Environmental Automated Measuring Systems for Flue Gas

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ABSTRACT

Flue gas regulations have been enacted into law in order to prevent air pollution in countries such as Japan, Europe and China. With a conventional-type continuous flue gas measuring system consisting of a sampling-type gas analyzer that samples flue gas and performs pre-processing, the realization of long-term stable measurements has encountered such problems as requiring the removal of blockage or contamination in the sampling pipe, periodic calibration of the analyzer, increased power consumption of heating tube, and so on. Fuji Electric's simultaneous seven-component measuring gas analyzer uses cross stack laser method for HCl measurement and is capable of overcoming the above problems. Fuji Electric is also advancing research and development so that the cross stack laser method can be used for measuring other components.

1. Introduction

The flue gas emitted from thermal power generation and boiler equipment, and from industrial furnaces used for steel production, cement production and the like is known as a stationary source, and is a major cause of air pollution. Countries such as China, India and Russia, have rapidly raised their GDP with vigorous production activities. However, global environmental pollution due to flue gas and waste water has become a serious problem, and environmental protection initiatives, especially the Kyoto Protocol, are essential for all countries. In Japan and Europe, restrictions on flue gas emission have already been deployed in each industry, and the results have been evaluated. Meanwhile, in China, legislation and implementation based on emissions standards in advanced countries are being advanced as a national project. However, so far such activities have only focused on large corporations. In India and Russia, environmental legislation is being advanced, and future full-scale implementation is anticipated.

For measurement of the regulated substances in flue gas, in addition to the official method of manual analysis (the specified analytic method used in international organizations, and national or official testing institutions and research laboratories that conform to national standards), the installation of an environmental measurement system containing a built-in continuous automatic analyzer is mandated in order to measure the total amount of emitted matter. The environmental measurement system used for flue gas is known as a continuous emission monitoring system (CEMS) and is equipped with an analyzer that has been approved by each country and is provided with functions for measuring the concentration, temperature, pressure and flow rate of regulated substances, and also with functions for forms control, for sending data to regulatory authorities, and so on. As a result of activities to protect the global environment, the CEMS market is expanding. Especially in China, the CEMS market is expected to grow by more than 10% annually, and Japanese, European and domestic Chinese manufacturers of analyzers are entering this market.

Fuji Electric's automation business is centered on "energy, environment and safety" technology, and aims to make a positive contribution to society. The development of an environmental measurement system for monitoring flue gas is based on sensing, data processing and transmission and other important automation technology. Below, Fuji Electric's environmental measurement system for monitoring flue gas and an implementation example are described. The future outlook is also discussed.

2. Each Country's Laws and Regulations Concerning Flue Gas

Table 1 lists each country's laws and regulations relating to air pollution control. In Japan, with the industrial development that began in the 1960s, adverse health effects have resulted from the photochemical smog caused by sulfur dioxide and nitrogen oxides contained in the flue gas emitted from factory stacks. As a result, the government enacted an "Air Pollution Control Law" (1968) and enacted regulations on smoke and soot emissions. Thereafter, flue gas washing technology that uses pollution control equipment such as

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Table 1 Laws and regulations of each country to prevent air pollution

Item	Japan			Europe (EU)			China		
Laws & regulations	Air pollution control Law (1968) Electricity Enterprises Law (1964) The Basic environment Law (1993)			Directive on Ambient Air Quality Assessment and Management (1996) Directive on the Incineration of Waste (2000) Directive on the Limitation of Emission of Certain Pollutants into the Air from Large Combustion Plants (2001)			Integrated Emission Standard of Air Pollutants (1997) Enactment of Emission Standards by Industry (1997)		
Measurement device certification	Measurement Law (revised 1996) JIS			European Norm EN1418 (2004) EN 14956 (2002)			China Environmental Protection Related Standard (2002) (HJ/T 76-2001) “Specifications and Test Procedures for Continuous Emission Monitoring Systems of Flue Gas Emitted from Stationary Sources”		
Certifying authority	JQA (Japan Quality Assurance Organization)			TÜV (Germany) MCERTS (England), etc.			Ministry of Environmental Protection of the People’s Republic of China		
Environmental standards	Components	Range	Method	Components	Range	Method	Components	Range	Method
	SO_2	0~50 ppm~	IR	SO_2	0~50 ppm~	IR	SO_2	0~50 ppm~	IR
			UV			UV			UV
	NO_x	0~50 ppm~	IR	NO_x	0~50 ppm~	IR	NO_x	0~50 ppm~	IR
			Chemiluminescence			Chemiluminescence			Chemiluminescence
	CO	0~50 ppm~	IR	CO	0~50 ppm~	IR	O_2	0~25%	Paramagnetic
	CO_2	0~20%~	IR	CO_2	0~20%~	IR			Zirconia
	O_2	0~25%	Paramagnetic	O_2	0~25%	Paramagnetic			Galvanic
			Zirconia			Zirconia	Dust	0~1,000 mg/Nm^3 ~	Light transmission
	Dust	0~100 mg/Nm^3 ~	Light transmission	Dust	0~100 mg/Nm^3 ~	Light transmission			Electrostatic quantity
			Electrostatic quantity			Electrostatic quantity	HCl	0~1,000 mg/Nm^3 ~	IR
	HCl	0~50 mg/Nm^3 ~	Ion-selective electrode	HCl	0~50 mg/Nm^3 ~	IR			
			IR						
	Measurement components and concentration may vary depending on the type of industry			Measurement components and concentration may vary depending on the type of industry			Measurement components and concentration may vary depending on the type of industry		
Sampling method	Direct sampling type, cross stack type			Direct sampling type, cross stack type			Direct sampling type, dilution type, cross stack type		

desulfurization and denitrification equipment, dust collectors and the like, and technology for the continuous automatic measurement of regulated substances has been developed(1).

In Europe, laws and regulations concerning air pollution control are well underway from 1950s and emission monitoring systems are being installed sequentially, beginning with business entities that emit large quantities of flue gas, and the installation of such equipment is nearly complete in Japan and Europe. In the future, in response to stronger local regulations, the addition and installation of automatic continuous measurement devices is anticipated for monitoring low concentrations and for newly regulated substances such as mercury.

In China, the Integrated Emission Standard of Air Pollutants (1997) and the Specifications for Continuous Flue Gas Analysis (2002) were enacted based on Euro-American standards, and emission regulations were initiated for large-scale coal power plants near large cities. Emission regulation in China is less strict than in Europe, the US and Japan, but in the future, the expansion of emission regulation to more than 20,000 medium and smaller-size boilers and heat treatment furnaces is estimated to result in the addition of regulated substances and to accelerate the regulation of emissions.

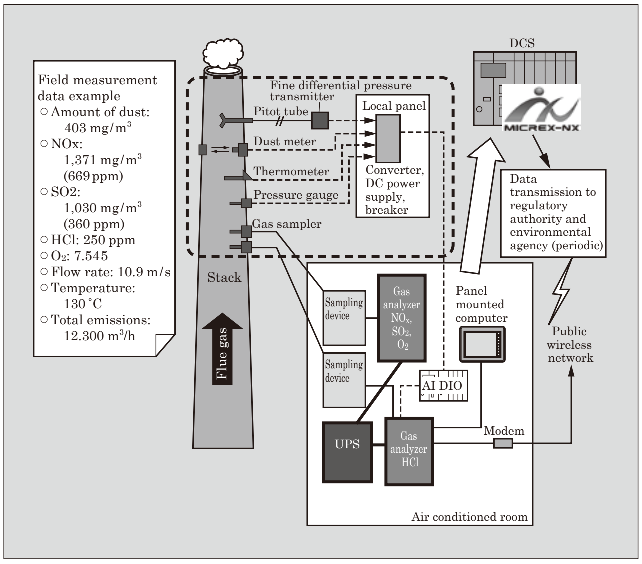
3. Current Status of Continuous Emission Monitoring Systems

Figure 1 shows an example of a continuous emission measurement system for measuring nitrogen oxides (NO_x), sulfur dioxide (SO_2), oxygen (O_2) and hydrogen chloride (HCl). A gas extractor, a dust meter, a pressure meter, a thermometer and flow meters (Pitot tube and differential pressure gauge) for measuring flue gas are installed in a smoke stack. In this system, after the primary filter of the gas extractor removes dust, a sampling device removes dust and moisture, and then the result is fed to an analyzer to continuously measure each measurement component of the flue gas. Hydrogen chloride content is measured with a separate dedicated analyzer since the measuring method is different. The system transmits measured values to a computer or distributed control system (DCS), performs temperature and pressure compensation, stores data, generates the appropriate written forms, and periodically transmits the measured values and equipment status to the regulatory authorities. An uninterruptible power supply is used frequently as the power supply. Continuous emission monitoring systems are housed in an air-conditioned analysis room or analysis chamber. The challenges for long-term stable operation of a continuous emission measurement system are described below.

(1) Stability of the sampling device

With a sampling-type analyzer, pre-processing of a sample gas that is suitable for the plant is essential, and the stability of the sampling device is important. In particular, in China where the main fuel is coal, care must be taken to remove sulfuric acid mist and dust, which cause pipe blockages and contamination, from the flue gas.

Fig.1 Example of continuous gas emission monitoring system



(2) Handling of analyzer

Because specialized knowledge is needed to resolve problems involving abnormal measurement values, the manufacturers of continuous emission monitoring systems must train and guarantee the availability of service personnel skilled in trouble resolution. The different measurement principles (Table 1) for the components being measured with an analyzer leads to complicated handling.

(3) Periodic calibration of analyzer

In order to maintain its precision, the analyzer must be calibrated periodically with a traceable standard gas for each measurable component. The calibration cycle ranges from once per week to once per month. Automatic calibration is possible with a sequence that uses the traceable standard gas in combination with a solenoid value, but the results are uncertain in cases involving piping anomalies or an empty gas cylinder, and a final check by a human is essential. Also, the periodic preparation of standard gas is very expensive.

(4) Power consumption

The gas sampling device and piping that feed the sample gas to the analyzer apparatus are heated to more than 100 °C in order to reduce dissolution loss of the measurable components due to condensation and to prevent corrosion of the metallic areas. The sampling tube extends from 30 m to 50 m, and accounts for more than 50 % of the total power consumption. In a continuous emission monitoring system for NO_x, SO_2 and O_2, and including a hydrogen chloride (HCl) analyzer based on the ion-selective electrode method, because each analyzer requires a heating pipe, the total power consumption exceeds 4,000 VA. Moreover, if a system is to be installed in an environment where the ambient temperature exceeds the installed temperature conditions, an air-conditioned analysis chamber or room is often used to house the system. However, this will lead to increased power consumption when the system is used for continuous emission monitoring.

To summarize the above challenges, it is desirable that a measurement system is capable of simultaneous and continuous measurement and is strongly resistant to sulfuric acid mist and dust, and that the analyzer is easy to handle, maintenance cost is low, and the operation is stable.

4. Environmental Measurement System Proposed By Fuji Electric

Shown in Fig. 2, the "ZSU-7" seven-component simultaneous gas analysis system that forms the core of an environment measurement system for monitoring flue gas is described below.

4.1 Environment measurement system

In order to overcome the abovementioned challenges, the ZSU-7 measures the four components of

NO_x, SO_2, CO and CO_2 with an infrared method, and measures O_2 with a zirconia method, using sampling system. Moreover, the ZSU-7 is an integrated analysis apparatus[2] that also measures HCl with a cross stack laser gas analyzer for which a sampling device is unnecessary, and measures dust with an electrostatic induction method. The necessity of sampling devices has not completely been eliminated for all measurable components, but a cross stack laser analyzer which does not require a sampling device is used to measure hydrogen chloride. The cross stack laser method provides significant benefits for overcoming the above abovementioned challenges.

4.2 Measurement method

(1) Laser type

The measurement principles of the laser-type gas analyzer are shown in Fig. 3, and a schematic drawing of its installation is shown in Fig. 4. The relationship between infrared absorption intensity and concentration of the measurement gas can be expressed with the same "Lambert-Beer Law" (see Eq. (1)) as with the conventional infrared gas analyzer, but the method of detecting the concentration is different. The emission wavelength of an infrared semiconductor laser light source is modulated at a fixed cycle, and the vicinity of the absorption spectrum of the measurement gas components is scanned. At this time, according to the gas concentration, sample gas that passes through the laser light is absorbed and the volume of transmitted light reaching the receiver unit decreases. This volume of transmitted light is detected at the photodiode of the receiver unit, and the gas concentration is measured with synchronous detection by detecting twice the frequency of the modulated signal[3][4].

The relationship between infrared absorption intensity and concentration adheres to the Lambert-Beer Law and is expressed by Eq. (1).

$$I = I_0 e^{-kCL} \quad \cdots\cdots (1)$$

I : intensity of transmitted infrared light
I_0: intensity of emitted infrared light
k : coefficient of absorption
C: concentration of measurable component
L : length of measurement cell

(2) Infrared type

Figure 5 shows the configuration of an infrared gas analyzer.

The infrared-type gas analyzer uses a double-beam non-dispersive infrared method. The light emitted from the infrared-red light source is split into two halves by a distribution cell, and irradiated on sealed reference cell containing inert gas having no infrared absorption and a sample cell through which sample gas flows. The incident infrared rays are absorbed in the sample cell according to the gas concentration.

The detector contains two detection spaces for re-

Fig.2 Appearance of the "ZSU-7" Seven-component simultaneous measurement gas analyzer apparatus

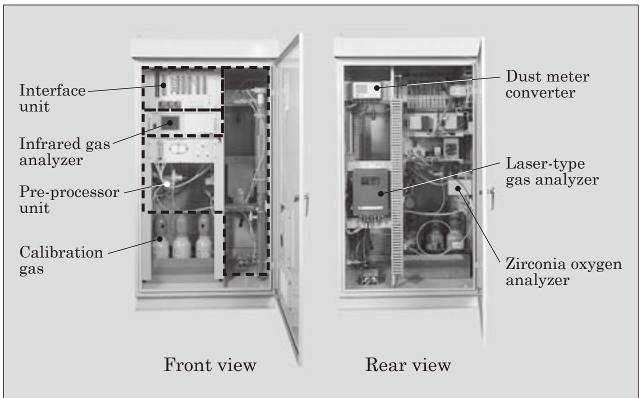


Fig.3 Measurement principle of laser-type gas analyzer

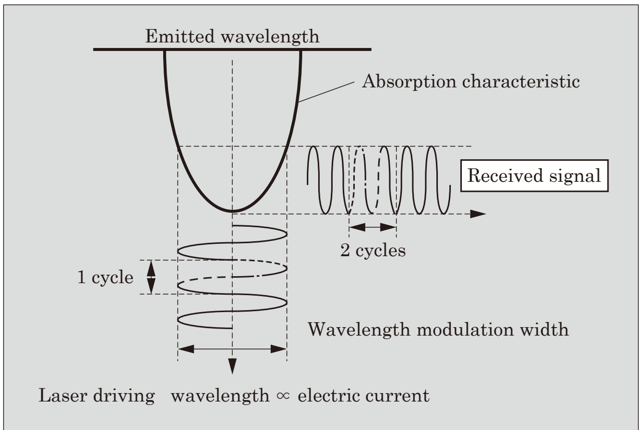


Fig.4 Schematic drawing of laser-type gas analyzer installation

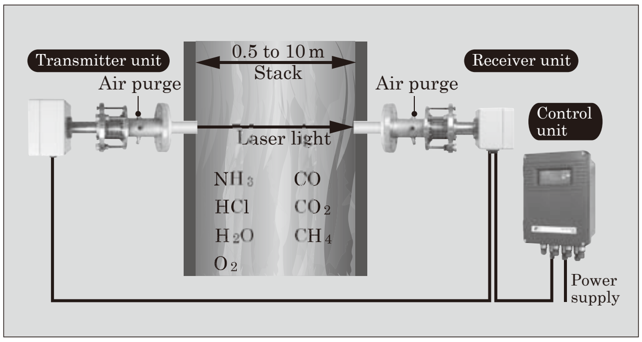


Fig.5 Configuration of infrared-type gas analyzer

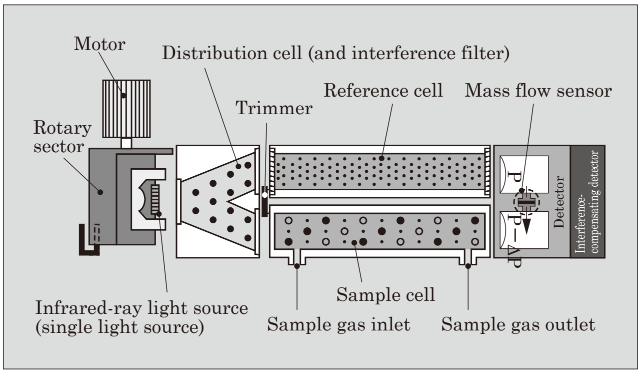


Table 2 Advantages of the cross stack laser gas analyzer

Item	Ion-selective electrode-type infrared gas analyzer	Cross stack laser gas analyzer	Advantage of cross stack laser gas analyzer
Sample gas sampling method	Sampling type	Cross stack type	Simple measurement system
Pre-processing Sampling device	Necessary	Unnecessary except for gas purging	Low lifecycle cost Low power consumption
Measurement gas	NO, NO_2, SO_2, HCl, NH_3, CO, CO_2, CH_4...	HCl, NH_3, CO, CO_2, O_2, CH_4, H_2O (NO, NO_2, SO_2)※1	Water-soluble, adsorptive gases such as NH_3 and HCl can be measured without loss
Response time	2 to 4 minutes (not including tube)	1 to 5 seconds	Applicable to plant control No deviation in responses to different measurement components
Dust resistance	0.5 g/Nm^3 (max.)	30 g/Nm^3 (max.)	Can be applied to combustion control and denitrification control without pre-processing
Maintenance	12 to 24 times/year	1 to 2 times/year	Low lifecycle cost Few parts requiring maintenance
Calibration	53 times/year (weekly)	1 to 2 times/year	Low lifecycle cost
Interference from other gases	Countermeasures may be implemented depending on measurement components and concentration	Rare	Almost none
Stability	±2 % FS*2/week	±2 % FS*2/6 months	Good stability adjacent zero point Low lifecycle cost

*1: Gas targeted in the next development
*2: Full-scale (FS): Measurement range

ceiving the infrared rays that have passed through the reference cell or the sample cell. The detection tanks are filled with the same gas as the measurable components, and according to the difference in absorption, a pressure difference proportional to the amount of light is generated in the two spaces. From the pressure difference (ΔP) of the detection tanks and the correlated change in resistance (ΔR) of the mass flow sensor, the concentration of measurement gas can be expressed with Eq. (2).

$$\Delta R \propto \Delta P \propto I_0 - I = I_0(1-e^{-kCL}) \fallingdotseq kCL \cdots\cdots (2)$$

4.3 Implementation example

A half-year field test of a continuous automatic measurement system that combines a laser-type analyzer and an infrared gas analyzer performed with the general waste incinerator of a certain Tokyo-based facility is described below as an example implementation.

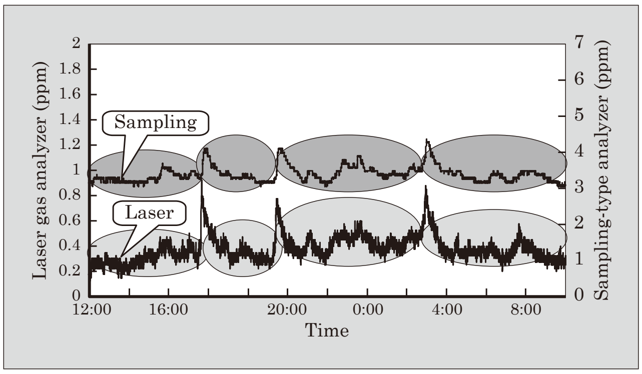
Figure 6 shows the correlation between the measured values of a sampling-type hydrogen chloride analyzer and a laser-type gas analyzer.

The sampling-type hydrogen chloride analyzer was installed at approximately the same site as the laser-type analyzer.

From the output trend, a correlation relationship can clearly be seen. In a manual analysis value for this period, the correlation with the laser-type analyzer was obtained at an average HCl concentration of 0.5 ppm. Zero drift performance was stable with no more than 0.5 % full-scale fluctuation over a half-month.

The power consumption could be reduced by at least 2,000 VA compared to a flue gas continuous monitoring system combined with a sampling-type hydrogen chloride analyzer

Fig.6 Correlation between measured values of sampling-type hydrogen chloride analyzer and laser-type gas analyzer



4.4 Advantages of the cross stack laser gas analyzer

Advantages of the cross stack laser gas analyzer are listed in Table 2.

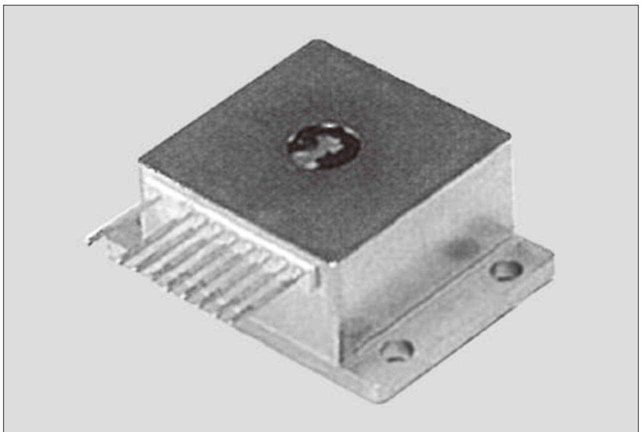
The cross stack laser gas analyzer does not have a sampling device and only needs gas purging control. With long-term stability that fluctuates by only ±2% full-scale over 6 months, the analyzer requires little maintenance and infrequent calibration. Since there is no need for a heated sampling tube, a greater than 40% reduction in power consumption compared to a hydrogen chloride analyzer was achieved. Compared to a sampling-type ion-selective electrode-type hydrogen chloride analyzer, the lifecycle cost for maintenance was reduced to less than half.

5. Future Efforts

If the cross stack laser gas analyzer becomes capable of measuring all regulated substances, the abovementioned series of problems could certainly be resolved all at once. Currently, cross stack laser gas analyzers can only be manufactured with semiconductor laser light sources that are in the near-infrared wavelength band (700 to 2,000 nm range). Therefore the detectable components and measurement sensitivity, and the number of components that can be detected simultaneously are limited. When monitoring air quality with a cross stack laser gas analyzer, because the absorption wavelengths for NO, NO_2 and SO_2 are in the mid-infrared wavelength band (4,000 to 8,000 nm), the difficulty of measurement and the inability to measure an arbitrary number of components simultaneously are problems.

Through joint research with Hamamatsu Photonics K.K., Fuji Electric is engaged in development work that will enable detection of NO, NO_2 and SO_2 using a quantum cascade laser capable of emitting light in the mid-infrared wavelength band (4,000 to 8,000 nm wavelength). Figure 7 shows the appearance of the newly developed quantum cascade laser light source that emits light at a wavelength of 7,300 nm and is capable of detecting SO_2. The SO_2 detection has been verified as having the same level of sensitivity as that of the previous sampling-type gas analyzer, and is ready for practical application.

Fig.7 Appearance of quantum cascade laser source



6. Postscript

As described herein, in addition to being energy-efficient, the cross stack laser gas analyzer also provides higher response, has fewer parts requiring considerable maintenance and is easier to maintain than the conventional sampling-type gas analyzer, and its range of applications is expected to expand. As awareness of environmental preservation heightens throughout the world, the addition of new components to measure and the ability to handle multiple components will become necessary. Fuji Electric will continue to develop technology to meet these needs and intends to make positive contributions to society with environmental technology that incorporates automation.

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