DIESEL ENGINES

1 Introduction

A new fuel economy standard for passenger vehicles mandating a 32.4% fuel efficiency improvement over actual 2016 values by 2030 came into force in Japan in April 2020. The applicability of the standard has been extended to electric and plug-in hybrid vehicles, which are expected to become more widespread. Diesel heavy-duty vehicles gradually began to comply with the 2016 emissions regulations in that year, and all new vehicles with a gross vehicle weight exceeding 3.5 tons have been subjected to those regulations. Tighter fuel economy standards are planned for 2025 have been finalized. They impose improvements of 13.4% for trucks and 14.3% for buses compared to the 2015 standards.

In Europe, real driving emissions (RDE) regulations applying to emissions from passenger vehicles on public roads have been in effect since 2017. The NO_x regulatory value set to a maximum of 2.1 times the Euro 6 regulatory value in the first stage was revised to a maximum of 1.5 times in 2020. At the same time, a target reduction equivalent to 15% of the 2021 targets has been set for the CO_2 emissions regulations applying to passenger and light-duty commercial vehicles starting on January 1, 2025. The reduction targets applying from January 1, 2030, have been set to 37.5% for passenger vehicles, and 31% for light-duty commercial vehicles compared to the 2021 targets. For heavy-duty vehicles, the reduction targets have been set to 15% for 2025, and 30% for 2030, relative to the CO_2 emissions values calculated during the July 1, 2019 to June 30, 2020 reference period.

In the U.S., the California Air Resources Board (CARB) announced an omnibus regulation for heavy-duty vehicle NO_x emissions in August 2020. It stipulates reducing the upper limit to one quarter of the current value starting with the 2024 model year, and to one tenth of the current value as of the 2027 model year. Similarly, the Advanced Clean Trucks (ACT) regulation on reducing CO_2 emissions was adopted in June 2020, and is scheduled to apply at the same time as the heavy-duty vehicle NO_x omnibus regulation, in 2024.

2 Trends in Japan

2. 1. Overview

(1) Diesel Engines for Passenger Vehicles: Mazda refined its SKYACTIV-D 1.8, a 1.8-liter in-line 4-cylinder DOHC 16 V direct injection diesel turbocharged engine. European passenger vehicle manufacturers also deployed many diesel vehicles in Japan.

(2) Diesel Engines for Commercial Vehicles: Although Japanese manufacturers made modifications or additions to the specifications of already available engines, they did not bring out or announce any new diesel engines in 2020.

2. 2. New Engine Characteristics (Table 1)

(1) Mazda S8-DPTS (SKYACTIV-D 1.8) (Fig. 1): Combustion control was revised through software updates, raising the maximum output from its original 116 ps/4,000 rpm to 130 ps/4,000 rpm. (The maximum torque of 27.5 kg･m/1,600 to 2,600 rpm remains unchanged.) Control was also modified to generate strong torque at a wider range of engine speeds, improving response as soon as the accelerator is pressed.

3 Trends outside Japan

3. 1. Overview

(1) Diesel Engines for Passenger Vehicles: Although it was actually at the end of 2019, Isuzu Motors released a new engine featuring better fuel economy and reduced noise compared to previous models in an effort to further expand its market for pickup trucks in Thailand, where demand is high. Similarly, several new engine models that enhance combustion efficiency and reduce NO_x emissions through the use of high pressure injection systems, introduction of mild hybrid systems, and adoption of newly developed SCR systems have

Table 1 Specifications of engines announced and launched in Japan in 2020

Application	Manu-facturer	Engine model	Cylinder ar-rangement	Bore diameter × stroke (mm)	Total displacement (L)	Compres-sion ratio	Max. output (kW/rpm)	Max. torque (Nm/rpm)
Passenger vehicles	Mazda	S8 -DPTS	L4	79.0 × 89.6	1.756	14.8	95/4,000	270/1,600–2,600

Table 2 Specifications of engines announced and launched outside Japan in 2020

Application	Manu-facturer	Engine model	Cylinder ar-rangement	Bore diameter × stroke (mm)	Total displacement (L)	Compres-sion ratio	Max. output (kW/rpm)	Max. torque (Nm/rpm)
Passenger vehicles	Isuzu	4 JJ3	L4	95.4 × 104.9	2.999	16.3	140/3,600	450/1,600–2,600
Passenger vehicles	BMW	B57 D30 B	L6	84.0 × 90.0	2.993	16.0	210/4,000 250/4,400	650/1,500–2,500 700/1,750–2,250
Commercial vehicles	Scania	DC16 120 121 122 123	V8	130.0 × 154.0	16.4	22.0 22.0 22.0 19.0	390/1,900 434/1,900 485/1,900 566/1,800	2,800/925–1,325 3,050/925–1,350 3,300/950–1,400 3,700/1,000–1,450
Commercial vehicles	Cummins	X12	L6	132.0 × 144.0	11.8	—	373/1,900	2,305/1,000
Commercial vehicles	Detroit Diesel	DD15 Gen5	L6	139.0 × 163.0	14.8	21.0	377/1,625	2,508/1,000
Commercial vehicles	BharatBenz	OM926	L6	106.0 × 136.0	7.201	17.5	210/2,200	1,100/1,200–1,600

Fig. 1 Mazda S8-DPTS (SKYACTIV-D 1.8)

Fig. 2 Isuzu Motors 4JJ3

Fig. 3 BMW B57D30B

been launched in Europe to comply with the current Euro 6d regulations.

(2) Diesel Engines for Commercial Vehicles: In the U.S. and Europe, the gradual tightening of CO_2 emissions for heavy-duty vehicles has led to the launch of refined heavy-duty truck engines. They feature reduced friction loss thanks to refinements such as reducing weight compared to the base established by the previous models, as well as enhanced fuel efficiency resulting from combining improved combustion efficiency with a newly developed transmission.

3. 2. New Engine Characteristics (Table 2)

(1) Isuzu Motors 4JJ3 engine (Fig. 2): As the next generation of the 4JJ1 sold by Isuzu Motors, the 4JJ3 offers high power, low fuel consumption, and reduced noise achieved by adopting a high injection pressure of 250 MPa, an electronically-controlled VGS turbocharger, pistons with thermal barrier coating, double scissor gears, and other technologies.

(2) BMW B57D30B (Fig. 3): The B57D30B engine launched by BMW supplements an optimized turbocharging system with the latest common rail injection system equipped with piezo injectors to achieve both performance and fuel efficiency. The injectors can inject fuel up to a maximum of 10 times per cycle at a maximum pressure of 270 MPa. Combining it with a 48 V mild hybrid system also substantially increased the amounts of electric power and regenerative braking energy. Aftertreatment technology includes an embedded SCR catalyst converter directly below the engine outlet to reduce NO_x emissions, and an SCR coating on the

Fig. 4 Scania DC16

Fig. 5 Cummins X12

Fig. 6 Detroit Diesel DD15 Gen 5

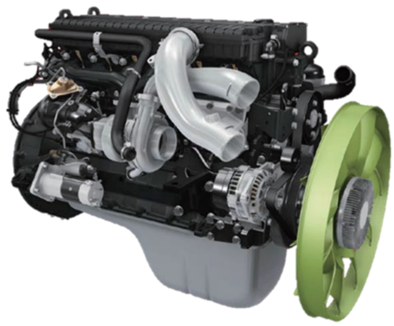

Fig. 7 BharatBenz OM926

DPF. The final result is a new inline 6-cylinder diesel engine that meets the Euro 6d emissions standards.

(3) Scania DC16 (Fig. 4): The DC16 V8 series launched by Scania offers four power specifications, with the highest 560 kW specification achieving a 6% or so improvement in fuel economy when used in combination with the newly developed G33 transmission that reduces internal loss by 50% and has been made 60 kg lighter. The aftertreatment system uses two-stage AdBlue injection, and enhances AdBlue evaporation during the load cycle by complementing the standard injection with a high-temperature injection immediately after exhaust braking. These features result in compliance with the Euro VId emissions standards.

(4) Cummins X12 (Fig. 5): The 11.8-liter X12 launched by Cummins represents the next-generation of the existing Euro V-compliant engine. The use of a high strength composite material for the oil pan and valve cover resulted in reducing the engine's weight significantly to less than 920 kg. Similarly, reducing friction loss not just in the water pump and lubrication system, but in the engine as a whole, and adopting the proprietary Cummins efficient XPI-based combustion system derived from the high power X15 eliminated the need for EGR. Compared to conventional engines that use cooled EGR, this engine reduces its overall heat loss by 40%, making it both more efficient and compliant with the Euro VId emissions standards.

(5) Detroit Diesel DD15 Gen 5 (Fig. 6): The DD15 Gen 5 launched by Detroit Diesel is a redesign of the previous generation DD15 that enhances the performance of the engine. The enhanced transient response obtained by adopting a ball bearing turbocharger, decreased engine speed required to reach maximum torque and output, a higher compression ratio, and a newly designed swirl piston combine to boost combustion efficiency, resulting in a maximum fuel economy improvement of 3% and a reduction of CO_2 emissions. It also features the new ThermoCoasting system to control the temperature of the aftertreatment device. This revolutionary control system shortens the DPF regeneration cycle by combining the engine brake (Jake Brake) of the front three cylinders and the engine firing of the rear three cylinders during coasting keeps the temperature of the aftertreatment system down while maintaining engine torque at zero while driving.

(6) BharatBenz OM926 (Fig. 7): Using the 7.2-liter OM926 engine that has been proven in the European market, BharatBenz, the Indian brand of the Daimler

Group, has improved the aftertreatment device through a combination of a turbocharger, DPF and SCR and launched a heavy-duty truck engine that targets the Indian domestic market and complies with the Bharat Stage VI (Euro VI equivalent) emissions regulations. Combining this engine with newly adopted technologies such as an electronically-controlled cooling fan, low-rolling resistance tires, and a gear shifting advice system, improves fuel economy by up to 10% compared to vehicles equipped with its OM904 predecessor. Thanks to its compatibility with the Daimler Group shared Truckonnect® remote diagnostics system, this engine also offers improved operation management and serviceability.

4 Research and Development Trends

In Europe, RDE regulations targeting passenger vehicles have gradually been strengthened to restrict emissions in real-world driving situations. With the Euro VIe standards for heavy-duty vehicles coming into effect in January 2021, a PEMS test for cold starts has been added due to the strengthening of ISC regulations. Furthermore, discussions on the introduction of event more stringent Euro VII regulations mean that upcoming research and development will focus on reducing emissions at low temperatures based on real-world driving for the vehicle.

Complying with such tighter emissions regulations requires raising the temperature of the catalyst to the high conversion efficiency range. Technologies under study for that purpose include catalyst heating systems that use a coil heater, and two-stage SCR catalysts. However, research and development faces many hurdles, such as the low number of catalyst heating system installations in diesel heavy-duty vehicles and the increase in back pressure resulting from the higher number of catalysts.

Nevertheless, measures to address the global warming caused by CO_2 emissions must be taken, and the attendant fuel economy standards must be met. Under the Paris Agreement enacted by the UN in 2016, the parties committed to the global long term goal of aiming for carbon neutrality by 2020, and automobile manufacturers around the world are being urged to take prompt action.

Notable existing applicable technologies include higher fuel injection pressure and the reduction of various forms of loss, and recent passenger vehicle development in Europe has led to the more widespread deployment of 48 V mild hybrid vehicles offering a potential 20% improvement in fuel economy. At the same time, the difficulty of replacing heavy-duty vehicles with electric vehicles is intensifying research and development into e-fuels, which could become an alternative to diesel. Since they combine CO_2 extracted from the atmosphere with H_2 drawn from renewable energy sources, e-fuels are carbon neutral and represent a promising technology to meet the major tightening of regulations in 2030.