The Present-Day State and Outlooks of Using Plasma-Energy Technologies in Heat-and-Power Industry

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Urgency of using plasma-energy technologies in power industry, is outlined, increasing of economical efficiency, decreasing of energy consumption and decreasing of environmental pollution, are shown, scientific and technical bases for plasma-energy technologies of fuel utilisation, are designed, results of theoretical, experimental and rig investigations of processes of plasma ignition, gasification, thermochemical preparation for burning and combined processing of coals, are presented, results of realisation of plasma technologies of residual-oil-free (mazout) pulverised-coal boiler kindling, lighting of torch and stabilisation of fluid slagging in furnaces with removal of fluid slag, are described.

Keywords: electric-arc plasma, a plasma generator, coal, ignition, gasification.

At present about 40% of the world electric power is produced at pulverised-coal thermal power stations (TPS). The existing technologies of using solid fuel don't satisfy modern requirements for increasing the effectiveness of fuel utilisation and providing ecological indexes of energy objects [1,2]. For boiler kindling and lighting of pulverised-coal torch natural gas or residual oil are used at TPS. The world price of residual oil is US $ 100-150 per one ton (in dependence of its quality).

The situation gains momentum in connection with decreasing of quality of power-generating coals, that requires increasing residual-oil output at pulverised coal TPS for boiler kindling, for lighting of torch and stabilisation of fluid slagging in furnaces with removal of fluid slag [3-6].

Simultaneous burning of coals and residual oil, with different reactive ability, deteriorates technical and economical and ecological indexes of TPS, i.e. combustion losses are being increased (approx. for 5-10%), boiler efficiency is being decreased (for 3-5%), nitrogen oxides effluents (NO_x) are being increased (for 40-50%), sulphur oxides effluents are being increased (for 20-30%) (in the case of high-sulphur residual fuel oils), vanadium oxide effluents are being emerged [1-6].

At pulverised coal TPS of the CIS over 20 mln. of tons of residual fuel oil to a total value of about US $ 2 mlrd. are spent every year for these purposes [4].

The topical problem of heat power industry aimed at removing residual fuel oil and natural oil out of the heat balance of pulverised coal TPS by using inferior coal. In 1995 to work out such problems of increasing the effectiveness of fuel utilisation at J.S.Co. "Gusinoozyorsk SRPS" was founded the Centre for Plasma-Energy Technologies. The Centre consists of three scientific and technical laboratories, thermotechnical and electrotechnical services.

By now the following plasma-energy technologies [1-4] have been designed and brought to a commercial level: residual-oil-free technology of boiler kindling, lighting of torch, stabilisation of fluid slagging with removal of fluid slag, thermochemical preparation of solid fuels for burning, allothermal (plasma-steam) and alloautothermal (air-steam) gasification and combined processing of coals.

During plasma boiler kindling residual fuel oil is displaced by pulverised coal (coal-dust) which is inflamed by electric-arc plasma generator. Technical characteristics of the plasma generators are given in Table № 1 and are presented in Figures 1,2 and 3.

Table 1.Technical characteristics of the plasma generators

Plasma generator power, kW	50-200
Voltage, V	250-400
Arc current, A	200-500
Weight of the plasma generator, kg	20-35
Weight of the power source, kg	450
Resource of continuous work, h	200-300
Torch temperature, K	2000-5000

The systems of plasma ignition of coals (SPIC) have been used successfully at 25 pulverised-coal boilers at 9 TPS (in Russia, Kazakhstan, Ukraine, Slovakia, Mongolia, Korea and China) with the steam output from 75 to 670 tons per hour featuring different systems of pulverised coal preparation (direct pulverised coal injection and systems with pulverized-coal hopper) since 1994 [1,5].

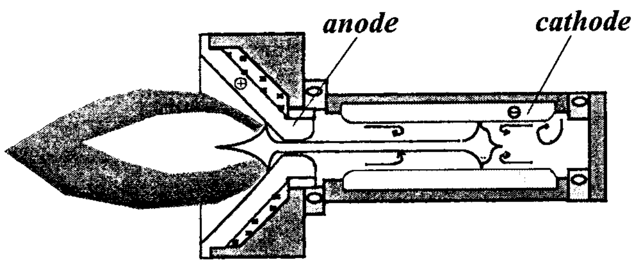


Fig.1. An electric-arc dc plasma generator with copper water-cooled electrodes is installed into pulverised-coal boiler burners without the reconstruction of the boiler itself.

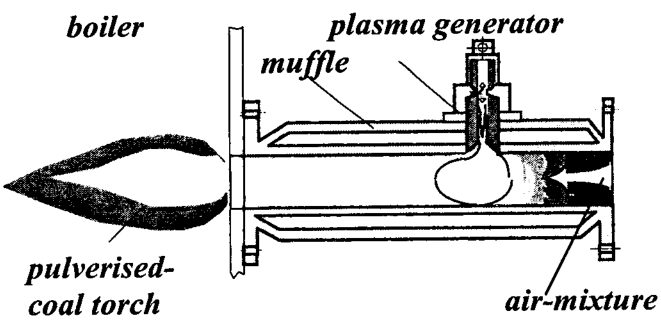
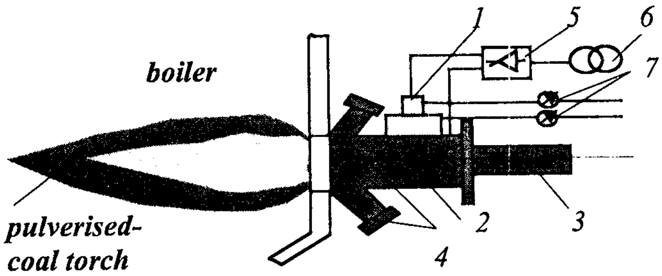


Fig.2. Variant of installation of a plasma generator with muffle section of a pulverized-coal furnace tube.

The installed before muffle with a plasma generator provides self-ignition of the air- coal mixture in the boiler furnace.



1. a plasma generator; 2. a muffle; 3. a pulverised-coal tube to the furnace; 4. a pulverised-coal furnace nozzle; 5. an electric power source; 6. a transformer; 7. water-air supply systems

Fig.3. Principal diagram of installation of electric- and thermotechnical equipment with a muffle and a boiler at TPS.

The plasma technologies have passed a test under commercial conditions with all types of power-generating coals (brown, black and anthracite) [1,5], characteristics of which are given in Table 2.

Table 2. Heat and technical coal characteristics ranges)

Coal type	W^w	A^d	V^d	$Q^w{}_l$ kcal/kg
Brown	25-35	15-20	35-50	3500-3800
Black	5-12	20-45	20-40	4000-5000
Anthracite	5-8	25-35	4-10	4300-5000

Comment W^w is moisture content per the working mass; A^d is ash content per the dry mass; V^d is yield of volatile per the dry mass; $Q^w{}_l$ is the lowest combustion heat per the working mass

The specific energy consumption for the process of ignition varies over the range from 0,05 kWh/kg (brown coals) to 0,35 kWh/kg (anthracite) [5]. Figure 1 illustrates a muffle variant of the plasma ignition system of coals which is the most effective [1].

A combined alloautothermal gasificator **(AAG)** with plasma stages shown in Fig 4 is installed on a boiler of 640 t/h steam-generating capacity [5]. The coal productivity of AAG is 32 t/h. The gas composition (volume %) is: $CO = 17{,}4$, $H_2 = 8{,}7$, $CH_4 = 1{,}5$, $CO_2 = 4{,}7$, $N_2 = 67{,}5$, NO_x = 40-60 mg/nm^3 (nm^3 means normal cubic meter), SO_x = 100-150 mg/nm^3.

The AAG is intended for thermochemical fuel preparation with produced high-reactive products (fuel gas and coke residue) supply directly into the boiler furnace. This allows to solve the problem of residual-oil-free boiler kindling, lighting of pulverized-coal torch, stabilization of fluid slagging in furnaces with removal of fluid slag, increasing of nitrogen and sulphur (on addition of dolomite to coal) oxides effluents, and to extend the range of coal types burned in one and the same boiler without decreasing of its technical and economical and ecological indexes [5]. Following the pilot operation of one AAG three more gasificators will be installed on the commercial boiler and all fuel will be taken preliminary preparation for burning (up to supply to the furnace), according to conception of "effective and environmentally friendly clean technology of TPS using solid fuel" [2-8].

Let us take a look at the mechanism of NO_x-formation at coal gasification [6,8-12].

The inhibitive action of prompt NO_x formation is based by us on the reaction scheme proposed in [9]:

$$HC + N_2 \rightarrow HCN + N \quad (1),$$
$$HCN + (H, OH) \rightarrow CN + (H_2, O_2) \quad (2),$$
$$CN + O_2 \rightarrow CO + NO \quad (3),$$
$$CN + OH \rightarrow CO + NH \quad (4),$$
$$NH + OH \rightarrow NO + H_2 \quad (5),$$
$$NH + NO \rightarrow N_2 + OH \quad (6).$$

It's seen that increase of H_2 (reaction (5)) or CO (reaction (3)) shifts the equilibrium of the group (3-5) to the left reaching the NO_x - output. So increasing in the CO and (or) H_2 contents is extremely important in NO_x - formation.

Formerly /10/ we considered the activated combustion in antechamber with the products of a rich auxiliary mixture ($a = 0.5 \div 0.7$) incompletely burned (CO, H_2) and delivered to the main combustion chamber.

But there we are considering one further way of CO and H_2 generating for NO_x reduction, namely, plasma gasification (thermochemical conversion) in antechamber - plasma generator in line with reaction:

$$C + H_2O \rightarrow CO + H_2 \quad Q = -131500 \text{ kJ/mol}$$

Endothermal heat of this reaction is compensated by energy of arc discharge [2,6,11].

The scheme of apparatus based on this principal is depicted in Fig.4 and influence of plasma generator power on NO_x - output in Fig.5 [6-8].

It's seen the NO_x output when working plasma generator is decreasing in 2 time. This result is consistent with known data on NO_x output for 100% reformed hydrocarbon fuel [12].

In 2001 it is planned to fit out with plasma systems of residual-oil-free boiler kindling (PSBK) 20 more boilers at TPS in Russia, Ukraine, Slovakia and Kazakhstan, including the largest in Russia coal boiler of 2650 t/h steam-generating capacity at Beryozovsk TPS.

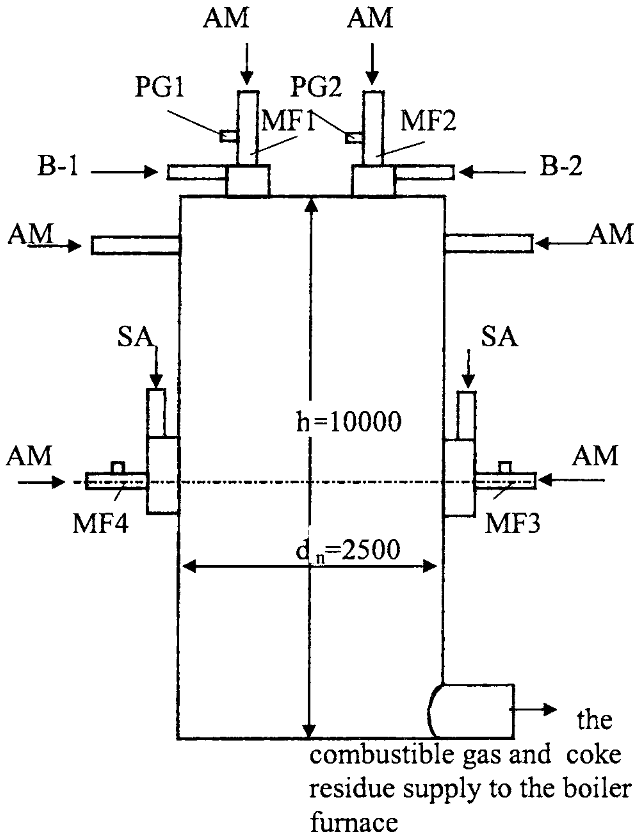
The economic effect from using PSBK is expecting to be US $ 300-500 per one ton of nominal steam-generating capacity of the boiler [1,8].

The starting data for PSBK design work (specific energy consumption, plasma generator capacity, process temperatures, geometrical dimensions and plasma system configuration) for particular boiler, burner and coal types are gained on the basis of comprehensive rig and theoretical investigations. In the latter case the data are obtained by the use of special thermodynamic and kinetic models and automated programmes for personal computers: "Plasma-coal-3", "Terra" and ASTRA-4 (ASTRA means automated systems of thermodynamic calculations) designed in CPET in collaboration with the scientists of the Bauman Moscow State Technical University (Moscow) and Kazakh Research Institute of Power Engineering (Almaty) [6].

In the CPET the plasma-steam gasificators for combined processing of coals of 100 kW and 1 MW capacity, in which syngas with the output of 94,2-96,1 % out of the organic mass is produced, and useful components (technical silicon, ferrosicilicium (FeSi), carbo-silicon (SiC), etc.) with the output of 44,5-47 % are recovered from the mineral coal mass, have been designed [2].

Plasma technologies and equipment for processing of natural quartzites and basalts (the capacity of the installation is 200 kg/h) have been developed.

This plasma-energy technologies and equipment for their realization have noticeable ecological and economical advantages over traditional technologies of fuel utilization.



Nomenclature :
AM- air-fuel mixture
SA-secondary air
MF- muffle
PG- plasma generator
B - burner

Fig. 4. Schema of the alloautothermal gasificator with plasma stages

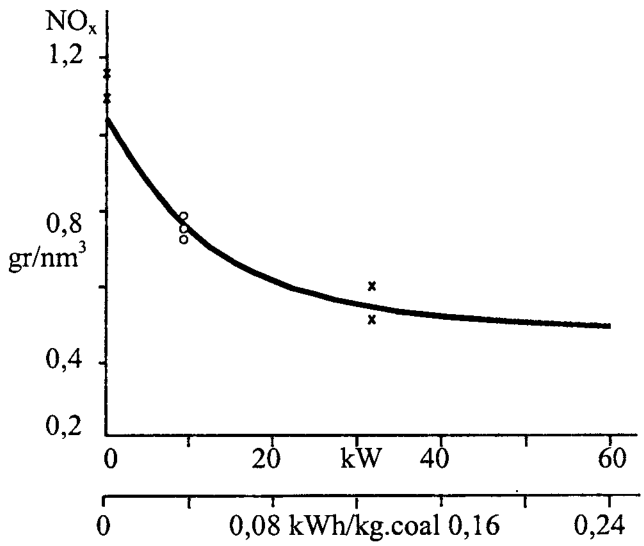


Fig. 5. Influence of power of plasma generator on NOx output (after the plasma-coal burner)

REFERENCES

[1] Zhukov M.F., Karpenko E.I., Peregudov V.S. et al. Plasma mazout-free kindling of boilers and stabilisation of coal-dust flame combustion. / Editor Messerle V.E.- Novosibirsk: Science, 1996. – 604p.

[2] Karpenko E.I., Messerle V.E. Plasma-energy technologies of fuel using. (Conception and calculation-theoretical investigations of plasma-energy technologies)V.1–Novosibirsk:Science,1998.–385p

[3] Engelsht V.S., Messerle V.E., Zhukov M.F. et al. Thermal plasma technology of rational combustion with simultaneous improvement of ecological characteristics / Proceedings of Japanese Symposium on Plasma Chemistry:v.5. - 1992. - p.283-290.

[4] Messerle V.E., Peregudov V.S. Ignition and stabilization of combustion of pulverized coal fuels by thermal plasma // vol.2: Investigation and design of thermal plasma technology / Cambridge Interscience Publishing, London, 1995. -p.323-343.

[5] Karpenko E.I., Messerle V.E Introduction into plasma-energy technologies of solid fuel using. Novosibirsk: Science, 1997. – 119p

[6] Sakipov Z.B., Messerle V.E., Ibraev Sh.Sh. Electrothermochemical coal preparation to burning. – Alma-Ata: Science, 1993. - 259 p.

[7] Karpenko, E.I.,Zhukov M.F., Messerle V.E et al. Science-technical bases and experience of the exploitation of the plasma ignition of coal of the Thermal Power Stations. Novosibirsk: Science, 1998. – 137p.

[8] Karpenko, Messerle V.E, Tchurashev V.N. et al. Ecology-economical efficiency of the plasma technologies of refining of solid fuels. Novosibirsk: Science, 2000. – 159p

[9] Harries R.S., Nasfell M. and Williams A. "Combustion Science and Technology", 1976, No.4, pp.85-94.

[10] Borodyanski G. and Chudnovski B. "Antechamber - activated combustion and inhibition of prompt NO_x", 9-th Annual Symposium The Israel Section of the Combustion Institute, Brn-Curion University of the Negev, Ber-Sheva, Dec. 16, 1994, pp. 53-54.

[11] Blackburn P. "Ignition of pulverized-coal with arc heated air", Energy,V.4,No.3,1980,pp.98-99

[12] Borodyanski G. et al. "Influence of fuel composition on NO_x - formation in gas turbine combustion chamber", 11th Annual Symposium The Israel Section of the Combustion Institute, The Hebrew University of Jerusalem, 21 Dec. 1995, pp. 10-11.