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Environmental study of use of coal-water slurry fuel as an alternative to traditional fuels

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Abstract. In this work we consider coal-water slurry fuels as an alternative to the traditional types of fuels, in particular, coal. Assessment is performed using a software tool for calculating the combustion process of coal-water slurry fuels. The obtained results will allow one to perform computer-aided environmental calculations during CWS combustion in experimental and industrial plants.

1 Introduction

Although the main public attention is focused on electrification of power sources and personal vehicles, liquid fuel still has a 100 times higher energy capacity than the best modern lithium-ion batteries, and this difference is predicted to last for more than a dozen years. Given this fact, investments in improving heat-generating devices and internal combustion engines continue to be relevant, especially owing to the fact that its efficiency increases together with significant reduction of harmful emissions to environment.

Currently, the problems of sustainable development of economic systems at the level of enterprises, regions, individual industries and the national economy as a whole are the subject of scientific research [1-5]. The modern conditions are characterized by acceleration the process of change and increasing uncertainty, both within economic systems and in the external environment, so solving problems of sustainable development are highly relevant. However, to date, the tools and mechanisms for ensuring sustainable growth remain insufficiently studied. This is due to variety of approaches for determination the content of the concept of sustainable development of an enterprise. Some works of Yu.P. Melentyev, V.M. Brodyansky, A.P. Merenkova and K.N. Trubetskoy are devoted to assessment the efficiency of the enterprise with transition to new energy sources and identification of the hidden reserves. However, most researchers studying the problems of energy conservation consider only factors providing energy conservation, affecting the development of preconditions for energy saving. Promising studies related to the use of new energy carriers are presented in the works of Delyagin G.N., Morozov A.G., M. J. Rini and others [6-8].

The authors of the present article believe that development of preconditions for energy conservation is only a necessary condition for energy conservation, while a sufficient condition for saving energy resources is to achieve an effective balance between the volume of energy and energy needs of the enterprise through the implementation of effective factors. The example is implementation of energy-saving technologies in modern energy systems of the real sector of the economy [9,10].

Currently, the world is rethinking the role and place of coal in ensuring the energy and economic security of countries. Moreover, an increase in the share of coal in the fuel balance is a stabilizing factor in protecting against the occurrence of deep energy crises. However, environmental problems arising from the use of coal fuel require the development and implementation of new environmentally friendly coal technologies [11]. In this regard, the use of coal in the form of coal-water slurry (CWS) is promising. The introduction of the CWS provides conservation of energy and material resources, as well as the environment. In addition, the use of CWS is the most effective and environmentally friendly method for disposal of thin coal sludge from coal mining and coal processing enterprises.

The focus was made on devices operating on vibrational (pulsating) combustion of solid, liquid, and gaseous fuels. The prospects of such studies are also emphasized by results of applying magnetic field to the fuel flow before its combustion.

The high price of traditional energy sources (gas and heating oil) makes one to look for ways to replace them with cheaper ones, which will reduce the cost of heat. One of the most promising products for such substitution is coal-water slurry fuel - a mixture of crushed coal (fractions of 1-70 microns), water and reagent. It is characterized by good calorific value and high degree of combustion.

Studying the practical experience in the production and use of CWS at the Amaltea LLC (Russia), special attention should be paid to the problem of increasing the environmental effect of replacing traditional fuel with a

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modernized one. The set task is to study the advantages and disadvantages of using water-carbon emulsion in real boilers based on the previously developed software tool for calculating the environmental indicators of the coal-water slurry combustion.

2 Subject of study

The subject of study is coal-water slurry fuel. To obtain coal-water slurry fuel, coal of gas grades is mainly used, which is characterized by high content of volatile substances. It is delivered to an open platform, and is fed into the receiving hopper of crusher using the front loader. Ball, roll and hammer mills are used for coal grinding. Almost each of these devices is characterized by the complexity and bulkiness of the equipment used, as well as by high energy costs. This requires implementation of new and more efficient grinders in the preparation of coal-water slurry fuels.

In general case, CWS is a complex heterogeneous structure consisting of finely dispersed coal and water, with addition of various additives and plasticizers that keep solid particles in suspension [11]. This structure complicates the creation and development of methods for combustion of slurry fuels, which should provide satisfactory indicators of combustion and emissions of nitrogen and sulfur oxides.

Theoretical and experimental studies on ignition of coal-water fuel particles prepared from various coals were carried out in [11-13]. The processes of pyrolysis, lighting, and combustion of water-carbon fuels were studied. Particles were suspended on quartz filaments. Heat was supplied by radiation. For ignition, air was introduced into the cuvette. The particle diameter ranged from 200 to 700 μm. The study identified six characteristic times of the process:

1. The beginning of thermal destruction and release of volatiles.
2. The beginning of the process of increasing the particle volume.
3. Completion of the process of increasing particle volume.
4. Completion of thermal decomposition and combustion of volatiles.
5. The beginning of burning of particles with charring of the agglomerate and its mechanical destruction.
6. Complete burnout of coke residue.

It was previously established that water has a significant influence on the ignition of CWS particles. As a result of moisture evaporation, a highly porous carbon skeleton with high thermal resistance is formed at the surface. In this case, the temperature of a water-coal particle rises much faster than that of conventional coal fuel. Water vapour resulting from evaporation is filtered through a porous skeleton. Accordingly, a zone of increased pressure is formed in the particle immediately near the evaporation front.

Water in any fuel is usually the ballast, which should be avoided. An alternative to dry grinding is wet grinding while homogenizing the resulting suspension. The use of wet grinding for grinding sludge solves several technological problems:

- Instead of a dry explosive powder, a liquid suspension is obtained, pumped by the pumps and evenly fed into the boiler furnace. The dosed supply of dry dust is a more complex process, and for boilers of both small and medium power it is even more expensive;
- The need for preliminary drying of sludge with the cost of evaporation is higher than just water evaporation;
- The overall cleanliness of fuel preparation area improves.

During wet grinding process, water is usually added to obtain a homogeneous suspension, although any waste, flushing from fuel oil tanks, etc. would be preferable. Given the moisture content of sludge from 25% and higher, the amount of added moisture is not more than 15%.

The presence of additional moisture will certainly affect the fuel balance of boiler. However, as numerous calculations show, such an increase in humidity is more economically effective than a set of measures for dewatering sludges and solving issues of their dosed supply. This is especially true for small and medium-sized energy facilities [12].

The environmental reasons for using CWS are fairly obvious: burning CWS should lead to reduction in formation of nitrogen oxides (NOx) and to more convenient measures for the capture of sulfur oxides (SOx). Nevertheless, the results on the completeness of burning coal in the form of CWS are widely known [11–16], but there are no real practical data on emissions from burning coal-water fuel both in large boilers and in boilers of small and medium power in the public domain.

In order to promote CWS on the market, Amaltea LLC (Moscow, Russia) together with Effective Energy Technologies GmbH (Vienna, Austria) created an industrial CWS preparation plant. A series of combustions of CWS from various types of raw materials was carried out using this equipment. The aim of works was to carry out measurements on the volume of emissions from CWS combustion according to the CE standards and to study some boiler operation modes.

This work presents the results of implementation of a previously developed mathematical model in a form of software and comparison of environmental friendliness of combustion of coal and CWS.

3 Environmental calculations using the developed program

The new software tool for computer-aided calculation of parameters of coal-water slurry fuel combustion process will simplify and speed up the calculations of the percentage composition of the resulting fuel; of the thermal characteristics of the source and obtained fuels with their subsequent comparison; of the amount of pollutants emitted with flue gases into the atmosphere when burning CWS; and of calorimetric temperature of fuel combustion. Automation of calculations avoids possible errors in calculations.

Table 1. Initial data for environmental calculations.

Parameter	Designation	Coal	CWS
1	**2**	**3**	**4**
Rated power of boiler, Gcal/h	Q_{rat}	0.4	0.4
Boiler efficiency,%	η	81	85
Heat losses with chemical incomplete combustion,%	q_3	2	0
Heat losses with physical incomplete combustion,%	q_4	7	0.7
Calorific value, kcal/kg	Q_c	5 453	4 112
The same, MJ/kg		22.8	17.2

The program has a form of file created in Microsoft Office. The software consists of three interrelated sections: “Composition and thermo-technical characteristics of fuels”, “Calculation of pollutant emissions during CWS combustion”, “Calculation of calorimetric temperature of CWS combustion”, and applications containing the necessary data in the form of tables and plots.

In order to quantitatively evaluate the economic and environmental effect of CWS usage, a calculation and comparison of fuel consumption and the amount of pollutants emitted into the atmosphere with flue gases during combustion of coal and CWS was carried out. The comparison was carried out under the following conditions: coal was burned in the KVr-0.4 boiler with a nominal heating capacity of 0.4 Gcal/h with an efficiency of 81% (accepted from its technical characteristics). The combustion of coal-water slurry fuel is carried out in a boiler having a similar heat output and an efficiency of 85% (accepted averaged over the published results of previous studies).

The following initial data were used for calculations (table 1).

The obtained calculation results are shown in table 2.

Fig. 3 presents the calculation results in graphical form.

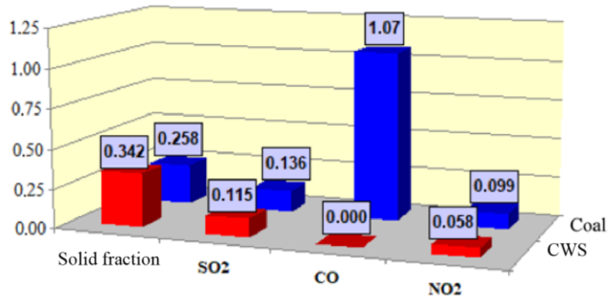

Fig. 3. Emissions of pollutants from combustion of coal and CWS.

Analysis of table 2 shows the following results:

1) Fuel consumption of boiler when using CWS increases by 21%;

2) Emissions of solid fractions increased by 33%;

3) Emissions of sulfur oxide decreased by 15%;

4) There are no emissions of carbon oxides when using CWS;

5) Emissions of nitrogen oxide decreased by 41%.

When using CWS the required fuel consumption for a given boiler capacity increases compared to that of coal. However due to more complete combustion of CWS coal particles, the total fuel consumption will be less by 10%. This is confirmed by the following calculation (table 3).

To sum up, we can conclude that the use of coal-water slurry fuel as an alternative to traditional types of fuels will reduce the cost of a unit of generated heat energy, make benefit from the products previously

Table 2. The calculated fuel consumption and the amount of pollutant emissions.

Index	Designation	Coal	CWS	Reduction in %
1	**2**	**3**	**4**	**5**
Fuel consumption per boiler, kg/h	B	90.6	114.4	-
The same g/s		25.2	31.8	-
Emissions of solid fraction, g/s	M_{sol}	0.258	0.342	-
Emissions of sulfur oxides, g/s	M_{SO2}	0.136	0.115	15
Emissions of carbon oxides, g/s	M_{CO}	1.07	0.0	100
Emissions of nitrogen oxides, g/s	M_{NO2}	0.099	0.058	41

Table 3. The economic effect of CWS usage.

Fuel type	The required consumption, kg/s	Efficiency of use, %	Total consumption, kg/s
1	2	3	4
Coal (grate firing)	90.6	70	129.4
Coal-water slurry fuels	114.4	98	116.7

disposed as waste, and save the environment.

4 Conclusions

The following conclusions can be made:

1) In general, the accumulated results of the previous authors and the present studies show the possibility of expanding the market for consumption of water-coal fuel, primarily in small and medium heat generation, and of eliminating the typical administrative and technical difficulties.

2) The use of compact devices for CWS preparation, the co-combustion of water-coal fuel and supporting fuel, accelerates its implementation, reduces the capital costs for implementation and operating costs associated with environmental protection;

3) Switching from grate firing of coal to the use of CWS results in an increase in the required fuel consumption of 21%, but due to more complete combustion of CWS coal particles, the total fuel consumption will be less by 10%.

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