ENGINES FOR ALTERNATIVE FUELS

1 Introduction

Automobiles that use for alternative fuels are unlikely to come into widespread use unless incentives are introduced or they can markedly distinguish themselves in terms of fuel cost, refueling infrastructure, cleanliness of emissions, or being free of CO_2. The balance with crude oil prices is an especially important factor. The price of crude oil plunged to approximately 20 yen/L in the spring of 2016. However, the price rose sharply due to the United States' move to withdraw from the Iran nuclear deal and production adjustments undertaken by OPEC.

Fuel cell vehicles using hydrogen are a potential future option, with hydrogen reciprocating engines offering high practicability. Dimethyl ether (DME), a strong possible alternative to diesel, is receiving renewed attention in the United States and Europe due to the possibility of manufacturing it from natural gas, shale gas, and biomethanol. Other alternatives are also exhibiting their strengths in niche applications, as in the case of Stirling engines serving as an air-independent propulsion power plant in submarines, which require quietness. This article summarizes the current trends in engines configured for alternative fuels.

2 LPG Engines

The number of LPG vehicle registrations in Japan at the end of February 2018 was 211,386[(1)]. Due to durability and economic efficiency considerations, about 80% of corporate taxis are LPG vehicles. Universal design taxis (UD taxis) were launched in October 2017. As of March 2018, 3,956 UD taxis had been registered and this number is increasing rapidly.

The Ministry of Land, Infrastructure Transport and Tourism (MLIT) established a certification system for standard UD taxi specifications on March 28, 2012[(2)]. These vehicles, which can accommodate wheelchairs, are designed for ease of use by the elderly and people with disabilities. Toyota Motor Corporation reacted by offering an LPG hybrid system engine-equipped vehicle[(3)] named JPN Taxi. Nissan, which is receiving high acclaim for the riding comfort and panoramic roof of the NV200 taxi it deployed in New York, is also supplying a UD taxi using LPG biofuel[(4)] in Japan. These UD taxis are expected to contribute greatly to the Tokyo Olympics 2020.

The LPG Vehicle Promotion Council issued a report on LPG vehicles in Europe covering their spread, year-on-year changes, autogas prices, vehicle prices, retrofitting costs, infrastructure conditions, and EU environmental regulations, as well as interviews conducted with automakers[(5)].

3 Natural Gas Engines

As of April 2018, the number of natural gas vehicles (NGVs) worldwide had reached 25.05 million vehicles. China, where they are the most common, had approximately 5.35 million, followed by Iran with approximately 4.5 million and India with approximately 3.7 million, highlighting their growing popularization on the Asian continent. The countries with the highest number of natural gas stations are China, coming first with 8,300 locations, followed by Pakistan, with 3,416 locations, and Iran, with 2,400[(6)].

Many papers on the latest research on natural gas engines have been released in and outside Japan. The 28th Internal Combustion Engine Symposium held from December 6 to 8, 2017 introduced research currently underway concerning emissions analysis, combustion characteristics analysis, and measures to improve thermal efficiency using a combustion chamber with a sub-chamber, including the "Research on Effect of Sub-Chamber in Natural Gas Lean-Burn Engine" report by Honda Motor Co., Ltd. Other research papers presented included the "Research on Combustion Characteristics Using a Rapid Compression and Expansion Machine" by Tokushima

Fig. 1 Heavy-duty LNG Truck Demonstration

University, and "A Basic Study of Higher Efficiency and Lower Emissions in the Turbo Charged Gas Engine Using the Low Calorie Gas" by Doshisha University.

Beyond the above research, the Ministry of the Environment is subsidizing a project to promote the development and verification testing of heavy-duty LNG trucks and optimum refueling infrastructure. The first on-road verification test in the transportation business in Japan started in June 2018 (Fig. 1). Since LNG has about three times the volumetric energy density of CNG, it is more suitable for heavy-duty trucks which mainly drive long distances. The introduction of LNG trucks to the market is expected to further contribute to the diversification of automobile fuels and to the reduction of CO_2.

4 Hydrogen Engines

Hydrogen, which can be manufactured from renewable energy and does not emit CO_2, is strongly expected be a next-generation fuel that effectively contributes to resolving the issues of global warming, environmental pollution, and energy resource depletion faced by the planet. The development of technology to use hydrogen as fuel for automotive power units has been pursued in various countries and sectors since the early 1990s.

This resulted, in December 2014, in Japan taking the global lead in the commercial production of fuel cell vehicles that use hydrogen as fuel. At the same time, hydrogen engines can leverage well-established technologies. Therefore, they are seen as having a high potential for commercialization at a lower cost, making them the object of worldwide research and development. Currently, the use of a combustion system based on direct injection into the cylinders has largely solved past issues such as backfiring or the low output unique to gas-based engines, and the combustion system to apply in high output engines is gradually taking shape. Issues to be solved for the practical use of hydrogen engines are to suppress NOx production under high load operating conditions and further improve thermal efficiency.

Reports concerning the research and development of hydrogen engines in 2018 cover a broad scope, including the above further improvements in thermal efficiency and suppression of NOx production, improvements in combustion characteristics with hydrogen-mixed fuel, and the examination of hydrogen engine characteristics. In Japan, Tokyo City University is conducting research to optimize injection timing and jet shape, as well as improve thermal efficiency by reducing cooling loss, an issue described as inescapable in hydrogen engines, using a rich mixture combustion system that significantly reduces NOx emissions through ignition and combustion of the jet during or immediately after injection, which has been reported to improve indicated thermal efficiency by over 46% while reducing NOx generation significantly[7]. Basic studies of closed cycles aiming to greatly improve thermal efficiency and eliminate NOx generation using argon have also been announced[8]. Research results covering basic techniques such as the numerical calculation of jet and thermal flux measurement related to the above research projects[9][10] have also been reported. There are many papers published outside Japan covering a wide scope of research investigating the characteristics of automobile hydrogen engines explained above[11]. Most of those papers are published by research institutes in China and India.

5 Dimethyl Ether (DME) Engines

The standardization of fuel supply systems (excluding the on-board fuel tank) and refueling port for DME vehicles is making progress. The International Organization for Standardization (ISO) established a working group (ISO/TC22/SC41/WG8), and has been holding meetings regularly since its first international meeting in 2016. In Japan, the Society of Automotive Engineers of Japan established a subcommittee for DME under the Environment Technical Committee in 2017 to address these issues. International meetings were held in Vancouver, Canada in February 2017, and in Ostuni, Italy in November 2017. Japan proposed the addition of the pressure-equalizing refueling port to the standard.

One example of technical initiative on DME vehicles undertaken outside Japan is the evaluation of the practicability of synthesized renewable DME alternative fuel for diesel engines from municipal waste conducted by the New York City in collaboration with Mack Trucks and Oberon Fuels. The DME trucks (garbage collecting trucks mounted with a 13 L MACK MP8 engine) are used in the day-to-day operations of the New York City Department of Sanitation. This verification test evaluates operating performance, noise, fuel efficiency, refueling time, and maintainability. The DME trucks have run over 1,400 km, and the reports give positive results[12].

Oberon Fuels announced a plan to operate 100 DME vehicles from 2018 to 2019[13].

In Canada, the Northern Alberta Institute of Technology (NAIT), Mack Trucks, Westcan Bulk Transport, and Oberon Fuels are studying the use of DME using biomass-based fuel as an initiative to realize a low carbon society. Using subsidies from the Province of Alberta, the four organizations above will develop a DME fuel system for heavy-duty trucks, and conduct a fleet road test between Calgary and Edmond.

In Germany, the FVV (which includes Ford and Oberon Fuels as members) is promoting research on the possibility of adopting DME and OME as automobile internal combustion engine fuels.

In Asia, the 10th Asian DME Conference was held in South Korea from October 24 to 26, 2017. At this conference, Shanghai Jiao Tong University and the Shaanxi Automobile Group from China gave a presentation on their joint research about DME trucks.

6 Stirling Engines

The Microgen system using a 1 kW-class free-piston engine has been commercialized in Europe as a compact combined heat and power (CHP) unit fueled by utility gas. The3.5 kW and 7.5 kW-class free piston engine generators by Qnergy of Israel, the 10 kW-class single-acting alpha-type V-cylinder arrangement engine by Cleanergy of Sweden, and the y-type L-type arrangement engine generator unit by Inresol of Sweden are used for the same applications.

ÖkoFEN of Austria started sales of wood pellet boilers fitted with generators from Microgen that provide 0.6 kW of electric power and 9 kW (maximum 13 kW) of thermal power, as well as of wood pellet combustion-based CHP systems fitted with engine generators from Qnergy that provide 4.5 kW of electric power and 55 kW of thermal power. In addition, Qnergy started sales of the standalone 7.5 kW engine in Japan. Several companies are undertaking initiatives to carry out applied development using that engine.

One special application is the air-independent propulsion 75 kW-class 4-cylinder double-acting engine (power generation output: 60 kW) for submarines by Kockums of Sweden. They are produced from knock-down kits by Kawasaki Heavy Industries Ltd., and four engines were commissioned for, and refitted to, the Sekiryu, the eighth of a planned twelve Soryu-class submarines. The plan involves mounting Stirling engines on of the ten submarines, and the remaining two are still under construction. The eleventh and twelfth submarine, will be equipped with lithium-ion batteries rather than Stirling engines.

With respect to Japanese engines, e-stir Co., Ltd. has started selling its direct heating β-type 10 kW engine for exhaust heat recovery to monitors[15]. Other Japanese engines include the α-type 5 kW engine from E&E system Co., Ltd. and the β-type 0.2 kW engine from Momose Kikai Sekkei. In addition, the independent 1 kW unit in operation at the foot bath facility in the Expo '70 Commemorative Park, as well as the interconnected 9.9 kW system operating at the Omachi civic center in Minami Soma City, use the indirect heating α+-type engine from Suction Gas Engine Mfg. Co., Ltd., which was developed in Japan.

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