Development of the Multi-Component Gas Analyzer VA-5000 Series

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The VA-5000 series is a series of Multi-Component Gas Analyzers that can measure up to four components with one unit. Measurement principles of NDIR (non-dispersive infrared method), CLA (chemiluminescence analysis), and Oxygen analysis method (MPA (magnetopneumatic method), zirconia method, and galvanic cell method) can be utilized. This product has been developed as a successor to the Multi-Component Gas Analyzer VA-3000 series[1]. It has been improved in such aspects as miniaturization of the device size, increasing the maximum number of components that can be measured (maximum: 4 components), high sensitivity (minimum concentration range: 50 ppm), operability. This article describes the features of the VA-5000 series and introduces examples of application to the IGCC (Integrated coal Gasification Combined Cycle).

Product Overview

The external appearance and main specifications of the VA-5000 system are shown in **Figure 1** and **Table 1**, respectively. It can be used in combination with a pretreatment device VS-5000 for dehumidifying and removing dust from the sample gas. This system, assembled into a 19-inch panel mount case, can accommodate up to four gas component measurements simultaneously.

Measurement Principle of the Flow Sensor Type Detector

The flow sensor type detector can be used in the NDIR measurement module. When a molecule consisting of more than two different atoms is illuminated with infrared light, transition between vibration and rotation energy levels of the molecule occurs in general, and the infrared light having a wavelength that is particular for this molecule is absorbed.

The NDIR module measures the amount of infrared absorption allowing the quantitative analysis of a particular gas component. The amount of infrared absorption changes depending on the concentration of molecules to be measured. This relationship is expressed by Equation 1 giving the Lambert-Beer law.

Figure 1   External Appearance of the VA-5000 and the VS-5000

Table 1   Specifications of the VA-5000 system

Measurement principle		NDIR (Non-Dispersive Infrared)	CLA (Chemiluminescence)	MPA (Magnetopneumatic)	Zirconia	Galvanic cell
Components to be measured		CO, CO_2, CH_4, SO_2, N_2O, etc.	NO	O_2		
Minimum range		0 to 50 ppm (depends on component)	0 to 20 ppm	0 to 5 % (vol)	0 to 5 % (vol)	0 to 5 % (vol)
Maximum range		0 to 100% (vol) (depends on component)	0 to 5000 ppm	0 to 100 % (vol)	0 to 25 % (vol)	0 to 25 % (vol)
Range ratio		1:10	1:100	1:10	1:5	1:5
Linearity		±1.0 % of full scale/week				
Drift		±2.0 % of full scale/week				±1.0 % of full scale/day
Response time		90 % response: within 30 seconds				
Warm-up time		60 min			20 min	40 min
Gas flow rate		Approx. 0.5 L/min				
External dimensions	(W)	430 mm				
	(H)	132 mm				
	(D)	380 mm	451 mm	380 mm		
Mass		7 kg to 18 kg (Depending on the combination of mounted components)				
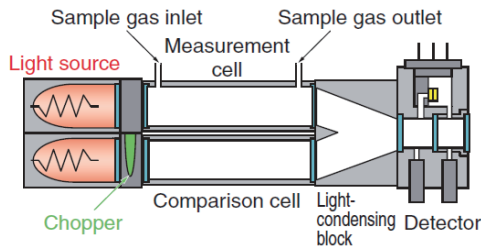
Figure 2   Structure of the NDIR measurement module used in the VA-5000 system

$$I= I_0 \exp (-\mu cd) \quad\text{.. (1)}$$

I_0 : Incident light intensity

I : Transmitted light intensity

c : Concentration of light absorbing molecules (gas component to be measured)

μ : Absorption coefficient (determined by molecule type and wavelength)

d : Thickness of absorbing molecule layer (gas layer)

Since I_0, μ and d are constants determined by the type of the gas to be measured and the equipment, it is possible to obtain the concentration (c) of the gas component by measuring the transmitted light intensity (I). In this method, the wavelength selectivity of the infrared detector is an important factor for measuring absorption without being affected by other gas components. In the VA-5000 system, an excellent wavelength selectivity has been realized by using a pneumatic type detector into which the same kind gas component as the target is charged[2].

Figure 2 shows the structure of the NDIR measurement module used in the VA-5000 system. The infrared light goes from the light source through the measurement cell or the comparison reference cell and enters into the detector after being condensed by the light-condensing block. These two infrared beams are split using a rotating chopper as the light enters alternately into the detector.

Figure 3 shows the structure of a flow sensor type detector used in the NDIR measurement module of the VA-5000 system. This
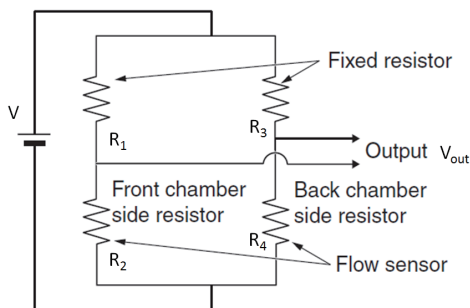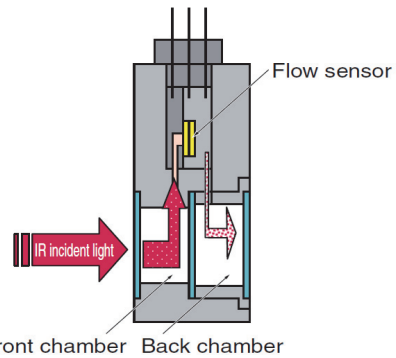

Figure 3   Structure of the flow sensor type detector

detector has two light input chambers; a front chamber and a back chamber, and a flow sensor using a hot wire resistance located between the two chambers. Inside the light input chambers, the gas of the same kind as the gas component to be measured is enclosed. If the target gas is present inside the measurement cell, infrared light is absorbed in proportion to the gas concentration and, as a result, the intensity of the infrared light transmitted through the measurement cell decreases. On the other hand, if a gas that does not absorb infrared light is enclosed in the cell, the infrared light is not attenuated, that is, the intensity of transmitted light will be unchanged. Since the transmitted light coming via the measurement cell and the light coming via the comparison cell enter alternately into the detector due to the operation of the chopper, different intensities of infrared light enter alternately into the detector. The gas enclosed in the front and back-chambers of the detector repeatedly contracts and expands depending on the exposure time and the intensity of the incident infrared light. Since the amount of infrared light incident into the back chamber is less than that incident into the front chamber (because of the absorption inside the front chamber), the expansion and contraction of the gas in the front chamber, is greater than in the back chamber. As the result, there is a movement flow of gas between the front and the back-chambers. The flow sensor comprised of two hot-wire resistors is placed perpendicular to the direction of the gas flow from the front chamber to the back chamber. The hot-wire resistors are biased to keep their temperature higher than the ambient temperature. When gas flows from the front chamber to the back chamber, the temperature of the hot-wire resistor of the front chamber side decreases and the temperature of the hot-wire resistor of the back chamber side increases, and vice versa. Since the resistance value depends on the temperature, by detecting the change of resistance value using a bridge circuit as shown in **Figure 4** as a change of voltage, it is possible to obtain the changing infrared absorption as an alternating electrical signal.
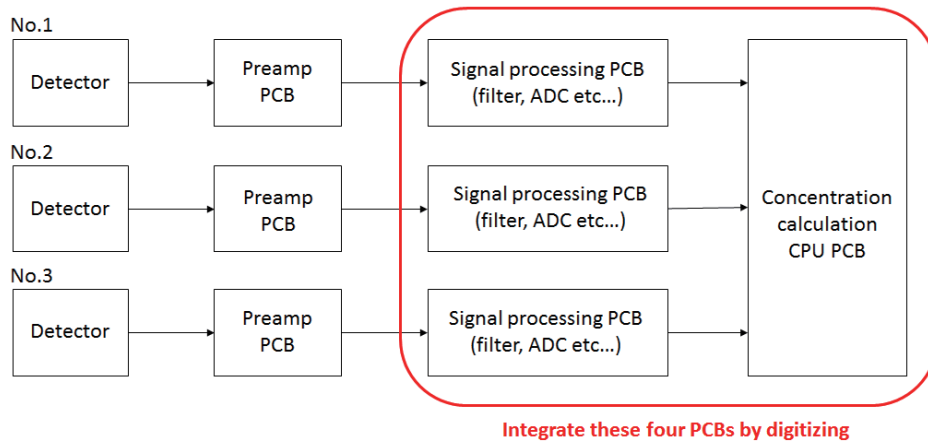

Figure 4   Bridge Circuit

Integrate these four PCBs by digitizing

Figure 5   Structure of the signal processing PCBs

Improvements Over the Previous Model

It was improved over the previous model in the following three points.

- Miniaturization of the device size and increasing of the maximum number of mounting components
- Sensitivity
- Operability

Miniaturization of the device size and increasing of the maximum number of mounting components

The demand for analyzer miniaturization has been increasing with such trends in customer needs, as device usability in a small space. For that, it was necessary to solve the following two issues.

- Measurement module size was too large
- Printed circuit board size was too large

In order to achieve a size reduction of 30% (15% for a CLA module), we first reduced the cell length of the NDIR measurement module by 20%. By shortening the cell length, the signal amount with respect to the gas concentration decreases.
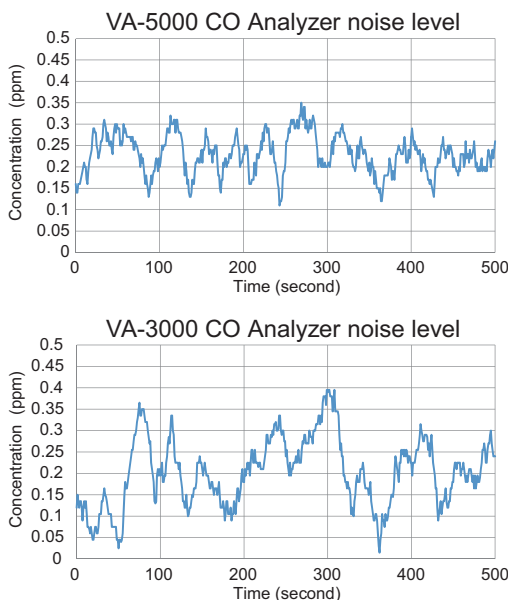

Figure 6   Difference in Noise Level

The details of this countermeasure against signal decrease are shown in the following section ("High sensitivity"). Regarding the printed circuit board, in the previous model, one signal processing circuit board was mounted for each measuring module. As shown in **Figure 5**, the signal processing circuit is now digitized and the printed circuit boards are integrated in one sheet in the VA-5000. Therefore, the analog circuit components are greatly reduced, and the board area of the entire analyzer has decreased down to 50%. As a result, the depth of 380 mm (451 mm when a CLA module) is achieved, compared to 430 mm (W) x 132 mm (H) x 550 mm (D) of the previous model. The measurement modules are independent of each other, and it is possible to combine them so that the maximum number of components measured by one unit increases up to four. Thereby, compared with the maximum number of 3 components in the previous model, more gas measurement targets have become possible with one unit.

High sensitivity

A higher sensitivity of the NDIR measurement module has also been achieved. In order to increase the sensitivity, it was necessary to increase the signal amount with respect to the gas concentration. It can be achieved by increasing the temperature of the hot wire resistance in the flow sensor type detector. The concentration signal (V_{out}), shown in **Figure 4**, can be obtained from Equation 2.

$$V_{out} (V \cdot (R_2/ (R_1+R_2) - R_4/(R_3+R_4) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

The voltage (V) to be supplied to the bridge circuit is increased, the power supplied to the flow sensors R_2 and R_4 is increased accordingly, and the temperature of the hot wire resistance is raised. As a result, the concentration signal (V_{out}) can be increased. **Figure 6** shows the zero noise level in comparison with the previous model VA-3000 in an observation at the 50 ppm range of CO measurement. Both cell lengths are set to be the same as the VA-5000 in the measurement. As the amount of signal has increased, a reduction of the zero noise level has been achieved. In addition, by improving the influence of temperature,

Table 2　Minimum range comparison

Components to be measured	Previous Model VA-3000	New Model VA-5000
CO	100 ppm	50 ppm
CO_2	100 ppm	50 ppm
CH_4	200 ppm	100 ppm
SO_2	200 ppm	100 ppm

Figure 7　Trend Graph

a lower concentration range has been attained as shown in **Table 2**. As a result, the range of the concentrations that can be selected increases, making it possible to provide an analyzer suitable for various purposes.

Operability

Focusing on easy of use, a 5.7 inch color LCD and a touch screen are adopted. Conventionally, if there was no peripheral such as a data logger outside of the device, it was not possible to save the gas concentration data or check the trend. However, the preparation of the peripheral device is troublesome and takes up space for installation. As an improvement, by displaying the trend graph shown in **Figure 7** on the LCD, it is possible to visualize the trend of the measured values and grasp the measurement situation instantaneously. In addition, the data logging function can be built in the analyzer, the measurement value, measurement time, and event information at the time of measurement can be recorded in real time, and the data can be transferred on a USB flash drive. Therefore, it became unnecessary to set an external data logger outside the analyzer, and it became possible to measure the gas more easily.
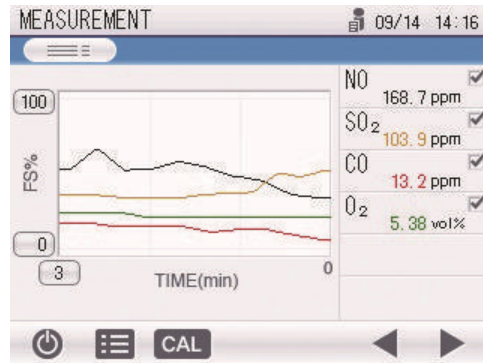
Measurement Combining Sampling Units

The VA-5000 can be combined with a VS-5000 series sampling unit which performs pretreatment of the sample gas more easily to measure the gas. The VS-5000 series has four models depending on the measurement application. **Figure 8** shows a flow chart of the combination of the VA-5000 series (model: VA-5111) with three NDIR measurement modules and VS-5000 sampling unit (model: VS-5001). The sample gas is pretreated with dehumidifying and dust removal by the VS-5000, after which the gas that has been object of the pretreatment is admitted in the VA-5000 analyzer and the concentration of the target gas is measured.

Application to the integrated coal gasification combined cycle (IGCC)

The VA-5000 is an analyzer that responds widely to the needs of the time, from environmental problems to supporting new energy development. Analyzing gas components has become very important in such fields as fuel cell development, catalytic agent research, bio-gas research, aeration tank monitoring, engine
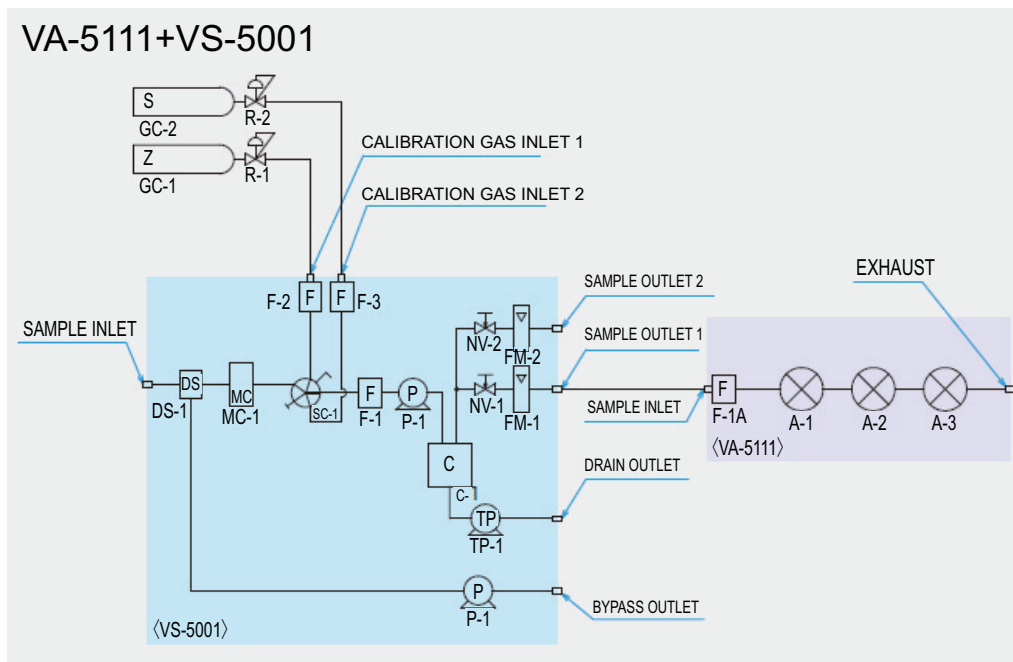

Figure 8　Flow chart

combustion efficiency research, and so on. In the field of the next coal power generation, an example of application in the integrated coal gasification combined cycle (IGCC) can be cited. The IGCC is a combined cycle power generation that converts coal into gas in a gasifier, combines a gas turbine and a steam turbine to generate electricity, has higher power generation efficiency than conventional coal-fired power generation and can reduce CO_2 emissions. The VA-5000 is used at each measurement point of the IGCC plant, and it is able to simultaneously measure CO, CO_2, O_2, CH_4. Therefore, it can be highly expected to contribute in such new energy development field.

References

[1] Norikazu IWATA, Multi-Component Gas Analyzer VA-3000 serise, Readout, **31**, pp.26-29 (2005).
[2] Junji AOKI, Pneumatic Infrared Detector, Readout, **7**, pp.64-71(1993).
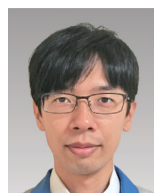
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