The assessment of the feasibility of power technological plants on the territory of the Russian Federation

I A Burakov¹, A Y Burakov², N A Burakova², I S Nikitina¹, Aung H N¹, Ye Y A¹, N A Bragina¹ and V N Fedorov¹

¹ National Research University "MPEI", 14 Krasnokazarmennaya str., Moscow, 111250, Russian Federation
² Limited liability company "Research and production enterprise "GIRAM", 9 Bartenevskaya str., Moscow, 117042, Russian Federation

e-mail: BurakovIA@mpei.ru

Abstract. To improve the environmental safety of thermal power plants, the use of an industrial complex for the preliminary preparation of the initial solid fuel – an power technological plant has been proposed. The basis of the functioning of this complex is the consistent application of processes of power technological processing of solid fuels, such as gasification, pyrolysis, enrichment, briquetting, the production of artificial composite fuels. The fuels obtained at an power technological plant have improved energy and environmental performance. In the future, the fuel from the power technological plant is distributed to the energy facilities of the region. In the present work, a selection of regions for the development power technological plants were developed, the calculated characteristics of the resulting fuels were presented: the net calorific value of the working and dry ash-free mass, the elemental composition, the amount of emissions generated by burning the resulting fuels. An assessment is made of the possibility of functioning of power technological plants in the construction region.

1. Introduction

According to [1, 2] for the period from 2015 to 2017 on the territory of the Russian Federation (RF) the share of coal consumption among the main energy fuels used at thermal power plants (TPP) is reduced. This trend is associated with a decrease in the competitiveness of coal, primarily in those Federal Districts (FD) where natural gas is the main fuel. According to [3] such FD at the beginning of 2015, six of the eight FD of RF.

The decrease in the competitiveness of coal is associated with both economic and environmental problems arising from its use as the main fuel for thermal power plants. Economic difficulties are expressed primarily in the pricing of the main types of fuel for thermal power plants, as well as in the cost of rail transportation of solid fuel, its production, its preliminary preparation (crushing, grinding, etc.). Environmental problems associated with the presence of high concentrations of harmful and toxic substances in its combustion. In addition, of the total amount of solid fuel reserves of the Russian Federation 68.7% are reserves of brown coal [1, 2, 4 – 6], that also has a negative impact on the environmental situation in the regions of the location of such power plants.

In the world, with the exception of a number of countries, there is a tendency to reduce the share of solid fuel consumption among the main fuels used at thermal power plants, similar to the Russian Federation. A striking example of this is the UK, where the last coal mine in the Western regions of the
country was closed by the end of 2016 [1]. The development of the coal mining industry in the Russian Federation cannot be similar to the scenario of the UK coal industry due to the presence of huge reserves of solid fuel, which play a strategic role, as well as due to the presence of a number of regions of the Russian Federation, in which according to [7] there is no alternative to coal generation, or it is competitive with respect to other types of energy fuels.

Thus, in order to improve the efficiency of solid fuel use in the energy sector of the Russian Federation and to solve the environmental problems arising from the use of solid fuel, it is necessary to develop a concept for the use of coal, which would imply the preservation or minimum reduction of its energy potential on the one hand, and on the other hand would significantly reduce the negative impact of the use of solid fuel on the environment. The issue of environmental impact becomes extremely relevant in the light of the upcoming tightening of environmental requirements [8, 9]. A number of countries with similar energy problems already apply a similar concept, which is expressed in the widespread use of pre-energy technological processing of solid fuels into environmentally friendly liquid or gas fuel. One of the striking examples of this is China and the EU [10, 11].

The use of individual complexes of energy–technological processing of solid fuel for energy facilities of the Russian Federation can be extremely expensive, so it is proposed to consider the possibility of creating energy complexes for the processing of solid fuel-energy-technological plants, the operation of which and interaction with the TPP will be carried out by analogy with oil refineries. That is, the products obtained as a result of the processes of energy technological processing of solid fuel should be distributed to the energy facilities of the construction region. Such coal-processing complexes can operate not only for energy purposes, but also for other types of industry. For example, the product of such a complex can be synthetic gasoline [12].

The idea of development and application of energy facilities using methods of energy technological processing of solid fuel is not an innovation for the world and domestic energy. There are a number of works [10, 13, 14], in which the topic of sequential conversion of the original solid fuel in order to obtain an environmentally friendly energy-efficient fuel product is touched upon, but the operation of direct coal-processing complexes, like the ones described above, has not been considered before. The author's team in the present work will try to assess the possibility of using energy technology plants in the territory of the Russian Federation.

2. Development of power technological plants

2.1. Processes of power technological use of solid fuel

According to [15], energy technology plants are called TPPs, where one or several energy technology types of processing of the initial solid fuel are used together. However, the presence of TPP directly on the site of solid fuel processing is not necessary. It is possible to operate an energy technology plant exclusively with the subsequent distribution of fuel products to the energy facilities of the construction region.

The processes of energy-technological fuel processing are understood as the processes of gasification, pyrolysis, coal enrichment, briquetting, production of artificial composite fuels (ACF) (artificial composite solid fuels (ACSF) and artificial composite liquid fuels (ACLF)).

In table 1 a list of the positive and negative sides, which entails the use of processes of energy technological use of solid fuel. When creating an energy complex for energy technological processing of solid fuel, one of the main tasks will be to select the right combination of energy technological processes that will produce an artificial fuel product with maximum energy and environmental value and with minimal economic costs.

On the base of Department of Theoretical fundamentals of heating (TOT) and thermal power plants, National Research University "MPEI" the work was carried out to assess the effectiveness of energy plants on the territory of the Russian Federation. As the object of the study were selected regions of the Russian Federation, which according to [3] at the beginning of 2015 had one of the lowest levels of
supply of natural gas for the FD, namely: Siberian FD (5.8% of the total needs of the district), far Eastern FD (15.8 %) and Ural FD (48.4 %).

Table 1. Processes of energy technological use of solid fuel [16].

| No | Kind of process | Positive side finished product | Negative aspects of the finished product |
|----|-----------------|---------------------------------|-----------------------------------------|
| 1  | Gasification    | Production of environmentally friendly gas fuel. | Reduced caloric value; different component composition compared to natural gas. |
| 2  | Pyrolysis       | Production of environmentally friendly gas fuel; production of other useful products. | Reduced caloric value; different component composition compared to natural gas. |
| 3  | Enrichment      | Reducing sulfur and ash content; increasing caloric content. Increase in caloric content; production of finished marketable product; the possibility of using waste from other industries and coal fines; reduction of entrainment during combustion. | In some cases, an increase in humidity; an increase in cost. |
| 4  | Briquetting     | Reducing emissions of toxic gases; the ability to use any type of water to produce a suspension. | Increased cost compared to the original product; reduced completeness of further processing. |
| 5  | Obtaining ACLF  |  | Reduced caloric content; significant increase in humidity; increased cost compared to the original product. |

2.2. Development and calculation of schemes of power technological plants

For all the regions represented, energy facilities with energy technological part were developed, which reflects the peculiarities of the use of fuel processing within the boundaries of the selected FD. Brown coals of grades B1, B2, B3 with elementary composition and energy characteristics, which are the most typical for these regions, were chosen as the initial fuel. The applied processes of energy-technological use of fuel were selected on the basis of environmental, economic and resource-saving assessment of FO on the basis of calculations on existing and developed by the team of authors techniques, as well as using the software package "Termoflow".

The initial data for the calculation were selected on the basis of the operational characteristics of the existing energy facilities and taking into account the features inherent in the considered FD (climatic conditions; available solid fuels; the need for electric and thermal energy; industries, products and waste of which can be used in energy technological processing).

The general technological scheme developed in the framework of research of energy technology plants is shown in figure 1. The study considered only sequential circuits of power technology plants. Schemes of other types of authors will consider in their next work.

Operation of the power technological plant as shown in figure 1 the scheme includes a sequential transformation of the original solid fuel in order to increase its energy characteristics, reduce the amount of polluting emissions into the atmosphere and the negative environmental impact on the environment during its processing and (or) combustion.

Before the processes of energy technological use, the initial solid fuel 1 should be prepared in advance: to reduce the size (size) of the pieces, to classify. The site preliminary preparation of fuel 2 includes crushing, separation, nodes, dosing and intermediate bunkers are prepared by the solid propellant 6 is supplied to the main scheme of power technological processing 11. The pre-treatment stage provides the size of the fuel pieces of the order of 10 – 20 mm. Further grinding (grinding) to the size of the pieces required for energy technological processing (1 – 500 microns) takes place on the mill systems installed directly on the main stages of processing.

As the first stage of processing for all considered FD, the process of enrichment of the initial solid fuel 3 was chosen, the task of which was to reduce the sulfur content and mineral impurities in the composition of the processed fuel. Since the coals of the deposits under consideration have the values
of the above characteristics in terms of sulfur content from 0.02 to 0.06 (%*kg)/MJ, which corresponds to low-sulfur solid fuel, at the enrichment stage the main attention was paid to the removal of mineral impurities from the solid fuel composition (ash content reduction). To reduce the cost of this process at the first stage of processing, the application of gravitational and flotation enrichment processes was considered. These methods make it possible to reduce the working ash content in solid fuel to 5% (the minimum value is given; the values of the demineralization depth in the work were calculated by the method [17]) at a sufficiently low cost of processes compared to chemical demineralization [10]. According to the calculated data, the enrichment of the initial fuel by the presented methods makes it possible to increase the value of its lower combustion heat to the working mass by 0.76 – 3.16 MJ/kg.

Enriched fuel 7, in the future, can be used both in the process of direct combustion, that is, when withdrawing it from the energy technological processing system 11 and redistributing it to the objects of the energy system FO 10, and for further processing at the energy technology plant. In all cases presented, the negative impact on the environment is significantly reduced. In the work done, the method of calculating the enrichment stage was based on the experimental data of the methods of enrichment of the initial coals described above [17 – 19]. The obtained energy characteristics of enriched coal are presented in table 2.

![Figure 1](image)

**Figure 1.** The general concept of the energy technology plant.

1 – the original solid fuel; 2 – the site preliminary preparation of solid fuel; 3 – enrichment node; 4 – node briquetting or site preparation ACLF; 5 – gasification unit; 6 – pre-prepared solid fuel; 7 – enriched solid fuel; 8 – coal briquettes or water-coal fuel; 9 – artificial gas fuel; 10 – redistribution of the finished product of the stage of energy technological processing among the power facilities of the FO system; 11 – the system of energy technological processing of solid fuel.

| FD                        | The elemental composition on the mass, % | Calorific value, MJ/kg |
|---------------------------|----------------------------------------|------------------------|
|                           | C% | H% | S% | N% | O% | A% | W% | Qᵢ | Qᵢdaf |
| Ural federal district     | 36.87 | 4.31 | 0.88 | 1.15 | 15.55 | 20.50 | 20.74 | 14.8 | 26.1 |
| Siberian federal district | 39.15 | 2.86 | 0.53 | 0.42 | 13.01 | 7.00 | 37.03 | 13.9 | 26.5 |
| The far Eastern Federal district | 59.04 | 4.17 | 0.46 | 0.73 | 8.42 | 18.50 | 8.68 | 23.2 | 32.2 |

The main task of the second stage of the energy technology plant 4 is to obtain finished products that can be distributed for sale. Products of the second stage of processing are coal briquettes, or ACLF, which in this work is presented in the form of a two-phase mixture of coal-water fuel (CWF) (coal-water slurry (CWS)).

During the briquetting process at the second stage, the task was set to determine the elemental composition, energy and technological characteristics of the resulting briquettes, as well as the choice of binder used in the formation of coal briquettes. Based on the papers [20 – 22] for consideration were
selected binder materials – lingosoft, bitumen emulsion and molasses. The results of the calculation of the received average power characteristics and the elemental composition of the briquettes. The values are shown in the table 3.

**Table 3. Energy characteristics of the obtained briquettes depending on the type of binder.**

| FD                | Binder          | The elemental composition on the mass, % | Calorific value, MJ/kg |
|-------------------|-----------------|-----------------------------------------|------------------------|
|                   |                 | C' | H'  | S'  | N'  | O'  | A'  | W'  | Q_i | Q_i\text{daf} |
| Ural ED           | molasses        | 38.20 | 4.83 | 0.90 | 1.18 | 16.05 | 24.90 | 13.96 | 15.93 | 26.63 |
|                   | lingosoft       | 37.20 | 4.82 | 1.10 | 1.18 | 15.90 | 25.70 | 14.10 | 15.61 | 26.52 |
|                   | bitumen emulsion| 38.50 | 4.90 | 1.00 | 1.19 | 16.10 | 23.31 | 15.00 | 16.08 | 26.68 |
| Siberian FD       | molasses        | 44.10 | 5.45 | 0.65 | 0.70 | 14.70 | 11.00 | 23.40 | 18.45 | 29.02 |
|                   | lingosoft       | 43.60 | 5.43 | 0.95 | 0.70 | 14.30 | 11.60 | 23.42 | 18.34 | 29.12 |
|                   | bitumen emulsion| 45.10 | 5.50 | 0.80 | 0.71 | 14.80 | 9.10  | 23.99 | 18.33 | 29.04 |
| The far Eastern FD| molasses        | 62.10 | 4.89 | 0.50 | 0.75 | 9.10  | 20.00 | 2.66  | 25.09 | 32.53 |
|                   | lingosoft       | 61.57 | 4.86 | 0.93 | 0.75 | 8.85  | 20.40 | 2.64  | 24.96 | 32.51 |
|                   | bitumen emulsion| 63.30 | 5.10 | 0.78 | 0.77 | 9.05  | 17.90 | 3.10  | 25.74 | 32.68 |

In the production process the CWS were compared with three currently known methods of obtaining this type of fuel: traditional, with the use of mills for wet grinding; by using cavitation technology (CaCWF); using hydraulic device for wet grinding (HDWG). Comparison of these methods is described in detail in [23]. The presented technologies were compared by economic and energy components. The team of authors believes that, based on the results of research presented in [23], at the moment the most effective method of CWF preparation is CaCWF. Thus, the organization of the second stage of energy technological processing of solid fuel is associated with the development of a unit of cavitation technologies for the preparation of CWS. In this case, the products of the second stage of the energy technology plant 4 are CWF, the main calculated energy characteristics of which are presented in the table 4.

**Table 4. Energy characteristics of the resulting CaCWF.**

| FD                | The elemental composition on the mass, % | Calorific value, MJ/kg |
|-------------------|-----------------------------------------|------------------------|
|                   | C' | H'  | S'  | N'  | O'  | A'  | W'  | Q_i | Q_i\text{daf} |
| Ural FD           | 25.81 | 3.02 | 0.61 | 0.81 | 10.89 | 14.35 | 44.52 | 9.6  | 26.1 |
| Siberian FD       | 27.40 | 2.00 | 0.37 | 0.30 | 9.11  | 4.90  | 55.92 | 9.0  | 26.5 |
| The far Eastern FD| 41.33 | 2.92 | 0.32 | 0.51 | 5.89  | 12.95 | 36.08 | 15.5 | 32.2 |

Based on the world experience in the use of CWS, the products of the second stage of energy technological processing 8 in the form of CaCWF can be distributed to FD energy facilities, or sent further to the system of the energy technological plant.

The final stage of solid fuel processing 5 of the developed scheme is gasification units, whose task is to obtain environmentally friendly artificial gas fuel-synthetic gas 9, which is the final product of the energy technology plant. Gas of this type, after cleaning and cooling systems, is supplied directly to the boiler burner installed behind the steps of the plant. There are various methods of gasification processes, the main of which are presented in the works [13 – 15, 24, 25]. To select the method of gasification used in the operation of the developed energy technology plant, the data of industrial use of gasification processing in the energy sector were analyzed. The team of authors relied on the data obtained in [26, 27] and on independent research.

The technologies of Shell, Siemens, HT-L, MCSG and MHPS (MHI) considered in the study are methods of in-line gasification with dry feed of initial solid fuel; technologies of GE, ECUST (OMB) and E-GAS are methods of in-line gasification with feed of initial fuel in the form of CWS; technologies
of Lurgi, SEDIN and BGL are methods based on the gasification process in a dense layer. Thus, depending on the type of fuel obtained after the processing unit 4, gasification technologies were selected for the final stage 5 of the energy technology plant:

– E-GAS (in the case when as a result of energy technological processing in the node 4 receive CWS);
– Lurgi (in the case when, as a result of energy technological processing in node 4, coal briquettes are obtained).

The E-GAS technology was chosen as a method of gasification with the maximum lower combustion heat of the synthetic gas obtained from all the considered solid fuel gasification technologies. Lurgi technology was chosen as the most well-studied of all the technologies of gasification of large fuel. The characteristics of the resulting synthetic gas are shown in table 5.

### Table 5. Averaged energy characteristics of the produced synthetic gas

| Method of gasification | Elemental composition of synthetic gas, % | Heat of combustion $\left( Q_i^r \right)$, MJ/m$^3$ |
|------------------------|------------------------------------------|--------------------------------------------------|
| E-GAS                  | CO 54.71, CO$_2$ 8.00, CH$_4$ 3.00, H$_2$ 32.32, H$_2$S 0.03, N$_2$ 1.55, H$_2$O 0.39 | 12.70                                            |
| Lurgi                  | CO 8.02, CO$_2$ 20.10, CH$_4$ 17.17, H$_2$ 5.27, H$_2$S 0.07, N$_2$ 4.74, H$_2$O 44.10, O$_2$ 0.53 | 9.75                                            |

2.3. Environmental impact of energy technology plant products

Within the framework of the presented work, a comparison of technical, economic and environmental characteristics of thermal power plants with the use of energy technological processing of the original solid fuel, coal-fired thermal power plants, and thermal power plants with steam-gas plants (SGP) operating on natural gas of the same capacity was carried out. According to the values of efficiency factors (efficiency) for TPP with SGP operating on natural gas, the net efficiency values were about 54%; gross efficiency was about 56%. Similar values for thermal power plants with SGP, in the operation of energy plant amounted to the order of 35 – 41% 42 – 47%, depending on the type of the schema factory. For coal-fired power plants, the efficiency values were: net efficiency -38.4%; gross efficiency-40.9 %. For the same thermal power plant, with the operation of the energy plant efficiency net amounted to about 25.5%; gross efficiency of the order of 27.9 %.

In figure 2 shows the data characterizing the total number of leaving flue gases produced by combustion of a unit of production (kilograms of standard fuel – kg. at. T.) energy plant. Depending on the type of plant products, there was a significant reduction in emissions of total flue gases for CWF and synthetic gas: for CWF the reduction was 1.53 times; for synthesis gas – 2.61 times.

![Figure 2](image-url)
Thus, the operation of the energy technology plant at the TPP reduces the overall efficiency of the energy facility, but significantly improves the environmental component of the products.

3. Summary
As a result of this work, the possibility of functioning of energy complexes-energy technology plants in the regions of the Russian Federation, where the results of research [3, 7] solid fuel is competitive or its generation has no alternative;
the use of energy complexes of this type will improve the environmental situation in the regions of construction of energy technology plants, as well as in the regions of the location of energy facilities that will receive the products of these plants;
the results of the work revealed that the operation of the thermal power plant with an energy technology plant reduces the efficiency of the station (net, gross) by 13 – 19%, but the number of emissions of total flue gases is also reduced by 2.6 times. Thus, the main task of using energy technology plants is to reduce the negative impact of energy facilities on the environment;
in the operation of energy technology plants, each subsequent stage of processing allows to obtain a fuel product with improved energy and (or) environmental characteristics (table. 7-10), namely: fuel with increased energy characteristics was produced at the coal enrichment stages (an increase in calorific value by 0.8 – 3.2 MJ/kg compared to the products of the previous stage) and coal briquetting (an increase in calorific value by 1.2-4.9 MJ/kg compared to the products of the previous stage); fuel with enhanced environmental characteristics was made on the steps of the receipt of the ACLF (total emissions leaving flue gases decreased by 1.53 times compared to the original coal) and gasification (total emissions leaving flue gases decreased by 2.61 times compared to the original coal);
the results of the work were not identified the prospects of using stage preforming with subsequent gasification of the briquettes obtained, as in the General process of gasification occur loss of the original product in connection with its low depth of conversion (70 – 75%) in the course of this process, greatly reducing the efficiency of the energy object;
in modern conditions of the energy market, the use of energy technology plants will create a positive trend in terms of the efficiency of the use of solid fuel reserves for thermal power plants;
the use of energy technology plants can allow the development of closed coal deposits to resume because of their unprofitability. For example, such as Kizelovsky coal basin, closed in 2002 for this reason, but not depleted in terms of reserves;
the operation of energy technology plants requires a revision of the traditional culture of operation of energy facilities and energy structuring of the construction region.
Energy technology plants require further study, but at this stage their development can create a positive experience, both for the energy of the Russian Federation and for the world energy as a whole.

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