Quality assessment of the fuel preparation production process at thermal power plants

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Abstract. The production of electrical energy from most of the thermal power plants currently in operation is achieved by converting the thermal energy generated by the combustion of hydrocarbons. At the same time, one of the central technological processes is the fuel preparation. The article considers the task of measuring the parameters of a drying unit used in dust preparation systems. A block diagram of a monitoring system with a multi-point principle for measuring process parameters is proposed. Such a plan for the placement of sensors makes it possible to implement a multi-version approach to the formation of measured parameters of the technological process, for which a generalized quality criterion is proposed.

1. Introduction

The main function of a thermal power plant (TPP) is the generation of electrical energy by converting thermal energy [1]. Ensuring this function is associated with many technological processes implemented in accordance with their own regulations.

The production of electrical energy from most of the thermal power plants currently in operation is achieved by converting the thermal energy generated by the combustion of hydrocarbons. At the same time, the efficiency of operated TPPs remains quite low and amounts to 30–40% [2]. The regulated flow of technological processes providing the main function of thermal power plants, such as fuel preparation, fuel combustion, exhaust gas filtration, as well as improvement of power equipment, high quality of initial fuel, plus experimental solutions for the selection of low-grade heat [3, 4], all this contribute to an increase coefficient of thermal power plants performance. Thus, from the point of view of economic efficiency, obtaining electric energy remains cost-effective. At the same time, the process of obtaining electric energy from heat remains unchanged, since the combustion of hydrocarbons is accompanied by the production of by-products, such as gases, suspended particles, ash and heat dissipated into the atmosphere [5]. These are the main factors affecting the environmental situation [6].

Thus, the task of industrial and environmental monitoring of the heat power facilities state is no less relevant and also requires improvement of methods and approaches in their implementation [7].
2. The technological process of fuel preparation

In modern steam boilers, solid fuel is predominantly burned in pre-crushed and dried form.

When designing a dust preparation system, using the physicochemical characteristics of a given fuel, a choice is made of the type and number of mills, dust preparation and dust supply system types. Also, there is performed a heat calculation of drying, and the consumption of a drying agent is determined. Next, the performance of the selected size of mills on the calculated fuel is determined, individual elements of the dust preparation system and auxiliary equipment (fuel and dust bins, feeders, heaters, emergency lights, separators, cyclones, safety valves, mixers, dust pipes, air ducts, etc.) are selected and calculated.

According to the connection strength between dust preparation and drying of fuel with the boiler, central and individual systems are distinguished.

Central systems are divided into the following types: systems with a dust plant, when grinding and drying of fuel is carried out at a special enterprise, and the finished dust is fed to a power plant; and systems with central drying of fuel.

Individual dust preparation systems are more diverse and are divided (depending on the method of supplying dust) to systems with direct injection, when the dust after the mill is sent to the furnace, and systems with an intermediate hopper, when dust is fed to the burners from the hopper located between the mill and the furnace.

As a drying agent in dust preparation systems, hot air, fuel combustion products (flue gases) or their mixture are used. The temperature of the drying agent in front of the mill is limited depending on the type of mill and the method of grinding parts cooling.

The choice of a dust preparation system is determined by the characteristics of the fuel required by drying, the type of grinding device and drying agent and is based on one of the technical and economic calculations. At TPPs, closed individual dust preparation systems are most widely used. After selecting the type of mill and dust preparation system, the number of mills per boiler is determined, and based on the heat calculation, the consumption of the drying agent per unit mass of crude fuel or its initial temperature is determined.

Most elements of the equipment of the dust preparation system, providing transport and storage of dust and fuel, are based on the volumetric principle of operation. For their calculation, the values of the density of fuel (dust) are used: bulk, apparent and real. Such densities are respectively defined as the ratio of the fuel (dust) mass to its volumes, taking into account voids between particles, solid particles with internal pores, or only solid material [3].

Thermal calculation of a dust preparation system is carried out by comparing the input and output components of the heat balance.

The analysis of the technological process involves a meaningful description of the object, which, in turn, can act as a technological control object when setting the task of automating the technological process of fuel preparation.

3. The use of the drying unit in the process of fuel preparation

As an object, we consider a drying unit, which, depending on the dust preparation system, has a drive mechanism, a metering device, shut-off and control valves [2]. At the same time, considering the central dust preparation system, we note that the drying pipe acts as an explicit element of the drying installation.

The drying process proceeds as follows [3]:

- From the hopper, the raw fuel enters the feeder, dosing is carried out using a shut-off gate, the shutter of which allows us to adjust the amount of fuel supply in accordance with the process regulations.
- Raw fuel enters the drying tube with a cylindrical design of a certain volume.
- Drying agent (steam) enters the drying pipe under pressure, after which it expands and fills the volume of the pipe with the raw fuel in it.
In the process of crude fuel movement through the pipe, it is mechanically mixed, while the process of heat transfer and removal of moisture from the crude fuel, evaporation and entrainment of the drying agent through the discharge device.

Dry fuel moves through the pipe and is forced out of the drying pipe by a new portion of crude fuel.

After the drying pipe, the fuel goes to the mill, where the next stage of its processing takes place.

Thus, mass transfer and heat transfer processes occur in the drying pipe, accompanied by a change in the physical parameters of the fuel and the drying agent.

The qualitative characteristics of this stage of the fuel preparation process require its monitoring. Due to the measurement of the process parameters it is necessary to estimate the amount of moisture evaporated from 1 kg of crude fuel, the heat used to evaporate moisture, etc.

The parameters of this process can be the temperature of the drying agent at the inlet to the pipe, the temperature inside the pipe (beginning), the temperature inside the pipe (end), the humidity inside the pipe (beginning), the humidity inside the pipe (end), the temperature of the drying agent in the outlet device [5]. Thus, it becomes possible to describe the functional dependence of the indicator, reflecting the qualitative characteristics of the process:

\[ q_i = f(T_i, W_i, Q_F, Q_{DA}) \]  \hspace{1cm} (1)

where \( q_i \) – amount of heat spent on the evaporation of moisture, MJ; \( T_i \) – drying tube temperature, °C; \( W_i \) – humidity in the drying pipe, %; \( Q_F \) – fuel consumption, ton/h; \( Q_{DA} \) – drying agent consumption, ton/h (m³/h).

4. Multi-point measurement of drying plant parameters based on the multiversion approach

Since the drying unit, like other elements of the dust preparation system, is based on the volumetric principle of operation, the problem of choosing the measurement place of parameters in the volumetric space arises [8].

As a solution, a multi-point principle of parameters measuring in one plane is proposed [9]. Thus, parameters such as temperature inside the pipe (start), temperature inside the pipe (end), humidity inside the pipe (start), humidity inside the pipe (end) can be determined (measured) to obtain objective information about the process with volumetric operating principle.

Let’s consider a structural diagram of a drying pipe with visualization of the multi-point principle of measuring process parameters (Figure 1).

![Figure 1. Structural diagram of the drying installation: 1 - place of the crude fuel input; 2 - place of the drying agent (steam) input; 3 - sensor installation locations in accordance with the multi-point measurement principle (t_{11}, t_{12}, t_{13}, w_{11}, w_{12}, w_{13}); 4 - sensor installation locations in accordance with the multi-point measurement principle (t_{21}, t_{22}, t_{23}, w_{21}, w_{22}, w_{23}); 5 - place drainage agent; 6 - place of the dry fuel withdrawal.](image-url)
The resulting plan for the placement of a multi-point measuring system sensors allows us to implement a multi-version approach to the formation of the process measured parameters, which, in turn, express a generalized quality criterion in the following relationship:

\[
\frac{|T_1 - X_1|}{x_1} + \frac{|T_2 - X_2|}{x_2} + \frac{|W_1 - X_3|}{x_3} + \frac{|W_2 - X_4|}{x_4} = K, \tag{2}
\]

where \(T_1, T_2, W_1, W_2\) – measured process variables; \(X_1, X_2, X_3, X_4\) – specified values of the technological process parameters (temperature, humidity), characterizing the regulated flow of the fuel preparation technological process (drying of raw fuel); \(K\) – generalized criterion for the quality of the technological process, according to \(n\)-l inputs.

The coefficient \(K\) characterizes the state of the process. In this case, depending on the regulations, a range of values taken by the coefficient \(K\) can be determined:

- From \(K0\) to \(K1\) - the process proceeds in a regulated manner (\(K0 < K1\)).
- From \(K1\) to \(K2\) - there are slight deviations from the regulations that do not affect the final product (\(K1 < K2\)).
- From \(K2\) to \(K3\) - there are significant deviations from the regulations that affect the final product (\(K2 < K3\)).
- From \(K3\) and more - the process proceeds with violations of the regulations; an emergency situation is possible.

It should be clarified that for the formation of the measured values of the process parameters (temperature and humidity), a multiversion approach is used, based on obtaining the \(N\)-th amount of measured data. The resulting value is obtained by voting.

5. Conclusion
As a result of the analysis, a model of the production process of fuel preparation at thermal power plants was developed, capable of issuing an estimate of the generalized quality criterion of the technological process by \(n\)-l inputs and assessing the allowable range of values of the \(n\)-th parameter.

The use of the approach proposed in the study will improve the quality of the fuel preparation production process by increasing the efficiency of its technological parameters monitoring and, accordingly, reduce the possible negative impact of the considered process on the environmental situation in the vicinity of thermal power plants.

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