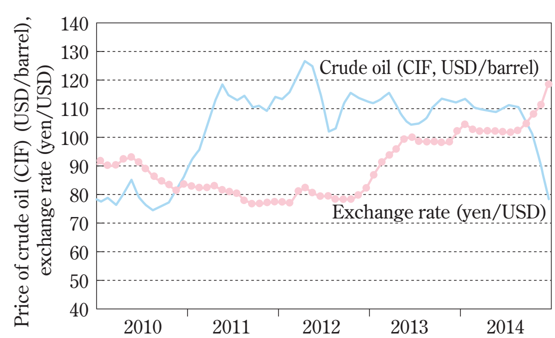
Fuel, Lubricant and Grease

1 Introduction

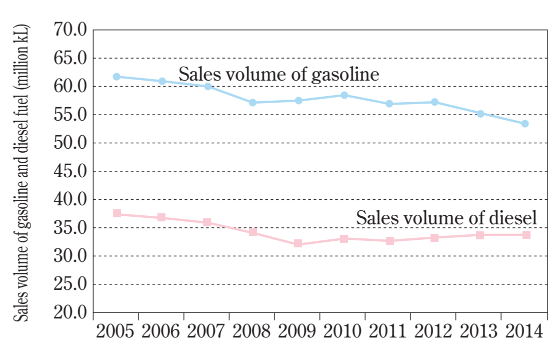
West Texas Intermediate (WTI) is a type of crude oil that has a large impact on crude oil prices around the world. At the start of 2014, the monthly average price of WTI was $95 to $105 USD per barrel, continuing the price trend from 2013. In June of 2014, the price briefly exceeded $105 USD per barrel over concerns about the civil war in Iraq between the government and Islamic militants, but after that, the price dropped back to around $100 USD per barrel. In July, concern about the geopolitical risk began to ease as exports of crude oil from Iraq did not decline and crude oil production in Libya began to recover. In August, the price of crude oil decreased due to the economic slowdowns in China and Europe and because the International Energy Agency (IEA) suggested that there would be a decrease in demand for oil. By October, the average monthly price of crude oil had fallen to around $85 USD per barrel. The price continued to fall even further after the OPEC meeting at the end of November decided to freeze the volume of oil production at current levels. Consequently, the average monthly price of crude oil had tumbled to $60 USD per barrel in December (1)(2). As a result, the average price to import crude oil (CIF) into Japan in 2014 was about $105 USD per barrel, lower than the CIF in 2013 of $110 USD per barrel. However, since the yen continued to weaken against the U.S. dollar in 2014, the average price of imported crude oil actually rose to 69 yen per liter from about 67 yen per liter in 2013 (Fig. 1) (3).

Figure 2 shows the changes in the annual sales volume of automotive gasoline and diesel fuel as an indicator of fuel oil trends in Japan (4). The sales volume of gasoline peaked in 2005 at about 61.6 million kL and then started to decline. From 2008 to 2012, the sales volume held relatively steady at around 57 million kL per year, but then continued to decline in 2013 to about 55.2 million kL (–3.3% compared to the previous year) and again in 2014 to about 53.6 million kL (–3.0% compared to the previous year). This continued decline is probably caused by the changes happening in the structure of Japanese society, such as a decreasing population, low birth rates, and a growing proportion of elderly citizens, as well as improvements being made to vehicle fuel efficiency. The sales volume of diesel fuel in Japan declined sharply to about 32.3 million kL in 2009, but has since held relatively steady around 33 million kL per year. In 2014, the sales volume of diesel fuel was about 33.8 million kL, essentially the same volume as in 2013. It is predicted that this trend will continue for the foreseeable future (5).



Source: Petroleum Association of Japan, Amount of Crude Oil and Petroleum Product Importation

Fig. 1 Changes in crude oil price (CIF)



Source: Petroleum Association of Japan, Supply and Demand of Petroleum Products

Fig. 2 Changes in gasoline and diesel fuel sales volumes

A new Basic Energy Plan was approved as the energy policy of the Japanese government by the cabinet in April of 2014 in accordance with the Basic Act on Energy Policy (6). This was the first such energy plan since the Great East Japan Earthquake. In the plan, petroleum is positioned as an important source of energy that will continue to be used in the future. The direction of the government's energy policy considers all of the following to be essential initiatives to be promoted: diversification of oil supply sources, cooperation with oil-producing nations, strengthening of crisis management resources (such as oil stockpiles), making effective use of existing crude oil, diversification of fuels used for transportation, and the use of oil-fired power plants as a source of regulated electrical power. Crude oil is identified as the "last bastion" of the energy supply in the event of a major disaster, so efforts will be made to strengthen the supply network even further. The demand for oil in Japan is decreasing at the same time that oil supply capabilities are being enhanced all across Asia. Consequently, the Basic Energy Plan indicates that it will also be necessary to strengthen the management foundation of the oil industry in Japan to maintain the national oil supply network, including during more ordinary times free from a disaster or some other crisis.

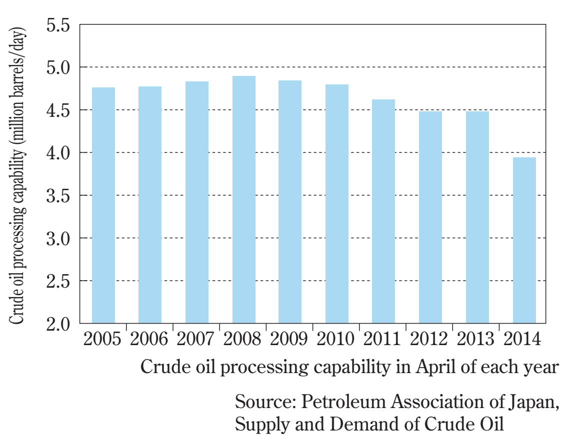


Fig. 3 Changes in crude oil processing capacity in Japan

In August 2009, the Act on Promotion of Use of Non-Fossil Energy Sources and Effective Use of Fossil Energy Material by Energy Supply Operators (7) (i.e., the Energy Supply Structure Sophistication Act) went into force. This was followed by the announcement of the Standards for the Judgment of Petroleum Refiners concerning the Effective Utilization of Crude Oil (7) in July 2010. This law and these standards both called for Japanese oil refining companies to increase the installation ratio of heavy oil cracking facilities in Japan up to around 13% by the end of 2013 compared to the processing capacity of crude oil atmospheric distillation facilities. Consequently, oil refining companies were required to expand and construct new heavy oil cracking facilities or reduce the number of crude oil atmospheric distillation facilities to comply with the law. Although some companies chose to enhance heavy oil cracking facilities, the majority simply reduced the number of crude oil atmospheric distillation facilities. Figure 3 shows the results of these efforts to comply with the law. From 2005 to 2010, the processing capacity was about 4.8 million barrels per day, as reported in April of each of those years. However, there was a significant reduction in crude oil processing capability down to about 3.95 million barrels a day by April of 2014 due to the closing of refineries and the disuse of atmospheric distillation towers (8). In July 2014, a portion of the Energy Supply Structure Sophistication Act was amended to stipulate that the Standards for the Judgment of Petroleum Refiners concerning the Effective Utilization of Crude Oil would be in effect for 3 years starting in FY 2013 (9). Consequently, "heavy oil cracking capacity" was changed to "residual oil processing capacity" and "heavy oil cracking facility" was changed to "residual oil processing facility." In addition, a target was set for increasing the installation ratio of residual oil processing facilities (i.e., the ratio of

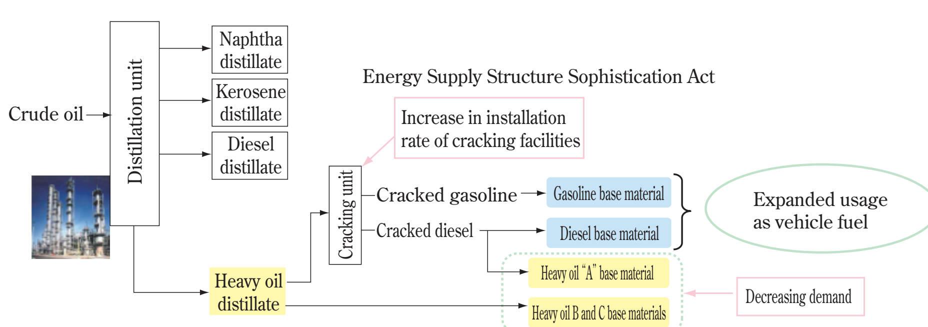


Fig. 4 Effective utilization of heavy oil distillates [12]

the processing capacity of residual oil processing facilities compared to the processing capacity of atmospheric distillation facilities) to around 50% by the end of FY 2016 from the current ratio of 45%. In the future, it is thought that the refining companies will make further efforts to comply with this target.

2 Fuels

Automakers are being required to comply with fuel efficiency and emissions regulations that are becoming stricter with each passing year. At the same time, it is becoming more and more important to make as effective use of limited petroleum resources as possible. Making effective use of all the heavy oil distillates that are produced when heavy oil is cracked and processed is necessary to achieve this. The Energy Supply Structure Sophistication Act required all the oil companies in Japan's petroleum industry to increase the installation ratio of residual oil processing facilities (7). Consequently, it is predicted that the cracked base materials distilled from these residual oil processing facilities will increasingly be used as vehicle fuels in the future (Fig. 4). The vehicle and petroleum industries in Japan are conducting a joint research project on vehicles and fuels called the Japan Auto-Oil Program II (JATOP II). Conventionally, the cracked diesel distillate was used mainly as the base material of heavy oil "A." However, the influence of the growing use of cracked diesel distillate as the base material of diesel fuel is now being evaluated from various points of view. Cracked diesel distillate possesses characteristics such as high aromatic content and a low cetane number compared to general diesel distillate. Research has shown that the use of cracked diesel distillate as a base material for vehicle diesel fuel has an influence on components, fuel injector internal deposits, and injector nozzle hole deposits (10). In contrast, results showed that cracked diesel distillate has only a small effect on exhaust gas after leaving the aftertreatment device. However, when the diesel particulate filter (DPF) load was examined, it was found that an increase in the mixture of cracked base material reduced the cetane number and increased the aromatic content. This in turn caused an increase in the speed of the DPF differential pressure, gradually increasing the DPF regeneration load. In particular, it was reported that when the cetane number was below 50 (aromatic content exceeded 30 vol%), the DPF regeneration load increased and, when the cetane number was 43 (aromatic content at about 40 vol%), the DPF could not regenerate well and there was a possibility of a serious malfunction (11).

A large portion of other research being conducted on diesel fuel is focused on biodiesel, especially the influence of biodiesel on the exhaust gas and fuel injection. The particle number (PN) corresponding to the amount of fatty acid methyl ester (FAME) blended into the diesel fuel was evaluated. The results of this evaluation showed that blending FAME into diesel fuel greatly reduced the number of particles in the 40 to 100 nm size range (13). There was also a report that showed FAME could be used as an additive to improve the cetane number, and that the use of FAME could shorten the ignition delay in numerical simulations of the combustion characteristics (14). Bio-hydrofined diesel (BHD) is also being evaluated to determine its particulate matter (PM) generation (15) and its effect on fuel injectors (16). Other research is also aiming to improve the low-temperature fluidity and reduce the smoke concentration of diesel fuel by mixing in butanol and fatty acid butyl ester (17).

Several reports examined mixing butanol into gasoline from the standpoint of biofuels. Marchitto et al. compared the state of the fuel spray in a multi-hole injector when gasoline and butanol were used. This report noted that these fuels had an influence on the different droplet sizes and particle velocities produced by the injection pressure and the spray location (core and edge of the spray) (18). The influence of butanol-blended gasoline on the exhaust gas was evaluated in SI engines (19) and HCCI engines (20), and it was reported that this fuel had different effects on NOx emissions in each engine. Greater emphasis is also being placed on the PM and PN of biofuels. One report examined the characteristics of the PM emissions of hydrocarbon fuels, which have various chemical structures, using laminar diffusion combustion (21). In the future, it is predicted that the use of cracked gasoline base materials will expand and that various research into gasoline fuels will be promoted in the same way that the JATOP II research is now examining diesel fuels.

3 Lubricants

3. 1. Trends in automotive lubricant oil standards

3. 1. 1. Gasoline engine oil

As vehicle fuel efficiency regulations become increasingly stringent, low viscosity engine oils, such as oil with an SAE viscosity grade of 0W-20, are becoming more popular in the gasoline engine oil market. In 2013, SAE 16 was added as the lowest viscosity grade to SAE J300, which stipulates the viscosity grades for engine oils. In 2014 the 0W-16 and 5W-16 engine oils were granted the API SN standard, which is the latest performance standard of the American Petroleum Institute (API) for engine oils that are used in gasoline engine vehicles (22).

Discussions about setting even lower viscosity grades are also proceeding and it is expected that SAE 12 and SAE 8 viscosity grades will be added to SAE J300 in January of 2015. In the case of engine oil with the SAE 16 viscosity grade, the specified value of the kinematic viscosity at 100° C is 6.1 to 8.2 mm^2/s and the lower limit value of the high temperature high shear (HTHS) viscosity at 150° C is 2.3 mPa/s. In comparison, the plan is to further lower these values for the SAE 12 and SAE 8 engine oils as follows: the specified values for the kinematic viscosity at 100° C shall be 5.0 to 7.1 mm^2/s and 4.0 to 6.1 mm^2/s respectively, while the lower limit value of the HTHS viscosity shall be 2.0 mPa/s and 1.7 mPa/s respectively (23).

The development of the next gasoline engine oil standard, ILSAC GF-6, is making progress. The main differences between this standard and the current GF-5 standard are as follows: to enable further improvement in vehicle fuel efficiency, improve the wear resistance of the timing chain, improve engine robustness, and as a measure against low-speed pre-ignition (LSPI) under low engine speed high-load operating conditions. The original target for the introduction of the ILSAC GF-6 standard was January 2017, but the development of the test method was delayed, so the plan is now to introduce this standard in December 2017 (22).

The ACEA European Oil Sequences are the engine oil standards for Europe and the revisions to the ACEA 2012 standards that were originally planned to be made in 2014 have been delayed. These are now scheduled to be implemented in mid-2015. In these revisions, it is planned that a new C5 standard will be added to the C category standards, which are the standards for passenger vehicles that conform to the latest exhaust gas regulations. As a result, it will become possible to introduce SAE 20 low-viscosity grade engine oil in Europe under the ACEA standards (24).

In Japan, due to the situation concerning the supply of standard engine oils and test engines, it was decided to abolish two test methods, namely JASO M328 (valve train wear test method), and JASO M331 (detergency test method), in March 2015.

3. 1. 2. Diesel engine oil

In Japan, the JASO diesel engine oil standard revision task force is continuing to revise the JASO M355 automotive diesel engine oil standards. In April 2014, the JASO M336 piston detergency test method was revised into a test method that uses a new engine that complies with the post-new long-term emissions regulations. JASO M355 was also revised to incorporate this content (25)(26). The revision work on JASO M354 (valve train wear test method), also continues to progress and it was reported that a new test method was adopted for evaluating the amount of wear on the tappet using the same test engine and test conditions as in the revised piston detergency test method (27). Starting in April 2015, there are plans to once again revise JASO M354 and JASO M355 to reflect these changes. Since FY 2015 is the target year for achieving heavy-duty vehicle fuel efficiency standards, the fuel efficiency standards for diesel engine vehicles are only going to continue to become more stringent in the future. Therefore, the same task force mentioned above is currently promoting the development of the world's first fuel efficiency test method for diesel engine oils with a goal of establishing it by the year 2017 (28).

In the U.S. the PC-11 standard is being examined as a possible replacement for the current API CJ-4 standard. March 2017 has been set as a target for adoption and enactment. In addition to PC-11A, which has backward compatibility with the existing PC-11 standard, the plan is for PC-11B to be established in parallel as a fuel-saving oil category that does not have backward compatibility. In PC-11B, the standard values for the HTHS of the new oils will be set low and in PC-11A the standard values for the HTHS will be the same as in the old CJ-4 standard, namely, 3.5 mPa/s or higher. The plan is to set the standard values for the HTHS in PC-11B to 2.9 to 3.2 mPa/s (29). In the case of the engine tests, the oxidation stability test will be changed to the Mack T-13 test and the Caterpillar C-13 aeration test is planned to be introduced as the as the oil aeration test. There are no changes to the items of the bench tests, but some of the items, such as shear stability, are predicted to have stricter standard values.

The release of the 2014 edition of the revised ACEA standards has been delayed to 2015. In these revisions, it is planned for CEC L-109 (oxidation stability test) and CEC L-104 OM 646 bio (piston detergency test) to be added to the E category, which is the standard for heavy-duty engine oil, as tests that use biodiesel fuel. However, the fuel-saving oil category (F category) that was originally planned to be newly established in these revised standards has been postponed until the next revision (24).

3. 1. 3. Gear oils

There were no revisions to the main standards that concern gear oil, namely ASTM D7450 and SAE J306. However, the possibility of changing the unit in the L-37 low-speed high-torque test (from a unit manufactured by Dana to a unit manufactured by Gleason) and extending the test time used in the CEC L-45-A-99 shear stability test method are both being examined and are planned to be revised in the future.

3. 1. 4. Automatic and continuously variable transmission fluids (ATF and CVTF)

There were no revisions to the ATF standards in regard to the widely known DEXRON® and MERCON® fluids. In Japan, the shear stability test method in the JASO M347 ATF standard was revised in March 2014 and a 5-hour test method and 10-hour test method were newly established in addition to the existing 1-hour test method. As a result of this change, there are plans to also revise JASO M315, which is the automatic transmission oil standard.

3. 2. Automotive lubricant technology trends

3. 2. 1. Gasoline engine oil

More and more automakers are adopting smaller turbocharged engines to satisfy the more stringent fuel efficiency and emissions standards. In these engines, LSPI that occurs in the low engine speed high-load operation region is an issue. It is thought that LSPI is a factor that may be causing engine oil droplets and deposits to form from engine oil. One report addressed LSPI by optimizing the engine oil formulation, such as by using a high-quality base oil and reducing calcium-based detergents (30). Even though the introduction of ILSAC GF-6 is currently being delayed, the development of gasoline engine oil formulation techniques that will help the oil to function under LSPI conditions and provide other performance at a high level is urgently needed

3. 2. 2. Diesel engine oil

As fuel efficiency regulations for heavy-duty diesel vehicles are also becoming more stringent, many reports examined the fuel-saving performance of diesel engine oils. One report detailed the development of a fuel-saving diesel engine oil capable of handling diesel fuel dilution (31). Another detailed how further fuel efficiency could be achieved by lowering the viscosity of the oil and optimizing the formulation of the oil additives (32). Emissions regulations for diesel engine vehicles are also becoming more stringent. Therefore, maintaining the functionality of exhaust gas aftertreatment devices is an important issue. It is well known that phosphorus and ash in engine oil additives have a negative impact on the service life of aftertreatment devices. One report examined the effect on the aftertreatment device of using an engine oil that was not blended with such additives (33). It is thought that one of the most critical technical issues facing diesel engine oils in the future will be the construction of oil formulation techniques that enhance fuel-saving performance and compatibility with aftertreatment devices, while also maintaining the practical performance of the oil.

3. 2. 3. ATF and CVTF

Many automakers are adopting CVTs to improve fuel efficiency. The adoption of multi-stage ATs is also increasing for the same reason. In Japan, the use of dual clutch transmissions (DCTs), which used to be concentrated in Europe, has also started to spread. The lubricating oils used in these transmissions have also been receiving attention and many new technological trends in the field of ATF and CVTF have been introduced, such as the use of lower viscosity oils and improved viscosity indexes to help improve fuel-saving performance (34). One report about ATF found that the fuel-saving performance of the transmission was improved by using a high viscosity index ATF with a reduced viscosity due to the use of a new comb-type polymer viscosity index improver (35). The friction characteristics of ATF have also been examined to reduce the weight and raise the efficiency of ATs. It was reported that a high coefficient of friction was achieved by optimizing the adsorptive properties of the ATF additives and the friction material (36). Furthermore, it was also reported that a low-viscosity type of oil exclusively for use in DCTs was developed during the development of a new DCT (37). It is fully expected that new types of transmission oils will continue to be introduced into the market in the future.

4 Grease

As every automaker develops new technologies to realize more fuel efficient vehicles, weight reduction has become a key theme.

To reduce the weight of the body, mechanical components, such as wheel bearings and constant velocity joints (CVJ), are being made more compact and integrated into single units. Since these types of mechanical components are subjected to complex rolling and sliding motions during straight-ahead driving and turning, the loads on these components (frictional heat and vibration, as well as load application) are becoming more and more severe as size is reduced. Consequently, urea grease is selected in many cases to handle these conditions due to its superior heat resistance, ability to reduce the level of required maintenance, and its good fretting resistance (38). In recent years, some metal parts have also been replaced with plastic parts to help reduce weight. For example, there are cases where a plastic material is used for the sliding portions of the vehicle's steering wheel. In this case, a grease that is compatible with the plastic material (i.e., a grease that can suppress the advance of degradation of the plastic component as much as possible) is required (39).

Another key theme in current vehicle development is the electrification or motorization of mechanical parts. For some time now, motors have been used for windshield wipers and side mirrors, and electric power steering (EPS) has become widely adopted on many vehicle models. Hydraulic power steering was the main technology that had been used up until now. EPS reduces energy consumption to approximately one-sixth of a hydraulic steering system (40). Now that hybrid and electric vehicles are growing in popularity, the electric drive motors in these vehicles will play an important role in the future. The main shaft of the motor is rotated at high speed to ensure the output torque (driving force). Therefore, the heat generated within the motor is a major issue and the grease that is used within the motor must therefore have excellent heat resistance. Research is also being carried out to help identify grease with an even lower stirring resistance so that it can be used within the axle bearing. The aim is to reduce the amount of electric power consumption required to move the motor as well as to reduce the amount of heat that is generated (41)(42).

References

(1) Petroleum Association of Japan: Petroleum Industry in Japan, 2015

(2) IMF Primary Commodity Prices: Prices & Forecasts and Monthly Data, http://www.imf.org/external/np/res/commod/index.aspx

(3) Petroleum Association of Japan: Oil Import Price, http://www.paj.gr.jp/english/statis/index.html

(4) Petroleum Association of Japan: Supply and Demand of Petroleum Products, http://www.paj.gr.jp/english/statis/index.html

(5) Petroleum Market Trends WG, Petroleum and Natural Gas Subcommittee, Natural Resources and Fuel Committee, Advisory Committee for Natural Resources and Energy: Petroleum Product Demand Forecast for 2015 to 2019 (Japanese only, published on April 9, 2015)

(6) Basic Energy Plan (April 2014) (Japanese only), http://www.enecho.meti.go.jp/category/others/basic_plan/pdf/140411.pdf

(7) Materials Relevant to Laws Related to the Encouragement of the Use of Non-Fossil Fuel Energy Sources and Effective Use of Fossil Fuel Energy Sources by Energy Suppliers (Japanese only), http://www.enecho.meti.go.jp/notice/topics/017/pdf/topics_017_002.pdf

(8) Petroleum Association of Japan: Supply and Demand of Crude Oil, http://www.paj.gr.jp/statis/

(9) Agency for Natural Resources and Energy: Enforcement of Judgment Standards etc. for Petroleum Refiners Related to the Effective Use of Crude Oil, etc. in the Three-Year Period after 2014 (published on July 31, 2014), http://www.enecho.meti.go.jp/notice/topics/030/pdf/topics_030_001.pdf

(10) Japan Petroleum Energy Center (JPEC): Announcement of JATOP II Results (Japanese only), http://www.pecj.or.jp/japanese/jcap/jatop2/pdf/index_jatop2_3-3.pdf

(11) JPEC, Announcement of JATOP II Results (Japanese only), http://www.pecj.or.jp/japanese/jcap/jatop2/pdf/index_jatop2_3-4.pdf

(12) JPEC, Announcement of JATOP II Results (Japanese only), http://www.pecj.or.jp/japanese/jcap/jatop2/pdf/index_jatop2_2-1.pdf
(13) Mori et al., Study of Influence of New Diesel Fuels on PM and PAH Exhaust Emissions from DI Diesel Vehicles, Proceedings of the Society of Automotive Engineers of Japan, No. 105-14, 20145801
(14) Morinaga et al., Research into the Combustion and Emissions Gas Characteristics of Diesel Engines Using Biodiesel as a Cetane Number Improver (Japanese only), Proceedings of the Society of Automotive Engineers of Japan, No. 105-14, 20145771
(15) Bhardwaj, et al., Utilization of HVO Fuel Properties in a High Efficiency Combustion System (Part 1): Impact of Soot Structure on the DPF Regeneration Behavior, Proceedings of the Society of Automotive Engineers of Japan, No. 55-14, 20145128
(16) Tipdecho, et al., Harmonization of FAME and HVO as components of Diesel Fuel on Advanced Diesel Common Rail Technology, Proceedings of the Society of Automotive Engineers of Japan, No. 55-14, 20145068
(17) Itakura et al., Combustion Characteristics of Coconut on Butyl Ester with Butanol, Proceedings of the Society of Automotive Engineers of Japan, No. 105-14, 20145724
(18) Marchitto, et al., Experimental Study on the spray Atomization of a Multi-hole Injector for Spark Ignition Engine Fueled by Gasoline and n-Butanol, SAE Paper 2014-01-2743
(19) Nagaraja, et al., Performance and Emi1ssion Characteristics of a MPI Engine Fueled with Iso-Butanol/Gasoline Blends, SAE Paper 2014-01-1390
(20) Liu, et al., Combustion and Emission Characteristics of a HCCI Engine Fueled with Different n-Butanol-Gasoline Blends, SAE Paper 2014-01-2668
(21) Kobayashi et al, Study on In-Flame PAHs and PM Emission Characteristics of Diffusion Flames with Various Hydrocarbon Fuels, Proceedings of the Society of Automotive Engineers of Japan, No. 56-14, 20145376
(22) Infineum Insight: ILSAC GF-6 and PC update (December 2014), http://www.infineuminsight.com/insight/dec-2014/ilsac-gf-6-and-pc-11-updates-december-2014
(23) Maruyama et al., Trends of Fuel-Economy/Low-Viscosity Gasoline Engine Oils, Journal of Japanese Society of Tribologists, No. 57-6, pp. 380-386, 2014
(24) Infineum Insight: ACEA update (March 2014), http://www.infineuminsight.com/insight/mar-2014/acea-update-march-2014
(25) Akamatsu et al., The Development of New Piston Detergency Test Method for Automobile Diesel Engine Oil (2nd Report), Proceedings of the Society of Automotive Engineers of Japan, No. 68-14, 20145104
(26) Japan Lubricating Oil Society (JALOS), Changes to Operating Manual after Revisions to Vehicle Diesel Engine Lubricating Oil Standard (JASO M355) (Japanese only, published June, 2014), http://www.jalos.or.jp/onfile/jaso_j-3-2.htm
(27) Kasai, et al., The Development of a New Valve Train Wear Test Method for Automotive Diesel Engine Oil, Proceedings of the Society of Automotive Engineers of Japan, No. 137-14, 20145743
(28) JALOS, Revision of JASO Diesel Engine Oil Standards – Report of the Activities of the JASO Diesel Oil Standard Revision Task Force, 2014
(29) McCarthy, The Future of Heavy Duty Diesel Engine Oils, Tribology & Lubrication Technology, Vol. 70, p. 38-50, 2014
(30) Fujimoto et al., Engine Oil Development for Preventing Pre-Ignition in Turbocharged Gasoline Engine, SAE Paper 2014-01-2785
(31) Wada et al., Development of Fuel-Saving Diesel Oil with Robust Fuel Dilution Performance (JASO DH-2/CF-4), Proceedings of the Annual Meeting of the Japan Petroleum Institute pp. 83-88, 2014
(32) van Dam, et al., Taking Heavy Duty Diesel Engine Oil Performance to the Next Level (Part 1): Optimizing for Improved Fuel Economy, SAE Paper 2014-01-2792
(33) Iwasaki, et al., Impact of Non-Phosphorus and Non-Ash Engine Oil on After-Treatment Devices, SAE Paper 2014-01-2782
(34) Yokomizo et al., Introduction of AT and CVT Fuel Saving Oil Technologies (Japanese only), Symposium Text, No. 03-11, pp. 11-16, 2014
(35) Naito et al., Improving Vehicle Fuel Efficiency with High Viscosity Index ATF (Japanese only), Proceedings of the Conference of the Japanese Society of Tribologists, pp. 349-350, 2014
(36) Sakai et al., Recent Technology of Wet Friction

Materials (Japanese only), Proceedings of the Conference of the Japanese Society of Tribologists, pp. 366-367, 2014
(37) Machida et al., Development of 8-Speed DCT with Torque Converter for Midsize Vehicles, Honda R&D Technical Review, Vol. 26, pp. 119-125, 2014
(38) Sakamoto, Technological Trends of Automotive Greases (Japanese only), Journal of Economic Maintenance Tribology, No. 526, pp. 32-36, 2009
(39) Nakata, Development and Application of Grease Lubrication Technology for Automotive Sliding Parts (Japanese only), Tribology Monthly, No. 325, pp. 16-18, 2014
(40) Nakata, Technology to Improve the Performance and Reliability of EPS Grease (Japanese only), Journal of Economic Maintenance Tribology, No. 589, pp. 6-9, 2014
(41) Nakao et al., "Low Torque Deep Groove Ball Bearings for EV and HEV, Tribology Monthly, No. 321, pp. 25-27, 2014
(42) Shinden et al., Effects of Sliding Friction on Rotating Torque of Grease-Lubricated Ball Bearings (Japanese only), Proceedings of the Conference of the Japanese Society of Tribologists, pp. 303-304, 2014