ENGINES FOR ALTERNATIVE FUELS

1 Introduction

Automobiles that use alternative fuels are unlikely to come into widespread use unless they can markedly distinguish themselves in terms of fuel cost, refueling infrastructure, cleanliness of emissions, or CO_2 reduction. This article summarizes the current trends in generally available LP gas and natural gas vehicles and in the development of their engines. The progress of research and development on hydrogen reciprocating and DME engines, which have the potential in terms of future automobile fuel use, are also introduced in this article.

2 LPG Engines

The number of LPG vehicle registrations[(1)] in Japan at the end of February 2019 was 202,799. Those registrations breakdown into a total of 179,840 units for taxis, private, cargo, special purpose, and shared vehicles, 10,786 JPN taxis, 8,031 bi-fuel vehicles, and 4,142 mini-vehicles.

Universal design taxis (UD taxis)[(2)] were launched in October 2017. The Toyota JPN taxi[(3)] has a hybrid engine based on the 1,500-cc engine of Sienta developed especially for LPG that is based on the 1,500-cc engine of the Sienta. The number of JPN taxis exceeded 10,000 units at the end of February 2019 and can be seen in Tokyo and many other places throughout Japan. Nissan supplies LPG bi-fuel engine vehicles in the NV200 taxi[(4)], which is a UD taxi. Since taxis have a short service life, trends are expected to change rapidly.

As LPG hybrid vehicles, JPN taxis are reported to be approximately twice as fuel efficient as conventional LPG vehicles. The consumption of the LPG as fuel has dropped, and some LPG stations are reported to have shut down due to deteriorating business conditions. In contrast, simplified autogas refueling stations[(5)], which mitigate equipment investment and maintenance costs and target taxi operators and driving schools, have emerged.

3 Natural Gas Engines

As of March 2019, the number of natural gas vehicles (NGVs) worldwide reached 27.38 million vehicles, an increase of 2.3 million vehicles from the previous year. As shown in Table 1, the Asia-Pacific region has the largest number of NGVs and natural gas stations. In China, Iran, and India, there are millions of NGVs, and they are continuing to spread. Similarly, the number of natural gas stations has grown to approximately 32 thousand locations worldwide[(6)].

At the JSAE 2018 Autumn Congress (Nagoya Congress Center, October 17 to 19, 2018), research on the performance and exhaust characteristics of dual fuel engines combined with diesel fuel (Kyoto University), and a numerical analysis of combustion characteristics (Waseda University), were presented as examples of research trends on natural gas engines. At the 29th Internal Combustion Engine Symposium (Doshisha University Shinmachi Campus, November 26 to 28), an evaluation of PREMIER combustion methane content in dual fuel engines combined with diesel fuel was presented. Regarding methane components, especially in the case of LNG containing a relatively large amount of LPG components, weathering (a phenomenon in which light methane evaporates and the LNG composition changes) may occur. In LNG trucks using such LNG, attention should be paid to changes engine power and exhaust characteristics.

The development and field testing of heavy-duty LNG trucks and optimal refueling infrastructure project con-

Table 1 Global Spread of NGVs and Gas Stations

Area	NGVs	Stations
Asia-Pacific	19,766,027	19,942
Europe	2,003,343	5,052
North America	205,000	1,857
Latin America	5,137,891	5,595
Africa	268,349	210

Fig. 1 LNG Trucks and L-CNG Station Built for the Project

Fig. 2 Light-Duty CNG Trucks Manufactured for the Demonstration

ducted by the Ministry of the Environment[7], in which transportation business operators participated in an on-road field test of LNG trucks providing service between Tokyo and Osaka from June 2018 to February 2019. The development targets were set to run a cruising range of 1,000 km or more and reduce CO_2 emissions reducing by 10% or more compared to diesel trucks. Based on the premise that the spread of the infrastructure in conjunction with LNG trucks is important, the project also simultaneously constructed the L-CNG station (stations with LNG tanks that can supply both LNG and CNG) at Nanko area of Osaka that operated as the first LNG stations in Japan (Fig. 1).

The Japan Gas Association conducted a project for three years from 2016 to develop and demonstrate increasing efficiency technology in engines for light-duty CNG trucks[8] in the background of research seeking at possible ways of improving the performance of natural gas engines (Fig. 2). In this project, a 3.0 liter diesel engine was converted to a CNG engine, applying downsizing with turbochargers and the Miller cycle as primary technologies compared with a currently mass produced naturally aspirated CNG 4.7-liter engine. Two commercial vehicles (with carrying capacities of approximately 2 and 3 tons) were manufactured and put in service, and their performances were evaluated. These trucks achieved a reduction in CO_2 emissions of 20% or more over the comparison diesel vehicles after driving distances of approximately 23,000 to 27,000 kilometers.

4 Hydrogen Engines

Hydrogen fuel is strongly expected to become a next-generation fuel that contributes greatly to solving issues such as global warming and air pollution, as well as the issue of energy resource depletion depending on the selection of the primary energy source. The technical development of hydrogen fuel engines has been pursued in various countries and sectors since the early 1990s. In December 2014, Japan took the global lead in the commercial production of fuel cell vehicles that use hydrogen as a fuel. In March 2019, Japan revised its hydrogen and fuel cell strategy roadmap and revealed plans to introduce a complete supply chain of hydrogen production, transportation, and storage to be put to practical use around 2030. 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. Issues to resolve for the practical use of hydrogen engines are the suppression of NOx production under high load operating conditions and the further improvement of thermal efficiency.

In fiscal 2018, there were reports of research and development of hydrogen engines conducted Japan that focused on the above-mentioned further improvements in thermal efficiency and suppression of NOx production[9-11]. Research by Tokyo City University[9][10] reported results for a highly efficient high output near-zero emission hydrogen engine. A large bore unit is used to optimize the injection timing and jet shape using a combustion system that ignites and burns the air-fuel mixture mass immediately after injection completes. Thermal efficiency is improved by reducing cooling loss, an issue described as inescapable in hydrogen engines, thereby achieving an indicated thermal efficiency of over 49% while reducing NOx generation to a single digit ppm in the high load region. Research results[12][13] covering basic techniques, such as measuring the mixture gas formation process, related to the above projects have also been reported. There have also been reports on basic research[14] on closed cycles that aims to eliminate NOx generation using argon and to greatly improve thermal efficiency. Many papers on simulations concerning the potential of the direct injection hydrogen engines mentioned above, as well as on research covering premixing hydrogen engines, have been published outside Japan[15][16]. Most such papers are published by research institutes in China.

5 Dimethyl Ether (DME) Engines

The standardization of fuel supply systems (excluding the on-board fuel tank) and refueling port for DME vehicles is being prepared by the ISO (ISO/TC22/SC41/WG8). A draft standard for refueling ports (ISO/DIS21058), Part 1 (ISO/DIS22760-1, general terms and definitions), and Part 2 (ISO/DIS22760-2, performance and test methods) are being studied as a Draft International Standard (DIS). In Japan, the Society of Automotive Engineers of Japan established a subcommittee for DME under the Environment Technical Committee to take part in the standardization. The refueling port mentioned above is based on the pressurizing refueling method. Fuel supply devices for DME vehicles contain recirculated fuel from the engine and the increase in temperature in the container tends to raise the steam pressure above the ambient temperature. There may be cases in which DME refueling pressure is needed in surplus when refueling in intense heat or when the remaining amount of fuel is low. The pressure-equalizing refueling method developed in Japan can be used under any environmental conditions and can suppress excessive pump pressurizing. This refueling port relying on pressure-equalizing refueling is under study as a draft standard.

In Europe, the Forschungsvereinigung Verbrennungskraftmaschinen e.V. (FVV) xME (DME, OME) project, led by Ford is progressing based on a three-year plan that includes a demonstration of a DME vehicle based on the Ford Mondeo. The fuel supplying system used in this vehicle is manufactured by Ford, Westport, and Prins. They are studying a system adapted from LPG direct injection engine conversion kits. In addition, the study of DIN standards for automobile fuels has also begun. Germany has been assessing e-fuels, which are synthesized using electricity originating from renewable energy to combine hydrogen obtained from water electrolysis and CO_2 taken from plants and the atmosphere, as part of a project targeting decarbonization. Research on e-DME production[17] is also being conducted.

The 8th International DME Conference was held in September 2018 in Sacramento (North America). In relation to the FVV project in Europe, Ford, PERDC, University of Windsor, Oberon Fuels, Herman Tech, and GV Energy Inc. are planning a demonstration of DME vehicles based on the Ford pickup truck. In Indonesia, a study on DME synthetic plant derived from low-grade coal as an alternative for LPG is being conducted[18].

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