FUEL, LUBRICANT AND GREASE

1 Introduction

According to an International Energy Agency (IEA) report issued in December 2022, the global demand for petroleum in that year remained robust despite the slowdown of the global economy and the energy crisis in Europe, reaching 99.9 million barrels per day and exceeding the preceding year's demand (1.7 million more barrels per day than the year before). In particular, the 2022 global demand in China, India, and non-OECD regions, including the Middle East, is estimated at 53.8 barrels per day, an increase of 1 million barrels per day over the previous year. The recovery of demand was especially remarkable in China (820,000 more barrels per day than the year before). In contrast, petroleum demand in OECD countries was robust in terms of jet fuel and kerosene consumption (an additional 610,000 barrels per day compared to 2021), but this was canceled out by stagnant demand for petrochemicals, particularly naphtha (760,000 fewer barrels per day than the year before), resulting in an overall slowdown.

The global oil supply in 2022 was 100 million barrels per year, exceeding that of the previous year (4.7 million more barrels per day than the year before) to reach its highest level ever. Led by the largest increase in the world in Saudi Arabia (1.6 million additional barrels per day), OPEC Plus supply increased by 3.0 million barrels per day, while in non-OPEC Plus countries, the U.S. led the way with a 1.2 million barrels per day increase, resulting in an overall production that rose by 1.7 million barrels per day compared to the previous year. Although Russia had been predicted to make an unprecedented increase in production in anticipation of its invasion of Ukraine, the increase stopped at a mere 180,000 additional barrels per day.

Figure 1 shows changes in FBO price of West Texas Intermediate (WTI) crude oil futures in 2022. In that year, prices opened at over 70 dollars per barrel, exhibiting robust demand thanks to global economic recovery. At the same time, rising geopolitical risks, such as the invasion of Ukraine prompting the EU to prohibit the import of Russian oil, as well as worsening conditions in the Middle East, affected supply and temporarily drove prices up to 120 dollars per barrel in June. After that, however, various factors combined to ease the pressure on prices. These factors included a slowing down of the economy induced by high inflation in the U.S. and the Eurozone, and the attendant monetary tightening by central banks. In addition, India and other countries increased their purchases of the cheaper Russian oil that had been excluded from international markets by the import ban imposed by Western countries, resulting in an actual increase in the production of Russian oil, which had previously seen a temporary drop. In addition, while the relaxing of zero-COVID measures in China and the ongoing policy of reducing production in OPEC Plus countries contributed to shoring up prices, strong concerns about a slowdown of the global economy due to monetary tightening in major countries resulted in a gradual fall of prices to around 80 dollars per barrel.

2 Fuels

2. 1. Fuel Trends

Figure 2 shows the demand forecast for petroleum products up to 2027 made by the Petroleum Market Trend Survey Working Group of the Petroleum Subcommittee of the Petroleum Committee of the Advisory Committee for Natural Resources and Energy under the Ministry of Economy, Trade and Industry (METI).

Looking at the entire 2022 to 2027 period, the overall demand for fuels is forecast to decrease by an average of 1.1% annually, for a total decrease of 5.4%.

Gasoline demand is predicted to drop by 1.4% in 2023 compared to the previous year (2022). Although passenger vehicle driving distances made shorter by the pandemic are anticipated to recover, this prediction stems

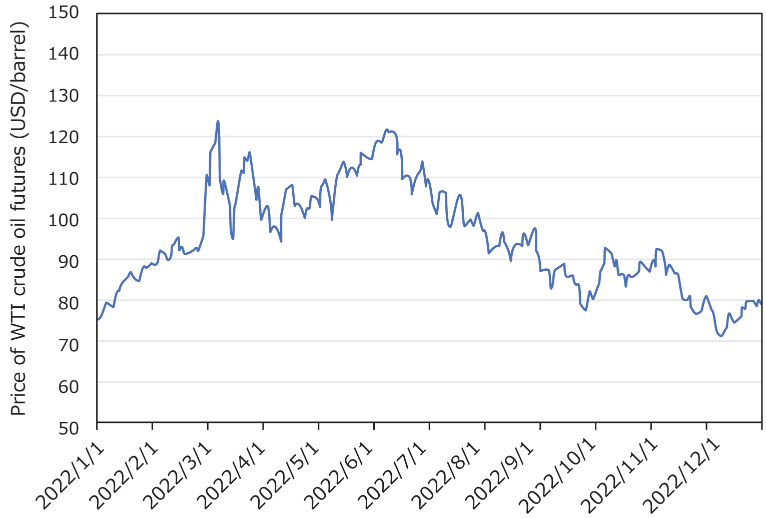

Fig. 1 Changes in FOB Price of WTI Crude Oil Futures

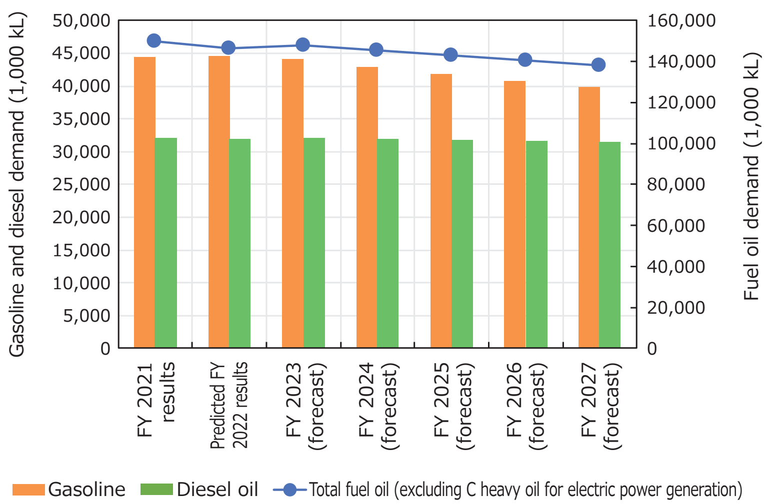

Fig. 2 Changes in Fuel Oil, Gasoline, and Diesel Demand

from a drop in the number of gasoline passenger vehicles owned and structural factors such as improvements leading to lower fuel consumption. In addition, gasoline demand for the entire 2022 to 2027 period is forecast to drop by an annual average of 2.3% due, in part, to increased hybrid vehicle ownership causing the number of gasoline vehicles owned to decrease, and to consumers switching to more fuel efficient vehicles.

For diesel, a 0.5% increase in demand compared to the previous year (2022) is predicted for 2023 based on the anticipated recovery of freight shipments from the decline caused by the pandemic. For the entire 2022 to 2027 period, demand is forecast to drop by an annual average of 0.3% in anticipation of a small decrease in freight shipments and improved truck fuel efficiency.

2. 2. Gasoline for Automobiles

Japan has established the *Act on Sophisticated Methods of Energy Supply Structures* (*Sophisticated Methods Act*) to secure a stable and suitable supply of energy by promoting the use of non-fossil energy sources. The *Sophisticated Methods Act* stipulates criteria for the targets concerning bioethanol usage, setting them at 500,000 kL of crude oil equivalent for 2018 to 2022. They are applied to gasoline in the form of bio-ETBE. The METI Expert Committee to Discuss the Future of Biofuel Introduction in Japan is discussing *Sophisticated Methods Act* criteria for 2023 and later based on upcoming initiatives for a stable supply of energy and carbon neutrality.

With respect to technological trends in automotive gasoline technologies, there is a significant amount of research targeting improvements in engine thermal efficiency and gasoline composition that reduces CO_2 emissions. In a study of fuel composition suited to super lean burn, Yasutake et al. examined how the lean limit is affected by switching between light and heavy hydrocarbon fuels and by modifying the aromatic hydrocarbon content. They also optimized fuel composition using base material produced in an oil refinery to compare thermal efficiency with existing fuels. The results demonstrated that using oil refinery base material to increase light hydrocarbon olefin content and decrease aromatic hydrocarbon content extended the limit and enhanced thermal efficiency compared to existing high octane fuels. In other research, Kaneko et al. used an engine capable of lean and EGR diluted combustion to examine the effectiveness of fuel composition at enhancing combustion and thermal efficiency, as well as reducing emissions, and presented a report on the factors involved.

Elsewhere, research looking into surrogate fuels consisting of hydrocarbons or ethanol under lean or EGR diluted combustion conditions, or investigating basic combustion characteristics such as laminar flow combustion velocity or ignition delay, and building response models, is also being conducted.

2. 3. Diesel Fuel for Automobiles

There was no notable activity concerning automobile diesel quality, standards, or regulations. In the pursuit of carbon neutrality, one technological trend involves studying the efficient use of synthetic fuel made from recovered carbon dioxide and hydrogen produced using electricity generated from renewable energy. For example, in the context of achieving carbon neutrality in diesel engines, Shimokawa et al. presented a report on fuel composition consisting of hydrocarbons and soot generation, and the relationship between the related lift-off and liquid phase lengths. Other reports have covered how biohydrogenated diesel, a carbon neutral fuel, and fatty acid methyl ester (FAME) blended fuel affect combustion and emissions characteristics. Combustion response models and injection models aimed at a numerical analysis of diesel combustion in polyoxymethylene dimethyl ethers (OME), another carbon neutral fuel, are also being built. Thermal efficiency, exhaust emissions, and other parameters at low temperature diesel combustion when Fischer-Tropsch (FT) synthetic oil, a type of synthetic fuel, or OME blended with diesel is used, constitute other areas of investigation and research. Other topics include investigations of the composition of OME and various other synthetic fuels, as well as studies on the changes in composition and compliance with current standards when those fuels are blended with Japanese gasoline or diesel.

2. 4. Contributing to the Future Carbon Neutral Society

The global pursuit of carbon neutrality, namely achieving net zero carbon emissions, is gaining momentum. In Japan, then-Prime Minister Suga announced, in October 2020, the goal of cutting overall greenhouse gas emissions to zero and achieving a carbon-free society by 2050. That announcement led to the formulation of the *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* to achieve that goal. Steps to concretize that strategy are being taken. Similarly, the *Plan for Global Warming Countermeasures* approved by the Cabinet in October 2021 sets the mid-term goal of cutting greenhouse gas emissions by 46% in 2030 as a step toward achieving carbon neutrality in 2050.

Most technologies with the potential to contribute to achieving carbon neutrality by 2050 are in the research and development stages. At present, boldly trying every technology and possibility is important.

3 Lubricants

3. 1. Gasoline Engine Lubricant

(1) Regulatory Trends

The American Petroleum Institute (API) is has started discussing the next-stage engine oil standard (expected to become the ILSAC GF-7 standard) to replace the ILSAC GF-6 standard issued by the International Lubricant Standardization and Approval Committee (ILSAC) in May 2020. The changes to the current GF-6 standard include (a) modifying the standard upper limits (modified WPD merit standard: 4.2 → 4.6, modified MRV standard: 60,000 → 40,000 mPa·s) for ASTM D8111 (Sequence IIIH), (b) modifying the engine platform (switch to a higher accuracy evaluation method) for Sequence V and VI, (c) removing ASTM D6709 (Sequence VIII) or replacing it with a bench test, (d) adding evaluation items (addition of degraded oil performance evaluation) to ASTM D8291 (Sequence IX), (e) modifying the standard upper limit (0.085% → no change) for ASTM D8279 (Sequence X), and (f) adding new or upgraded bench tests (ASTM D5800 (modified NOACK test method), ASTM D6795 (modified filterability test method), and ASTM D129 (was D874) (added sulfuric ash content upper limit)). Various discussions are currently underway. The 0W-8 and 0W-12 viscosity grades were not added in ILSAC GF-7, but rather in the JASO M366 firing fuel economy test procedure in effect in the Japanese Automotive Standards Organization (JASO)-issued JASO GLV-1 standard that has been adopted as a fuel economy test. They are expected to be added to ILSAC GF-6B, which currently covers the 0W-16 viscosity grade. In Japan, the JASO M366 firing fuel economy test procedure in effect since 2019 has served as the basis for establishing JASO M367 method of evaluating the sustainability of fuel economy performance.

(2) Technological Trends

Oil film retention is more of an issue than ever in the typical ultra-low viscosity grade engine oils in JASO GLV-1. Therefore, flat viscosity engine oil is being developed to achieve both reliability and fuel economy at the oil level, and measures such as applying coating to engine parts to reduce friction loss are being taken for parts. The piston system, in particular, accounts for a large proportion of friction loss in the engine, and pattern coating is now frequently applied to piston skirts to reduce that friction loss. Efforts to visualize oil retention in the pattern coating and take actions such as checking the impact of oil viscosity are underway.

3. 2. Diesel Engine Lubricant

(1) Regulatory Trends

The American Petroleum Institute (API) established CK-4 in the C category in 2016. It also defined a new F category for fuel economy, and established FA-4. No standards were revised in 2022. In 2022, the Association des Constructeurs Européens d'Automobiles (ACEA) introduced ACEA 2022. In the E class, the contents of the ACEA 2016 standard were maintained for E4 and E7, while E6 and E9 were upgraded to E8 and E11, respectively. The E8 and E11 categories add new engine tests to the contents of the E6 and E9 standards, and now require the Volvo T-13 Engine Oil Oxidation test (ASTM D8048) and Caterpillar Oil Aeration Test (COAT) (ASTM D8047). Similarly, the ACEA 2016 Class E used the OM-501LA engine for the piston cleanliness test, but this has been changed to engine tests using the OM471 engine (CEC L-118-21) in the E4 and E8 categories, the CAT 1N engine (ASTM D6750) in the E7 category, and the CAT C13 engine (ASTM D7549) in the E11 category. The fuel efficiency F class was not released in ACEA 2022.

The Japanese Automotive Standards Organization (JASO) updated the JASO M355 automotive diesel engine oil standard from JASO M355: 2017 to JASO M355: 2021 in 2021. A new JASO DL-2 light-duty standard was also added to JASO M355:2021. No standards were revised in 2022.

(2) Technological Trends

The installation of a diesel particulate filter (DPF) on vehicles became mandatory with the emissions regulations established in the first half of the 2000s. The DPF is known for catching the particulate matter (PM) and ash from the metallic components contained in engine oil during driving. Although forced combustion can be used to remove the PM in the accumulated deposit through post injection, the ash content cannot be removed. The DPF is replaced when accumulated ash causes fuel efficiency to deteriorate and power to drop. This has led to efforts to develop engine oil without metal additives offering the same performance as existing engine oils to decrease the frequency of DPF replacements.

The demand for wear resistance in engine oils is intensifying as diesel engines become even more efficient and powerful. Until now, oil soluble additives such as zinc dithiophosphate have been used as anti-wear agents, and providing wear resistance by adding non-oil soluble additives such as nanoparticle hexagonal boron nitride or molybdenum disulfide is being studied.

In addition, soot gets into diesel engine oil during use due to the effects of diesel fuel. This causes zinc dithiophosphate to adhere to the soot and inhibits the original performance of the oil. To counter this, removing soot in the filter and adding a small amount of zinc dithiophosphate to restore performance to its original level is being examined.

3. 3. Gear Oil

(1) Regulatory Trends

There was no notable activity related to gear oil regulations in 2022.

(2) Technological Trends

Reducing the viscosity of typical transmission fluids such as ATF or CVTF makes it possible to increase fuel efficiency. However, the severe environment of the extremely high contact surface pressure of the differential gear oil used in the final reduction gear makes the contact state prone to transitioning from the elastic fluid lubrication range to the limit lubrication range. This is believed to increase friction loss and deteriorate gear transmission efficiency. In that respect, using a polymer oil film forming agent to expand the elastic fluid lubrication range and reduce friction in the limit lubrication range has been reported to benefit fuel efficiency.

3. 4. Automatic Transmission Fluid (ATF)

(1) Regulatory Trends

There was no notable activity concerning ATF or CVTF regulations in 2022.

(2) Technological Trends

The viscosity of ATF continues to be reduced to achieve better fuel efficiency. There have been recent examples of using ATF as transaxle fluid in electric-powered vehicles. Although there are calls for oil exhibiting requirement characteristics that differ from those of the conventional drive system oil used in the drive units of electric-powered vehicles, the importance of low viscosity remains unchanged. In that respect, it has been suggested that fuel efficiency and low-energy characteristics can be improved using a new PAO that improves the volatility, oxidation stability, and low-temperature fluidity characteristics of the conventional poly alpha olefin (PAO) low viscosity base oil, and also reduces the traction coefficient through a specific molecular structure.

4 Grease

The rapid transition from conventional internal combustion engine vehicles to hybrid and electric vehicles is part of measures to address environmental issues. Fuel-efficient technologies relying on downsizing, higher speeds, and reduced torque are also used in various automobile parts and units. With respect to the grease used in those parts and units, this situation calls for enhancing technologies in areas such as the handling of high speed rotation, service life, torque reduction, electrolytic corrosion resistance, quietness, and water resistance. Urea thickener evaluation, polymer blending, and the application of nanomaterials are among the reported grease-related technologies expected to answer those calls.

Although lithium soap has long been a typical grease thickener, the higher prices of lithium hydroxide resulting from the ongoing increased demand for lithium batteries, as well as the EU proposal to classify specific lithium salts as harmful, is anticipated to lead to the extensive use on non-lithium greases. Proposals for non-lithium greases include calcium complex grease, urea grease, which offers excellent heat resistance and bearing life, and calcium sulfonate complex grease, which also has superior heat resistance, as well as excellent seizure resistance and anti-corrosion performance.

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