FUEL, LUBRICANT AND GREASE

1 Introduction

According to an International Energy Agency (IEA) report issued in January 2021, the global demand for petroleum was 91.2 million barrels per day, dropping significantly from the previous year's demand (a drop of 8.8 million barrels per day compared to 2019) due to the impact of the COVID-19 pandemic. The global spread of the pandemic was notably pronounced during the second quarter, when lockdowns were imposed in many cities and demand fell to 83.1 million barrels per day (a 16.6 million barrel decrease compared to the same quarter in the previous year.) The margin in the drop in demand subsequently shrunk, but not enough to recover to the previous year's level in the fourth quarter, which decreased by 6.4 million barrels per day compared to the previous same period (fourth quarter of 2019).

The 2020 supply of petroleum saw its worst annual drop in history due to COVID-19 causing demand to plunge. The 2020 supply was 6.6 million barrels per day less than the previous year, dropping to 93.94 million barrels per day, a figure that nevertheless considerably exceeded the reduced demand. The reduction in supply broke down to 5.3 million barrels per day for OPEC Plus countries, and 1.3 billion barrels per day for non-OPEC countries. On a quarter by quarter basis, there was an excess of supply until the second quarter, but in the third and fourth quarters, adjustments in production started to decrease inventory, leading to the rise in crude oil prices that will be described later.

Figure 1 shows the 2020 crude oil price trends based on the U.S. WTI and European Brent crude oil prices. Although 2020 started with prices above 60 dollars per barrel, the adverse economic impact of the spread of COVID-19 caused it to plunge. In conjunction with the breakdown in production adjustment discussions in OPEC Plus in March, prices dropped to 20.09 dollars per barrel on March 30. Prices continued to fall after that, registering a price of -37.63 dollars per barrel on April 20, 2020, the first negative value in the history of WTI crude oil futures. Factors such as the recovery of demand in China subsequently had prices hovering around 40 dollars per barrel, and after November, the results of the U.S. presidential election combined with the announcement of vaccines to spur a rise in prices. At the end of 2020, the WTI had recovered to 48 dollars per barrel, and Brent to 51 dollars per barrel. Prices have continued to rise since then, returning to 2020 beginning of the year level in March 2021.

2 Fuels

2. 1. Fuel Trends

According to the FY 2019 Annual Report on Energy (Energy White Paper 2020), the proportion of energy consumption by source in the transportation sector was 53.8% for gasoline and 32.2% for diesel as of fiscal 2018.

The statistics on resources and energy released by the Ministry of Economy, Trade and Industry (METI) indicate that the total volume of fuels sold in Japan have exhibited a monotonous decrease since 2012. In 2020, that total was 151.35 million kL. That represents an 8.4% decrease over the previous year, and a major drop compared to previous years.

While all types of oil decreased significantly, as shown by the fuel type break down of 45.77 million kL for gasoline, a 7.8% decrease from the previous year, 31.88 million kL for diesel, a 6.2% decrease, 10.04 million kL for A class heavy oil, a 5.5% decrease, the drop was particularly notable for BC class heavy oil, which accounted for 6.27 million kL, a huge 19.1% plunge compared to the previous year. Figure 2 shows the gasoline and diesel trends.

2. 2. Gasoline for Automobiles

(1) Regulatory Trends: In Japan, the standard calorific value for fuel and the carbon emissions coefficient are revised every five years. The standard calorific value for gasoline and the carbon emissions coefficient in the

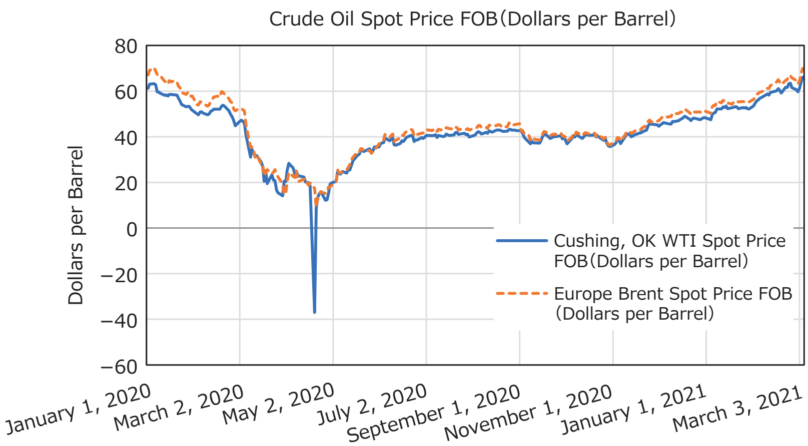

Fig. 1 Crude Oil Price Trends in 2020

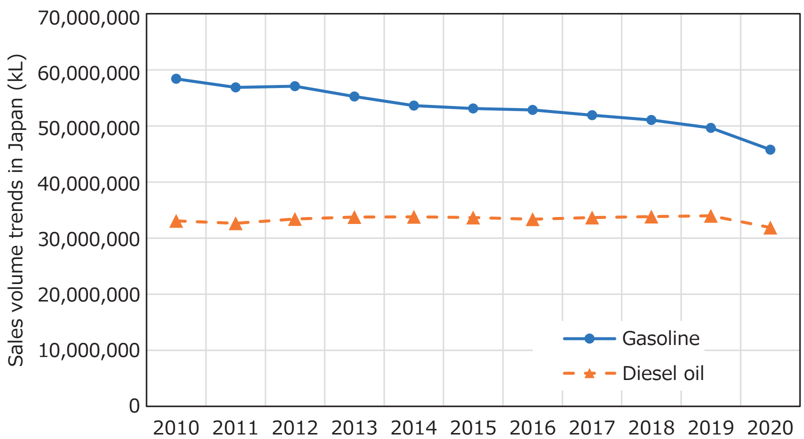

Fig. 2 Annual Trends in Gasoline and Diesel Sales Volume in the Japanese Market

second official announcement of the Act on Sophisticated Methods of Energy Supply Structures consist of the revised values defined in April 2015 as the standard calorific value and carbon emissions coefficient applied in the comprehensive energy statistics for fiscal 2013 and later. The standard calorific value for gasoline and carbon emissions coefficient applied in the comprehensive energy statistics for fiscal 2018 and later were announced in January 2020. They include a revision to the gasoline values, and using those to calculate CO_2 emissions when gasoline is burned yields a result of 73.08 gCO_2/MJ, an increase from the 72.25 gCO_2/MJ in the second official announcement.

The METI Expert Committee to Discuss the Future of Biofuel Introduction in Japan has been discussing GHG emissions from gasoline. Although the main topic of the fifth meeting held in June 2020 was the calculation of GHG emissions during crude oil production using the latest information, revisions to the above standard calorific value and carbon emissions coefficient were aligned, and GHG emissions from the production to the combustion stage were raised from the 84.11 gCO_2/MJ of the second official announcement to 88.74 gCO_2/MJ.

(2) Technological Trends: There was no notable activity concerning automobile gasoline quality, standards or regulations. Among technological trends, research on the properties of gasoline and the performance of engines has featured many papers concerning the nozzle spray characteristics of direct injection gasoline engines published by a group consisting of Senda and others. The series of experiments investigated the details of gasoline spray characteristics when a high boiling point component fuel such as diesel is mixed into a low boiling point gasoline component fuel to produce a dual component fuel. Research on expanding the lean limit of super lean burn engines relying on hydrocarbon-based fuel has also been conducted.

While past studies of lean burn (combustion at $\lambda = 2$

or higher) by Obata and others had reported an expansion of the lean limit using mainly oxygen-containing or nitrogen-containing compounds, this new research demonstrated that expansion by forming a special structure in hydrocarbon-based fuel, which is close to gasoline and contains neither oxygen nor nitrogen.

Elsewhere, Ishigai and others have looked into the ignition characteristics of bio-blended gasoline under lean conditions, and reported a tendency for the ignition delay time to differ from gasoline alone when a biofuel such as ethanol, ethyl tertiary butyl ether (ETBE), furan, or 2-methylfuran (2MF).

2. 3. Diesel Fuel for Automobiles

There was no notable activity concerning automobile diesel quality, standards or regulations. Among technological trends, research on blending e-fuel, which is synthesized from recovered carbon dioxide and hydrogen produced using electricity generated from renewable energy, into diesel has been announced. Sasaki and others presented the results of their tester-based experimental investigation of the spray and combustion characteristics when polyoxymethylene dimethyl ether (OME), an e-fuel, is blended into diesel. Similarly, Morita and others announced the results of their research on blended OME and diesel, which investigated the effect of adding OME on rubber ending parts, and on engine performance using that blended fuel.

2. 4. Preparing to Contribute to the Future Carbon Neutral Society

The global pursuit of carbon neutrality, namely achieving net zero carbon emissions, is gaining momentum. In Japan, Prime Minister Suga announced the goal of cutting greenhouse house gas emissions to net zero in his policy speech on October 26, 2020. That announcement was followed by the release of the *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* by the Ministry of Economy, Trade and Industry (METI) on December 25, 2020.

The petroleum and automotive industries have initiated joint research aimed at reducing CO_2 through an optimized combination of future combustion methods and types of fuel to respond to such social requests. Similarly, in addition to its existing examination on introducing biofuels, the METI also launched a new research group on synthetic fuels and initiated a detailed investigation on issues surrounding their introduction.

Many of the technologies with the potential to contribute to achieving carbon neutrality in 2050 are in the research and development stage, and at this time, it is important to pursue all technologies and possibilities.

3 Lubricants

3. 1. Gasoline Engine Lubricants

(1) Regulatory Trends: The American Petroleum Institute (API)/International Lubricant Specification Advisory Committee (ILSAC) standard, which stipulates performance for the North American and Asian markets, started licensing API SP/ILSAC GF-6 in May 2020. The ILSAC GF-6 standard includes a GF-6B category stipulating an XW-16 low viscosity grade in addition to the GF-6A category stipulating the existing low viscosity grades of 0W-20 or higher. The main performance attributes compared to GF-5 are (a) improving fuel efficiency and its duration, (b) improving robustness to protect the engine, (c) decreasing occurrences of low speed pre-ignition (LSPI), and (d) improving wear prevention for timing chains and other engine components. For engine testing, the Sequence (Seq.) IX test to evaluate LSPI prevention, and the Seq. X test to evaluate wear prevention have been added. Their purpose is to determine compatibility with the direct injection turbocharged engines that are becoming more common. In those engines, the abnormal combustion prior to ignition known as LSPI at low speed and high torques is a concern that places restrictions on improvements to torque. There are various theories on the causes of LSPI, and there have been reports that drops of engine oil constitute the ignition source and that the frequency of LSPI is affected by the composition of additives. The introduction of Seq. X was prompted by concerns over chain wear due to the soot intrusion that comes with the switch to direct injection.

A new edition of the Association des Constructeurs Européens d'Automobiles (ACEA) standard, ACEA 2021, which applies concurrently to diesel engines in the European market, is scheduled for publication. Discussions held to date suggests that the A3/B3 and A5/B5 categories of the high ash grade A/B classification will be eliminated in favor of a new A7/B7 category. Similarly, the low ash grade C1 category will be eliminated, and a new C6 category will be established for oils with an XW-20 SAE viscosity grade. Performance attributes planned to differ to the current ACEA 2016 are the addition of prevention performance against LSPI and timing chain wear, and the adoption of the Seq. IX and X tests applied in the ILSAC GF-6 standard. A deposit test intended to improve turbocharger efficiency and, consequently, the engine is also going to be updated.

(2) Technological Trends: The stipulation of 0W-8 and 0W-12 low viscosity oils in JASO GLV-1 calls for advances in technology that both improves fuel efficiency through reduced viscosity and ensures reliability. Research indicating that combining low evaporation loss Group III base oils with molybdenum dialkyldithiocarbamate (MoDTC) can counter the decline in wear resistance and increase in evaporation loss that occur at lower viscosities has been presented. Technology that makes use of the large proportion taken up by the boundary lubrication region in low viscosity oils and modifies metallic detergents with boron to stimulate the friction reduction effectiveness of MoDTC, as well as technology that uses an oil film forming agent to maintain the oil film and avoid metal-to-metal contact, thereby preventing friction, are gradually being adopted.

Oil with an ultra-high viscosity index doped with many high performance polymers is being considered for low viscosity base oils to reduce viscous resistance in the low- to mid-temperature range in hybrid vehicles. Based on the premise of alleviating restrictions on evaporation loss when using low viscosity base oils, that makes it possible to secure a high temperature viscosity equivalent to 0W-20 at high temperatures while bring low temperature viscosity down to the equivalent of 0W-8.

Decreasing the Ca concentration in engine oil is an effective way to achieve the LSPI prevention performance introduced in ILSAC GF-6 and scheduled for inclusion in ACEA 2021, and formulation technology that replaces Ca with Mg in some metallic detergents is frequently applied. In contrast, validating the effect of applying fuel dilution conditions or Mo additives on LSPI has demonstrated differing tendencies depending on load conditions or other additives present. Studies to elucidate the LSPI mechanism and establish preventive technology continue to be carried out.

The tightening of emissions regulations, notably in Europe and China, along with the spread of vehicles with direct injection gasoline engines, suggest that the number of vehicles equipped with a gasoline particulate filter (GPF) will rise. An investigation of the effect of adding metallic additive components based on the premise that ash originating in engine oil clogs the GPF and affects the filter's service life suggests that the impact of Mg or Ca detergents is stronger than that of Zn antifriction agents or Mo friction modifiers.

3. 2. Diesel Engine Lubricants

(1) Regulatory Trends: In Japan, a revision of the Japanese Automotive Standards Organization (JASO) standard or automotive diesel oil (JASO M355) from JASO M355: 2017 to JASO M355: 2021 is scheduled for the first half of 2021. Based on the JASO DL-1 diesel oil standard for passenger vehicle classes compliant with exhaust aftertreatment, the new JASO DL-2 is scheduled to update the sulfated ash regulatory value of 0.6 mass% or less to the 0.7 to 0.8 mass% sulfated ash levels in the C2, C3, C5 and C6 (planned addition) in the European ACEA standard. For the high temperature oxidation prevention test, the ASTM D8111 (Sequence IIIH) will become the new test method replacing the ASTM D6984 (Sequence IIIF) and ASTM D7320 (Sequence IIIG) quoted until now, as their provision of engines has been suspended. However, the heavy-duty vehicles diesel oil DH standard will use the regulatory values from API CH-4, and the passenger vehicle diesel oil DL standard those from API SL.

The new ACEA 2021 European standard is scheduled to be issued in the first half of 2021. Discussions held to date indicate that in the heavy duty diesel engine oil E category, E6 will be replaced by E8, and E9 by E11. The Mack T-13 oxidation stability test and Caterpillar oil aeration test applied in API CK-4 and FA-4 will be introduced in the aforementioned E8 and E11. The F8 and F11 categories will be established in a new fuel-efficiency standard in the second half of 2021. Based on E8 and E11, the F8 and F11 categories stand out for lowering the HTHS viscosity at 150° C regulatory value from 3.5 MPa・s or higher to the same 2.9 to 3.2 MPa・s as in API FA-4, and assessing the development and introduction of an engine wear test under the low soot conditions known as LSWT.

(2) Technological Trends: The latest strengthening of emissions regulations in Europe, the U.S., China and other countries, highlights the ongoing importance diesel particulate filter (DPF), selective catalytic reduction (SCR) and other exhaust aftertreatment systems that reduce particulate matter (PM) and NO_x emissions. In a DPF, PM is captured by passing exhaust emissions through a porous filter, and ash originating in engine oil clogging that filter is believed to affect the service life of the DPF. Therefore, research on the effect of metallic additive components, as well as research on mitigating the consumption of oil entering the combustion chamber is underway.

The former includes research on how the temperature of the reaction field affects the reaction that generates ash from the calcium metallic detergent. It has also been reported that using a poly alpha olefin (PAO) base oil or boron-containing disperser satisfies the regulatory values for the API CK-4 piston detergency test and the JASO DH-2 valve train wear prevention test, even with detergent blends that do not contain a calcium metallic detergent or zinc dithiophosphate.

In the latter, although decreasing the tensile strength of the ring helps increase fuel efficiency, the rise in oil consumption worsens the functionality of the GPF or DPF. Accordingly, as part of its collaborative industry–academia research, the Research Association for Automotive Internal Combustion Engines (AICE) is working on understanding and modeling the oil route to the combustion chamber phenomenon by visualizing the oil film and measuring the piston ring behavior to ascertain the cause of aggravated oil consumption.

3. 3. Gear Oil

(1) Regulatory Trends: The SAE J306 standard on automotive gear oil viscosity underwent a major revision in 2019. New viscosity grades were added, and the existing grades were modified.

The push for greater automobile fuel efficiency is leading to lower viscosity gear oils aimed at reducing agitation loss to improve transmission efficiency in the gear shifting mechanism. Prior to this first major revision since 2005, the lowers viscosity grade in the standard was SAE 80, covering gear oils with a kinematic viscosity of 7.0 mm^2/s or higher at 100° C. In the mid-2000s, the appearance of products with a lower viscosity on the market and the gradual expanding global shift toward lower viscosity led to the revision.

The revised standards adds the new SAE 65, SAE 70, and SAE 75 viscosity grades. The respective range of kinematic viscosity at 100° C for those grades is 3.8 mm2/s to less than 5.0 mm^2/s, 5.0 mm^2/s to less than 6.5 mm^2/s, and 6.5 mm^2/s to less than 8.5 mm^2/s, extending the applicability of the standard to gear oils with a kinematic viscosity of 3.8 mm^2/s or higher. With the addition of SAE 75, the lower limit of the SAE 80 kinematic viscosity was raised from 7.0 mm^2/s to 8.5 mm^2/s.

(2) Technological Trends: Efforts to lower the viscosity and enhance the efficiency of lubricants for drive elements have centered on oils for gear shifting mechanisms such as ATF or MTF. More recently, differential gear oil, which calls for high levels of reliability, is also being studied. Balancing extreme pressure properties with reduced friction through optimal additive selection while decreasing agitation loss by lowering viscosity has been reported to reduce differential gear unit loss by 40%.

3. 4. Transmission Fluid (ATF)

(1) Regulatory Trends: There was no notable activity concerning ATF regulations in 2020.

(2) Technological Trends: For ATF, lowering viscosity to improve fuel efficiency remains an ongoing trend, and ATF with a significantly lower kinematic viscosity than previous fluids have been announced over the last several years. At the same time, oils targeting EVs and other electric-powered vehicles are being studied, and lubricant makers have issued press releases.

4 Grease

Amid the constantly growing movement to protect the environment, Europe and China have taken the lead in tightening regulations on fuel economy and CO_2 emissions. These stricter regulations are spurring a rapid shift in vehicle power sources from internal combustion engines to hybrid or full motor drives.

Electric vehicle drive motors operating at high speeds of up to 30,000 rotations are being studied to ensure sufficient output while keeping them compact and lightweight. Since the bearings supporting the drive motor shaft also rotate at extremely high speeds, greases that decrease stirring resistance and friction, mitigate heat generation, and increase oil film retention to prevent damage to the bearings are being developed. In addition, studies on greases given conductive properties to prevent the electrification-specific issue of damage caused by current flowing into the bearing have also been presented.

Research on using grease to decrease the torque of hub bearings and general motor bearings for the purpose of decreasing fuel and electricity consumption is also being actively pursued. Due to its adhesion properties and velocity dependency of its viscosity, grease exhibits complex fluidity in the bearing, and resistance varies considerably depending on the inflow state in the bearing race. Greases that considerably improve quietness in addition to decreasing torque by controlling the inflow state through appropriate thickener selection have been developed.

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