steering systems, electric power steering (EPS) does not need constant power from the engine to turn a hydraulic pump. Therefore, an improvement in fuel efficiency of about 3% was obtained. In 2010, the number of vehicles equipped with EPS accounted for approximately 40% of all vehicles and this trend is likely to continue accelerating. Due to the need to further reduce the weight of EPS systems, plastic is becoming widely used in component parts. Consequently, there is a need for grease that is both compatible for use with plastic parts and that can also provide lubrication (low friction) between plastic parts or between plastic and metal parts. The technological development of grease that can satisfy these demands is being pursued actively. In addition, there has also been active development of electric brake units in recent years. It is strongly expected that multi-functional grease will be developed to handle this growing diversity of electronic components as well.