FUEL, LUBRICANT AND GREASE

1 Introduction

The price of West Texas Intermediate (WTI) crude oil in 2018 started of year at $60 USD per barrel and fluctuated thereafter. Production cuts in oil-producing countries brought oil stocks in OECD countries to average levels (average for the past five years) in March, almost eliminating the surplus in the oil supply at that point. The price rose moderately until September in the wake of the United States announcing its withdrawal from the Iran nuclear agreement and the resuming of sanctions against that country in May. On October 3 the price had risen to $76.41 USD per barrel (closing price). However, this was followed by a sharp drop in the price due to the volatility in US stock prices, the impact of the US and China tariff war on the US economy, and the fear of chaos in the European region due to the possible no deal exit of the UK from the EU. On December 24, the closing price dropped to $42.53 USD per barrel and finished the year at $45.41 USD per barrel. The price of crude oil therefore fell over the course of 2018 as a whole[1].

The amount of crude oil imported into Japan in 2018 was 177.48 million kL, a decrease of 5.4% from the previous year, and the amount of crude oil processed in Japan was 177.77 million kL, a decrease of 4.8% from the previous year. Both of these statistics are lower than the previous year, and the rate decrease is accelerating[2].

Figure 1 shows the changes in the Japanese domestic fuel oil sales volume (total volume, gasoline sales volume, and diesel oil sales volume). The total fuel oil sales volume in 2018 was169.97 million kL (a decrease of 3.2% from the previous year), the sales volume of gasoline was 51.05 million kL (a 1.6 % decrease), and the sales volume of diesel was 33.85 million kL (a 0.6% increase). The domestic sales volume of diesel oil in 2018 increased slightly, matching the prediction in the (draft) petroleum product demand forecast for 2018 to 2022[3] published on the website of the Ministry of Economy, Trade and Industry (METI).

Figure 2 shows the predicted demand for fuel oil in Japan from fiscal 2018 to fiscal 2022[3]. This forecast reflects the impact of the consumption tax increase in October 2019, but not that of new sulfur regulations by the International Maritime Organization (IMO) because the trends in alternative fuel selection (depending on fuel prices and other factors) cannot be foreseen. For the entire period from fiscal 2018 to fiscal 2022, the demand for gasoline is expected to maintain an average annual rate of −2.3%, as a result of shorter distances driven by passenger vehicles and ongoing improvements in fuel efficiency. Demand for diesel fuel is expected to maintain an average annual rate of +0.1% on the assumption that solid economic growth will support a steady level freight transportation despite the continuing shift toward a service

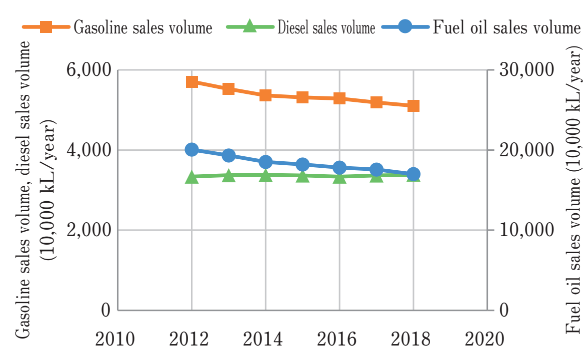


Fig. 1 Changes in Japanese Fuel Oil Sales Volume

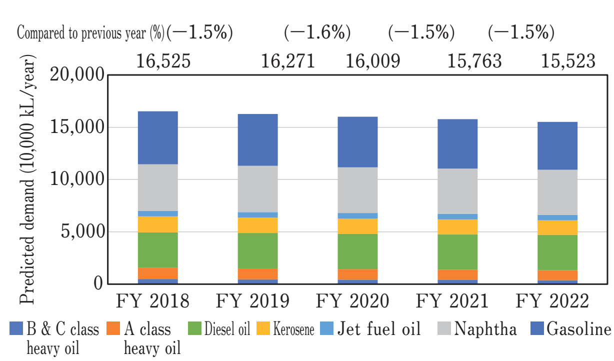


Fig. 2 Predicted Demand for Petroleum Products

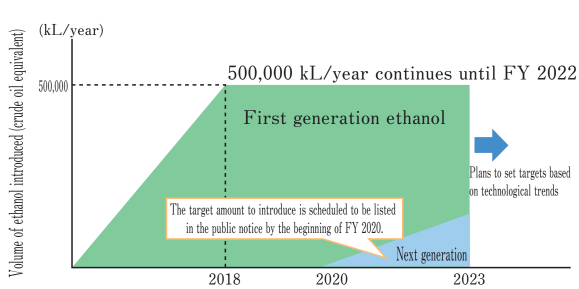
economy and higher added value.

2 Fuels

2. 1. Fuel Trends

The Fifth Strategic Energy Plan, which serves as the basic guideline for the comprehensive measures to take in regard to energy supply and demand in Japan, was approved by the Cabinet on July 3, 2018[4]. This plan presented a scenario for 2050 that covers taking on the challenge of decarbonization following the coming into effect of the Paris Climate Agreement. Petroleum, which accounts for a large portion of the energy consumed in transportation sector, is not only the last bastion of energy supply in the event of a disaster, but is also seen as the main energy source during the period of transition to alternative energy sources. Therefore, it is important to strengthen the supply network and supply base of petroleum. At the same time, in an effort to achieve a low-carbon society, the plan presents policies to increase the use of alternative energy sources such as biofuels, electric power, natural gas, LP gas, and hydrogen, for various segments of the transportation sector and not just for automobiles.

With respect to the introduction of biofuels in Japan, petroleum companies, notably, achieved the 500,000 kL per year of bioethanol use (in crude oil equivalent) by fiscal 2017 target set in the Act on Sophisticated Methods of Energy Supply Structures[5]. Furthermore, these companies have indicated that they will continue to introduce 500,000 kL per year into the market from fiscal 2018 to fiscal 2022, and promote the introduction of a domestic, next-generation bioethanol that will not compete with food sources (Fig. 3). As demand for gasoline in Japan declines, bioethanol is mainly used in gasoline in the form of ETBE (ethyl tert-butyl ether), increasing its abundance ratio while contributing to the reduction of CO_2. The Fifth Strategic Energy Plan also notes that approaches to the further introduction of biodiesel fuel will be studied.



Reference: Document 3 of the Expert Committee to Discuss the Future of Biofuel Introduction in Japan (2nd meeting)

Fig. 3 Path toward the Future Introduction of Biofuels

Despite the declining demand for petroleum in Japan, strengthening the foundation of the oil industry remains important to maintaining domestic oil refining capacity, prompting the establishment of the Oil Industry Competitiveness Research Council[6]. The rapidly growing surplus in the global gasoline supply and the quality of fuel in Asia reaching parity with that of developed countries has raised the possibility of increased pressure on Japan to import oil. The council is discussing (1) strengthening international competitiveness (such as upgrading existing businesses), (2) transformation of the business portfolio (enhance and expand the basic scientific field around surplus gasoline) and, (3) promoting overseas business development as necessary actions to maintain the Japanese oil refining base and secure a flexible and strong petroleum supply capacity.

At the same time, the International Maritime Organization (IMO) has decided to reduce the limit on sulfur content in marine fuel oil in general sea areas from the current 3.5% to 0.5% by 2020[7]. The application of desulfurization treatments, decomposition treatments, and low sulfur fraction blending to cope with this regulatory change is expected to result in a fuel composition that differs from conventional Class C heavy oil. Treatments such as desulfurization and decomposition of heavy distillates may affect the composition and properties of gasoline and diesel fuels. Since fiscal 2018, the METI-subsidized Analysis and Evaluation of the Effects of Using Cracked Diesel Oil on Automobiles and Other Vehicles project[8] has examined the impact of those treatments on marine fuels, and producers (the oil industry) and users (the automotive and shipping industries) are jointly studying the use of cracked petroleum distillates.

2. 2. Gasoline

The Innovative Combustion Technology program within the Cross-ministerial Strategic Innovation Promotion Program (SIP) of the Cabinet Office in Japan achieved its goal of developing an internal combustion engine with a maximum thermal efficiency of 50% through the establishment of a system for industry-academia collaboration in 2018, bringing the project to an end[9]. This project furthered studies to understand the ignition and combustion characteristics of hydrocarbon structures. Examining numerical calculation results of the ignition delay behavior of various branched chain alkanes[10], unsaturated hydrocarbon structures, and laminar burning velocities revealed that the difference between linear alkanes and alkenes is small under conditions with a low equivalence ratio of 0.6, but the hydrocarbon structures increase that difference as the equivalence ratio rises. Consequently, alkenes were reported to exhibit a faster laminar burning velocity than alkanes[11]. Another study that looked at the influence of the fuel structure on the laminar burning velocity focused on the generation of ethyl radicals. This report stated that ethylbenzene and phenetole have higher laminar burning velocities and better knocking suppression effects than toluene and anisole[12].

Ethanol and butanol are the subject of many reports on the effects of biofuels in gasoline, and include reports on using hydrous ethanol to suppress knocking[13] and on suppressing soot with butanol through a laminar diffusion flame evaluation[14].

2. 3. Diesel Fuel

There have also been many reports on the use of various biofuels in relation to diesel fuel. These reports examined not only fatty acid methyl esters (FAME), but also rapeseed oil[15], soybean oil[16], butanol[17], and alcohols such as propanol[16] to determine how they affect deposits, combustion, emissions, and other factors. Studies on FAME fuels made from different raw materials[18][19] found that although a common improvement due to oxygenation is observed, the cetane number and other properties differ depending on the types of raw materials and the respective fuel property results were reported individually.

Another report looked at the use of cracked diesel fuel and measured the PM (particulate matter) generation process using an in-cylinder gas total sampling system[20]. A reduced intake oxygen concentration in JIS No. 2 diesel fuel does not affect the soot generation process significantly, but it suppresses the subsequent soot oxidation process, resulting in an increase in soot emissions. Conversely, using a fuel with increased aroma and naphthenic components to simulate cracked diesel fuel, promoted the soot generation process itself, again increasing soot emissions.

3 Lubricants

3. 1. Gasoline Engine Oil

3. 1. 1. Regulatory Trends

Growing concern about global warming and other environmental issues that affect the entire planet is intensifying demands for automobiles to reduce emissions and improve fuel efficiency. These circumstances have led to adopting downsized engines equipped with turbochargers, which present the issue of low speed pre-ignition (LSPI) in the low engine speed and high load range. Although the next set of gasoline engine oil standards and specifications, specifically the American Petroleum Institute (API) SP and International Lubricant Standardization and Approval Committee (ILSAC) GF-6, are scheduled to incorporate measures against LSPI, the delay in the issuance of the SP and GF-6 standards led, to the release of API SN Plus, which adds LSPI prevention performance requirements to the existing SN standard, in May 2018. Therefore, oils certified under this standard will address the LSPI issue until SP and GF-6 are issued.

At its April 3, 2019, the Auto-Oil Advisory Panel (AOAP) decided that licensing for the SP and GF-6 standards would start on May 1, 2020[21]. The standard values in the Sequence VIE (GF-6A) and Sequence VIF (GF-6B) fuel efficiency tests and in the Sequence IIIH high-temperature oxidation stability test have been relaxed relative to the 2018 draft, but are nevertheless stricter than in the SN and GF-5 standards for many items and therefore require higher temperature cleanliness and fuel efficiency. In addition to the above LSPI prevention performance requirements, Sequence X has also been added to the SP and GF-6 standards to evaluate chain wear prevention.

The lowest -viscosity grade covered by the SP and GF-6 standards is 0W-16, which means the even lower viscosity grades such as 0W-12 and 0W-8, cannot receive certification. The Japanese Automotive Standards Organization (JASO) will be issuing the new JASO M364 (automotive gasoline engine lubricant) standard that covers such ultra-low viscosity grade engine oils[22]. Engine oils that meets this standard receive the GLV-1 designation. Two new related standards have been established as fuel economy test methods: JASO M365 (Automotive Gasoline Engine Lubricant - Motoring Fuel Economy Test Method) and JASO M366 (Automotive Gasoline Engine Lubricant - Firing Fuel Economy Test Method). Engine oils must pass either the motoring or the firing fuel economy test to obtain the GLV-1 certification. The standard values differ between the motoring and firing tests. In comparison to the 0W-20 reference oil, the standard values are 2.0% or higher (0W-8) and 1.7% or higher (0W-12) in the motoring test and 1.1% or higher (for both the 0W-8 and 0W-12 oils) in the firing test. These fuel economy tests were designed with an eventual application global lubricant standards such as ILSAC in mind. However, the ILSAC GF-6B standard remains the basis for evaluation items other than fuel economy.

3. 1. 2. Technological Trends

There are strong calls to also make engine oils fuel efficient to achieve better overall fuel efficiency in automobiles. Variations in the frequency of LSPI occurrence has been linked to the type of detergent, which is one of the additives in engine oil, indicating the need to develop engine oils with excellent LSPI prevention properties. In that context, one report presented the results of an investigation into the LSPI prevention performance of both new and deteriorated oils(23), while another described efforts to develop an engine oil that achieves both good LSPI prevention and fuel economy performance through the combined use of a magnesium (Mg) detergent, a boron dispersant, and a MoDTC (molybdenum dithiocarbamate) friction modifier(24). A third study evaluated the friction characteristics of 0W-8 oil manufactured using an ester base oil to examine the possibility of lowering the viscosity of engine oil even further(25).

3. 2. Diesel Engine Oil

3. 2. 1. Regulatory Trends

In Japan, JASO DH-2F, an engine oil standard that assigned fuel economy performance requirements to the existing JASO DH-2 standard, went into effect in 2017. Since then, oil certified with that standard has gradually spread throughout the market. Outside Japan, the European Automobile Manufacturers Association (ACEA) is scheduled to issue the F8 and F11 fuel-efficient oil standards, which are currently expected to go into effect in mid-2020(26). Similarly, China is expected to issue a standard called D1 in 2019, followed by D2 in 2025(27).

3. 2. 2. Technological Trends

Diesel engine oil technologies that improve fuel efficiency are also receiving attention, but the need to ensure sufficient engine reliability makes it necessary to construct fuel efficiency improvement technologies that do not simply rely on low oil viscosity. In that respect, the development of a diesel engine oil that improves fuel economy by optimizing the viscosity index improver and using a friction modifier while maintaining the viscosity grade at 5W-30 has been reported(28).

3. 3. ATF and CVTF

3. 3. 1. Regulatory Trends

A revision of the test standard for the automatic transmission fluid shudder prevention performance test method (JASO M349:2012) is under consideration to address variations that occur in the test results because current test conditions do not take the material characteristics of the friction material and the formulation of the additives in the standard oil (RTF-1) into account. The JASO Automatic Transmission Oil Subcommittee studied ways to reduce this variation and subsequently reported that changing the surface pressure in the test conditions to stabilize the formation of the lubricating film in the mixed lubrication region, where slip speed is slow, decreased the problematic variation(29).

3. 3. 2. Technological Trends

Efforts to further raise the transmission efficiency CVT are underway to enhance overall automobile fuel efficiency. The viscosity of CVT fluid (CVTF) is being reduced to lower oil stirring resistance, which in turn decreases friction loss. In one reported case, optimizing the CVTF base oil and viscosity index improver achieved a viscosity drop of about 7℃ over the entire temperature range compared to conventional oil while maintaining the same oil film thickness(30).

3. 4. Gear Oil

3. 4. 1. Regulatory Trends

The reference fluid was revised in the CEC L-45-99 shear stability test method. The RL210 lubricant, which had served as the reference fluid to determine whether to use a bearing, has been abolished and replaced with RL267 and RL268.

3. 4. 2. Technological Trends

A fuel-saving differential oil exhibiting improved fuel efficiency in the JC08 driving mode compared to other formulations containing a molybdenum-based friction modifier (FM) or synthetic oils has been developed. Simply lowering viscosity is considered to reduce oil film thickness, shifting the gear tooth surfaces toward a boundary lubrication state, which multiplies friction loss and worsens gear transmission efficiency. Reduced gear durability due to the increased friction loss resulting from the direct contact between gear tooth surfaces is also a concern. Solving these issues will require reducing viscosity in the practical range while maintaining it at the highest oil temperature by raising the viscosity index. However, a synthetic or other high-performance base oil and a viscosity index improver are required to raise the viscosity index, resulting in a higher cost. These issues have been addressed by applying a low-cost solvent refined base oil and optimizing the polar high-viscosity base materials and GL-5 additives to maintain reliability matching that of conventional oils and make them more affordable[31].

4 Grease

Year after year, regulations on automobile fuel economy and emissions are becoming stricter worldwide to address environmental issues such as global warming and air pollution. As automobile parts are made smaller and lighter, as well as redesigned to use electric power, to reduce fuel consumption, the greases used in those parts are also expected to contribute to improved fuel efficiency. Most recently, the pursuit of enhanced efficiency has led manufacturers to develop various low-torque technologies for grease, as exemplified by the development of a low-torque grease for the hub bearings used in automobile axles[32] and of a low-torque grease for the worm reduction gears used in electric power steering systems[33].

In addition, as the number of EVs, HEVs and other electrified vehicles has grown, noises previously masked by the sound of the engine, including the whirr of various actuators and the rattling caused by vibration, have become more conspicuous. Greases used in automobiles are therefore increasingly called upon to not only fulfill their conventional role as a lubricant, but also to dampen noise, and various types of sound attenuating greases have been developed to address different types of abnormal noises[34].

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