Efficiency of technology of mechanically activated coal for ignition and lighting of pulverized coal boilers

G V Chernova, A P Burdukov, E B Butakov
Kutateladze Institute of Thermophysics SB RAS, Novosibirsk, Russia
E-mail: chernova@itp.nsc.ru

Abstract. To increase the energy efficiency of coal flaring, a technology with mechanochemical activation of coal by the mills is being developed at the Institute of Thermophysics SB RAS. The technology is aimed at increasing coal reactivity and can be used to replace high-reactive expensive and difficult-to-obtain fuel oil for ignition and lighting of pulverized coal boilers of thermal power plants (TPP) using mechanically activated microground coal. A technique for assessing the technical and economic efficiency of using the technology of mechanically activated microground coal is suggested. The investment attractiveness of replacing fuel oil ignition and lighting with mechanically activated microground coal on a number of pulverized coal boilers of thermal power plants of Siberia is presented.

1. Introduction
In the long term, coal remains one of the most important resources of the thermal power complex due to its large global reserves and competitive low prices [1]. In the Siberian regions of Russia, the “large” energy sector is mainly coal (in Eastern Siberia, more than 90%). However, the pulverized coal boilers of thermal power plants with flame combustion often receive coal with varying qualitative composition, as well as brown coal with low caloric value, high humidity and ash content. Their low reactivity causes problems of their ignition and steady burning of the flame. Therefore, the existing technologies of coal flaring for ignition and lighting on pulverized coal boilers use highly reactive fuels (gas-oil, diesel). For the Siberian regions, this is mainly expensive, highly reactive fuel oil, from 0.1 to 3.5 %.
But consumption of fuel oil is problematic both in terms of its supply, storage, and its deficiency and high cost. Its cost can exceed the cost of coal by up to 5 - 7 times (natural fuel) and up to 3 - 4 times (equivalent fuel).

Improvement of coal reactivity is an important task of their energy use. For this purpose, a new mechanochemical coal technology, leading to an increase in its reactivity due to coal micro-grinding by mills – disintegrators, is being developed at the Institute of Thermophysics of the Siberian Branch of the Russian Academy of Sciences (IT SB RAS). To develop a technology with mechanochemical activation of coal, a wide range of experimental studies on coal combustion using the large-scale pilot-type fire setups with a thermal capacity of up to 1 and 5 MW, as well as numerical calculations by specially developed mathematical programs, are carried out [2-5]. The obtained positive results allow the developed technology of mechanically activated micro-grinding of coal to be recommended for the replacement of fuel oil ignition and lighting.

2. Technology of mechanical activation of coal fuel
An alternative option of fuel oil ignition and lighting is the technology developed at IT SB RAS to replace the fuel oil with pulverized coal subjected to mechanochemical activation. The technology allows an increase in coal reactivity by 2 - 3 times [2-3]. An increase in reactivity is achieved by mechanochemical activation of coal fuel with an average size of pulverized particles of 40 μm in special mills. The technology is developed using special experimental thermal setups with the power of up to 1 and 5 MW with the involvement of modern measuring equipment and numerical calculations.

The physicochemical changes of coal take place at its fine and ultra-fine grinding. Two processes are characteristic of fine dispersion of coal: grinding with an increase in specific surface $S$ and aggregation of fine particles with a sufficient duration of grinding, which leads to a decrease in the value of $S$. This causes a sharp increase in coal reactivity in various processes and chemical reactions [6]. Under the mechanical effects in a special mill-disintegrator, local concentrations of both mechanical and thermal energy are created, which leads to breaking the chemical bonds with formation of free radicals, including macroradicals, which explains an increase in the chemical activity of coal, including the tendency to oxidation and ignition.

The technology being developed is a new system of ignition and lighting for the boiler, which includes the additional equipment: micro-grinding equipment (mills - disintegrators) and non-standard equipment for coal dust supplying, burning and cleaning (input units, device of initial fuel acceleration, fuel discharger, separator, bunker for fuel accumulation, muffle pre-furnace, air line, etc.).

An experimental pilot-type fire setup with a thermal capacity of up to 5 MW with additional equipment, used for a series of studies on coal combustion with various supply schemes of coal of different stages of metamorphism: coal and brown coal (single-stage and two-stage, sequential and parallel) is shown in Figure 1.

![Figure 1](image)

**Figure 1.** Photograph of a fire setup with a thermal power of up to 5 MW with single-stage combustion and straight-line supply of pulverized coal into the combustion chamber.

The studies performed with mechanochemical microgrinding of coal in a mill - disintegrator showed ignition and steady burning of coal. It is shown that combustion of mechanically activated microground coal is similar to combustion of highly reactive fuels. The time dependences of temperature measured during the experiment on two-stage coal combustion with the supply of 90 kg/h of mechanically activated microground coal into the first stage (I) and 140 kg/h of standard-ground coal into the second stage (II) are presented in Figure 2. The data was obtained from six thermocouples, arranged in numbering order from the flame base to its tail.
Figure 2. Temperatures of pulverized coal flame in the reaction chamber versus time; supply of 90 kg/h of microground coal into the first stage and 140 kg/h of coal after the ball-drum mill into the second stage.

The activation energy of a flame of coal subjected to grinding with mechanical activation at an average particle size of 40 µm decreases in a special mill-disintegrator by a factor of 2-3 and, according to its characteristics, the combustion of such coal is similar to the combustion of highly reactive gas-oil/diesel fuel.

The conducted studies allow us to recommend the use of technology of mechanically activated microground coal for the replacement of fuel oil ignition and lighting of pulverized coal boilers at operating power plants.

3. Technique for an assessment of technical and economic efficiency of the project of replacing fuel oil ignition and lighting of a pulverized coal boiler at a thermal power plant with mechanically activated microground coal

To implement the technology of fuel oil replacing with mechanically activated microground coal, the additional equipment is installed on the pulverized coal boiler. This requires involvement of additional one-time costs $K_{ad}$, including both the cost of additional equipment (the cost of mills $K_{mill}$ and cost of non-standard equipment $K_{n-s eq}$), and the cost of development $K_{dev}$ (design work, construction and installation, contract supervision during commissioning and testing, reserve of funds for unforeseen works and costs of its installation on the boiler):

$$K_{ad} = K_{mill} + K_{n-s eq} + K_{dev}$$

(1)

Economy of annual current costs $E_{c.c.}$ is achieved due to the use of cheaper coal instead of fuel oil:

$$E_{c.c.} = P_{f.o.} * V_{f.o.} - P_c * V_{c.i.g} + T_{e.i.n.} * V_{e.i.n.} * V_{c.i.g}$$

(2)

where, $P_{f.o.}$ is fuel oil price, $V_{f.o.}$ is the volume of fuel oil, $P_c$ is price of coal, $V_{c.i.g}$ is the volume of coal that replaces fuel oil at ignition and lighting of boiler, $T_{e.i.n.}$ is electricity tariff for inner needs of the enterprise, $V_{e.i.n.}$ is the amount of electricity spent for microgrinding of coal.

The last term of expression (2) represents the additional energy costs spent for coal microgrinding on the mill - disintegrator.
The economic efficiency of the project on substitution of fuel oil with mechanically activated microground coal is determined by a simple payback period of the project \((T_{p.p.})\) is calculated as:

\[
T_{p.p.} = \frac{K_{ad}}{E_{c.e.}}.
\]

4. Investment attractiveness of using the technology of mechanically activated microground coal for ignition and lighting of pulverized coal boiler

The performance of microgrinding mills \((t/h)\) required for ignition and lighting is determined by consumption of combusted coal \((t/h)\), which replaces fuel oil \((4)\). Coal consumption is determined as follows:

\[
V_{c,ig} (t/h) = V_{f,o} (t/h) * K_{f,o} : K_{c,ig},
\]

where, \(V_{c,ig} (t/h)\) is consumption of coal per hour, \(V_{f,o} (t/h)\) is consumption of fuel oil per hour, \(K_{f,o}\) is calorificity of fuel oil, \(K_{c,ig}\) is calorificity of microground coal.

Assessment of economic efficiency was carried out both for the current period (option 1) and for the near-term outlook, taking into account the forecast changes in the economy based on the analysis of economic indicators (option 2), including the changes in prices for additional equipment, fuel, and electricity \([7,8]\). For the near-term outlook, the cost of additional equipment is assumed to be increased by the factor of 1.1, the cost of fuels is increased: by 1.031 times for fuel oil, by 1.283 times for coal, by 1.316 times for brown coal, and by 2.2 times for electricity. Types of the used fuels do not change.

Cost \(K_{mill}\) of mills with a capacity of 100 kg \(/t\) \((DM\ 0.1)\) and 1 \(/t\) \((DM\ 1.0)\), costs of non-standard additional equipment, development, as well as additional costs when installing one and two mills on the boiler for the current period and the near-term outlook are presented in Table 1.

**Table 1.** One-time additional costs for equipping the boiler with a system for replacing fuel oil ignition and lighting with mechanically activated microground coal.

| Type of mill \((t/h)\) | Installation of one mill, mln.rub. | Installation of two mills, mln.rub. |
|----------------------|-----------------------------------|-----------------------------------|
|                      | \(K_{mill}\) \(K_{n-s\ eq.}\) \(K_{dev}\) \(K_{ad}\) | \(K_{mill}\) \(K_{n-s\ eq.}\) \(K_{dev}\) \(K_{ad}\) |
| Current period       |                                   |                                   |
| DM-0.1               | 0.42                              | 0.84                              | 1.26                              | 2.52                              | 0.84                              | 1.68                              | 2.52                              | 5.04                              |
| DM-1.0               | 1.50                              | 3.00                              | 4.50                              | 9.0                               | 3.00                              | 6.0                               | 9.0                               | 18.0                              |
| Near-term outlook    |                                   |                                   |
| DM-0.1               | 0.462                             | 0.924                             | 1.386                             | 2.772                             | 0.924                             | 1.848                             | 2.772                             | 5.544                             |
| DM-1.0               | 1.65                              | 3.30                              | 4.95                              | 9.90                              | 3.30                              | 6.6                               | 9.90                              | 19.80                             |

Prices of fuel and electricity are shown in Table 2.

**Table 2.** Prices of fuel and electricity.

| Resource                  | Current period | Near-term outlook |
|---------------------------|----------------|-------------------|
| Fuel oil, rub./t          | 12431.0        | 12816.0           |
| Coal, rub./t              | 1679.0         | 2154.0            |
| Brown coal, rub./t        | 1181.0         | 1554.0            |
| Electricity for inner needs, rub./kWh | 1.0               | 2.2               |

The considered technology of mechanically activated microground coal can be implemented in practice at ignition and lighting in dozens of pulverized coal boilers of the Siberian region. Table 3 below shows the investment attractiveness of four projects for different pulverized coal boilers with...
burning coal. Experimental studies of the combustion process of coal with mechanically activated grinding at an experimental pilot-type fire setup of up to 5 MW in IT SB RAS have confirmed ignition and achievement of stable autothermal combustion.

5. Results
The greater the amount of replaced fuel oil, the higher the economic efficiency of the projects. For the considered coal-fired boilers of Siberian TPPs operating on substandard and low-grade coals, the projects for the replacement of fuel oil ignition and lighting with by activated microground coal are cost-beneficial (Table 3). The payback period of the projects for the current period and near-term outlook is 1.39 and 1.6 years for PK-40 boiler of Belovskaya State District Power Plant (SDPP), 3.53 and 4.04 years for boiler PK-10P of South-Kuzbass SDPP, and 1.93 and 2.24 years for BKZ-420-140PT boiler of Krasnoyarskaya SDPP, and 1.39 and 1.60 years for BKZ -420 boiler of Omsk TPP -5.

Table 3. Investment attractiveness of pulverized coal boilers with replacement of fuel oil ignition and lighting by mechanically activated microground coal.

| Heat plant boiler, replaceable fuel oil, replacement coal | Combusted coal | Economic indices | Evaluation period | $K_{ad}$ mln.rub. | $E_{cc}$ mln.rub. | $T_{pp}$ year |
|---------------------------------------------------------|----------------|-----------------|------------------|------------------|-----------------|--------------|
| PK-40 boiler $V_{f.o.} (t / h) = 1407$ $V_{e.ig} (t / y) = 2772$ | Kuznetsk coal grades G and D: Volatiles > 25% | Current period | 18.0 | 12.199 | 1.39 |
| | | Near-term outlook | 19.8 | 12.244 | 1.62 |
| PK-10P boiler $V_{f.o.} (t / h) = 149.53$ $V_{e.ig} (t / y) = 261$ | Kuznetsk coal of grades TR: Volatiles of 10-15% | Current period | 5.04 | 1.428 | 3.53 |
| | | Near-term outlook | 5.544 | 1.371 | 4.04 |
| BKZ - 420 boiler $V_{f.o.} (t / h) = 978$ $V_{e.ig} (t / y) = 2476.6$ | Kansko - Achinsk coals of grade 2 BR with increased humidity of up to 40% | Current period | 18.0 | 9.308 | 1.93 |
| | | Near-term outlook | 19.8 | 8.849 | 2.24 |
| BKZ - 420 boiler $V_{f.o.} (t / h) = 1349.29$ $V_{e.ig} (t / y) = 6026$ | Ekibastuz coals of the KSN grade with a volatile yield of 24% and with high ash content > 40% | Current period | 18.0 | 12.968 | 1.39 |
| | | Near-term outlook | 19.8 | 12.345 | 1.60 |

6. Conclusion
To replace fuel oil ignition and lighting of pulverized coal boilers using substandard and low-grade coals, the technology with mechanochemical activation of coal is proposed. The technological aspect has been worked out. The given assessment of technical and economic efficiency of a number of projects for replacement of fuel oil ignition and lighting with mechanically activated microground coal indicates the investment attractiveness of projects, simple payback periods of the projects are within the economically acceptable limit (up to 4 years). The projects on replacement of fuel oil ignition and lighting with mechanochemical activation of coal can be proposed for consideration.

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