THE USE OF MECHANICALLY ACTIVATED MICRONIZED COAL IN THERMAL POWER ENGINEERING

by

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Coal is one of the main energy resources and development of new promising technologies on its basis is certainly topical. This article discusses the use of new technology of gas and fuel oil replacement by mechanically activated micronized coal in power engineering: ignition and stabilization of pulverized coal flame combustion, as well as gasification of micronized coal in the flow. The new technology coal combustion with two stages of grinding is suggested. Optimization of the scheme of two-stage combustion is calculated. The first experimental data on the combustion process are obtained. The first demonstration tests on gas and heavy oil replacement by micronized coal during boiler ignition were carried out in the real power boiler with the capacity of 320 tons of steam per hour.

Key words: *micronized coal, thermal power engineering*

Introduction

Coal is the most common energy fuel in the world. Despite the long period of its use in thermal power engineering, the difficulties in its efficient and clean combustion, arise due to deterioration of its consumer qualities [1]. The bulk of produced coal is used in the energy sector, although a significant portion of it is used in chemistry, metallurgy, and other industries.

In contrast to the limited reserves of oil and gas, the coal resources are enormous: its commercial reserves are more than one billion tons, and forecast resources are about fifteen billion tons.

Based on the most long-term energy forecasts of the global fuel and energy balance, coal will remain the most important source of energy until 2050. At the present level of consumption, the coal reserves will last for 200-300 years, while the reserves of natural gas are limited by 60-70 years, and oil – by 40-50 years.

Russia is the largest coal power; one-third of the world's resources are concentrated in its interior. At the same time, the quality of coals supplied to the power plants, is getting worse. At that, combustion of low-grade coals in boiler installations causes significant difficulties related to coal flame ignition, stabilization of its combustion, and fuel burnout at simultaneous reduction of environmental performance of the power plants.

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Moreover, due to the lowering of coal quality, the consumption of heavy oil and gas for boiler lighting, flame flashing, and stabilization of molten slag output in furnaces with low slag removal becomes higher at thermal power plants.

A huge amount of scarce liquid fuel oil is spent for lighting with heavy oil and stabilization of the pulverized coal flame; at that, the joint combustion of heavy oil and coal affects negatively the environment. Only in CIS, the consumption of heavy oil for ignition and lighting the boiler flames exceeds twenty-five million tons per year.

To improve the ignition and stabilization of pulverized coal flame combustion, the methods of increasing grinding fineness, high heating of fuel-air mixture and secondary air, application of highly concentrated dust, and joint combustion of heavy oil and coal are usually used. However, these methods have a number of disadvantages and only partially solve the above problems.

Recently the plasma technologies of pulverized coal ignition and flame lighting are being developed actively [2], however, due to the relatively low resource of plasmatrons, this technology is more applicable for the processes of ignition in boilers.

The fact of increasing coals reactivity at their grinding in highly stressed mills of the disintegrator type was determined at the Institute of Thermophysics, SB RAS. Some results on the study of ignition and combustion of mechanically activated micronized coals of various metamorphic stages were published [3, 4]. Based on these data, a new technology for replacement of highly reactive gas and heavy oil by micronized coal in power installations was suggested.

Experimental set-up

The main experiments have been performed at the set-up of 5-MW heat capacity. The scheme of this set-up and its general view are presented in figs. 1 and 2.

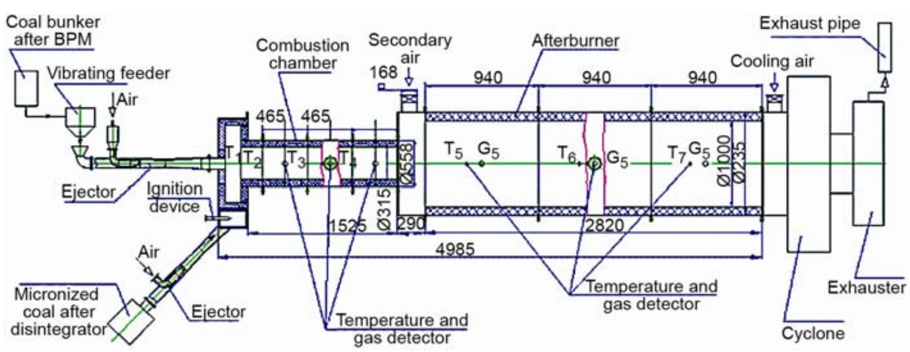

Figure 1. The 5-MW thermal set-up with two-stage supply of fuel

The goal of research is determination of operation parameters for pulverized coal ignition and burning at single– and two-stage combustion:

– single-stage coal-dust combustion after mechanically activated grinding, and
– two-stage combustion with supply of micronized coal to the coal-dust flame in the burner after the conventional boiler mill (ball pulverizer mill).

The two-stage system can significantly reduce the costs of preparing the micronized coal and the number of igniting burners because fuel from the conventional boiler mill is supplied with the ratio of 1:1 – 4:1, depending on the reaction properties of the used fuel, *i. e.*, we can repeatedly increase the power of igniting burner as compared with single-stage combustion.

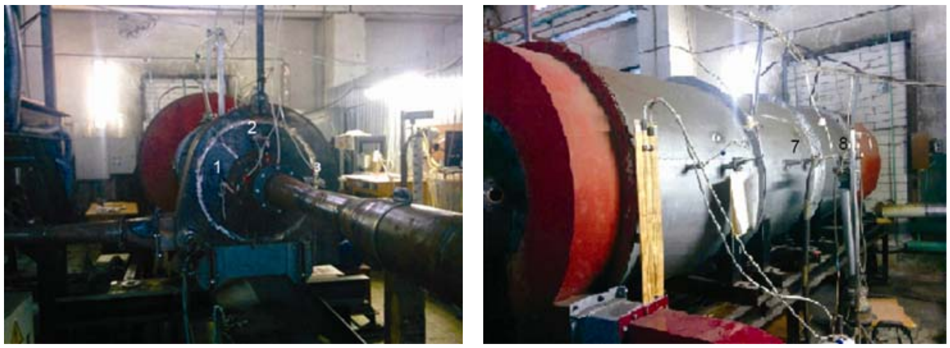

Figure 2. Thermal 5-MW set-up with two-stage combustion

Figure 1 shows scheme of the experiments carried out at the set-up.

At single-stage combustion of coal dust, obtained after grinding in a ball pulverizer mill (BPM) at the power plant (Belovo, Kuzbass TPP), it is fed by a screw feeder into the disintegrator-activator, then it is transported by an ejector into the scroll burner.

The pulverized coal is ignited by a standard device used at ignition of fuel in the gas-oil-fired boilers. Ignition and combustion of pulverized coal is implemented in three-section reaction chamber with the total length of 1510 mm and inner diameter of 315 mm, lined inside with a refractory material. Pulverized coal afterburning occurs in the lined combustion chamber with the diameter of 1000 mm and length of 2800 mm. The combustion products mixed with cooling air are released into the atmosphere through the horizontal cyclone and exhauster.

The gas flow rate is measured by the flow meters; the temperature is measured by the platinum – platinum-rhodium thermocouples. The coal feeder regulates the flow rate within 50--1000 kg per hour.

The spectrum of particles with the standard sizes of grinding at two-stage combustion is shown in fig. 3.

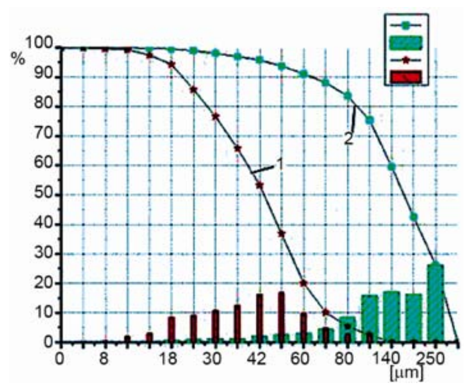

Figure 3. Spectrum of coal particles after disintegrated mills (1), BPM (2)

The coal-dust from a hopper is supplied by a vibrating feeder to the ejector inlet and then it is mixed with micronized coal flame in the form of a coal-air jet along the combustion chamber.

This system allows investigation of ignition, combustion, and gasification processes under the single and two-stage conditions of combustion.

Numerical studies

Numerical studies of the optimal design of the burner with two-stage combustion of coal fuel based on the use of micronized coal for sustainable ignition will be presented.

Based on numerical studies, the design of the burner was selected in relation to the PK-40 boiler with the steam capacity of 320 t/h. This device is designed for oil-free ignition of the burner using mechanically activated micronized coal. The construction of a two-stage device burner of the set-up with the heat capacity of up to 5 MW, developed at Institute of Thermophysics, Siberian Branch of the Russian Academy of Sciences, was used as the basis.

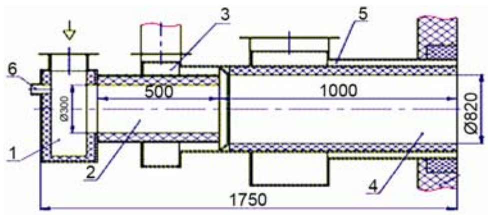

Figure 4. Two-stage coal burner

The micronized coal dust in the amount of 1-1.2 t is fed to the first burner stage (fig. 4) after the disintegrator-mill. The micronized Kuznetsk coal in the amount of 4-5 t is fed to the 2nd stage of the burner after the ball pulverizer mill.

The first stage of the burner is lined snail (1) with cylindrical bore (2) at the outlet. In the snail there is opening (6), where the igniting device – gas burner, oil burner or a low-power plasmatron (with the power of 5-10 kW) can be inserted. The main objective for the first stage is thermochemical preparation, ignition and sustained combustion of micronized coal at the outlet of the 1st stage for ignition of dust in the 2nd stage (4), fed from the dust hopper after BPM through snail (3). Secondary air at the 1st stage can also be fed through this snail, mounted coaxially with the first one, *i. e*., channel (3) is simultaneously the channel for the oil-air mixture in the second stage of burner.

Secondary air in the second stage of burner is fed to the furnace though coaxial channel (5) with the integrated vane swirler. After coal ignition in the 2nd stage and boiler heating, sufficient for launching on the main coal, the supply of micronized coal to the 1st stage of the burner is stopped, and the igniting burner works on coal dust after BPM, supplied through snail (3).

Two schemes of burners were considered: with coaxial pulverized coal supply through snail (1) and supply of standard grinding coal through snail (3), and the scheme, where the pulverized coal (1) is mixed at the burner inlet with standard grinding coal, supplied at an angle to the flow of pulverized coal. In fact, there is no a muffle region for the coarse coal dust, and the thermal conditions of ignition and stable flame combustion of pulverized coal and coal of standard grinding are complicated by high emission of heat to the furnace.

The universal CFD software package *SigmaFlow* was used for calculations. The program complex was intended for research and analysis of spatial liquid and gas flows, heat and mass transfer and chemical reaction. Built-in software for visualization of simulation results allows the rapid analysis of results and presentation of graphic materials. This program complex has been successfully used to calculate the furnaces and burners [5, 6], including those with the use of *mechanically activated* coal [7].

The Reynolds equations considering interfacial interactions are used to simulate numerically the turbulent flow of incompressible liquid. The Reynolds equations are closed by means of a two-parameter model of turbulence: the standard k-ε model of turbulence. To describe the processes of particle motion, the Lagrange method is used. The particle motion is described by equations of material point dynamics with consideration of the resistance and gravity forces. Flow turbulence at particle motion is taken into account by introducing the random fluctuations in gas velocity into the equation of particle motion. The solution to the radiative transfer equation is based on P1 approximation of the spherical harmonics method for the gray two-phase two-temperature medium.

To describe combustion of a coal particle, model [8] is used, where combustion is presented as the consecutive stages: moisture output, volatile output, and coke burning. Some empirical coefficients, allowing more accurate estimate of heat transfer and time of coal particle combustion, are also used.

To solve the conservation equations for the gas phase, the method of control volume is used. To calculate the diffusion fluxes on the faces of a control volume, the central-difference scheme of the second accuracy order is applied. To approximate the convective terms, the scheme of the second order of accuracy is used. To solve the resulting system of equations, the method of incomplete factorization, which factorized only the diagonal terms, is used.

To connect the pressure field and velocity, the SIMPLE-like procedure on the combined grids is used. When particles move through the control volume, a source term, which takes into account momentum and energy exchange between gas and dispersed phase, is formed.

Results and discussion

The calculation results obtained using "σFlow” mathematical model for the scheme shown in fig. 4 are presented in figs. 5-11. Mechanically activated coal is fed through the tangential inlet to the furnace pre-chamber, where ignition of coal dust occurs. The bulk of the primary oxidant reacts with volatile components of the fuel. Due to rapid release of volatiles and their good reactivity, concentration of volatiles at the outlet of the first stage is close to zero (figs. 4 and 6) and concentration of oxygen is about 4 wt.% (fig. 9). The maximal temperatures at the first stage are 1800 °C. At the output of stage 1, highly reactive dust air mixture with the temperature of 1600 °C is formed (figs. 3 and 5), which interacts with pulverized coal and secondary air of stage 2, fed from the hopper through the snail after BPM. Analysis of calculation results showed that in spite of formation of highly reactive dust air mixture from the first stage, the burner geometry for the proposed length of the muffle of stage 2 does not allow stable flame front at the outlet of burner stage 2 at combustion of the mixture of micronized coal and coal dust after BPM.

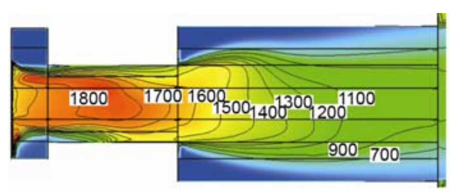

Figure 5. Temperature field in the central cross-section, [°C]

Figure 6. Concentration of volatiles in the central cross-section, [kgkg^{-1}]

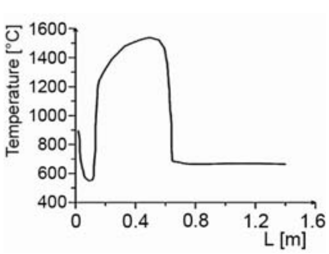

Figure 7. Temperature, average over the cross-section along the burner, [°C]

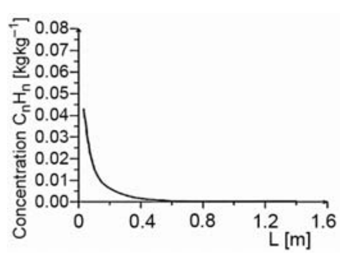

Figure 8. Volatile concentration, average over the cross-section along the burner, [kgkg^{-1}]

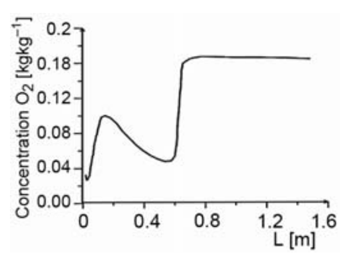

Figure 9. Concentration of O_2, average over the cross-section along the burner, [kgkg^{-1}]

It can be expected that with more intense flow mixing we can obtain more efficient ignition of the coal dust at the second stage. Figure 8 shows the first modified scheme, and fig. 9 presents the second modified scheme of the burner.

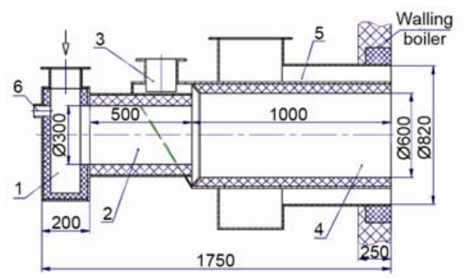

Figure 10. First modified scheme of lighting-up burner for PK-40 boiler

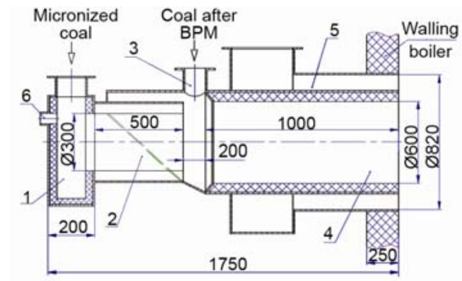

Figure 11. Second modified scheme of lighting-up burner for PK-40 boiler

The first modified scheme of the burner (fig. 10), calculated using the "σFlow" mathematical model, is shown in figs. 12-15. Figures 12 and 11 show the coal feed from the hopper together with air. Despite we expected more intensive interaction of the first stage flow with the flow of pulverized coal from the bunker, the calculation results show that the spiral motion of particles along the walls of the 2nd stage chamber (fig. 15) does not give the expected result, and at the outlet of the 2nd stage, we have the flow with the average temperature of 700 °C (fig. 14).

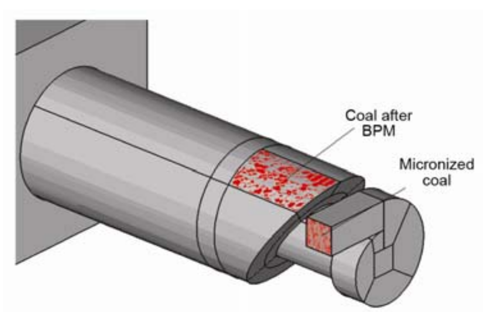

Figure 12. Geometrical model of the burner

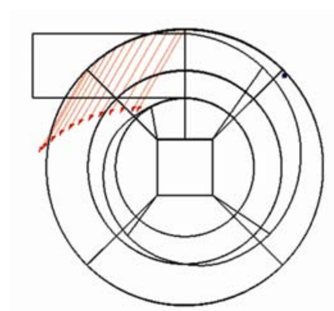

Figure 13. Flow through the channel of coal supply from the hopper

Results of calculation of the 2nd modified scheme of the burner (fig. 11) are shown in figs. 16 and 17. The geometrical model of the burner is shown in figs. 15 and 16, there is organization of coal supply from the hopper together with air.

This organization of air and coal supply leads to intense interaction of the high-temperature dust air mixture of the first stage with the pulverized coal flow of the second stage (fig. 16). The release of volatile substances is intensified, their ignition occurs, and the average temperature at the outlet of the second stage is 1100 °C. The temperature field at the outlet of the 2nd stage of the burner characterizes stable combustion of the flame of micronized and pulverized coal mixture after the conventional mill (fig. 19). This makes it possible to consider this scheme of the 2-stage burner optimal for different technological solutions, when creating the igniting burners on micronized coal in a wide range of metamorphism.

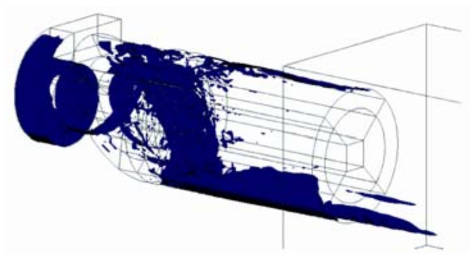

Figure 14. Temperature field in the central cross-section, [°C]

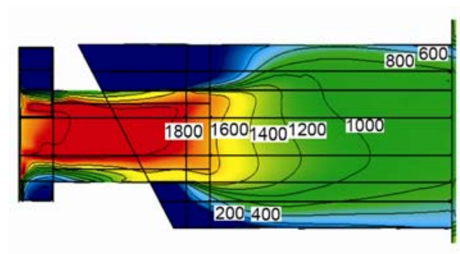

Figure 15. Isosurface of coal particles of 0.4 kg/kg*)*

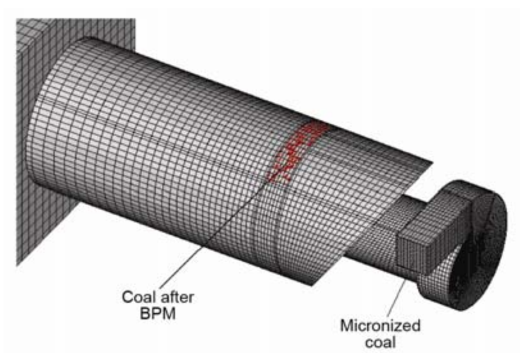

Figure 16. Geometrical model of the burner

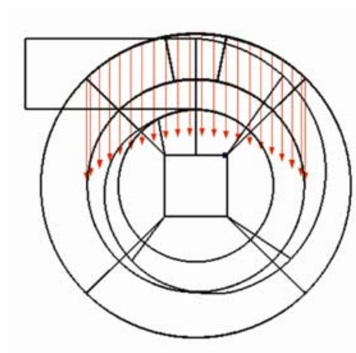

Figure 17. Flow through the channel of coal supply from the hopper

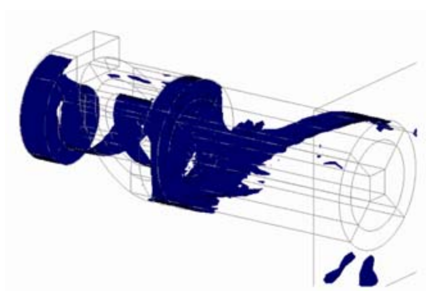

Figure 18. Isosurface of coal particles of 0.4 kg/kg

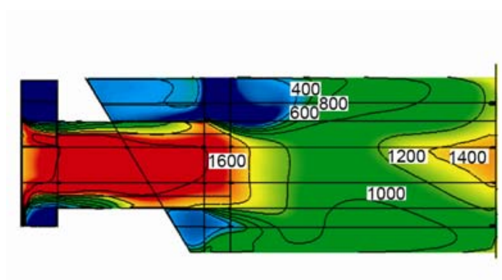

Figure 19. Temperature field in the central cross-section, [°C]

These calculations allow the selection of the optimal scheme of two-stage combustion and further gasification using micronized coal. The first experiments on two-stage combustion by the scheme of fig. 1 are presented in next chapter.

The main goal of these experiments is to confirm the possibility and feasibility of two-stage combustion using a simplified scheme (fig. 1).

Experiments

Combustion of micronized coal in the two-stage process

Since the results of research on combustion of mechanically activated micronized coals are partially published in [4], here we present the results of one of experiments on ignition and combustion of long-flame Kuznetsk coal after its grinding with activation in a mill-disintegrator in the single-stage process.

According to the diagrams, the combustion temperature at the first stage of combustion chamber is 1600 °C at air excess coefficient of $\alpha = 0.3$, the processes of ignition and stabilization occur during 100-170 s, combustion takes place with predominant formation of CO_2 and maximal burnout of oxygen. The igniting device was switched-off after 1 min of operation, and combustion occurred under the auto-thermal conditions.

Similar experiments have been carried out with coals of different metamorphic stages.

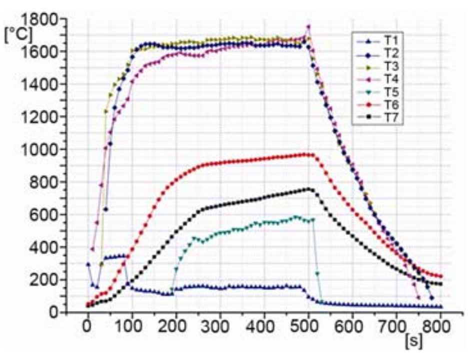

Figure 20. Distribution of temperatures in the burner at single-stage combustion of Kuznetsk coal of grade D

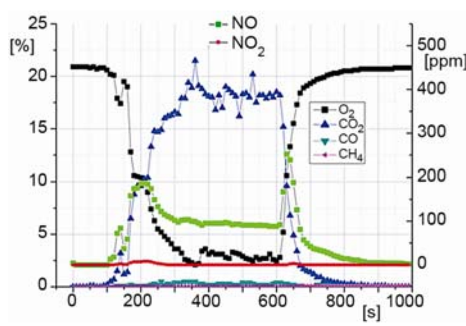

Figure 21. Composition of gas at the burner outlet at single-stage combustion of Kuznetsk coal of grade D

Two-stage combustion and gasification of coal

The two-stage burner – reaction chamber is a new step in development of the technology of coal-dust combustion and gasification. This article presents the results of the first experiments in this field. Although the experiments were carried out at the set-up (fig. 1) with almost coaxial fuel supply after the disintegrator and conventional mill (BPM), where interaction of micronized coal flame with coal after the conventional mill is not optimal (according to calculations, for such a scheme mixing occurs at the distance of 8-10 channel caliber), in experiments we have achieved fast flame ignition after flow mixing with the maximal temperature of 1300-1400 °C in the second and third sections of the reaction chamber with air excess in the first stage $\alpha = 0.9$-1.1.

At that, in the process of ignition, when micronized coal is fed, combustion enters the autothermal mode during 150-200 s, and when coal pulverizing by the conventional boiler mill is fed, combustion becomes stable in 350 s after a slight temperature drop at the end of the third section of furnace extension at the level of 1400 °C.

According to gas analysis, oxygen burns out completely in the end of the reaction chamber, and concentrations of CO and H_2 become 16% and 8%, respectively, *i. e.*, the process of air gasification occurs.

When the secondary air with $\alpha > 1$ is supplied, stationary two-stage combustion of pulverized coal will occur, and this will allow the reasonable approach to the creation of burners for coal-dust flame ignition and lighting in boilers with minimizing costs of coal regrinding and activation at creation of oil-free systems of ignition and stabilization of combustion.

The program of works on ignition and combustion of coal by the two-stage scheme plans to study the optimal proportions of coals at various stages of metamorphism, supplied to the first and second stages, to achieve the maximal technical and economic parameters for the systems of ignition and lighting of the coal-dust flame in the power boilers.

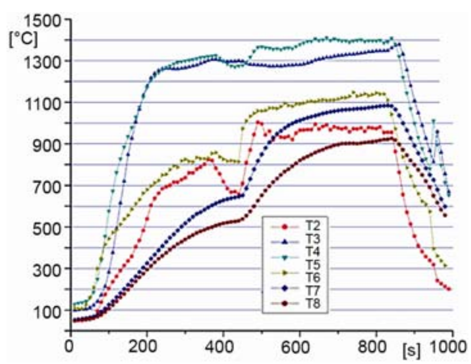

Figure 22. Temperature measurement during two-stage air gasification of coal

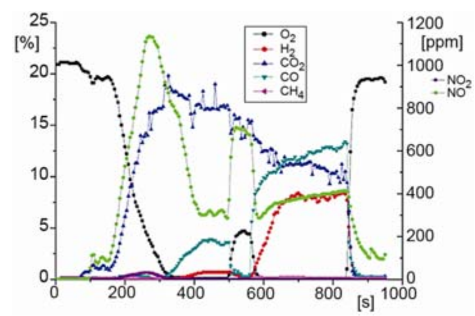

Figure 23. A change in gas concentration at air gasification in the two-stage process

Studying the processes of air and air-steam gasification, using mechanically activated micronized coals in the single- and two-stage systems is of the great interest because gasification processes occur with significant energy absorption and enhancement of fuel reactivity due to its mechanical activation, and this allows the autothermal process.

Commercial tests

The first tests on using micronized coal instead of heavy oil for kindling PK-40-1 boiler have been performed at Belovo Thermal Power Plant of Kuzbassenergo by the commissioning company R. V. S.

Based on investigation results on burning the micronized coals, performed at an enlarged set-up of IT with thermal capacity of up to 5 MW, the R. V. S. company carried out the tests on a real power boiler PK-40 with steam capacity of 320 t/h at Belovo TPP of Kuzbassenergo.

The used coal had the following characteristics: working humidity *W*-12.6%, working ash content *A*-19.3%, volatile output per hot mass V^{daf}-42.9%, and lower operating heat of combustion of 5015 kcal/kg. The volume of combustion chamber is 2100 m^3, square furnace of 8500-8500 mm. The boiler body is equipped with 10 straight-through pulverized coal burners arranged in two floors. Heavy oil nozzles (6 pcs.) are integrated into the secondary air channels of the straight-through burners. In each boiler body, there is the individual system of pulverizing with intermediate dust hopper with the capacity of 135 t. Coal dust from this hopper is supplied to the pulverized coal circuit of high concentration and is sent to the burners. On one of the burners (No. 18), heavy oil supplied into the burner was ignited by the firing system, and this ignited pulverized coal from the mill-disintegrator; after its ignition, the heavy oil supply was stopped.

The combustion regimes of pulverized coal flame were studied at coal supply from 1.75 t/h to 2.5 t/h. Stable combustion of the flame was observed everywhere. The series of experiments on the effect of the secondary air consumption on the size and luminosity of the flame were also carried out.

In experiments, the system on the use of ultra-fine coal dust in the boiler burners worked 4 hours 20 min., and this corresponded to the average time of boiler kindling. At that, stable combustion of pulverized coal flame was observed under different regimes all the time.

The chemical analysis of ash at micronized coal combustion under the regime of kindling showed mechanical underburning; however, it is not explosive. In general, the obtained results are positive.

Currently, the works on equipping the 4-burner boiler PK-40-1 with the ignition systems based on micronized coal begin. This will allow the full-scale testing of the system of oil-free ignition and lighting on a real power boiler. In the future, based on this technology, it will be possible to conduct the tests on the use of micronized coal in the "rebening" process to reduce NO_x emissions. According to preliminary calculations of [9], the use of "mechanically activated" coal for "rebening" in the coal-fired boiler E-500, which burns brown coal, allows reduction of nitrogen oxide formation by 30% and mechanical underburning by 35% as compared to the current version of boiler.

Conclusions

The new ways of two-stage combustion and gasification of coals in the first stage after mechanical activation of micronized coal, and in the second stage after the conventional mill (BPM) of the real boiler are considered in the paper. Optimization of the system of burner – combustion reactor was calculated for two-stage combustion. The first successful experiments on two-stage combustion and air gasification of Kuznetsk coal of grade D were performed at the modernized set-up with the thermal power of up to 5 mW.

The first demonstration tests on the use of mechanically activated micronized coal in the system of oil-free kindling were carried out in the PK-40 boiler with the steam capacity of 320 t/h at Belovo TPP of Kuzbassenergo.

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