DOG optical gas analyzers

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Received November 12, 2001

Stationary gas analyzers for continuous monitoring of sulfur and nitrogen oxides in exhaust gases of the electric power plants burning fossil fuels are developed. Gas-analyzers use of non-laser UV radiation sources and DIAL measurement technique. Operation of the gas-analyzers at Russian electric power plants showed their high efficiency, reliability, and easiness in operation at lower cost as compared to similar foreign devices.

The increasing role of anthropogenic factors in nowadays global and regional nature and climate changes is closely connected with the increasing scale of environmental pollution. Among the main technogenic substances polluting the atmosphere are nitrogen and sulfur oxides coming to the atmosphere from burning of fossil fuels, and their amount and composition depend significantly on the kind of fuel and burning conditions. Thus, at burning of natural gas, sulfur oxides are almost absent in the exhaust gas mixture, but they are present in large amounts at burning of such sulfur-containing fuels as coal and black oil.

The largest amount of fuel are now burnt at heat and electric power plants, which are the main sources of nitrogen and sulfur oxides emissions to the atmosphere. Monitoring of pollutant emissions and their minimization are among the main tasks of the environmental management in heat-and-power production, to accomplish which both portable multicomponent gas analyzers and stationary continuous automated gas analyzers are employed. The former are used for start-and-adjustment works at a electric power plant and express analysis of the exhaust gases by ecological inspections, while the latter ones are applied for optimization of the process of fuel burning and organization of objective and continuous ecological monitoring at the sources of atmospheric emissions. Gas analyzers of the second type are most promising for monitoring of pollutants and therefore they are of particular interest in technical modernization of already existing and new electric power plants.

The Laboratory of Ecological Instrumentation of the Institute of Optical Monitoring SB RAS has developed a series of stationary automated gas analyzers for measuring nitrogen and sulfur oxides in exhaust gases of electric power plants.[1,2] DOG-1 gas analyzer is designed to measure the content of nitrogen monoxide (NO) in exhaust gases of electric power plants burning natural gas, DOG-2 gas analyzer is intended for measuring sulfur dioxide (SO_2) at electric power plants burning coal and black oil, and DOG-3 gas analyzer is designed for simultaneous measurements of both nitrogen monoxide and sulfur dioxide at electric power plants burning any kind of a fossil fuel. All these optical gas analyzers employ the same operating principle, have similar design (Fig. 1), and differ only by spectral regions used, operating algorithms, and methods of signal processing.

Fig. 1. External view of the DOG gas analyzers.

The DOG optical gas analyzers use the differential absorption lidar (DIAL) technique to measure the content of the gaseous species. This method assumes comparison of optical fluxes passed through the cell with the gas medium studied in some specially selected spectral intervals, which are characterized by essentially different absorption coefficients of the gases under control. The number of spectral intervals, in which the absorption coefficient is measured, is determined by the number of absorbing components of the gas medium studied and varies from no less than two for the medium with one absorbing component to no less than three for the medium with two absorbing components. Technologically, the use of DIAL method in DOG gas analyzers is implemented with a cw UV radiation source and interference filters separating from the continuous spectrum some spectral regions, whose width is determined by the filter pass band. The filter pass band is changed through filter turn by a stepper motor through a given angle. This method of tuning allows the filter pass band to be shifted by several half-widths toward shorter wavelengths.

DOG gas analyzers operate in the spectral region from 219 to 235 nm. Selecting just this region is motivated by the fact that it includes molecular absorption bands of only NO, NO_2, and SO_2 molecules.

0235-6880/02/01 74-04 $02.00

Since the content of nitrogen dioxide (NO_2) in exhaust gases does not exceed 5% of the total amount of nitrogen oxides,[3] we can avoid measuring NO_2, and its small amount in exhaust gases does not affect considerably the accuracy of determination of the nitrogen monoxide and sulfur dioxide concentrations. The absorption coefficients of nitrogen monoxide and sulfur dioxide[4] in the spectral region of 219–235 nm are depicted in Fig. 2, from which it can clearly be seen that nitrogen monoxide has a well localized absorption band with the half-width ~1.5 nm in this spectral region, and the absorption band of sulfur dioxide has a complex structure overlapping the entire spectral region. Under this conditions, selection of intervals for gas analysis is determined by the structure of the absorption bands of NO and SO_2, as well as by the filter tuning range. Thus, DOG-1 gas analyzer uses the intervals centered at 227.6 and 230 nm, in DOG-2 gas analyzer they are 221 and 223.5 nm, and DOG-3 gas analyzer employs the intervals centered at 226, 227.6, and 230 nm (see Fig. 2).

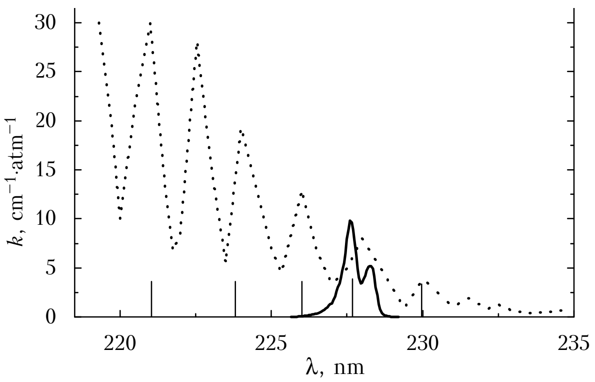

Fig. 2. Absorption coefficients of NO (solid curve) and SO_2 (dotted curve) molecules in the region of 219–235 nm. Vertical bars show the centers of filter pass bands selected for gas analysis.

DOG gas analyzers consist of two units: a measuring head and a control unit. The measuring head includes an LD2(D) gas-discharge deuterium lamp, temperature-controlled cell with pipes for inflow/outflow of the exhaust gas, interference filter (pass band HWHM ~1.5 nm and transmittance at maximum about 15%), and an F-29 photocell. The control unit is a microprocessor system developed by us based on Z80 (DOG-1 and DOG-2) and ATmega103 (DOG-3) CPUs. An operator works with the system through a keyboard and a PC1602 LCD display. The control unit houses also power supplies for the lamp, photocell, and a stepper motor.

Since DOG-1 and DOG-2 gas analyzers have identical operating algorithms and methods for signal processing, only DOG-1 gas analyzer is considered here.[5] When starting the gas analyzer, the control program turns on the deuterium lamp, whose radiation is directed into the cell with the exhaust gas and then spectrally referenced through filter turn. Then the cyclic algorithm of the control program starts. First, the filter is tuned to the spectral interval centered at 230 nm and the photocell signal I_1 is measured. Then the filter is tuned to spectral interval centered at 227.6 nm and the photocell signal I_2 is measured. Using the obtained values I_1 and I_2, the processor calculates the concentration of NO molecules in the exhaust gas by the following equation:

$$N_{NO} = a_1 + a_2(I_2/I_1) + a_3(I_2/I_1)^2 + a_4(I_2/I_1)^3, \quad (1)$$

where the coefficients a_i are determined at calibration of the gas analyzer, which consists in measurement of I_1 and I_2 at different reference concentrations of nitrogen monoxide in the cell and following determination of the coefficients a_i by the least squares method. The obtained values of nitrogen monoxide concentration are shown on the display situated on the face panel of the control unit. Then they come to an external plotter in the form of standard current signals from 0 to 5 mA. In the normal mode, the gas analyzer measures the nitrogen monoxide concentration automatically every 5 seconds.

Operation of the DOG-3 gas analyzer differs by the fact that the cyclic algorithm of the control program involves measurement of three photocell signals I_1, I_2, and I_3 in the spectral intervals centered, respectively, at 230, 227.6, and 226 nm (Ref. 6). The concentrations of nitrogen monoxide N_{NO} and sulfur dioxide N_{SO_2} are calculated in this case by solving the system of equations:

$$I_2/I_1 = b_1 + b_2 N_{NO} + b_3 N_{SO_2} + b_4 N_{NO}^2 + b_5 N_{SO_2}^2 + b_6 N_{NO} N_{SO_2},$$
$$I_3/I_1 = c_1 + c_2 N_{NO} + c_3 N_{SO_2} + c_4 N_{NO}^2 + c_5 N_{SO_2}^2 + c_6 N_{NO} N_{SO_2}, \quad (2)$$

where the values of the coefficients b_i and c_i are also determined through calibration. This system is solved by the iteration method using, as a zero approximation, the values N_{NO}^0 and $N_{SO_2}^0$, which are solutions of the simplified system of equations:

$$I_2/I_1 = a_1 + a_2 N_{NO}^0 + a_3 N_{SO_2}^0,$$
$$I_3/I_1 = b_1 + b_2 N_{NO}^0 + b_3 N_{SO_2}^0. \quad (3)$$

This iteration algorithm provides for unambiguous calculation of the nitrogen monoxide N_{NO} and sulfur dioxide N_{SO_2} concentrations accurate to 1 mg/m^3 already after two iterations.

The specifications of the developed gas analyzers are tabulated below. By their performance characteristics, DOG gas analyzers are highly competitive with similar foreign devices, but have much lower cost.

Specifications of DOG gas analyzers

Parameter	DOG-1	DOG-2	DOG-3
Measured component	NO	SO_2	NO, SO_2
NO concentration measurement range, mg/m^3	0–1000	–	0–1000
Maximum error of NO measurement, %	10	–	10
SO_2 concentration measurement range, mg/m^3	–	0–2500	0–2500
Maximum error of SO_2 measurement, %	–	10	10
Measurement time, s	5	5	10
Supply voltage, V/Hz	220/50	220/50	220/50
Power consumption, W	150	150	150
Dimensions, mm			
measuring head	870×140×200	670×140×200	870×140×200
control unit	280×280×380	280×280×380	280×280×380
Mass, kg			
measuring head	15	12	15
control unit	10	10	10
Time of continuous operation (before replacement of lamp), h	9000	9000	9000

Now only DOG-1 gas analyzer is placed in commercial operation. This gas analyzer passed two-year factory testing at Tyumen TETs-1 electric power plant under the conditions of round-the-clock operation and was recommended for series production. DOG-1 gas analyzer passed state acceptance tests as well and it was included in the State Measuring Technique Register with the number 18915–99 and accepted for use in the Russian Federation.[7] This gas analyzer is produced in small series at the IOM and Research-and-Production Enterprise "Elektrooptika" (Tomsk). By now about 70 gas analyzers are fabricated; they are used at all large electric power plants in the Tyumen Region as standard tools for monitoring of atmospheric emissions of nitrogen monoxide. DOG-2 and DOG-3 gas analyzers designed for boilers burning sulfur-containing fuels are now at the stage of factory testing.

In the process of factory testing of DOG-1 gas analyzer at Tyumen TETs-1 electric power plant, the content of nitrogen monoxide was measured in exhaust gases under different conditions of natural gas burning.[5] Figure 3 depicts gas analyzer data for different conditions of fuel burning in one boiler. Five modes of boiler operation are clearly seen on the plot, the scatter of readouts in the established modes does not exceed 5%. It can be seen from Fig. 3 that the amounts of atmospheric emissions of nitrogen monoxide depend significantly on the conditions of fuel burning.

The ecological and economic efficiency of DOG gas analyzers can be evaluated using the Tyumen TETs-1 electric power plant as an example, because all boilers of this electric power plant are equipped with these gas analyzers. Now each boiler of the Tyumen TETs-1 electric power plant has its own operating chart, which reflects gas analyzer readouts at optimal burning of gas for different operating modes. Such charts allow the operator to follow the fuel burning process by gas analyzer readouts in real time and, correspondingly, to control the optimal conditions of burning of natural gas. At the same time, such continuous monitoring of the nitrogen monoxide concentration in exhaust gases provides for round-the-clock observation of the ecological indices of fuel burning and allows the computational method of determining total emissions of nitrogen monoxide to be replaced with actual values. Thus, thanks to the real-time monitoring, the total emission of nitrogen oxides from the Tyumen TETs-1 electric power plant was decreased by 1500–1700 ton a year (in terms of nitrogen dioxide), what makes up about 30% at the annually mean total emission of 5000 ton (Ref. 8).

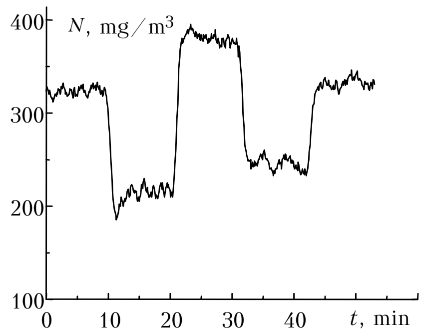

Fig. 3. NO concentration in exhaust gases under different conditions of fuel burning.

Thus, based on the DIAL method in the UV spectral region, we have succeeded in design and manufacture of a reliable, easy to use, and relatively inexpensive gas analyzers of nitrogen and sulfur oxides in exhaust gases of heat-and-electric power plants. These analyzers demonstrated high promises of this method for ecological instrumentation and high efficiency of the design solutions used.

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