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PLASMA LIGHTING SYSTEM OF LOW-REACTIVE FUELS FOR BOILERS

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ABSTRACT
A new plasma lighting system was developed to ignite and combust low-reaction fuels for heat generation. In this study, the possibility of usage of coal energy was investigated as an accompanying combustion fuel to the plasma torch produced by electric energy. For this purpose, brown coal BR-1 was adopted. Experiments with such coal were carried out at a mass flow rate over 100 kg/h and with a 17,5 kW plasmatron. Reliable and stable ignition and combustion of coal-water suspension with plasma has been proven with experimental results. During the combustion in the developed plasma coal burner, complete carbon burn-out was achieved with the release of a thermal power over 290 kW. The lifetime of electrodes of such a plasma coal burner is expected to be more than 1000 hours. The low-power plasma system is produced in a compact and modular structure that can fit into most of the pulverized coal boiler designs, eliminating the necessity of the additional high-reaction fuel - fuel oil or gas.

KEYWORDS: plasma lighting, low-power plasmatron, low-reaction coal, water-coal suspension.

I. FORMULATION OF THE PROBLEM

There are many world energy forecasts, in which the main indicators are close to each other. The balance between energy-generating sectors determines specific aspects of policy measures, for example; to the reduce greenhouse gas emissions based on carbon prices, mandates favoring low-carbon technologies may come into action, etc. According to the “Statistical Review of World Energy” data from British Oil and gas company BP from June 2017, market share of coal is decreasing in the last years and seemingly will decrease more due to the developments in renewable and oil-based energies; but in fact, the coal source of the Earth is enough to meet the energy demand of the World until 2100 with no problem [1]. This data is also supported by American Coal Foundation who claims that the USA has enough coal for 253 years if the coal usage growth rate keeps current value. Since the Earth is this many generous of coal, the share of coal will mandatorily increase as other fossil fuels encounters a danger of depletion. In many documents, such as "The Long-Term Program for the Development of the Coal Industry of Russia for the Period to 2030" it is stated that the share of coal will significantly increase in the fuel sector, reaching 32-35 percent in a short time. It should be noted that even in optimistic forecasts, new technologies related to fuel usage are needed, and being developed, including the so-called "clean coal" technologies.

Due to the intensive research and development on clean coal burning technologies since the mid-1960s, clean coal burning technologies comprising the pulverized coal-fired power thermal power plants (TPPs), which are still basic ones, have reached the limit of their perfection; determined and limited by the laws of thermodynamics and properties of materials used in boilers and turbines. At the same time period, capital expenditures for the construction of such TPPs have also substantially increased due to stricter requirements for protecting the environment from harmful emissions. Naturally, this resulted in a significant rise in the electricity generation cost at coal-fired TPPs, thus their attractiveness has declined. The main reason for the significant increase in the cost of electricity production at coal-fired TPP is the fact that most of the TPPs are built with the technology of 1960s and 1970s and have extremely inefficient coal combustion technology in the boilers. The TPPs are designed with available technologies and knowledge in their time; but they are now old and inefficient, a heat and power engineering specialist can confirm this even at the first glance [2]. One of the main reasons to the inefficiency is the usage of natural gas or fuel oil; the cost of these combustibles is constantly increasing making the ignition of coal-fired boilers more expensive. At the same time, the stabilization issue of combustion processes (lighting of a

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pulverized-coal torch) cause inefficiency and expense. This problem has been worsened in the heat power engineering, where small and medium-sized boilers are used with turbulent vortex pulverized-coal burners. For such boilers, combustion processes are characterized by regimes with a variable thermal load. In this case, the fuel oil is required in almost all burning processes to stabilize high ratio burning at the pulverized-coal burners. As a result, long term need of additional fuel at TPP makes the fuel oil the second main fuel, not the additional fuel in minor amounts. With such coal combustion, the carbon content in the ashes reach 20-30%. Constraining factors when using coal in power engineering makes the coal usage an extremely dirty and relatively low efficient technology.

It should be noted that, this article is predicated on low grade-coals that are used in the operation of Ukraine thermal power plants [3]. Therefore, it is expected that the escalating deficit in fuel oil and gas along with the increase in their cost, will actualize the development and introduction of technologies for efficient low-fat burning of high-ash low-reaction coal dust. Currently, it is considered that large-scale projects with long-term payback are difficult to implement; therefore, based on this logic, priority should be given to integrated projects aimed at joint optimization of economic and environmental performance of energy-generating enterprises [4]. The efforts of the authors have been focusing in this context.

II. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

In 1983, in order to solve the problem with the high efficiency usage of low-grade solid fuels with minimal negative impact on the environment, with the suggestion of the leading experts in the field of plasma technology such as M.F. Zhukov, L.S. Polak et al; with the support of the State Committee for Science and Technology, work has begun on the creation of a fundamentally new plasma technology for the combustion of pulverized fuel by means of electric arc gas heaters - plasmatrons [5]. Detailed experimental and theoretical studies of the processes of ignition and lighting of a pulverized-coal torch have been carried out, and a theory of thermochemical preparation of fuel for combustion has been developed [6, 7, 8, 9]. For the first time, the plasma ignition technology was used at the Gusinoozerskaya TPP on boilers of type TPE-215, BKZ-640, BKZ-420. For a long time, these developments did not receive industrial distribution, and only began to be used in recent years at coal-fired power plants of developed countries. Today in China, this technology is equipped with more than 470 coal-fired boilers with a total capacity of more than 200 million kW, which is about 30% of the total installed capacity of the country. Plasma ignition is also used in Indonesia (6 units of the Indonesia Thermal Power Plant "Sunalaya"), Mongolia (Ulan Bator Thermal Power Plant), Taiwan (1, 2 blocks of the Hopping Power Plant) and Slovakia ("Voyany" TPP) [4]. Plasma Fuel Systems (PFS) have already been tested on a large number of power boilers with a steam production range from 75 to 670 ton / hours (t/h) and equipped with various types of pulverized-coal burners (direct-flow, muffle and vortex burners). In the testing of plasma-fuel systems, coals of all sorts (brown, stone, anthracite and their mixtures) were burned. The content of "volatile" in was 4 to 50%, the ash content was 15 to 48%, and the calorific value was in the range of 1600 to 6000 kcal / kg. However, although these stations with PFS are connected to the grid and provide electricity, they must be worked out more before the acceptance decisions on replicating the project after a full test cycle.

The technology of PFS consists in shock heating of a part of the air mixture (coal dust + air) in a pulverized coal burner to the temperature of the outlet of volatile coal and partial gasification of the coke residue. The shock heating operation is done by an electric arc plasma. This is sufficient when burning low-grade coals (with a constant operation of the plasma torch) and allows the ignition of the boiler at a short-term, necessary to achieve the boiler's pilot parameters for the operation of the plasma torch. According to various estimates, the electric power consumed by the plasma torch does not exceed 2.5% of the thermal power of the pulverized coal burner and is around 0.3-0.5 % of the boiler's thermal output. The principal problem that constrains the industrial realization of plasma-coal technology is the need of using sufficiently powerful plasmatrons (over 200 kW). The power of the plasma torch is determined by the minimum relative energy expenditure, equal to the ratio of the thermal powers of the plasma torch and the pulverized-coal burner, for the anthracite culm is 1.5-2.0 %. The real resource of continuous operation of such plasmatrons at best is 200 - 300 hours (more is declared, but in real conditions no one can demonstrate it). Such a resource is quite enough for ignition, but not for lighting [10, 11].
It should be noted that to increase the resource of the fuel-plasma system, studies are being conducted on the use of microwave plasma torches [3, 12], since they do not require the use of special carbon or copper electrodes. Also, microwave plasma torches can create a critical electron concentration, i.e. to shock thermal effects to connect plasmochemical effects. This contributes to the early ignition of the cold carbon-air mixture at relatively short time interaction of the carbon particles with the plasma flame (~ 0.05 s), resulted in the intense burning out of carbon particles.

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III. FORMULATION OF THE PROBLEM

The purpose of this study is to overcome the main drawback of the plasma arc system of PFS associated with the service life of the plasma torch and to justify the possibility of their use for ignition and lighting of low-reaction coal dust with the prospect of replication. The main idea of the approach developed by the authors is to implement a three-stage scheme in order to multiply the plasma power using base low-grade coal to the fuel oil power level. The fuel oil power level is necessary in achieving ignition and accompanying combustion parameters of the boiler. At this stage, a low-power (15 - 20 kW) special plasmatron with a service life of copper electrodes of more than 1000 hours is used.

IV. STATEMENT OF THE MAIN MATERIAL

At the first stage of development of the technological scheme for the process, an activated water-coal suspension (WCS) was prepared in two versions of BR-1 brown coal. The technical specifications are given in Table 1.

Table 1:Technical characteristics of coal BR-1.

Parameter	Value	Method of determination
Moisture (working condition).	35.00 %	GOST 11014-81
Ash (working class.)	11.23 %	GOST 11022-95
Ash (dry)	25.00 %	GOST 6382-91
Volatile substances (working state).	22.70 %	
Volatile substances (dry state).	59.50 %	ISO 195796: 2006
Sulfur (working state).	1.46 %	
Sulfur (dry state).	3.33 %	
The lower heating value of combustion (working state)	3100 kcal/kg, 13.02 MJ/kg	ISO 1928: 2009
The higher heating value (calorific value) (dry state)	6500 kcal/kg, 27.31 MJ/kg	
The higher heating value (dry ash content)	7500 kcal/kg, 31.51 MJ/kg	

The process to obtain WCS (version 1) according to the traditional scheme included the following operations: crushing of the initial coal to 3 mm sized particles, fine grinding of coal in a mill together with the aqueous phase and mixing. For the preparation and investigation of the WCS from brown coal BR-1, a laboratory ball drum two-chamber mill MBL-100 was used. The mass of a single portion of coal loaded into the mill was 10 kg. The ratio of coal and water was determined from the dry weight of the coal in a way that the concentration of the slurry corresponded to a predetermined value. In the mill, coal was crushed mainly up to the class 0 - 0.4 mm. The fraction content less than 50 μm was ~ 60%. The grinding time in the mill was 60 minutes. The concentration of the solid phase obtained by the WCS was determined by drying process at a temperature of 105 ° C. The granulometric composition is analyzed with the wet fractionation method on sieves by a standard procedure. The rheological characteristics were determined on a universal rotational viscometer Rheotest RN4.1. Suspensions were prepared using drinking water and adding a plasticizer (NaOH). The additives were introduced together with the aqueous phase formation in the first grinding stage. Thus, a sufficient number of WCS was obtained with the following characteristics:

- Solids content in the WCS is 52.3%;
- Additive concentration - 0.1%, calculated on dry weight of coal;
- Structural viscosity - 0,7 Pa · s;
- Initial shear stress - 12.5 Pa;
- Stability - up to 30 days;
- Yield strength - 1,2-1,4 Pa;
- The lowest heat of combustion of the suspension is 10,500 kJ / kg.

When the finished fuel stored in a storage bin, the stability was determined by using sampling devices at several levels. If the quality is decided to be low, the slurry was returned to the mill for processing. After completion of the cooking step, the coal-water slurry from the pump storage tank was fed to the fuel-plasma burner for combustion.

The preparation of the WCS (version 2) was carried out by cavitation grinding of coal in an aqueous medium in a wet grinder - HORIZONT-3000 MK-VA. No chemical additives were used in the process, and the maximum coal particle that is fed was not more than 10 mm. Before submitting to the disintegrator, the water was trained in

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a rotary-pulse apparatus RIA-150-VUT. The output of the suspension with the specified parameters occurred 1 minute after switching on the apparatus. A WCS with a particle size up to 50 μm was obtained. This suspension remained stable for 5 days. It is believed that as a result of shock-cavitational destruction of the coal, in contrast to traditional mechanical grinding processes in grinding-abrading grinding mills, the WCS acquires some useful properties:

1) Humic acids are released with the formation of humates acquiring a jelly-like state, which increases resistance against delamination;

2) High efficiency of the combustion process with the active role of water, insensitivity to the quality of the initial coal [13, 14].

Based on both own research and the analysis of existing methods for burning low-reaction coal dust the main principles of an optimal system for the ignition and combustion support were formulated:
• The proposed system should not change the design of the boiler;
• The most difficult part of the process - the ignition of fuel and its PFS should be taken out of the furnace space into a special module in which it is possible to control the process;
• The special module should be compact, high-heat-stressed to ensure reliable ignition of fuel at the initial stage of combustion, when it is still not reactive;
• The availability of various types of fuel (main and ignition) is undesirable, only one type of fuel should be used;
• To date, the best system for the tracking of fuel combustion and ignition would be a plasma system;
• The ignition system and the combustion must be controlled automatically by using a processor or a computer.
To implement such an approach the coal used in the boiler can be used, in this study brown coal BR-1 was adopted, as fuel for the ignition accompanying combustion. The main problem with the use of the WCS, which has not yet been finally and qualitatively solved, is its low reactivity in the initial part of the combustion. Since the active ignition of fuel determines its further burning, this problem restrains the development of the technology of water-coal fuel in general. Efforts to solve the problem of stable and reliable burning of water-coal fuel should be directed primarily to intensifying of the ignition of fuel in the initial part of the combustion. The problem is that during the short flight times of the dust particles in the burner, solid carbon is burnt out and the autothermal combustion mechanism is started. The ignition and stabilization of combustion using WCS has its own peculiarities [15], which should be considered with the use of a plasma system. The dewatering time of the carbon particle for sizes less than 50 microns will be about 0.1 sec with the corresponding ignition delay time under conditions of thermal shock of the plasma. Due to the need to achieve the complete evaporation of water from its porous structure, there is an ignition delay time and it is related with the particle diameter. For each characteristic size, the particles of the WCS are temperature-limiting conditions for the ignition. Costs increase for heating and evaporation of water as the porous structure of the coal particles increases. It is possible to distinguish between two modes of ignition: low-temperature (<950 K) and high-temperature (> 950 K). This is due to the fact that at higher temperatures of the external environment, the heating of the particle occurs more intensively. For fine particles of the WCS ($0{,}4 \cdot 10^{-3} m$), the difference in the ignition delay times is not significant. In the general case, in the temperature range of the environment (900 - 1300 K), the difference between the ignition delay times does not exceed 30%. Ignition occurs after complete evaporation of all moisture contained in the porous structure of coal particles at sufficiently low surface temperatures. Ignition process may vary time-to-time depending on the coal particle's surface temperature. There are three characteristic areas. The first one corresponds to the time interval for heating the particle to the boiling point (or close to it) and means its complete "dehydration". The second section corresponds to the period of heating and thermal decomposition of dry coal. After this, the ignition condition of the WCS is fulfilled and further temperature rises cause combustion. Varying the mass fraction of components (water and coal directly) in a fairly wide range does not significantly change the conditions and characteristics of ignition of small-sized water-coal mixture.
The analysis of existing methods shows the superiority of plasma technology, as it is simpler and more convenient than ignition with the use of pilot fuels. As for the influence of the plasma, it should be noted that there is no general theory of the course of reactions of vapor-plasma gasification under nonequilibrium conditions, and in many cases even the approach to it. The available material is scattered and extremely few. Thus, the most unexpected manifestations are expected in this field. Low-temperature plasma of atmospheric pressure contains a large number of charged and neutral active particles like radicals. These active particles with a high ability to emit energy (they will participate the reaction with very low activation energy requirement) can significantly accelerate chemical reactions and allow for reactions that are difficult under normal conditions. Experimental evidence of

the significant effect of mentioned active radicals on steam-plasma coal gasification under conditions of an arc plasma of atmospheric pressure was obtained in the article named "Mechanism of coal gasification in a steam medium" [16]. Coal under plasma conditions undergoes rapid decomposition and dissociation reactions with liberation of volatile substances and a coke residue that, upon further decomposition, form many active particles; including hydrocarbons, excited C and H atoms, etc. Then various gases are formed thanks to a complex of parallel-chain reactions. Most importantly, such gases as CO_2 and H_2 are converted into CO with the release of many active particles, such as OH, H radicals and electrons, which take part in the reactions with (1) to (11) in the recycling scheme:

Active species in the presence of steam (water):

$H_2O + e^* \rightarrow OH + H + e$ (1)

$OH + OH \rightarrow H_2O + O$ (2)

Active species formed with the addition of coal:

$Coal + Energy \rightarrow Char + Volatile$ (3)

$Volatile + Char + e^* \rightarrow C_mH_n + H + C + C_2 + e$ (4)

Gases formed in the system:

$C + OH \rightarrow CO + H$ (5)

$H + H + M \rightarrow H_2 + M$ (6)

$CO + OH \rightarrow CO_2 + H$ (7)

$CO + O + M \rightarrow CO_2 + M$ (8)

$H + CH \rightarrow H_2 + C$ (9)

$CH + O \rightarrow CO + H$ (10)

$CO + e^* \rightarrow CO^+ + 2e$ (11)

During this research work, a laboratory installation for the combustion of water-coal fuel with plasma ignition and combustion support was developed, installed and tested to obtain the initial data in the design of a fuel-plasma burner in a boiler operating on low-reaction coal dust. The installation included the main elements necessary to provide the ignition process and support the stable combustion process of the WCS: the storage system and the controlled supply of the WCS, water and gas supply system and the plasma equipment with a plasma-coal torch. Burning of the burner and stabilization of the flame were performed by a plasmatron with a power of up to 30 kW (so-called low-power plasma torch). This is a plasmatron of a linear circuit with two coaxial cylindrical electrodes and a vortex stabilization of the arc (Figure 1). The plasma torch is cooled by water. The plasma gas is air. When operating in air, the average mass temperature of the plasma jet was about 4000 K, with a thermal efficiency about 80 %.

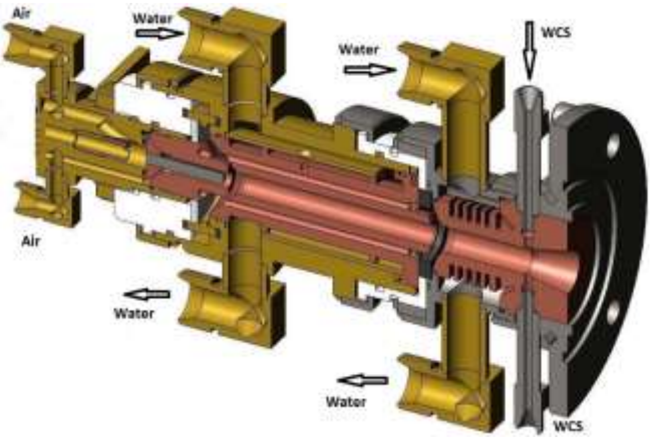

Figure 1:Plasma torch for plasma- coal burner

Such a plasma lighting system was used for the ignition of a plasma-coal burner when the plasma torch was located along the axis of the flame tube. The type of experimental plasma-coal burner (plasma torch combined with a flame tube) is shown in Figure 2 The plasma jet, brought to the root of the sprayed fuel, warmed up and ignited the brown coal WCS. The Figure 3a show the plasma jet in the absence of the feed of the WCS, and 3b - when it is fed.

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Figure 2:Experimental plasma-coal burner in operation

Figure 3:Plasma jet (on the left, without the supply of WCS; on right, with the feed of WCS.)

In the plasma-coal burner (Figure 1), the problem of sufficiently rapid mixing of the transversely fed feedstock and the coolant in the minimal volume of the reaction zone was solved. The mixing takes place by intensely colliding of each opposing jet of the WCS. In this case, the collision of the jets leads to their self-crushing and intensive flow turbulence. The interaction of the flow of a hot arc plasma with a pulverized cold WCS begins in the zone near the anode portion of the electric arc column. Optimization of the mixer was reduced to the choice of such a geometry (diameter and opening angle of the nozzle channel of the plasma torch, the diameter and angles of the holes for feeding the WCS in relation to the axis of the plasma torch channel), at which uniform distribution of the sputtered WCS in the channel is ensured. The number of transverse jets is 2 or 4. It should be noted that to ensure the required range, it was necessary to maintain the hydrodynamic parameters with high accuracy - small changes in the inputs or temperatures lead to very significant fluctuations in the range. All this must be considered when designing a plasma-chemical mixer.

The process of burning the WCS in a fuel-plasma torch (Figure 1) can be conducted in two modes - the "full burnout" mode and the "gasification" mode. The first is due to the supply of all the air necessary for combustion directly to the entrance of the flame tube. The second assumes the work of a burner is done with a deficiency of an oxidizer. In the second case, the additional air is blown into the transition duct or boiler furnace. Thus, the "gasification" regime assumes a stepwise combustion of fuel.

The geometric diagram of the fuel-plasma torch intended to test these technical solutions in laboratory conditions has two sections: a plasma pre-gasification module containing a plasmatron with a pre-chamber and a gasification and a full burn-out module (a flame tube with a diameter of 150 mm) with a secondary air injection unit. In the gasification experiments, the flame tube was insulated.

The process of ignition of the coal-water suspension was carried out in the following order. The plasma torch (Figure 3a) was turned on and the prechamber was heated until a luminosity in the inner surface of the site appeared. After the prechamber was heated by the plasma flow for 1.5-2 min to a temperature of 700 -750 °C, a valve was opened on the pipeline, the WCS was delivered at a flow rate of 100 - 400 kg/h (Figure 3b), and stable ignition and stable combustion of the WCS occurred. During operation of the plasma torch, the following parameters were recorded: the diameter of the anode nozzle was 10 mm, the prechamber length was 20 mm. The discharge of the plasma-forming air G was $20 nm^3/h$, the arc current I was 50 A, the arc voltage U was 350 V,

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the power N was 17.5 kW and the length of the initial section of the plasma jet was 15 cm. The inner surface of the prechamber and the flame tube was fused with heat-insulating material. The plasma torch worked steadily both in the plasma heating mode and when feeding the slurry through the nozzles.

During the studies, erosion characteristics of plasmatron electrodes were confirmed (Figure 1). The erosion of the copper hollow cathode in the air atmosphere is of the order of $2 \cdot 10^{-9}\,\mathrm{kg/Cl}$. The average erosion level of the anode is lower and is $4 \cdot 10^{-11}\,\mathrm{kg/Cl}$. The erosion of copper electrodes is mainly determined by the density of the heat flux, the temperature of the surface and the speed of displacement of the near-electrode sections of the arc. With a good stability of the electrodes, we can now speak of a guaranteed resource in the air of the plasma torch cathode (Figure 1) for more than 1000 hours at a current level of 50 A and a material activation depth of $1{,}5 \cdot 10^{-3} m$. For plasma torch anode, this time increases up to 2000 hours.

The greatest interest from the scientific and practical points of view when processing the WCS in a fuel-plasma torch is the gasification regime. In the design, the possibility of carrying out the gasification process with a lack of oxidizer guarantees a "full burnout" mode. Investigations carried out in [17] established that, at process temperatures of 1500 - 2500 K, practically only the components of the synthesis gas obtained during the gasification of the WCS. Their content in the gas phase reaches 93 – 97 %. Energy costs in this case are 3.0 - 3.5 kWh / kg. The heat of combustion of the resulting synthesis gas in the case of plasma gasification is around 11.5 - 12.5 and it is 10 – 30 % higher than the heat of combustion of the gas, with steam-oxygen gasification. This is due to the increased content of hydrogen (50 – 55 %) in the synthesis gas, which is obtained by plasma gasification of coal in comparison with the hydrogen content (35 – 45 %) in the steam-gasification. To reduce the energy costs of the process of plasma gasification of the WCS, it is advisable to use combined allo-autothermal gasification, which combines the plasma stage with the traditional autothermal gasification stage.

The limiting stage of the process of gasification of solid carbon of the WCS occurs due to the flow of two main reactions:

$$2\mathrm{C} + \mathrm{O_2} \rightarrow 2\mathrm{CO} + 218{,}8...\,\mathrm{kJ/Mol}$$

$$\mathrm{C} + \mathrm{H_2O} \rightarrow \mathrm{CO} + \mathrm{H_2} - 131{,}4...\mathrm{kJ/Mol}$$

Studies of the kinetic characteristics of the WCS using a derivatograph [18] show that the combustion of volatiles ends and the transition to burning out of the coke residue begins even at low temperatures of 300 – 400 ºC and combustion of the coke increasingly continues in higher temperatures. Thus, the thesis is confirmed that efforts to solve the problem of stable and reliable combustion of the WCS should be aimed primarily at intensifying the ignition of fuel in the initial part of the combustion. This problem is solved with the help of a low-power plasmatron. The further process of autothermal oxidation will be determined mainly by the difference between the amount of heat that is released because of the first reaction and heat that is absorbed as a result of the second reaction.

As a result of the studies, [19] it was confirmed that when a WCS is sprayed, a polydisperse stream is formed containing both pure charcoal particles and water-coal droplets. In case of water-coal droplets, fine charcoal particles are surrounded by a liquid phase. Obviously, the mechanisms of ignition and combustion of the polydisperse flow of WCS drops are different. For the new burner designs and the determination of optimal operating conditions, basic experimental studies were carried out at the stand (Figure 2) according to the degree of mass-average carbon burn-up along the length with the corresponding temperature distribution of the wall of the lined flame tube. The dust was taken by a water-cooled probe along the axis of the flame tube. The Figure 4 shows the averaged dependences of the degree of carbon burn (a) and the distribution of wall temperature (b) along the length of the flame tube of the plasma-coal burner for the WCS of Execution 1. The main yield of volatiles and their combustion occur in the secondary air supply zone, is small (of the order of 0.2 - 0.4), due to the heat emitted by the lining. Combustion of the coke residue continues along the entire length with the supply of all the air necessary for combustion in the flame tube. The degree of burnout level of the fuel at the outlet is around ≤ 90 % (further combustion of the coke residue must take place in the next section or in the combustion chamber of the boiler). The wall temperature corresponded to the upper limit of measurement ≤ 1100 °C. When using the WCS of Execution 2, the degree of carbon burn-up and, correspondingly, the wall temperature increases by approximately 10 %. The reason is not yet clear, but to connect this effect with better activation of coal dust, more research is needed. Proceeding from the degree of carbon burn at the expense of the WCS of 100 - 300 kg/h, it can be concluded that; when using a plasma torch for intensification of ignition in the initial section with a power of 17.5 kW, the thermal power in the output flare of the order of 260 - 700 kW can be obtained.

To date, the reality is that the deterioration of fuel quality, moral aging, physical deterioration of boilers and equipment led to a reduction in the efficiency of boilers to 80 - 82 % and an increase to 40 - 45 % (by heat release) of the share of natural gas or fuel oil. At the same time, the scarce high-reaction fuel is consumed not only to

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illuminate the pulverized-coal flare, but also to compensate for the deficit of dust caused by insufficient productivity when the boiler is run on fuel of deteriorated quality.

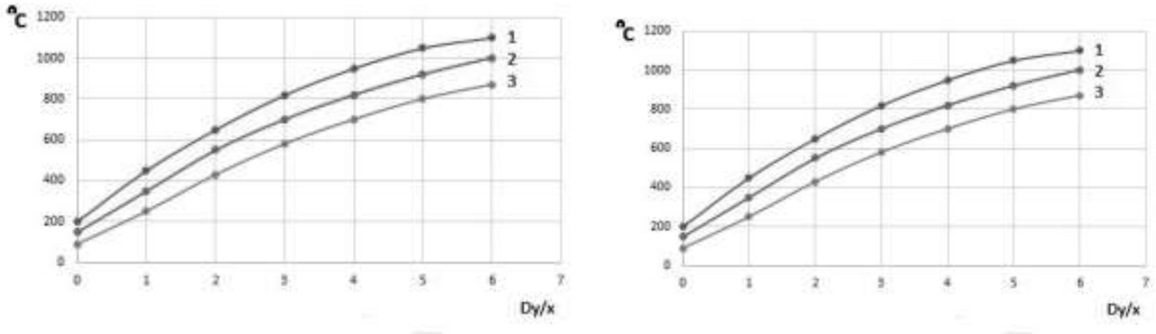

Figure 4: Dependences of the distribution along the length of the flame tube, a- degree of carbon burn-up, and b-wall temperature. 1 - consumption of WCS of 100 kg/hour, secondary air - 150nm^3/h; 2 - consumption of WCS of 200 kg/h, of secondary air - 300nm^3/h; consumption of WCS 300 kg /h, secondary air - 450nm^3/h.

Various solutions are offered, but they are mostly partial [20]. The real way to increase the efficiency of previous generations of boilers when working on low-quality coals of deteriorated quality, is the complete abandonment of using oil and gas fuel without a drastic change in the combustion technology. In the place of the abandoned gas and fuel, plasma fuel systems should be adapted to the current system. Also, for the further development of power systems, the structure of the combustion devices is important and should be modernized or reconstructed in time and equipped with combined plasma system (Figure 5).

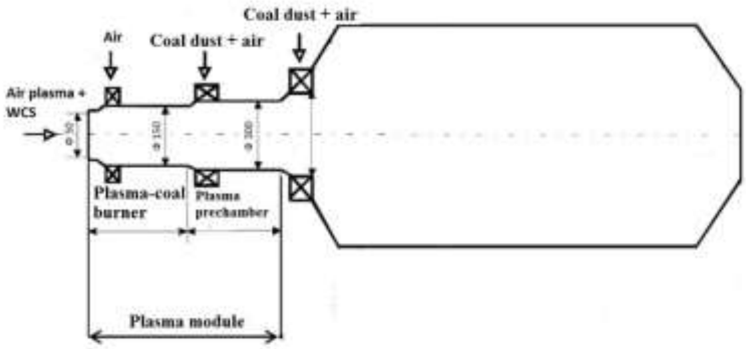

Figure 5:Geometric diagram of the plasma module for ignition and lighting of a pulverized-coal flare.

V. CONCLUSION

Due to the unique properties of plasma such as having very high electron temperature (over 10000K), high energy density and high concentration of active ions, radicals, excited atoms and molecules; it provides more than enough electrochemical conditions to destroy all organic structure into basic elemental forms and all inorganic structure into glassy inert structure. Thus, the efficiency of any chemical reactions including burning of low reactive coal are increased when done by plasma technology. Also, in this way, since there will be no need of additional fuel such as fuel oil or natural gas, coal-based plants will only be dependent on the coal and small portion of the electricity produced. When the plasma is needed to use longer time as igniter or burning stabilizer, another critical point is the elimination of electrical cost of plasmatron. To do that, the concept is to mix a portion of pulverized coal into the plasmatron in order to obtain the thermal energy mainly from this coal. In this case the cost efficiency will be far higher when compared with the use of fuel oil. So, it can be evaluated that only option to use the low quality, high ash and humidity inclusive coal which cannot be used with the current conventional technologies at thermal plants is the usage of PFS.

From the above analysis and research, the conclusion is that plasma technology and plasma fuel systems, even without taking into account the environmental side of the problem, is more reliable, more efficient and more convenient for lighting with the accompaniment of combustion of low-reactive coals rather the conventional coal technologies with pilot fuel usage, and plasma fuel systems are recommended for use in power engineering due to their superior properties.

VI. REFERENCES

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