Komatsu's Low Emission Engine, STA6D140, Using Water Emulsified Fuel

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The business of onsite diesel power generation is rapidly expanding in Japan, as the nation's electric power supply industry is being deregulated and liberalized. Diesel engines are commonly used for onsite power generation for their good fuel consumption ratio.

Komatsu successfully developed an emulsified fuel manufacturing facilities called Emulsion Mixer which produces emulsified fuel blending fuel and water at an equal ratio of 50% each. Then Emulsion Mixer has been followed by the development of STA6D140 diesel engine which uses emulsified fuel produced by Emulsion Mixer. This is an ultra low NOx engine (100 ppm at O_2 13% level) which has succeeded in reducing the NOx level to one-tenth of the conventional diesel engines, while maintaining better exhaust gas color and fuel consumption ratio. This thesis discusses the development and features of Emulsion Mixer and the STA6D140 diesel engine.

***Key Words**: Diesel Engine, Engine Performance, Emulsified Fuel, Diesel Engine, Power Generation*

1. Preface

Over the past several years, an onsite power generation system is widely disseminating throughout Japan. Diesel engines are commonly used for the stationary generators due to their excellent fuel consumption ratio. In this connection, emission gas from generator engines is regulated by Japan's Air Pollution Law, which sets forth that the emission level be less than 950 ppm at O_2 13% level. However, some municipal governments in the metropolitan areas further tighten this level to 100 ppm out of consideration to their environments. (See **Fig. 1**)

In those areas of 100 ppm regulation, mainly gas engines and gas turbines have been in use so far. Diesel engines, when used, have depended on an NOx removal system, because it is difficult with them to sufficiently reduce NOx level. But a problem of black exhaust gas still remains.

Against such background, we set about the development of reliable manufacturing facilities which can constantly produce water emulsified fuel blended with fuel and water at a 50 to 50 ratio, and then the development of a low emission gas diesel engine using that fuel which will reduce both NOx and black exhaust gas at a time, thereby becoming compatible with the regulations in big cities. In this thesis, we will discuss the development of the water emulsified fuel and the engine, and introduce their features.

2. Outlook of system of water emulsified fuel and diesel engine

Fig. 2 shows an outlook of the system of water emulsified fuel and a diesel engine that uses such fuel. The new diesel engine differs from the conventional ones in the following points of configuration.

(1) Water emulsifier unit
(2) White exhaust gas preventive system including a hybrid aftercooler system

Now let us elaborate on each of them.

Japan's NOx Regulation (for reference) 950 ppm

Air Pollution Law
(under the jurisdiction of Ministry of the Environment)

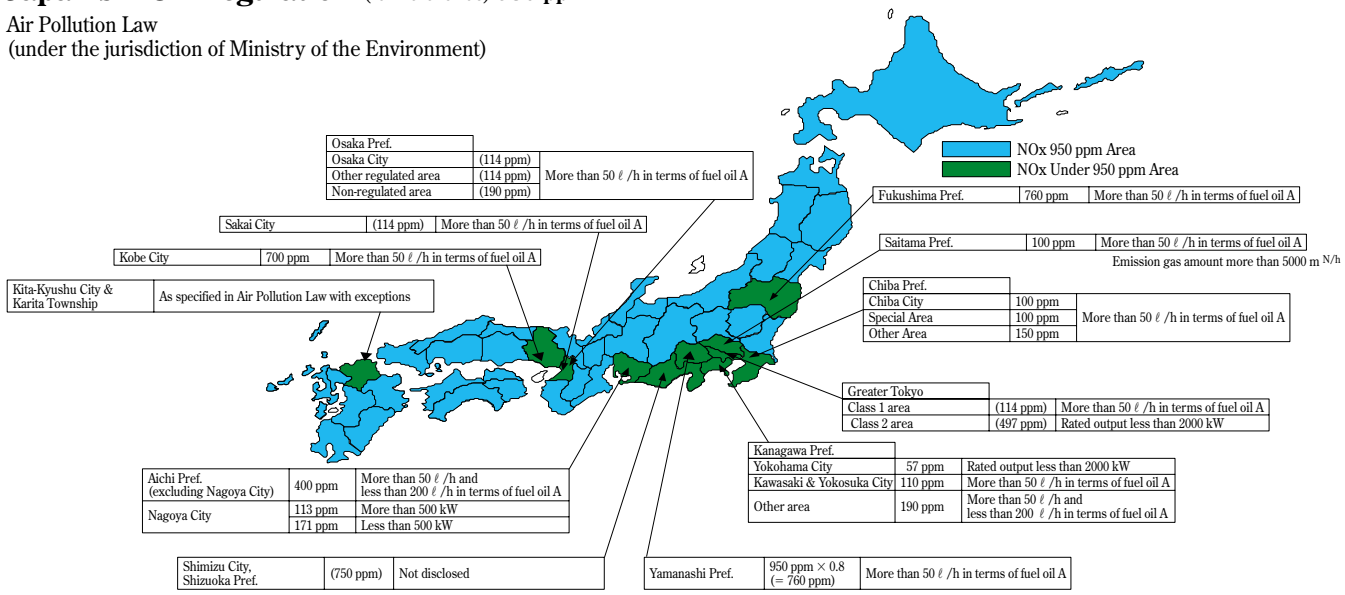

Fig. 1 NOx Regulation

2.1 Water emulsifier unit

Fig. 3 shows the simplified structure of the unit. The fuel production consists of the following automatic processes.

(1) Preliminary agitation
- Filling the mixer with fuel oil A
- Adding surfactants
- Adding water

(2) Emulsification process is started by letting the mixed liquid pass through the emulsifier and return to the mixer by means of the circulation pump. After repeating this process for a certain period of time, the emulsification process is completed.

(3) After the mixed liquid is emulsified, it is transferred to the tank.

The emulsifier is basically so constructed that the mixed liquid repeats collision and diffusion. After passing through the emulsifier several times, the particle size becomes even and constant. **Fig. 4** shows the distribution of this particle size. The average particle size is approx. 3 μm.

In order to emulsify water and fuel, surfactants are required. Out of characteristics required of the surfactants, we attached importance to easy-to-emulsify, rustproof and antiseptic properties in our development activities.

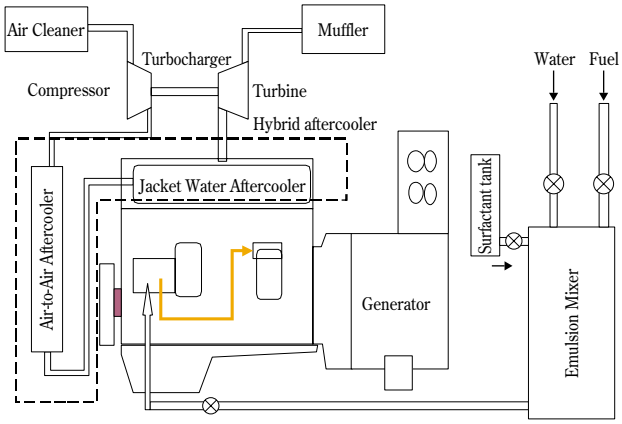

Fig. 2 Emulsions Engine System

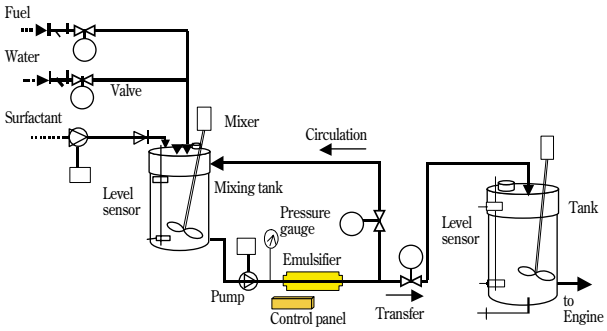

Fig. 3 Fuel Mixing System

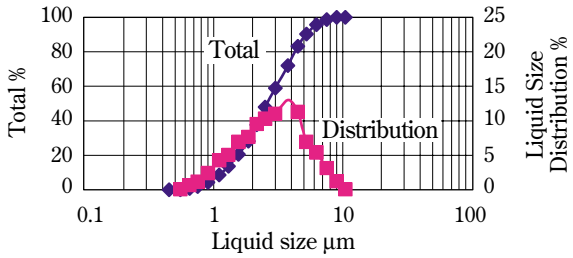

Fig. 4 Liquid Size Distribution

Emulsified fuel has to be easy to handle (must be classified as nonhazardous material). Meanwhile, water content of the water emulsified fuel has to be 50% to achieve the target value of NOx as discussed later on. Out of these two considerations, such type of a surfactant was selected that helped create O/W type emulsified fuel that held fuel in water. (See **Fig. 5** & **Fig. 6**)

2.2 White exhaust gas preventive system

An emulsion engine consumes fuel containing a large amount of water. For this reason, starting the engine is not easy when the engine is cold, or the piston compression ratio is low, so it needs a starting aid. **Fig. 7** explains this mechanism.

(1) Hybrid aftercooler with opening-closing valve
When the piston compression ratio is high, the hybrid aftercooler closes the coolant opening-closing valve, letting no water through the water-cooled aftercooler, but sending air cooled by air-to-air aftercooler into the engine, and controls NOx.
When the piston compression ratio is low, it sends water through and raises the intake air temperature so as to prevent white exhaust gas.

(2) Coolant heater
When the engine stands, the coolant heater is controlled so as to keep the coolant temperature at a certain level.

(3) Intake air heater
This electric heater heats intake air until the engine interior warms up after startup.

(4) Exhaust shutter
The exhaust shutter closes after the engine startup so as to raise the load on the engine and shorten the engine warming-up time. It is opened when engine speed reaches high idling and the engine is ready to receive load.

(5) Electronic governor
This is a pump which quickens injection timing to attain proper ignition when the engine is started, or when load on the engine is still low, and likewise retards injection timing to contain NOx when high load is applied to the engine. A Komatsu-made KP21 injection pump is in place, assuring the optimum injection timing.

(6) Big capacity nozzle
Because emulsified fuel containing a large amount of water is used, the fuel injection amount necessarily increases. That is why a nozzle of large capacity and high performance is required. To meet with this requirement, a nozzle with fluid-lapped orifices has been adopted.

(7) High compression FCD piston
In this development, we decided on FCD for the piston material in consideration of easy startup and eliminating white exhaust gas. With the conventional diesel engines, the piston compression ratio is 15, against which we have established a compression ratio of 20. This is a level never witnessed before in this class of engine with the piston displacement of 15 liters. (See **Fig. 8**)

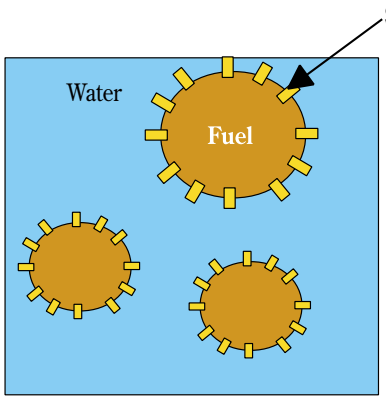

Fig. 5 O/W Type Emulsion Fuel

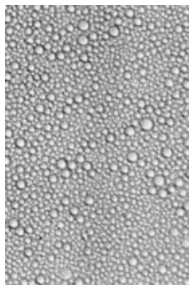

Fig. 6 Microscopic View of Water Emulsified fuel

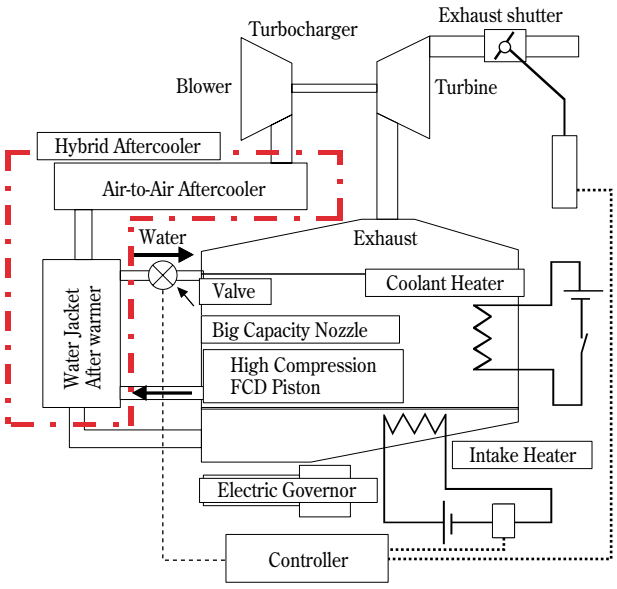

Fig. 7 Engine System

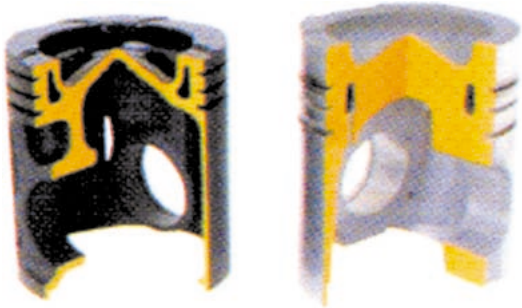

Fig. 8 FCD Piston

3. Engine performance of STA6D140

3.1 Engine specifications

The specifications of this STA6D140 engine are shown in **Table 1**.

3.2 Engine performance

Fig. 9 shows how NOx emission level varies in proportion as water contained in emulsified fuel increases.

Since it is an engine with intended application for power generation, it has to be accepted under the current regulatory scheme almost on a nationwide basis. Hence we set the NOx reduction ratio at 90% as compared with the conventional engines.

The mixed water ratio stands in a trade-off relationship with white exhaust gas, and as such was determined to be 50%. As other means to bring down NOx level, ideas of retarding injection timing and adopting an air-to-air aftercooler, etc. were implemented. With these devices combined, we could arrive at the target value of 90% reduction.

When we measured the effect of water emulsified fuel in terms of smoke, using both the newly developed STA6D140 engine and its base engine, its improvement is remarkable in that the smoke has been brought down to nearly 0% with the former engine and 5% with the latter.

Table 2 tells us a fact that ultra low NOx and lower smoke have been established while incurring no deterioration in the fuel consumption ratio.

As a result of having used emulsified fuel composed of 50% water and another 50% of fuel, latent heat of water vaporization brought down the combustion temperature locally, which in turn drastically reduced NOx amount.

It seems that an increase in a momentum at the time of injection due to the doubled fuel injection amount and an increase of the injection pressure (approx. by 20%) must have contributed to the improvement of smoke. On the other hand, as far as the conventional engine is concerned, smoke is not nil even when load on the engine is 50%. Judging from this fact, a mixing ratio between fuel and air must have been improved in the case of emulsified fuel, because being 3 μm, its particle size is so small that the fuel presumably became finer particles.

Table 1 Structure of Backpack Engine Blower

Engine		STA6D140
Engine Type		4-Cycle Water-Cooled DI
Aspiration		Turbocharged with Hybrid Aftercooler
Displacement	ℓ	15.24
Compression Ratio	–	20 : 1
Valve Train	–	4-valve OHV
Fuel Injection System	–	Inline with Variable Injection Timing
Cly. No. − Bore × Stroke	mm	L6 − 140 × 165
Oil Capacity	ℓ	77

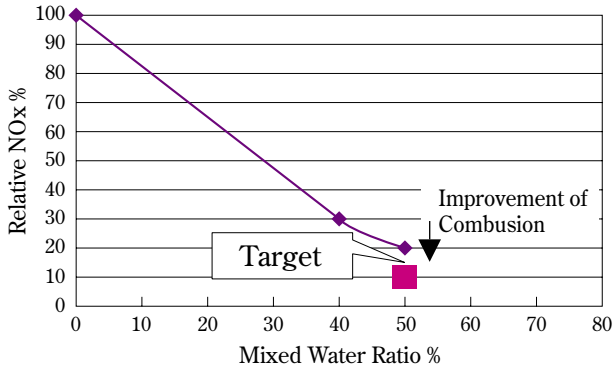

Fig. 9 NOx vs. Mixed Water Ratio

Table 2 Engine Performance

NET			SA6D140A Conventional	**STA6D140 Emulsified Fuel**
Displacement		ℓ	15.24	**15.24**
50Hz	Power	kW	272	**272**
	BSFC	g/kWh	211	**213**
	NOx	ppm	750	**95**
	Smoke	BSU	0.5	**0.0**
60Hz	Power	kW	272	**272**
	BSFC	g/kWh	218	**218**
	NOx	ppm	732	**95**
	Smoke	BSU	0.5	**0.0**

4. Conclusion

We could develop water emulsifier unit and a new diesel engine for power generation application that conformed to almost all the NOx regulations in this country. The following is a summary of the achievements we have made in the course of the development activities.

(1) Developed unit that enables constant and stable production of emulsified fuel that consists of 50% water and 50% fuel
(2) Developed a surfactant for emulsified fuel that can satisfy emulsifiable, rustproof and antiseptic properties
(3) Achieved 100 ppm at O_2 13% level that conforms to nearly all of the NOx regulations throughout the country
(4) Largely decreased white exhaust gas as compared with the conventional diesel engines

Introduction of the writers

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[A few words from the writers]

We came to a dead end several times in the course of the development and received a helping hand from the people concerned on each such occasion. Thanks to their assistance and cooperation, we could manage to bring the project up to the stage of mass production. In particular, an anticorrosive measure, which is essential to the emulsified fuel production, troubled us all. Our special thanks go with people in the surfactant manufacturers as well as those concerned who helped us outside of Komatsu in the solution.

Emulsified fuel is yet to be approved by EPA or other government agencies responsible for the earth environmental protection. Its application to construction equipment comes only after those authorities approve its usage. In the meantime, we plan on improving the entire system such as simplifying the starting aid so that this technology for drastically reducing NOx level may be widely accepted in other fields of industry.