Choice of Chelyabinsk and Kuznetsk coals as main fuel for steam generator PK-14 using elements of cluster analysis

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Abstract. The article is devoted to the questions of rational and optimal choice of solid fuel burned in a torch in an energy boiler with natural coolant circulation. The possibilities of using cluster analysis in determining the basic organic fuel for a thermal power plant are shown. Properties of coal are different depending on the place of their extraction, even within the same coal basin. The ways of improving the flaring of existing fuel at the present time and planned for burning on a boiler are considered. The issue of expediency of using coal-water suspensions from brown coals with low heat of combustion at the basin of CHPP remote from coal is also touched upon.

1. Introduction

The article is devoted to analysis of possibility of burning the two types of coals of different deposits on the boiler type PK-14. An analysis of the thermal characteristics was conducted, which allowed us to determine that the Chelyabinsk coal burning compared to Kuznetsk is the most harmless, and Kuznetsk coal is used most economically. The authors conducted technical analysis on the possibility of combustion of Kuznetsk and Chelyabinsk coal and analysis of schemes to reduce the fire and explosion risk at the enterprise thermal power station, which are high-tech and efficient when dealing with fire and explosion hazard. This article proposes to consider a variant of burning two fuel types. Chelyabinsk coal has a low calorific value, and the coal basin is almost depleted, so it is necessary to look for a replacement for this fuel type. Various researchers have worked on similar issues of safe fuel supply technology and safe combustion, as well as fuel economy in different conditions [1,2]. There are two options. The first is the replacement of fuel with Kuznetsk coal. The second is the use of a water-coal suspension. The purpose of research is the analysis and comparison of the Kuznetsk and Chelyabinsk coal combustion in the boiler PK-14. To achieve this goal, the following research tasks were set:

- to carry out analysis the thermal characteristics;
- to carry out a technical analysis of Kuznetsk and Chelyabinsk coal burning capability;
- to compare transport-logistical component of coals at their price;
- to identify the possibility of using a coal-water suspension from Chelyabinsk brown coal grade B3 when transporting it over long distances;
- to carry out analysis of schemes for the reduction of fire hazard and explosion hazard at the CHPP.

2. Analysis of CHPP equipment and combustion technologies

CHP plant capacity is P = 196 MW, N = 670 MW. Station equipment can operate on such fuels as coal and gas. The carbon content was approximately 49 % of the fuel energy balance of the thermal power plant. CHPP has nine boilers, four redesigned steam boilers have performance D = 170 t/h and five steam boilers PK-14 have performance D = 230 t/h and heat capacity N = 170 MW. The technology is similar to analogs [3]. CHPP is gradually moving from one coal to another, starting with 2010. In order to achieve energy efficiency fuel consumption, CHPP consumes other form of coal and thus reduces toxic emissions that are released into the atmosphere [4, 5].

The feature of coal intended for combustion in different capacity boilers - an open mining, which significantly reduces their cost. However, features of the structure of coals themselves essentially determine the combustion technology. In particular, the Kuznetsk and Chelyabinsk brown coals belong to «rumpled» coal, combusted in a pulverized state with a crushing ratio of R_{90}= 36-42% and R_{90}= 16.4%, respectively.

Figure 1 shows the boiler PK-14, on which two types of coals will be investigated; it is designed as a U-shaped pattern and is provided for producing steam with initial data (D_{ss} = 230e/h P_{ss}=9.8 MPa, T_{ss} = 510°C). The Boiler unit has a four-coal grinder. They are attached to the front surface. There are four nozzles of tertiary blast on the back surface.

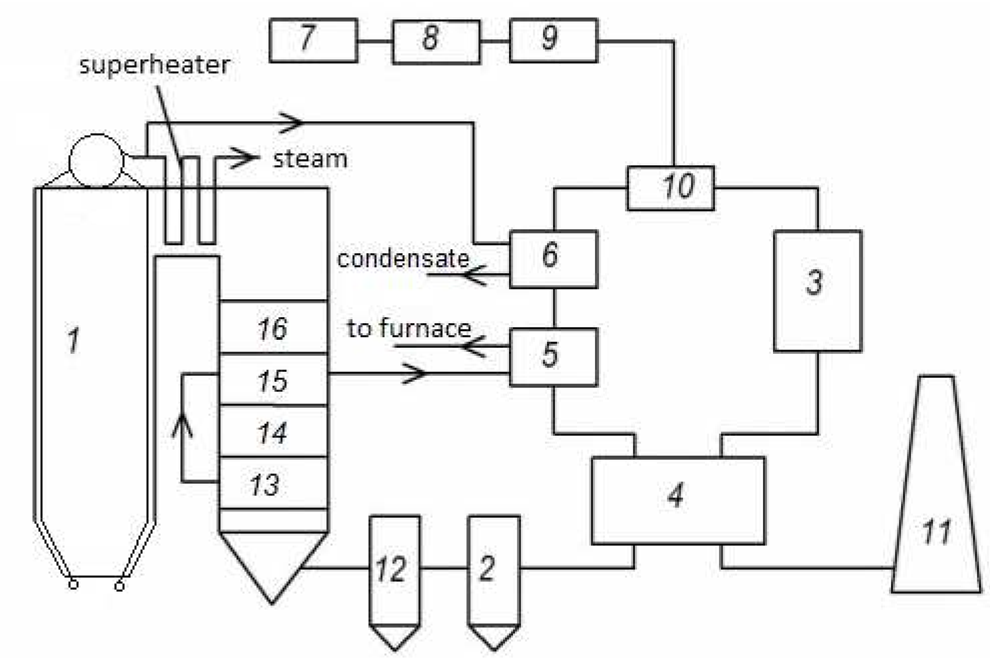

Figure 1. A schematic diagram of the cleaning system of flue gases from sulfur dioxide [9]: 1 – boiler PK-14; 2 – absorber to clean SO_x; 3 – reactor selective catalytic cleaning of NO_x; 4 – regenerative heat exchanger; 5 – tubular gas heat exchanger; 6 – gas-vapor heat exchanger; 7 – capacity of storage of liquid ammonia; 8 – evaporator of ammonia; 9 – valve; 10 – input and distribution ABC; 11 – chimney; 12 – electrostatic precipitator; 13 - the first stage of the air heater; 14 - the first stage of the economizer; 15 - the second stage of the air heater; 16 - the second stage of the economizer

The fuel-air mixture is supplied to the furnace of the boiler unit via direct injection mills and secondary and tertiary blast nozzles. In the window of the mine-mill system installed stabilizers of combustion, through which the introduced secondary air, and tertiary air is supplied through nozzles located on the side and rear surfaces of the combustion chamber [6].

Properties of Kuznetsk coal are LHV=27000 kJ/kg, A=9.5%, W=10.5%. Thus, if we take into account the accumulated experience of burning coal-water suspensions on industrial boilers, it is hardly possible to expect any qualitative transitions [6]. Excess water in suspension is conventional ballast, which reduces the specific combustion heat in proportion to its content in the mixture. For Kuznetsk coals with a heat of combustion 27000 kJ/kg, the mixture has a working heat of combustion 15500 kJ/kg. This is a very high indicator for coal and brown coal mixtures. It is quite possible to organize joint enrichment and formation of a mixture with sizes of coal particles ≤ 3 microns.

Properties of Chelyabinsk coal and water-coal suspension are LHV=14500 kJ/kg, A=40%, W=15% and LHV=8500 kJ/kg, A=30%, W=22% At the same time, when analyzing the ash residue, it was found that the largest contribution to the integral values deviations of the burnout degree is made by the largest fractions with $R \geq 90$ microns. This also applies to dust combustion and incineration of the WCM. Fractions with $R < 90$ microns burn out in the furnace to 90 - 95%, and the isolated particles with $R \leq 40$ microns are burned almost completely. Volatile substances present in the initial coal partially dissolve in the suspension water, partially retained in the dust component, and also as in pulverized coal flame, burn first with coke breeze [7, 8].

3. Research methodology

The methodology is based on the data of experimental burning of coal at the thermal power station located in the Chelyabinsk region. It is obvious that the burning of coal Mycuban compared to Chelyabinsk is the most effective and reduces harmful emissions. The task is to make a comparative analysis of the ability to burning Chelyabinsk and Kuznetsk coal on a boiler PK-14 of CHPP.

Consider the features of the Kuznetsk and Chelyabinsk coal. It is necessary to analyze new fuel, because a steam boiler PK-14 is designed for burning a particular coal with its own specific characteristics. It is necessary to consider the system of fuel preparation for another type of the redesigned boiler unit, because PK-14 was not designed for combustion of the Kuznetsk coal (Table 1).

In addition, the boilers operation parameters during the combustion of coals and the flue gases parameters were compared.

Table 1. Characteristics of steam generators

Methods of suppression of nitrogen oxides	Steam productivity of the boiler, t/h	Heat output, MW	Fuel	Content of NO_X, mg/m^3, original condition	Content of NO_X, mg/m^3, after upgrades	Steam generator
Staged	230	170	Chelyabinsk coal	720	360-380	PK-14
combustion	230	170	Kuznetsk coal	570-600	350-400	redesigned

Another type of boiler unit has a chamber furnace, which is applicable for burning pulverized fuel in a pulverized state. Fuel for the fire is oil M – 40 or M – 100. This steam generator has 4 fuel oil nozzles, which are installed under the 4 burners. The boiler unit has an individual dust preparation system with an intermediate dust collector. In order to clean the flue gases from ash, the boiler is equipped with wet ash collectors. Each unit has a smoke exhaust and fan unit [6].

The boiler PK-14 fuel preparation system is characterized in that it comprises a combustion stabilizer and is supplied by secondary and tertiary air. Modes start, stop, and emergencies are explosive in the redesigned boiler unit, so the boiler unit is required to provide an aspiration system. Using inert gases and water vapor reduces the amount of oxygen in the dust-air mixture, which reduces the risk of an explosive situation. In addition dust can be suppressed by water spraying [9, 10].

4. Theoretical part

Let us consider the scheme for the use of inert gases, Fig.2. According to Table 1, in order to suppress the nitrogen oxides, NO_x staged combustion is used. But such methods of the step input of air into the combustion chamber typically cause the change (deterioration) of specific parameters characterizing the efficiency of boilers design solution - increase of heat losses with leaving gases and mechanics under burning of fuel. While maintaining the combustion technology, the heat loss from mechanical under burning is reduced to less than 2 %, increasing as a deviation of operating parameters from the design values up to 4-5 %.

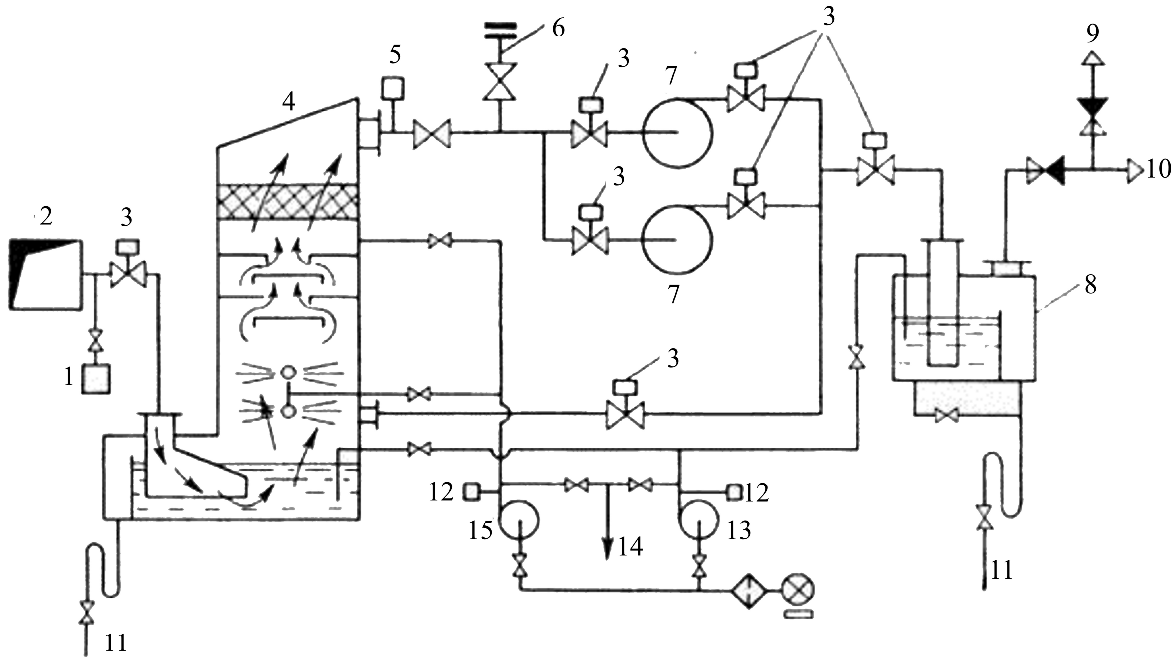

Figure 2. A scheme of the inert gas system with gas extraction from the boiler flues:
1 – alarm sensors oxygen; 2 – boiler flue; 3 – valve; 4 – scrubber; 5 – alarm sensors high temperature gases; 6 – nozzle; 7 – fan; 8 – water paddle; 9,10 – pipelines; 11 – drainage; 12 – alarm sensors for low flow of water; 14 – pipeline of emergency relief; 13,15 – pumps.

Attempts of burning in the grate furnaces lead to an increase in mechanical under burning, which cannot be reduced to at least the level of 15 %, which leads to low values of efficiency. In addition, in order to improve technical and economic characteristics and to reduce the mechanics under burning PK-14, it is necessary to transfer the boiler on the input mode of secondary air through the built-in embrasures of flame stabilizers [6].

According to the main thermal characteristics of brown Chelyabinsk and Kuznetsk coals, it can be concluded that the combustion of the Kuznetsk coal is the more environmentally friendly because it is volatile~42% (Chelyabinsk coal – 38%).

Let us consider the specific heat of combustion and compare the performance of the Kuznetsk and Chelyabinsk coals. The greater the calorific value of the fuel, the lower its consumption. From this it follows that specific heat of the combustion is one of the most important parameters. These indicators should be used for the design of the boiler for solid fuels. Consequently, the use of Kuznetsk coal will be most economical.

5. Application. Brown Chelyabinsk and Kuznetsk coals for fire and explosion safety

The coal and dust have been maintained for a long time and the transport is predisposed to self-ignition. The threat of spontaneous combustion increases with an increase in air entrapment in the part of the fuel during heating fuel. Aspiration increases spontaneous ignition of dust with its thinning and reduction of moisture, increasing the amount of O_2.

In order to evaluate the explosion hazard in this case, the criterion of the explosive K_T is introduced, which is given in table 2. A specific fuel type is assigned to the 4 hazard category for which one wants to install explosion safety [1, 2, 3].

Table 2. Fire and explosion limits of coal dust

Explosion group	Range of K_T	Kind of coal	K_T
The first group	$K_T < 1,0$;	-	-
The second group	$1,0 < K_T < 1,5$	Chelyabinsk basin – 3B	1,24 – 1,46
The third group	$1,5 < K_T < 3,5$	Kuznetsk basin – D, G	3,40
The fourth group	$K_T > 3,5$	-	-

The criterion of explosion hazard for Kuznetsk and Chelyabinsk coals will determine the experimental data, which are summarized in table 2.

The pulverizing system with the dust collector when grinding fuels II and III groups of explosion hazard, which include the Kuznetsk and Chelyabinsk coals, are equipped with:

- instruments for measuring differential pressure across the throttling device built into each dust line before the dust mixer;
- alarm when the differential pressure in the throttle device in the dust line is lowering.

Since there is a class of fire and explosion of Kuznetsk coal, then it is needed to undertake the necessary measures, but some of them were already implemented during the burning of coal Mycuban.

6. Application of the cluster analysis

The applied method implements a hierarchical agglomerate algorithm. Before starting clustering, all objects are considered separate clusters, which are combined in the course of the algorithm. At first, n objects are taken and distances are computed in pairs. Then let us select a pair of objects that are closest to each other; and these objects are combined into one cluster. As a result, the number of clusters becomes equal to n-1. The procedure is repeated, but at any stage the union can be interrupted, having received the necessary number of clusters. Thus, the result of the algorithm of aggregation determines methods for calculating the distance between objects and determining the closeness between clusters. If the data are understood as a point in the characteristic space, the cluster analysis problem is formulated as a selection of point condensations, the division of the population into homogeneous subsets of objects. Cluster analysis can be used in various industries, including in the energy sector, Fig. 3

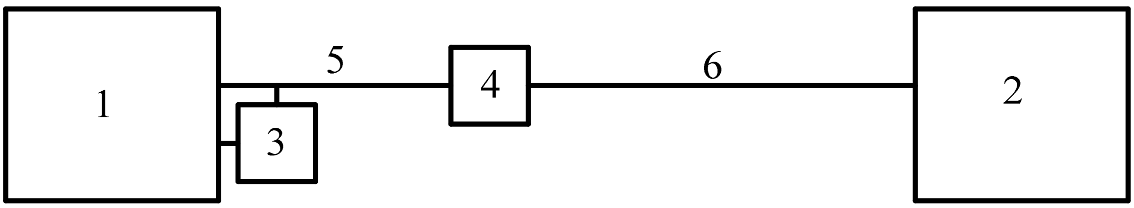

Figure 3. A cluster analysis scheme: 1 – Chelyabinsk coal basin, 2 – Kuznetsk coal basin, 3 – coal water slurry preparation station, 4 – CHPP, 5 – railways length L_1, 6 – railways length L_2

As the results of calculations show, the limits of economic feasibility of fuel in this case depend on two main parameters: railways lengths $L_1<L_2$ heat of the coal-water suspension combustion and the length of its transportation to the CHPP.

7. Conclusion

Analysis of the thermal characteristics of the Kuznetsk and Chelyabinsk coal allows us to conclude that according to their thermal characteristics, the burning of the Chelyabinsk coal is the most harmless, and the use of Kuznetsk coal will be the most economical, because its specific heat of combustion is around more than twice than that Chelyabinsk coal.

A technical analysis of the possibility of burning Kuznetsk and Chelyabinsk coals showed that for both Kuznetsk and Chelyabinsk coals, stepwise combustion is used to suppress nitrogen oxides. But the known methods increase heat losses with outgoing gases and mechanical under burning of fuel. In addition, in order to reduce the mechanical under burning of boiler PK-14, which carries out the combustion of coals, it is necessary set the boiler on the input mode of secondary air through the built-in embrasures flame stabilizers.

The creation of coal-water suspensions from Chelyabinsk coal is possible when it is used in a thermal power plant near a coal basin. Transportation of this suspension is disadvantageous.

Based on the schemes for aspiration and the use of inert gases, it can be concluded that these measures are highly technological and effective if it is necessary to reduce fire and explosion hazard.

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