FEATURE ARTICLE

Measurement Systems for Diesel Exhaust Gas and Future Trends

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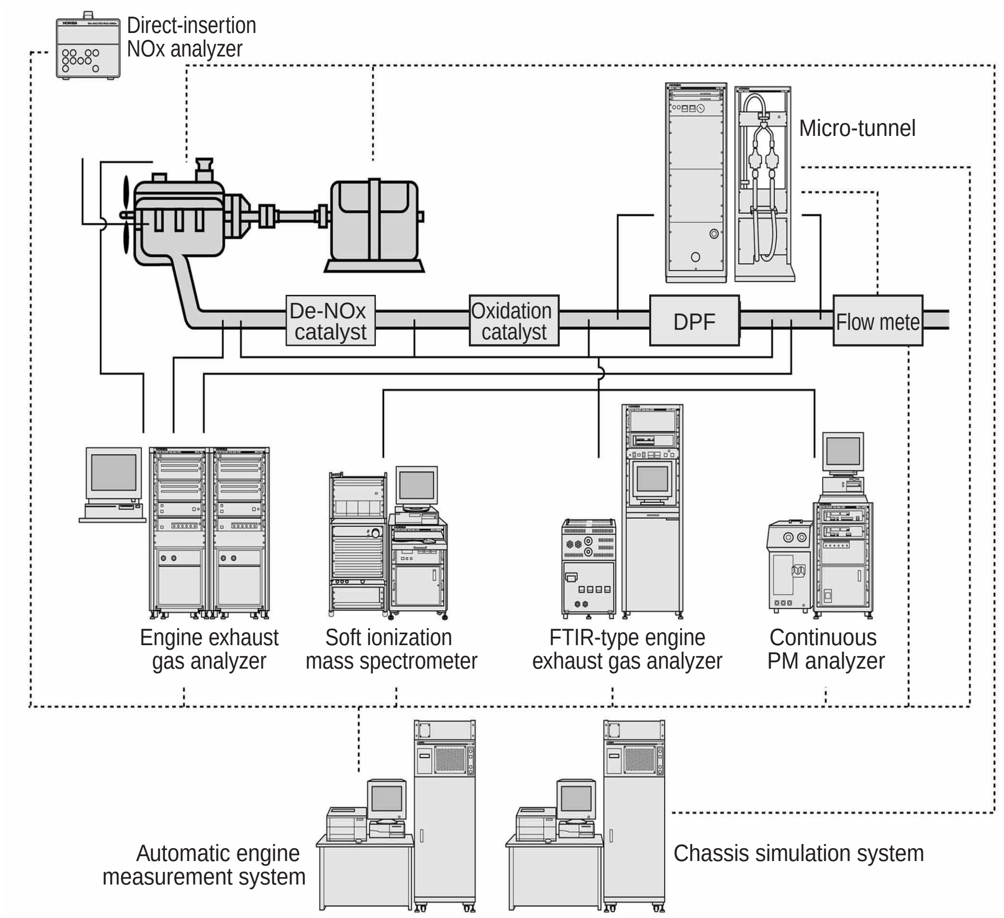

Abstract

Diesel exhaust emission measurement systems have undergone successive improvement to keep pace with improvements of diesel engines and rein forcements of the exhaust emission regulations. It is likely that future emission regulations will require emissions levels that are close to zero. For this reason, the achievement of a high level of precision in the measurement of gaseous and particulate emissions is a critical issue. In addition, diesel exhaust measurement has come to play an important role in the improvement of increasingly complex diesel engines and in the development of exhaust after-treatment systems.

1 Introduction

Diesel engines are very durable and economical, and for this reason they are widely used as motors for large vehicles, construction and agricultural machines, power generators, and ships. There is also hope that diesel engines can play a role in reducing carbon dioxide (CO_2) emissions, which are a cause of global warming in recent years. At the same time, there is a strong need to reduce the emission of nitrogen oxides (NOx) and particulate matter (PM) from diesel engines.

Measurement systems for diesel engine emissions have undergone successive improvement as emissions regulations have grown stronger. However, the regulations have recently become extremely demanding, and thus there is a strong need for even higher sensitivity and precision in emissions measurement systems. In this paper I would like to discuss recent emissions regulations, the current state of emissions measurement systems, and future trends.

2 Trends in Emissions Regulations

Compared to gasoline engines, diesel engines are clean and "green," with fewer carbon monoxide (CO) and hydrocarbon (HC) emissions. However, no pollution prevention technologies have appeared that have made the dramatic reductions in diesel emissions in the same way as three-way catalysts have reduced emissions for gasoline engines, and thus diesel emissions have been reduced in stages. However, the rate of attainment of environmental standards for atmospheric nitrogen dioxide (NO_2) and suspended particulate matter (SPM) is low, particularly in major urban areas, and thus there is now a strong need for a substantial reduction of these pollutants from diesel engines.

2.1 Regulatory Limits on Emissions

In its third report on Future Measures for Automobile Emissions Reductions, the Central Council for Environment, an advisory body of Environmental Agency of Japan suggested attainment of the target limits (short-term targets) shown in Table 1. Passenger cars and light vehicles are to attain the limits by the end of 2002, mid-weight and heavy vehicles 12 tons and under are to attain the limits by the end of 2003, and heavy vehicles–over 12 tons–are to attain the limits by the end of 2004. The council also suggested the establishment of new long-term targets whereby the limits are to be reduced by half by about the year 2007[1].

Europe is also studying similar emissions targets, which are shown in Tables 2 and 3.

The testing mode is different, and thus a simple comparison is not possible, but Japan has established stricter targets for NOx, while Europe has established stricter targets for PM.

Vehicle typej	NOx	HC	CO	PM	Measurement method
Passenger cars to 1.25 tons	0.28	0.12	0.63	0.052	10-15 mode (g/km)
Passenger cars from 1.25 tons	0.30	0.12	0.63	0.056	
Light vehicles to 1.7 tons	0.28	0.12	0.63	0.052	
Mid-weight vehicles from 1.7 tons to 2.5 tons	0.49	0.12	0.63	0.06	
Heavy vehicles from 2.5 tons	3.38	0.87	2.22	0.18	D13 mode (g/kWh)

Table 1 Target Emissions Limits for Diesel Vehicles

	CO	HC+NOx	NOx	PM	Effective Date
Step 3	0.64	0.56	0.5	0.05	2000
Step 4	0.5	0.3	0.25	0.025	2005

Table 2 Proposed EU Emissions Limits for Diesel Passenger Cars

		CO	HC	NOx	PM	Effective Date
EURO III	ESC	2.1	0.66	5.0	0.10	2000
	ETC	5.45	0.78		0.16	
EURO IV	ESC	1.5	0.25	2.0	0.02	2005
	ETC	4.0			0.03	

Table 3 Proposed EU Emissions Limits for Diesel Heavy-Duty Vehicles

2.2 Emissions Testing Methods

The U.S. Environmental Protection Agency (EPA) requires transient testing for heavy-duty truck and bus engines however; until now, Japan and Europe have required only steady-state testing for heavy-duty engines; however, EURO III regulations in Europe will introduce a transient test cycle (European Transient Cycle "ETC") to be added to the steady-state test cycle (European Steady-state Cycle "ESC").

In addition, with respect to the new long-term targets, the report of the Central Council for Environment states that, "The introduction of testing methods for transient running ("transient mode") must be studied." Thus it is likely than transient testing will also be introduced in Japan when the new long-term regulations go into effect.

<Direct Measurement >

In steady-state testing of heavy-duty engines, the exhaust gas from the engine is directly collected without dilution and the concentrations of components such as CO are measured.

The mass emission of the pollutants are obtained during the test from the quantity of exhaust gas flow, which is obtained from the air intake flow and fuel flow, and the average concentrations of exhaust gas components. Because direct measurement does not dilute the exhaust gas, this method is better than dilution measurement for measuring low-concentration exhaust components. However, transient testing requires measurement of exhaust gas flow, which can change suddenly, and thus direct measurement is currently only used for steady-state testing.

<Dilution Measurement>

In transient testing, a Constant Volume Sampling (CVS) system is used to obtain the mass emission of exhaust gas components. A CVS system dilutes the entire exhaust gas with clean air to produce a constant flow. A fixed proportion of the entire diluted exhaust gas is collected in a sample bag to obtain a diluted exhaust gas that is representative of the average concentration while the engine runs.

The diluted exhaust gas can also measured continuously to obtain the average concentration during running. Mass emission of exhaust gas components are obtained from the entire diluted exhaust gas flow and the average concentrations of the pollutant in the diluted gas.

Fig.1 shows an example of the configuration of a CVS system.

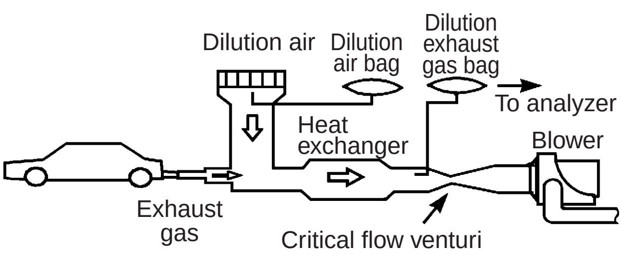

Fig.1 Example of CVS System Configuration

The use of a CVS system is an excellent method for obtaining the mass emissioin of components of exhaust gas in transient testing, and this method has been in wide use since the early 1970s. However, as regulations have grown stronger, the concentration of diluted exhaust gas has fallen to the same level as that found in dilution air, and measurement precision cannot be maintained, making new improvements necessary. Furthermore, when testing emissions from heavy-duty engines which have large displacement and is run at close to the rated speed, it is necessary to use a very large CVS system that can dilute a large amount of exhaust gas.

<Particulate Matter Measurement>

To measure particulate matter (PM) emitted from a diesel engine, the exhaust gas from the engine is diluted and cooled to 52° C (or less) in a dilution tunnel in which clean air flows. The PM is collected on a filter and then weighed using a micro balance. In transient testing, a full-flow dilution tunnel is used to dilute the full flow of exhaust gas so that it forms a constant flow. Fig.2 shows an example of the configuration of a full-flow dilution tunnel.

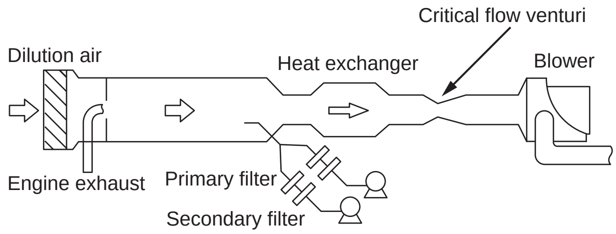

Fig.2 Configuration of a Full-Flow Dilution Tunnel

When transient testing is performed on a heavy-duty engine using a full-flow tunnel, the dilution flow must be ten times as great as the exhaust flow, and thus a huge tunnel is required. To lower the gas temperature avoiding this enlargement of the equipment, after the full flow of the exhaust gas is diluted, a secondary dilution tunnel may be used to further dilute a portion of the diluted gas.

In steady-state testing of heavy-duty engines, in addition to a full-flow dilution tunnel, a partial-flow dilution tunnel is used to take part of the exhaust gas in proportion to the flow and dilute it[2,3]. Partial-flow dilution tunnels that dilute 1/10 to 1/50 of the exhaust gas and have a diameter of 75 mm or greater are called mini-tunnels. Smaller tunnels with a diameter of about 30 mm that take a small flow of exhaust gas in proportion to the flow of exhaust gas and dilute it, are called micro-tunnels. (In Europe all partial-flow dilution tunnels are called mini-tunnels.)

3 Applications of Direct Measurement and Partial-Flow Dilution Tunnel to Transient Testing

In 1997, the Worldwide Heavy Duty Certification Procedure (WHDC) Working Group was established in the Working Party on Pollution and Energy (GRPE) of the Working Party on the Construction of Vehicles under the United Nations Economic Commission for Europe (ECE), and efforts thereby began under the leadership of each government toward international harmonization of heavy-duty engine emissions testing procedures. The WHDC requested Technical Committee TC22/SC5 (engine test) of the ISO to draft standards for emissions measurement procedures for heavy-duty engines, and a working group (WG2) was formed.

The WG2 is currently studying and drafting standards for PM measurement using a partial-flow dilution tunnel compatible with transient testing and emissions measurement by means of direct measurement. WG2's draft standards were scheduled for completion in December of 1999, and they are scheduled for listing as measurement methods in the future EURO IV regulations. In Japan as well, for international harmonization of standards it is likely that these standards will be adopted as measurement methods in the new long-term regulations. It is also very likely that these standards will be used for non-load (other than automobile) engine testing, for which transient testing with a full-flow dilution tunnel has not been possible due to the excessive size of the equipment.

4 Low-Pollution Technology and Emission Measurement

Exhaust Gas-Recirculation (EGR) has been in use for some time as a technology for reducing NOx in exhaust gas from diesel engines. The EGR rate can be obtained from the following equation measuring the concentration of CO_2 in exhaust gas and the concentration of CO_2 in intake air that increased due to recirculation of exhaust gas.

$$EGR_{ratio} = \frac{CO_{2(In)} - CO_{2(amb)}}{CO_{2(Exh)} - CO_{2(amb)}} \times 100(\%)$$

The concentration of NOx in exhaust gas can be easily measured using a chemiluminescent analyzer or non-sampling type NOx analyzer[4)] based on a direct-insertion sensor; however, PM measurement requires a large-scale dilution tunnel and continuous measurement has not been possible.

A continuous PM analyzer that uses flame ionization detectors has recently been developed, and it is hoped that this instrument will help in the reduction of PM because it can simultaneously and continuously measure soot and the soluble organic fraction in PM.

To meet the targets of EURO III and the new short-term regulations, engine combustion must be improved through such measures as multistage injection, high-pressure injection using a common-rail combustion injector, and improvement of the combustion chamber structure. To meet the targets of EURO IV and the new long-term regulations in Japan, it is likely that after-treatment systems, such as de-NOx catalysts that remove NOx and continuous regenerative traps, must be used.

With respect to the constituents of nitrogen compounds occurring before and after catalysis, Fourier transform infrared (FTIR) exhaust gas analyzers can simultaneously measure not only nitrogen oxide (NO) and nitrogen dioxide (NO_2), but also nitrous oxide (N_2O) and ammonia, making it possible to analyze oxidation, reduction, adsorption, and desorption.

Fig.3 shows infrared absorption spectra of CO, CO_2, and N_2O obtained with an FTIR exhaust gas analyzer.

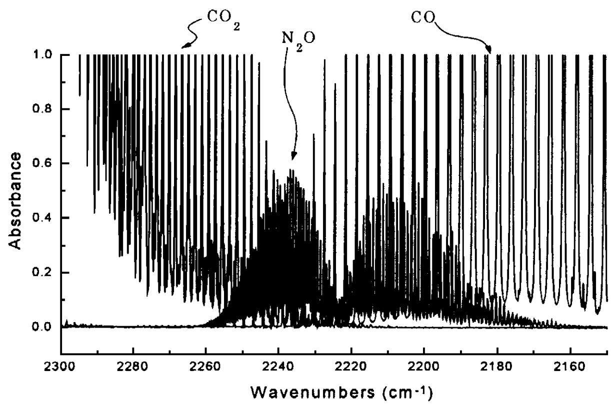

Fig.3 Infrared Absorption Data for CO, CO_2, and N_2O[5)]

The N_2O absorption spectrum coincides with the CO and CO_2 absorption spectra, and thus when a non-distributive infrared analyzer is used; CO and CO_2 interfere with the N_2O spectrum and cause an error in the N_2O measurement. When an FTIR exhaust gas analyzer is used, measurement can be performed at high resolution to reduce the coincidence of the spectra, and CO and CO_2 can be simultaneously measured. A correction calculation is performed to obtain an N_2O measurement that does not suffer from the effects of interference. In addition, a soft-ionization mass spectrometer can be used to measure sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) in exhaust gas before and after catalysis, which makes it possible to investigate the dynamics of sulfur compounds that make catalysis ineffective.

Fig.4 shows a schematic of a soft-ionization mass spectrometer

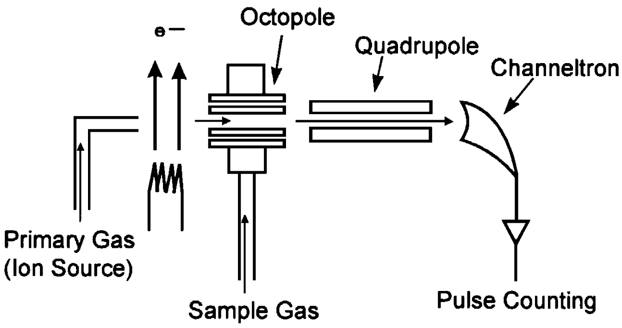

Fig.4 Schematic of a Soft-Ionization Mass Spectrometer

In the octopole, portions of the constituent molecules of the sample gas are ionized through charge exchange with the primary ions of mercury or xenon, which are ionized using the electron collision method. Among these ions, only those of the specified mass number can go through the quadrupole forward into the detector, and the concentration of the relevant component is obtained by counting the number of ions that arrive. Quick switching of the mass number to be detected makes it possible to simultaneously measure the concentrations of multiple gas components at high sensitivity[6)].

Soft-ionization mass spectrometers can also be used to continuously measure 1,3-butadiene and benzene, and thus this instrument is expected to play an important role in reducing such harmful hydrocarbons in exhaust gas.

4 Conclusion

In this paper I have discussed the current state of measurement systems for diesel engine emissions, and future trends. Although I did not discuss computer-aided automatic measurement systems here, it goes without mention that these systems help maintain the accuracy of increasingly complex emissions measurements and are an important factor in improving measurement efficiency.

Emissions measurement is becoming increasingly important for the improvement of diesel engines and the development of exhaust gas after-treatment systems. We hope that our measurement systems will serve in the reduction of diesel engine pollution.

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