Expert study of emission monitoring equipment for Russian thermal power plants

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Abstract. The equipment for production and environmental monitoring, which is operated at many thermal power plants of the Russian Federation at the lower level of systems for continuous monitoring of emissions, is considered. At this level, measurements are carried out on the basis of agreed and certified methods, the collection and conversion of primary information to a standard type, routine maintenance and monitoring of the functioning of measuring systems and auxiliary equipment. The choice of specific gas analytical systems is associated with certain difficulties, since they all have their own advantages and disadvantages, and for the optimal choice of equipment it is necessary to take into account many different factors and parameters. The expert analysis carried out can complement the results of a preliminary survey by personnel of pulverized coal-fired power plants or by a specialized organization that designs systems for continuous monitoring of emissions of such stations, used in the development of the reference terms.

1. Introduction

The organization of permanent systems of continuous industrial monitoring of harmful emissions of thermal power plants (TPP) into the atmosphere is one of the priorities of the global energy industry, as well as the energy strategy of Russia [1-2]. There are two types of harmful emissions monitoring: environmental monitoring (determination of harmful substances in the atmosphere and control of its current state) and production monitoring (monitoring of a specific industrial source of emissions - TPP [3-5]). The implementation of the production monitoring of flue gases from pulverized thermal power plants is one of the most important ways to implement clause 1.1.7 “Obligations of an employee of a power facility” CO 153-34.20.501-2003 (“Rules for the Technical Operation of Power Plants and Networks of the Russian Federation”), requiring from each employee [6]:

- To reduce the harmful effects of production on people and the environment.
- To use the achievements of scientific and technical progress in order to improve efficiency, reliability and safety, to improve the ecology of the energy facility and the environment.
Meeting the requirements allows the implementation of modern systems for continuous monitoring of emissions (SCME) of thermal power plants, which is based on a clear distribution of functions and information exchange between its constituent parts. In [7], it was shown that, taking into account the analysis of the functional scheme of the SCME and the organizational structures of the TPP, as well as the regional energy system, the three-level organizational and hierarchical scheme of the SCME is the most optimal.

This article discusses the lower level of SCME, which includes station equipment and measuring equipment, as well as serving technical staff. It is at the lower level that measurements are carried out on the basis of agreed and certified methods, the collection and conversion of primary information to a standard type (format), routine maintenance and monitoring of the measuring systems and auxiliary equipment functioning.

For this level of the SCME hierarchy, an important aspect of the technical implementation, as shown in [6], is the resolution of issues related to what and how to measure to ensure the production monitoring of flue gas pulverized by thermal power plants. When organizing continuous monitoring at TPPs, various gas analyzers and gas sections can be used to determine the composition of the combustion products. Fundamentally, there are three ways of organizing industrial monitoring at TPPs:

- Continuous monitoring of harmful substances mass emissions on the chimney of a TPP.
- Continuous monitoring of concentrations of harmful substances in the flue gases at each boiler unit of TPPs.
- Combination of the first two ways.

2. Documentation review
Considering the main regulatory documents, we note that the main regulatory document defining the range of flue gas measurements is the CO 34.35.101-2003 “Methodological guidelines for the volume of technological measurements, signaling, automatic control at thermal power plants”, binding all thermal power plants to continuously monitor and record the content of O2, CO and NOx in the flue gases, as well as in the presence of an ash collecting, desulfurization and gas cleaning unit - the concentration of sulfur oxides in the lane based on SO2 and nitrogen oxides concentration in terms of NO2.

In the period from 1990 to 2010 by order of RAO UES of Russia, regulatory documents were developed on the organization and conduct of chemical process monitoring, measurement methods and the calculation of the above technological parameters in flue gases for pulverized thermal power plants:

- RD 34.11.306-86 (MT 34-70-021-86) “Methods for measuring the oxygen content in the flue gases of power boilers”.
- RD 153-34.1.11.353-2001 “Methods of measuring mass emissions of pollutants from boilers using gas analyzers with electrochemical sensors”.
- RD 34.02.305-98 “Methods for determining gross emissions of pollutants into the atmosphere from boilers of thermal power plants”.
- CO 34.02.320-2003 “Organization of control of the composition of products of combustion of stationary steam and hot water boilers”.
- CO 34.02.304-2003 “Guidelines for the calculation of emissions of nitrogen oxides from the flue gases of boilers of thermal power plants”.
- STO 70238424.13.040.40.002-2008 – standard of organization NP “INVEL” “Thermal power plants. Ecological safety. Installations for the cleaning of flue gases from sulfur oxides. Rules and requirements”.

The aforementioned documents were the starting point for the development, implementation and improvement of instruments and systems for the production and environmental monitoring of flue gases for pulverized thermal power plants.
Currently, a large number of Russian enterprises are developing and producing instruments and systems for the production and environmental monitoring of flue gases for thermal power plants. The need to equip them with pulverized coal-fired power plants is dictated by the Federal Law of 21.07.2014 No. 219-FZ “On Amendments to the Federal Law “On Environmental Protection” and certain legislative acts of the Russian Federation” as part of developing programs for the environmental efficiency of enterprises and determining increased rates when calculating fees for the negative impact on the environment for legal entities and entrepreneurs engaged in economic activities to stimulate the implementation of measures to reduce impact on the environment.

One of the solutions to this issue is to equip and reconstruct the already existing gas cleaning and environmental monitoring systems for flue gases of pulverized thermal power plants. In this context, it should be noted that the developers and manufacturers of boiler equipment, starting from 2000, within the framework of requirements for the volume of continuous measurements of boiler equipment technological parameters, separately distinguish the requirement for equipping with means of continuous environmental monitoring of flue gases.

In [7], it was shown that the choice of specific gas analytical systems is associated with certain difficulties, since they all have their advantages and disadvantages, and many different factors and parameters need to be taken into account for the optimal choice of equipment, that is, this task is multicriteria. Moreover, a number of criteria may contradict each other (for example, high technical capabilities may complicate the operation of the system and increase its cost) and not be quantified.

However, the choice of gas analysis systems for production and environmental monitoring should be as objective as possible, independent of the preferences of individual experts and specialists. However, even with the use of a more objective mathematical apparatus of criterial analysis in [8], it is noted that a quantitative assessment of the significance of each criterion (weight coefficient) can be established only by an expert.

3. Materials and equipment
For consideration in the article, the equipment for production and environmental monitoring of the following developers and manufacturers, which is already in operation at many thermal power plants of the Russian Federation, has been selected:

- FSUE SPO “Analitpribor” (Smolensk, Russia) developing the whole range of instruments and systems for environmental monitoring for many industries, energy and transport;
- JSC “Promanalitpribor” (Berdsk, Russia) specializing in the development and production of flue gases analyzers under the brand name “Ekomer”;
- Firm of analytical instrumentation “Informanalitika” (St. Petersburg, Russia), developing and producing a line of analyzers for the control of flue gases for thermal pulverized coal power plants.

Consider the construction and operation of selected gas analyzers.

The stationary multi-component gas analyzer of techno-environmental monitoring “ANKAT-410” (figure 1) that is developed and manufactured by FSUE SPO “Analitpribor” (Smolensk), continuously monitors the entire range of O2, CO and NOx percentages in the exhaust gases NO2.

Figure 1. Stationary multi-component gas analyzer of techno-environmental monitoring “ANKAT-410”.
The principle of the gas analyzer operation is electrochemical, based on the use of the oxidation effect or reduction of the gas being detected on the working electrode of an electrochemical cell (EC). The current that occurs during an electrochemical reaction is a concentration measure of the component being detected. A current signal proportional to the concentration is amplified, normalized and converted to digital form.

Structurally, the gas analyzer is a single-block, in a metal case and consists of a switching module and analog inputs, two relay and current output devices (RCO), RCO device for control of sample preparation elements, interface adapter, primary converter module, keyboard, display, power boards and solenoid valves.

The gas analyzer has software, the structure of which includes the following modules: a communication module; data visualization module; a module for measuring and calculating the content of components to be determined; a module of control actions formation for controlling actuators; a data conversion module for generating an output unified current signal proportional to the content of the mass concentration of the detected components.

The main functions of the software: calculation of the component content to be determined for each measuring channel; calculate the value of excess air ($\alpha$); calculating the volume concentration of carbon dioxide (CO2); calculating the volume concentration of nitrogen oxides (NOx); registration of input unified current signals 4 ÷ 20 mA; display of measured and calculated units on the indicator; the formation of a unified output signal proportional to the content of the designated component of the assigned measuring channel; the inclusion of an audible alarm when the content of the detected component reaches a set threshold value while simultaneously switching the “dry” contacts of the relay; communication with external devices via digital channels RS232 and RS485.

In the electrochemical method of measurement, the gas mixture enters the module of the electrochemical cell. When a detected gas penetrates through the porous membrane, the electrochemical cell generates a current signal proportional to the concentration of the measured component. Passing through the conversion and amplification path, the signals of the electrochemical cell concentration are converted into proportional voltages and fed to the analog inputs of the microcontroller (control board of the electrochemical cell).

The module of primary converters (MPC) is designed to convert physical quantities (content of measured components) into an electrical signal, process the signal and transmit it through the channel to the central computer (CC), as well as control the valves of the pneumatic circuit (if present) and monitor the state of the environment.

The MPC includes an electrochemical cell module with an electrochemical cell control board and gas path elements.

The microcontroller performs the following functions: converts analog signals into digital form; performs signal processing, control of the gas path elements and the electric modes of the motor on the CC command.

The central computer manages all elements of the gas analyzer, calculates physical quantities, and displays.

RCO devices switch contacts of relays to control external circuits by a CC command, and also provide an output current signal. The RCO device for controlling the elements of sample preparation controls the stimulator of sample consumption, air and heaters upon the command of a CC.

The interface adapter is designed to connect to the personal computer (PC) gas analyzer via RS232 and RS485 channels. The module of switching and analog signals is intended for connection of unified input signals 4 ÷ 20 mA from external sensors.

The stationary gas analyzer “PEM-2M” (figure 2) continuously monitors the entire range of percentages in O2, CO, SO2 and NO2 exhaust gases (developed and manufactured by JSC “Promanalitpribor” (Berdsk)).

In accordance with the device and structural diagram of the gas analyzer, the gas sample from the duct through the sampling probe enters the sampling control module (SCM), which includes: valves of the sampling system, heated filter purge, protective, SCM controller, power supply unit, controller
power supply, switching panel, power supply unit of power line for sample transportation and automatic circuit breaker for power supply SCM.

![Stationary gas analyzer “PEM-2M”](image)

Figure 2. Stationary gas analyzer “PEM-2M”.

Information from the SCM controller over the internal RS485 interface is transmitted to the controller of the sample receiving unit (SRU) and then to the remote computer. Next, the sample through the sample valve enters the sample transportation line and along it into the control room located in the cabinet. Transportation of the sample is provided by the pump SRU. From the transportation line, the sample enters the SRU. The purpose of the SRU controller is to control according to a given program all the components of the SRU.

The gas sample injected into the measuring cell of the analytical unit (AU) is released: from mechanical impurities in the filter system, from excessive moisture in the refrigerator. Moisture extracted from the gas sample, according to a given program, is removed outside. The clogging of the filter system, the operability of the gas pump and the concentration of oxygen in the gas are monitored by a moisture control unit (MCU).

The LCD alphanumeric display is used to show the readings of the gas analyzer and to provide service information when testing the gas analyzer and carrying out calibration. The built-in keypad is designed to select the mode of the gas analyzer operation. On the same panel are located the power button of the AU, the button for the backlight of the display (optional), the connector for connecting the AU with the SRU via RS485 interface, the RS232 connector for service maintenance.

The refrigerator unit is a completely autonomous module, controlled by its own controller. The controller of the refrigerator is connected to the SRU controller via the internal RS485 interface, through which the state of the refrigerator is transmitted and the settings can be changed, which can also be changed using the buttons located on the front panel of the controller.

Refrigerator - thermoelectric, based on the Peltier element. The cold surface of the Peltier element (thermoelectric module) is in contact with the heat exchanger through which the gas sample passes, and the heat from the hot surface is removed by an air radiator blown by a fan. The temperature in the heat exchanger is maintained at 3-4 °C, which corresponds to the residual moisture content of the sample at the level of 5-6 mg / m3.

The transportation of the sample is provided by the SRU pump. The sampling device is designed to collect the gas sample in the duct. Structurally, the sampling device is a heated filter with stainless steel probe, which is mounted on the duct. The lines are heated by a heating cable with a maximum heat output of 40W/m. Thermal insulation is made of an aluminized cylindrical heat insulator.

The RS485 decoder - 8x (4-20mA) is used to convert the signals of the selected measurement channels (from 1 to 8) from digital to analogue - current signal (2 decoders are allowed). The selection
and adjustment of the channel range occurs when programming the converter and is determined by the customer at the stage of forming the technical specification and is not subject to change by the user.

The stationary high-speed gas analyzer “ANGOR-S” (figure 3) that is developed and manufactured by Analytical Instrumentation Firm “Informanalitika” (St. Petersburg), controls the percentage of O2, CO and NO in the exhaust gases. The gas analyzer is made in the form of two blocks: a sensor unit (SU) and a display and control unit (DCU).

Figure 3. Stationary high-speed gas analyzer “ANGOR-S”.

Additionally, a gas analyzer cabinet (shield) for controlling the flow of calibration mixtures to the gas analyzer, as well as a network power source for generating a 24 V supply voltage, can be included in the gas analyzer.

The principle of operation of the gas analyzer is based on measuring signals from electrochemical sensitive elements (sensors). The type of sensor used is determined by the gas to be monitored.

The sample preparation method is filtration and heating to a temperature above the dew point, the sample flow to the gas analyzer is diffusion due to the dynamic pressure of the analyzed gas flow in the gas duct.

Consider the device and design of the gas analyzer “ANGOR-S”. The sensor unit is designed to select, prepare and transport the sample to be analyzed to concentration measurement sensors, process the sensor signals and generate an output digital signal containing information about the measured components and the functional state of the main database elements. The sensor signals are sent to a multichannel analog-to-digital converter (ADC), processed by a microcontroller, after which the calculated concentrations and the necessary diagnostic signals are output to the RS-485 digital serial port for transmission to an external display and control device - the DCU. The SU includes a sampling probe with a mounting flange.

The analyzed part of the flue gas stream is transferred by means of the probe tube to gas sensors separated from the analyzed medium by a multilayer steel mesh filter. A solid electrolyte potentiometric sensor based on zirconium ceramics is used as an oxygen sensor, and high-temperature electrochemical sensors are used as sensors for CO and NO.

DCU is designed to indicate the measured values of concentrations, emergency and other diagnostic signals of the gas analyzer, as well as to control the calibration procedure and the formation of output signals for secondary recording devices and actuators.

4. Expert study
The presented description of the equipment for production and environmental monitoring allows an expert comparison of the technical characteristics of gas analyzers [9]. Further, based on the methods of substantiating decisions on the choice of the equipment composition in innovative projects [10-13], an analysis is made according 11 expert-relevant parameters. Results of analysis are presented in figure 4.
1. According to the preferences of controlled gases, the stationary multicomponent gas analyzer of techno-environmental monitoring “ANKAT-410” and the stationary gas analyzer “PEM-2M” meeting the requirements of regulatory and technical documentation for the list of controlled gases are on the same level.

   To fully comply with the requirements of the documentation for the list of monitored gases, along with the use of stationary high-speed gas analyzer “ANGOR-S”, it is necessary to use an additional gas analyzer that measures the content of sulfur dioxide.

   It should be noted that the Analytical Instrumentation Firm “Informanalitika” (St. Petersburg) produces a whole range of electrochemical primary converters of sulfur dioxide concentration (sensors) for use in gas analysis devices of other manufacturers.

2. The highest average lifetime of sensors (electrochemical cells) is in the stationary multicomponent gas analyzer of techno-environmental monitoring “ANKAT-410”. Data on the average service life in the documentation for the stationary high-speed gas analyzer “ANGOR-S” is missing.

3. The ambient temperature range for normal operation of the gas analyzer are the highest for the high-speed gas analyzer “ANGOR-S”.

4. One of the most important parameters in a market economy is the labor costs for maintenance. This parameter for all types of gas analyzers is the time of gas analyzers operation without adjustments.

Figure 4. Results of gas analysers expert study.

| Parameters                        | Gas analyzers                                      |
|-----------------------------------|----------------------------------------------------|
| Controlled gases                  | *ANKAT-410*                                        |
|                                   | *PEM-2M                                            |
| Lifetime of sensors               | *ANKAT-410                                         |
| Operation temperature range       | *ANKAT-410                                         |
| Labor costs for maintenance       | *ANKAT-410                                         |
| Measuring range of impurities     | *ANKAT-410                                        |
|                                   | *PEM-2M                                            |
| Output analog signals interface   | *ANKAT-410                                        |
|                                   | *ANGOR-S                                           |
| Output discrete signals interface | *ANKAT-410                                         |
| RS-485 interface                  | *ANKAT-410                                        |
|                                   | *(plus RS-232 and ModBus RTU)*                     |
|                                   | *(plus ModBus RTU)*                                |
|                                   | *PEM-2M                                            |
| Software protection level         | *ANKAT-410                                        |
|                                   | *(level "A")                                      |
|                                   | *(level "B")                                      |
| Mean time between failures        | *All gas analyzers                                  |
| Designated service life           | *ANKAT-410                                         |
(the less labor costs for this operation, the more effective). The longer the operation time of the gas analyzer without adjustment, the better. The longest period of work without adjustment at gas analyzers of stationary multi-component gas analyzer of techno/environmental control “ANKAT-410” is 6 months.

5. Measuring range of impurities in the exhaust gases.

5.1. The measurement range of the oxygen content in the exhaust gases of all gas analyzers complies with the requirements of regulatory documents on the organization of the oxygen content measurements in exhaust gases.

5.2. The widest range of carbon monoxide content measurement in flue gases is in stationary multicomponent gas analyzer of techno-environmental monitoring “ANKAT-410” - 0 ÷ 4000 mln-1.

5.3. With a measuring range of 0 ÷ 4000 mln-1 of the content of nitrogen oxides in exhaust gases is in the lead: stationary multi-component gas analyzer of techno-environmental monitoring “ANKAT-410” and stationary gas analyzer “PEM-2M”.

5.4. The widest sulfur oxides content measurement range of 0 ÷ 5000 mln-1 is in the stationary gas analyzer “PEM-2M”. It should be noted that the gas analyzers of all manufacturers fit into the requirements of regulatory documents for this technical characteristic.

6. The option for the availability of output analog signals is implemented only in two gas analyzers: in the stationary multi-component gas analyzer of the techno-environmental monitoring “ANKAT-410” with the formation of two types of analog output signals - 0-5 mA and 4-20 mA and in the stationary high-speed gas analyzer “ANGOR-S” with the formation of the output analog signal 4-20 mA. It should be noted that due to the availability of these output signals, the above-mentioned gas analyzers can be used for integration into the unit-wide automated process control system (APCS) with connection to the analog input modules of communication devices with the object (CDO).

7. The option for the presence of output discrete signals is implemented only in the stationary multi-component gas analyzer of the techno-environmental monitoring “ANKAT-410”. It should be noted that due to the availability of these output signals, “ANKAT-410” gas analyzer can be used to integrate into a general-block APCS with connection to the discrete input modules of the CDO.

8. All gas analyzers have a digital output with an RS-485 interface. The stationary multicomponent gas analyzer of the techno-environmental monitoring “ANKAT-410” has a digital output with an RS-232 interface. Manufacturers of stationary high-speed gas analyzer “ANGOR-S” and stationary multicomponent gas analyzer of techno-environmental control “ANKAT-410” use also ModBus RTU exchange protocol.

9. The highest level of software protection from unintentional and deliberate changes, corresponding to the protection level “A” in accordance with MI 3286-2010 was made in the stationary multicomponent gas analyzer of the techno-environmental monitoring “ANKAT-410”.

The stationary gas analyzer “PEM-2M” has the firmware protection level “B” in accordance with R 50.2.077-2014.

The documentation for the stationary high-speed gas analyzer “ANGOR-S” does not define the level of the firmware protection in accordance with the above documents, although this gas analyzer includes its own microcontroller and production.

10. All gas analyzers according to such technical characteristics as mean time between failures are in equal position with a period of 15,000 hours.

11. According to the designated service life, the highest rate is 10 years for the stationary multi-component gas analyzer of the techno-environmental monitoring “ANKAT-410”.

5. Conclusion

Thus, the conducted expert analysis can complement the results of a preliminary survey by the TPP personnel or a specialized organization that carries out the design of the TPP’s SCME. In particular, based on the above characteristics comparison, the best in technical specifications and architecture for use in production and environmental monitoring systems for pulverized thermal power plant flue gases
is the stationary multicomponent gas analyzer of the techno-environmental control “ANKAT-410” (Smolensk).

It is also necessary to take into account that the design of TPP’s SCME on the basis of the approved technical task is carried out in accordance with the current regulatory documents [21]. It is recommended to carry out a feasibility study of the decisions made, taking into account the features of the equipment, production conditions, safety requirements and ease of maintenance.

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