Improving the efficiency of technological measurements when monitoring production and environmental indicators of thermal power plants

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Abstract. The approaches are considered that provide an increase in the efficiency of technological measurements when monitoring production and environmental indicators of thermal power plants. The experience of expert evaluation of gas analytical systems is analyzed taking into account the technological parameters of equipment used in production processes at thermal power plants. The need for expert assessment is justified by the fact that currently there are no universal (generalized) formulas expressing the dependence of production and environmental parameters on each other or on the parameters of the technological process at thermal power plants. As practice shows, such dependencies are determined experimentally and most often with the involvement of specialists from commissioning organizations.

1. Introduction
The basis of the production process at coal-fired thermal power plants (TPPs) is the process of burning solid fuel [1]. The process goes through a series of stages superimposed on each other:

- Heating.
- Evaporation of moisture.
- Release of volatile substances.
- Formation of coke.
- Combustion of volatile substances and coke.

The determining stage is the burning of coke, that is, carbon, since carbon is the main combustible component of almost all natural solid fuels. In addition, the coke burning stage is longer than the rest (it can take up to 90% of the total time required for burning). Moreover, all stages of combustion require heat (sometimes up to 20-25% of fuel combustion).
Analysis of technological processes (TP) at TPPs consists in obtaining information about the status of TP, operating modes and the efficiency of TPP functioning. The effectiveness of the organization of the process is determined by the system of environmental, technological and economic indicators [2].

The analysis, as a rule, is carried out during the development and design of a new production process, to compare various options for the implementation of production, during the modernization and reconstruction of the existing thermal power plant, for the development and implementation of new environmental recommendations.

The basis of the analysis is the determination of technological and environmental performance indicators [3]. By the method of calculating and compiling material and heat balances, a number of other indicators are obtained, such as the efficiency of the raw materials and energy use, economic indicators.

The analysis of technological processes at thermal power plants is carried out in several stages:

- Highlight the elements and subsystems of the technological scheme that determine the properties of thermal power plants.
- Establish the dependence of the output streams data on the indicators of the input streams for each element (block) of the TPP. Since flow transformations occur in TPP elements, this description is based on the physicochemical and physical laws of the processes occurring in them.
- Find out the relationship between the elements responsible for the necessary properties of processes, i.e. determine the structure of thermal power plants.
- Calculate indicators characterizing the properties of the production process at TPPs;
- Determine the paths of processes evolution that contribute to the improvement of properties and performance indicators of the object.
- Form the generalized criterion of the technological process quality by n-1 inputs and determine the allowable range of the n-th parameter values.

The TP mode at a TPP is characterized by flow parameters and the state of the equipment [4].

Flow parameters are a collection of chemical, physico-chemical, and physical flow data. These include information on the flow rate, phase and chemical composition, temperature, pressure, as well as the properties of the flow - heat capacity, density, and viscosity of moving materials.

The state of the element includes data that affects the flow rates in the element. These include parameters that control the process, such as temperature, pressure, reagent concentrations, coolant properties, etc. It is also necessary to take into account the characteristics of the equipment that change during its operation and affect the process (for example, a change in the operation of heat exchangers as a result of the deposition of salts on its inner surface, a decrease in the efficiency of chemical reactors due to catalyst deactivation).

TP calculation is the determination of flow parameters in a TP of a given structure and obtaining the dependences of the state change and flow parameters in each element at the output from the parameters and the state of flows at the input. TP calculations are based on compiling material and thermal balances taking into account the laws of conservation of mass and energy for each TP element or TPP subsystem as a whole. At the same time, it is taken into account that relations between elements do not change the state of flows.

The calculations performed in the preparation of material and heat balances, allow us to determine other indicators of production [1-4]. These data characterize the effectiveness of the process organization according to economic and environmental indicators.

Further work associated with reducing the production cost by using cheaper types of raw materials and energy, with reducing expenditure coefficients by increasing the efficiency of the process and making better use of resources, etc., is decided at the stage of synthesis (construction) of the complete technological system of the production process at thermal power plants.
2. Monitoring of production and environmental indicators of thermal power plants

Ecological criteria of the production process are widely used in industry to assess the state of the environment and improve technological processes [5-8]. It can be distinguished the environmental indicators, determined empirically, and the indicators that are obtained by calculation.

The first group of indicators includes the maximum permissible concentration (MPC) and tentatively safe exposure levels (TSEL). After the development and approval of these indicators, they acquire legislative force and are mandatory on the entire territory of the Russian Federation. In some cases, these values can be adjusted (for example, in regions with abnormal environmental conditions). But in any case, the changes are fixed in legislative documents with a clear restriction of the range boundaries.

The calculated environmental criteria include the maximum permissible emission (MPE) and maximum permissible discharge (MPD). These criteria take into account the numerous factors operating in a limited area of a region or enterprise, such as environmental conditions, climate, geographical location, and the saturation of the region with industrial enterprises. They are calculated by local environmental services, have a limited scope and can be changed many times.

The main criteria for assessing the state of the environment (atmospheric air, ponds) are standard normative indicators: MPC of chemicals and TSEL.

In some cases, the quantitative characteristics of the content of individual compounds in the atmosphere are of decisive importance. Especially this statement applies to substances that have a global impact on Earth's climate change. The most dangerous pollutants are carbon dioxide, fine particles of solid and liquid substances and ozone as an additional component.

In this regard, a system of criteria has been created that normalizes the absolute amount of harmful substances entering the environment (for gases - MPE, for liquid effluents - MPD).

A system of economic indicators is established, providing a charge for emissions, and tougher sanctions are imposed for exceeding limits, which increases the responsibility of manufacturers and helps to develop technical measures to improve the technology of manufactured products and improve the cleaning system.

As criteria for the amount of emissions both in Russia and in foreign countries, several quantitative indicators are used [9].

Mass emission flow [kg/s, kg/h, t/year] - mass of emitted pollutants per time unit. This indicator provides information on the total amount of emissions and is a hygienic and balance criterion. It is mainly used to determine the total degree of air pollution.

Mass emission concentration [g/kg, mg/kg, mg/m³] - the mass of emitted pollutants, referred to the production volume unit, most often gas. The criterion is useful for assessing the excellence of technology and the operation of treatment facilities. It is used in many European countries. Concentration criteria can represent both mass and volume relationships. In the first case, the ratio of the released pollutant mass to the exhaust gas mass is used. This expression is useful in estimating the content of solid particles (dust) in the exhaust gases, since both components - solid and gas - have mass indicators, and quantitative data about them do not change when the state of the gas changes.

To express the concentration of gaseous pollutants, the ratio of the released pollution volume to the total volume of off-gas is used.

In accordance with the requirements of ISO 4226, it is preferable to express both gaseous and solid emissions in mg/m³.

Emission factor (specific emission output) [kg/t, kg/(kWh), kg/GJ] - the ratio of the released pollutant mass to the mass or other value expressing the amount of industrial production. This is a criterion of a production-technical nature, since the amount of emission is related to the amount of manufactured product or processed raw material.

The determination of the emission factor for various enterprises producing the same products allows us to identify those that use more advanced technology. It provides a rational basis for setting lower emission limits for other enterprises.
At thermal power plants, heating plants and thermal installations, the characteristic parameter is the heat output [GJ/h, kW/h] (1 MW approximately corresponds to 2.5 - 3.5 t/h of steam). If volume flow rate \( V_w \) and capacity \( P \) are known, then a third parameter can be determined from any two basic emission parameters.

This allows us to formulate a generalized criterion of the process quality for \( n-1 \) inputs in order to assess the allowable range of values of the \( n \)-th parameter [9]. It should be noted that gross emissions are calculated using the results of either portable instruments or automatic gas analysis instruments.

Currently, a large number of domestic enterprises are developing and manufacturing instruments and systems for industrial and environmental monitoring of flue gases for thermal power plants [11]. The need to equip pulverized coal TPPs with such systems is due to the Russian 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 the development of the environmental performance programs for enterprises and the implementation of increased fees rates for negative environmental impact to stimulate the introduction of measures to reduce negative impact on the environment.

One of the solutions to this issue is the equipment and reconstruction of existing gas cleaning systems and environmental monitoring of flue gases from coal-fired thermal power plants. In this context, we would like to note that the developers and manufacturers of boiler equipment, within the framework of the requirements for the volume of continuous measurements of technological parameters of boiler equipment separately highlight the requirement of equipping the exhaust gas systems with continuous environmental monitoring.

It was shown in [12] that the choice of specific gas analytical systems is associated with certain difficulties, since they all have their own advantages and disadvantages. For the optimal choice of equipment, it is necessary to take into account many different factors and parameters, that is, this problem is multi-criteria. Moreover, a number of criteria may contradict each other (for example, high technical capabilities can complicate the operation of the system and increase its cost) and not have a quantitative assessment.

However, the choice of gas analytical systems for industrial and environmental monitoring should be as objective as possible, not depending on the preferences of individual experts and specialists. Even when using a more objective mathematical apparatus of criterial analysis in [13], it is noted that a quantitative assessment of the significance of each criterion (weight coefficient) can only be established by experts.

3. Technological measurements parameters of exhaust gases at thermal power plants

In accordance with the requirements of the “Methodological guidelines for the volume of technological measurements, signaling, automatic regulation at thermal power plants. CO 34.35.101-2003”, the following parameters of the flue gases shall be measured, including the content of the following components in the flue gases:

- Flue gas temperature - this parameter is measured at all thermal power plants, since it is necessary for calculating the technical and economic parameters (TEP).
- Percentage of oxygen in the exhaust gases - this parameter is measured, since it is necessary for the process, including auto-regulation (in particular, the thermal load controller (TLC)), and, given this parameter, it is possible to adjust the state of soot (oxides CO are the main component of soot). In flue gases with a higher oxygen content, a more intense burning of fuel occurs with a lower soot content (less dark smoke from the pipe).
- Carbon monoxide (CO) must be measured, but at many thermal stations it only now is taken to measure, since the supervisory authorities begin to monitor the state of the smoke (the “blacker” the smoke, the greater the soot content in it).
- Sulfur oxides SOx and nitrogen oxides NOx should be measured provided that there are desulphurization and gas purification plants at the heat station. Many thermal power plants
(especially those built before 1997) do not have these installations. In connection with the intensification of the regulatory authorities’ activities in the field of atmospheric air protection, many TPPs are forced to start measuring these parameters.

In accordance with the requirements of legislation on the protection of atmospheric air, it is also necessary to measure the dust content in the flue gases. Monitoring is carried out taking into account the following documents:

- STO 70238424.13.020.30.002-2010 “Methodology for calculating and establishing maximum allowable specific emissions for existing boiler plants of thermal power plants”.
- RD 153-34.02.303-98 “Instructions for the regulation of atmospheric emissions for thermal power plants and boiler plants”.
- RD 153-34.02.305-98 “Methodology for determining gross emissions of pollutants into the atmosphere from boiler plants of TPPs”.
- RD 153-34.02.306 “Rules for the organization of emission control at thermal power plants and boiler plants”.
- PND F 13.1.3-97 “Methodology for measuring the mass concentration of sulfur dioxide in the exhaust gases from boiler plants, TPPs, state district power stations and another fuel-burning units FR.1.31.2013.16442”.
- PND F 13.1.4-97 “Methodology for measuring the mass concentration of nitrogen oxides in the organized emissions of boiler plants, TPPs and state district power plants FR.1.31.2013.16446”.
- CO 153-34.02.304-2003 “Guidelines for the calculation of nitrogen oxides emission with flue gases from boilers of thermal power plants”.
- RD 153-34.0-02.313-98 “Instructions for the inventory of atmospheric emissions of pollutants from thermal power plants and boiler plants”.

However, most of the methods for measuring the above parameters of flue gases using specific models of gas analyzers, including smoke meters, were published until 2010. To date, it can be stated that there are no universal (generalized) formulas expressing the dependences of the above parameters on each other or on the parameters of the technological process [14]. All dependencies are determined experimentally and most often with the involvement of specialists from commissioning organization, in particular, the All-Russian Thermotechnical Institute (VTI, Moscow).

This is explained by the following. Firstly, the presence of a large number of models of boiler units (up to several hundred), the parameters of which are significantly different, including the process itself. Secondly, even two identical boilers of the same model can “behave”, as they say, in different ways. Although, theoretically, their parameters should be the same. For example, the PK-38 boiler, which was produced in the 60s and 70s of the last century. Its temperature of sharp steam (at the exit from the boiler) should theoretically be 565 ºC according to all factory instructions, but in real operating conditions, many boiler units of this model operate in modes with a temperature of 545 ºC and 535 ºC.

For gas analyzers used today at TPPs, there are also no series of observations. There are only the results of instrumental observations (using portable laboratory gas analyzers), which are carried out by the adjustment units of TPPs or adjustment organizations (VTI, Moscow).

When using modern automatic gas analyzers, there are also a number of problems. For example, the gas analyzer of the Berdsk plant IKTS-11, measuring CO, works only in the indication mode (i.e. shows the presence or the absence of CO). Moreover, the sensors of these gas analyzers very quickly fail - they are being “poisoned”, in particular, with sulfur.
There is a mathematical dependence of the conversion of individual components on the oxygen content in the exhaust gases (in particular, IKTS-11 has the ability to convert CO2 from O2 and CO, SO2 through SO and O2, and similarly for nitrogen compounds).

However, at a number of TPPs before choosing IKTS-11, which measures the oxygen content in the flue gases, many tests of other models of gas analyzers were conducted. Other models had significant drawbacks in terms of their operation, and also had a rather high cost. At state district power station No. 2 (Zelenogorsk City, Krasnoyarsk Region, Russia) IKTS-11 for measuring the oxygen content in the flue gases at the boiler is optimal in terms of price-quality ratio. However, at other stations (both with other and similar boiler units), gas analyzers of other models can show themselves from the better side.

4. Conclusion
The choice of specific gas analytical systems is associated with certain difficulties, since they all have their advantages and disadvantages. For the optimal choice of equipment, it is necessary to take into account many different factors and parameters [15]. The expert analysis can supplement the results of a preliminary survey by TPP personnel or a specialized organization designing continuous TPP emissions monitoring systems used in the development of technical specifications. Thus, expert analysis of gas analyzers used at modern TPPs to analyze the technological parameters of the flue gases is required.

In works [1-4, 10, 13], equipment for industrial and environmental monitoring of a number of Russian developers and manufacturers, which is already in operation at many thermal power plants of the Russian Federation, is considered. Among the main ones, it is worth mentioning:

- Enterprise SPA “Analitpribor”, which develops the whole range of devices and environmental monitoring systems for many industries, energy and transport.
- JSC “Promanalitpribor”, specializing in the development and production of flue gas analyzers under the trademark “Ecomer”.
- Analytical company “Instrumental Engineering Informanalitika”, which develops and manufactures a line of gas analyzers for flue gas monitoring for thermal pulverized coal power plants.

Authors reviewed the construction and operation principle of these gas analyzers, as well as an expert comparison of their technical characteristics [11]. Further, based on the methods of substantiating decisions on choosing the equipment composition in innovative projects, an analysis was conducted based on 11 expertly significant parameters [13].

Note that the expert analysis carried out in [11, 16] supplements the results of a preliminary survey by TPP personnel or a specialized organization involved in the design of TPP’s continuous emission monitoring system (CEMS) used in the development of technical specifications. In particular, based on a comparison of the above characteristics, the best in technical characteristics and architecture for use in dust-coal thermal power plants for industrial and environmental monitoring of flue gases is the ANKAT-410 stationary multicomponent gas analyzer for technological and environmental control (developed and manufactured by SPA “Analitpribor”). It should be noted that the design of TPP’s CEMS based on the approved technical specifications is carried out in accordance with regulatory documents [17], therefore, it is recommended to carry out a feasibility study of the decisions taken, taking into account the characteristics of the equipment, production conditions, safety requirements and ease of maintenance.

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References
[1] Poleschuk I Z and Tsirelman N M 2003 Introduction to Thermal Engineering: Textbook (Ufa, Ufa State Aviation Technical University Publishing house)
[2] Kravchenko V M 2016 Current state of the heat supply industry Heat supply news 10(194) 32-6
[3] Tolstova Yu I and Golubenko S A 2015 Assessment of the strategic plan for transferring heat supply systems to a closed circuit Plumbing, heating, air conditioning 12 46-9
[4] Yunusov A Sh and Saveliev V N 2012 Energy: from the present to the future through intellectual and innovative potential Heat power engineering 1(2) 46-51
[5] Venkatesh B 2018 Thermal energy storage for homes 2018 IEEE International Conference on Smart Energy Grid Engineering (SEGE) 36-9
[6] Roslyakov P V and Kondratyev O Y 2016 Priority measures for the implementation of new environmental legislation New in the Russian electric power industry 5 6-17
[7] Roslyakov P V, Zakirov I A, Ionkin I L, Egorova L E and Karankevich E N 2003 The system of continuous control (monitoring) and regulation of harmful gaseous emissions of thermal power plants in the atmosphere Notes of the Mining Institute 154 94-6
[8] Roslyakov P V, Novozhilova L L and Egorova L E 2008 Organization of monitoring of harmful emissions from chimneys of TPPs based on numerical studies Vestnik MPEI 4 28-39
[9] Roslyakov P V 2007 Methods of environmental protection (Moscow, Publishing house MPEI)
[10] Saramud M V, Kovalev I V, Kovalev D I, Voroshilova A A and Kuznetsov A S 2018 Measurement accuracy of real time parameters in environmental monitoring IOP Conference Series: Materials Science and Engineering 450 (6) 062012
[11] Kovalev I V, Kovalev D I, Kolesnik V V, Losev V V and Karaseva M V 2018 Analysis of technological equipment of systems for automated monitoring of flue gases of thermal power plants Siberian Journal of Science and Technology 19(4) 683-90
[12] Kondratiev O E 2016 The main approaches to creating systems for monitoring the environmental impact of thermal power plants Energetik 12 32-40
[13] Samkov A V and Zyatkova A V 2015 Methods for substantiating decisions on choosing the composition of equipment in innovative projects Ventilation, heating, air conditioning, heat supply and building thermal physics 3 68-72
[14] Tynchenko Ya A and Kovalev I V 2019 Expert study of emission monitoring equipment for Russian thermal power plants IOP Conference Series: Earth and Environmental Science 315(6) 062021
[15] Kovalev I V, Losev V V, Saramud M V, Kovalev D I, Karaseva M V and Kuznetsov A S 2019 On the problem of monitoring a technological process based on multipoint spatial measurement of parameters IOP Conference Series: Earth and Environmental Science 315(6) 062030
[16] Tynchenko Ya A, Gofman P M, Kovalev I V and Voroshilova A A 2019 Russian stationary vibration control and mechanical displacement systems for electric power pumps of thermal power plants IOP Conf. Series: Materials Science and Engineering 537 052035
[17] Kondratyev O E and Roslyakov P 2016 The main stages of the introduction of continuous monitoring systems for air emissions at TPPs Power plants 9 25-9