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The Technology of the Anthracite Combustion in Torch with Preliminary Thermochemical Preparation (TCP)

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Abstract

A significant number of the TPP's coal-fired boilers of Ukraine are outdated, have low efficiency and high level of emissions. It is necessary to find low cost way which helps to reduce usage of gas on TPP as supporting fuel and to reduce total emission of the nitrogen oxides. The 60 MW_{th} burner that meets these demands has been developed in Coal Energy Technology Institute for 300 MW_{el} unit. Experimental studies showed reducing usage of gas down to 3 times on Ukrainian anthracite. The burner operation was reliable in all load ranges of the boiler for 1.5 year. Environmental operation analysis showed that TCP burners' installation could lead to total reduction of the NO_x up to 20 %.

Keywords: Coal combustion, TPP, boiler, burner, pulverized coal.

Introduction

In the mid-80s of the last century, the intensive research of the bituminous coal dust preheating technology by the combustion products to reduce the nitrogen oxide emissions at TPPs have been conducted at All-Russia Thermal Engineering Institute (VTI, Russia)[1]. A substantial volume of researches was conducted, and the technology has been implemented at some TPPs of Russia. In the period of wide application of the natural gas extensive use in the power sector and low level of payments for flue gases emissions, such works were suspended but found further development in Ukraine not only to reduce the nitrogen oxide emissions but to improve the combustion efficiency of the low-reactive high-ash anthracite of the local deposits.

A significant number of the TPP's coal-fired boilers of Ukraine built in 50s – 70s years of the last century. At 6 from 14 Ukrainian TPP's the design fuel is Donetsk anthracite with ash content up to 20 % and heating value Q^r_i = 24-25 MJ/kg and have wet bottom removal (WBR). Due to different reasons, (obsolete equipment, working in regimes of lower load, periodical combustion of off-design fuel and so on), overconsumption of coal equivalent for production of 1 kWh of electricity exceeds design fuel for 50 – 70 g. The anthracite is low-reactive coal with small content of volatile matters and therefore requires special events for increasing of torch stability and completeness of combustion.

One of the peculiarities of the anthracite pulverized combustion with wet bottom removal is also increased emissions of NO_x due to high temperature in the furnace. It is known that the most fraction of the nitrogen oxide during coal combustion are fuel and thermal components[2, 3]: a high contribution of the first component is connected with pyrolysis of anthracite particles in oxidative medium, the second – with high temperatures in torch core at excess air coefficients of $\alpha \geq 1$. The NO_x emissions' reduction at TPP's of Ukraine with using of DeNOx process systems'[2, 3] requires substantial investments which are too heavy for current state of the industry.

Nowadays, the average ash content of the anthracite supplied to TPPs is A^d = 22-25 %[4], which is higher than the design requires for anthracite boilers. The carbon conversion degrees are 82-85 %, total efficiency - 30-31 %, NO_x emissions' concentration – up to 1200 mg/nm^3 that is the best for existing technologies at existing state of boiler units. Further improvement of such performances is only possible when new technological decisions regarding organization of ignition and combustion processes will be provided. In such conditions, the coal dust thermochemical preparation technology (TCP technology) is one of the problems' solving by means of low cost reconstruction of existing swirl burners which allows to work without gas support at more reactive coal or at usage of coal blends (Anthracite + Lean Coal or Anthracite + Bituminous Coal) and at deterioration of coal quality or decrease of boiler load – with small gas consumption at TCP without using of supporting fuel in the boiler.

The TCP technology consists in heating of the coal dust part (~30%) in burner itself to ignition temperature. Within the short time of coal dust residence in the burner (≤0,1 s), rapid pyrolysis and thermal grinding of coal particles are occurred[4]. This promotes devolatilization of combustible gases, increase of coke residue's porosity and formation of two-phase mixture of combustible gases' flow at burner outlet (mainly, CO and H_2) with coal dust particles heated to ignition temperature. Under the influence of such flow and radiation flux from furnace, the whole dust ignites in the lower radiant section of the furnace.

Considering the literature sources and own scientific works[4-7], the significant advantages are known which gives method of preliminary thermochemical preparation especially at combustion of low reactive and high ash grades of coal but creation of such industrial burners in Ukraine until developments of Coal Energy Technology Institute has not been emerged from the stage of scientific, design and short-term tests.

The burner 60 MW with TCP chamber was first designed at All-Russia Thermal Engineering Institute (VTI) for CHPP-22 of Mosenergo[6] with purpose to reduce the nitrogen oxides' generation at preliminary heating of dust up to 600°C. Furthermore, the burners of lower power (20-35 MW) were designed at JSC *Uraltechenergo* to reduce the nitrogen oxides' output at combustion of Kuznetsk lean coal with preliminary thermochemical preparation up to 700 – 750°C[7]. All of them were designed following the technology at which coal with maximal concentration is fed to cocurrent flow gas (oil) combustion products, previously burnt in air flow.

Known technologies of plasma thermochemical coal preparation of different metamorphism stage (from lignite to anthracite) are used for firing-up oil less dry bottom boilers[3].There is experience of their short-term operation during firing-up of the anthracite boilers only. Methods of coal torch combustion with preliminary gas thermochemical preparation of coal dust[6,7] are also known but such burners have been constructed for high reaction grades of bituminous coal only with volatile matter's yield of 12-25 % where heating to 600-700°C is sufficient for their pyrolysis, but for anthracite combustion where for ignition initiation only the heating to 900-950°C is needed, they are useless.

Following the technology at which the anthracite with maximal concentration supplies to cocurrent flow of gas (fuel oil) combustion products previously burnt in air flow, the 70 MW pilot burner (Figure-1) of the TPP-210A boiler unit of Zmiivska TPP (Figure-1) was constructed[2]. It was a first attempt of standard swirl burner's reconstruction for application of gas thermochemical preparation technology (TCPT) of the anthracite.

The analysis of identified disadvantages shown the necessity of aerodynamics' significant changes and distribution of the air-pulverised coal streams in the burner, the developments of new construction of gas-coal pilot burner which would allow to burn gas directly in air-and-fuel mixture due to air that transports dust. It has been experimentally shown that the gas burning in air-and-fuel mixture stream has key distinctions from combustion in a pure air. It runs slower due to heat absorption by coal particles and does not give too high temperature perturbation (~1100°C against 1900°C during combustion in air). This eliminates the possibility of explosive combustion. At the same time, this accelerates the heating of coal particles and their temperature is almost not differing from it of gas phase in the gas combustion zone. In the course of combustion zone the gas in whole (or in part) burns out oxygen, and pyrolysis of the heated in oxygen-free (or much depleted) medium coal particles is occurred, so the output of nitrogen compounds from coal runs at lack of oxygen that leads to significant reduction of the nitrogen oxides' formation.

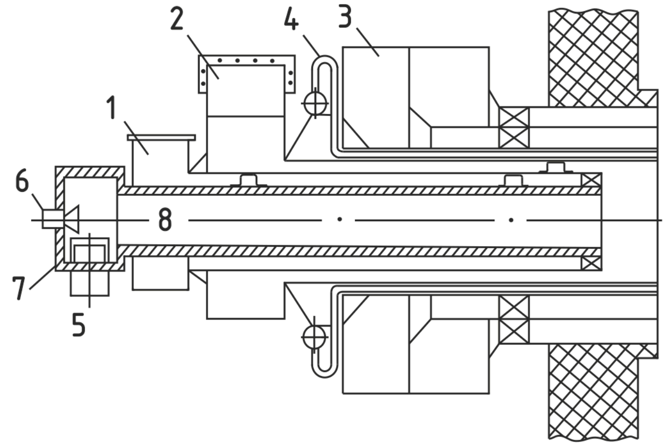

Figure-1
70 MW pilot burner of the TPP-210A boiler unit of Zmiivska TPP with "combustion stabilization device" of the anthracite embedded

Materials and Methods

With further improvement of technology, a new technological scheme of the TCP technology's step process was proposed (Figure-2)[8]. It involves the distribution of air-fuel mixture in the burner for separate streams that are heated in steps in the line of the burner's channels. In the part of the muffle chamber the stream (6) is heated during the gas combustion (9) in fuel-air mixture. Due to centrifugal forces, the part of the coal dust (7) is pushed to inner walls forming aerodynamic curtain that protects a wall absorbing radiation thermal fluxes that heat the coal. Along external surface of the muffle flows part of the air-fuel mixture flows which is fed to furnace past the TCP chamber (8). Its temperature at inlet is ~190-210°C that gives a possibility to cool the muffle metal down to 350-400°C and heat up the air-fuel mixture due to heat losses of the muffle.

At burner's outlet all flows (10, 11, 12) with different stage of heating are mixed and along with secondary air (13) are fed to the boiler's furnace.

Burner's Construction: The construction of the 70 MW standard swirl burner[9] for TPP-210A boiler of Trypilska TPP was taken as a base during the process of TCP industrial burner's development. For realization of the low-cost reconstruction, it was necessary to save maximal existing metal structures, parameters and coal, air and gas feeding schemes, as well as burner's operation regimes at variable boiler's loads.

The burner's construction scheme is shown in Figure-3.

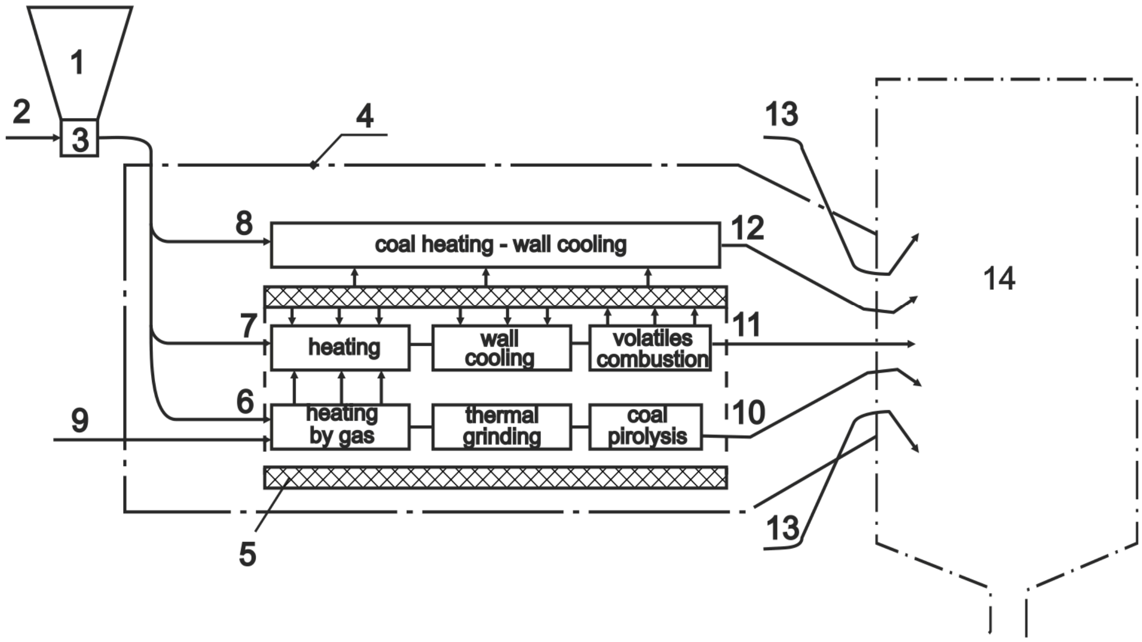

Figure-2
Scheme of the TCP technology's step process
1 – Pulverized-coal bunker; 2 – Primary air; 3 – Aeration pulverized-coal feeder; 4 – Boiler's burner; 5 – Pulverized-coal thermochemical treatment chamber; 6, 7, 8 – Input flows of fuel-air mixture; 9 – Natural gas; 10, 11, 12 – Output streams of heat treated fuel-air mixture; 13 – Secondary air; 14 – Boiler furnace.

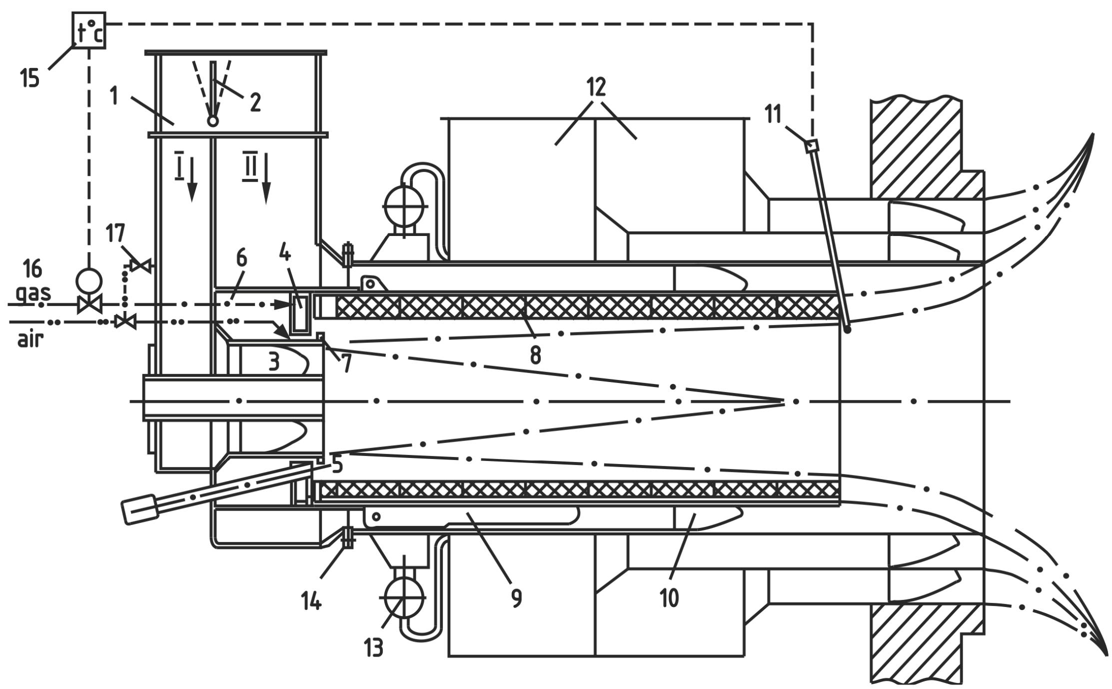

Figure-3
Burner construction scheme
1 – Pulverized-coal feeding box; 2 – Angling damper; 3 – Central swirler; 4 – Gas chamber; 5 – Igniter; 6 – Air chamber; 7 – Flame stabilizer; 8 – Muffle chamber of pulverized-coal thermal treatment; 9 – Support stand; 10 – Peripheral swirler; 11 – Temperature sensors; 12 – Casing of existing burner; 13 – Existing gas chamber; 14 – Existing connector flange; 15 – Temperature control; 16 – Gas supply regulator at TCP process; 17 – Muffle blowing at operation without TCP

The scroll coal swirler and the central air tube were dismantled in the existing burner. At their place the combined box of the coal handling (1) and the muffle chamber of the pulverized-coal heat treatment (7) manufactured in the form of connecting units were assembled (Figure-3). The combined box (1) equipped with the angling damper (2), distributed air-and-fuel mixture at internal flow **I** which is fed at TCP in the muffle, and external flow **II** that washed the muffle outside and fed to the furnace excluding TCP. At internal flow for the heat treatment the ~30±5% of dust has been fed and the rest – through peripheral channel directly to the furnace. Both flows are swirled by axial-shovel swirlers (3) and (10). The swirling stage of the flows is different. For peripheral flow it's maximal[10,11], and for internal nd the swirler's shell (3), air is fed from the chamber (6) in stoichiometric amount (α=1). The heat-resistant control-torch flame stabilizer (7) is installed at the swirler's shell face (3) in front of which the gas-air mixture has been formed and behind it – the zone of its stable burning in the form of ring torch from which streams of basic gas are ignited in the muffle's swirled fuel-air mixture.

The regime of its stable existence at different burner's loads was examined experimentally during the boiler's burner operation.

Such constructive distribution of the fuel-air mixture's streams allows to heat actively the coal dust in the muffle's centre, to protect its lining by aerodynamic pulverized-coal screen which actively absorbs both convective and radiative heat flows from torch and, moreover, to cool the muffle with external stream of the relatively cold air-and-fuel mixture with the temperature of 200-250°C.

The muffle ends at a distance of ~0,5-0,8 m from the burner's cut. At this area, all swirling flows with different temperature levels are mixed by centrifugal forces and additionally heated by intense radiation from the furnace volume that allows to burn flow – less and is designed to ensure that coal concentration which is pushed to the inner wall gradually increase along the muffle and coincide with zones of maximal heat generation of the burning gas.

In the box around the swirler's shell (3), the auxiliary gas burner being a part of the gas chamber (4) and air chamber (6) was mounted. The gas chamber through the system of the holes distributes the gas at main flow (90 %) that supplies by streams directly to the muffle's fuel-air mixture and auxiliary (10%) – for formation of the inner control torch which in its turn ignited by the external igniter (5). To ensure the stability of the control torch through annular gap between the gas chamber (4) a anthracite without using of and saving support gas. The optimal and the safe mode of the coal heat treatment at different burner's operation regimes is provided by the coal feed control in the muffle by the damper 2 and gas – by the regulator 16 at the level of 900±50°C. The burner is connected to the secondary air line without any changes. The oil warm-up spray burner is mounted under the coal burner.

Following data of the Trypilska TPP, during combustion of the non-standard high ash anthracite the gas consumption for lighting was usually 2000-2400 Nm^3/h for one boiler casing through 4 corner burners, i.e. 500-600 Nm3/h per the burner. For TCP burner, the designed gas consumption was determined in an amount of 200 Nm3/h or 800 Nm3/h for casing that almost three times lower.

The TCP processes' computer simulation using ANSYS package allowed to predict the distribution of the temperatures, velocities and TCP products' composition inside the burner and at output to furnace that gives a opportunity to find the optimal operating options. As an example, the computational grid and the particles' tracks in the burner during the thermochemical treatment of the anthracite dust is shown in the Figure-4.

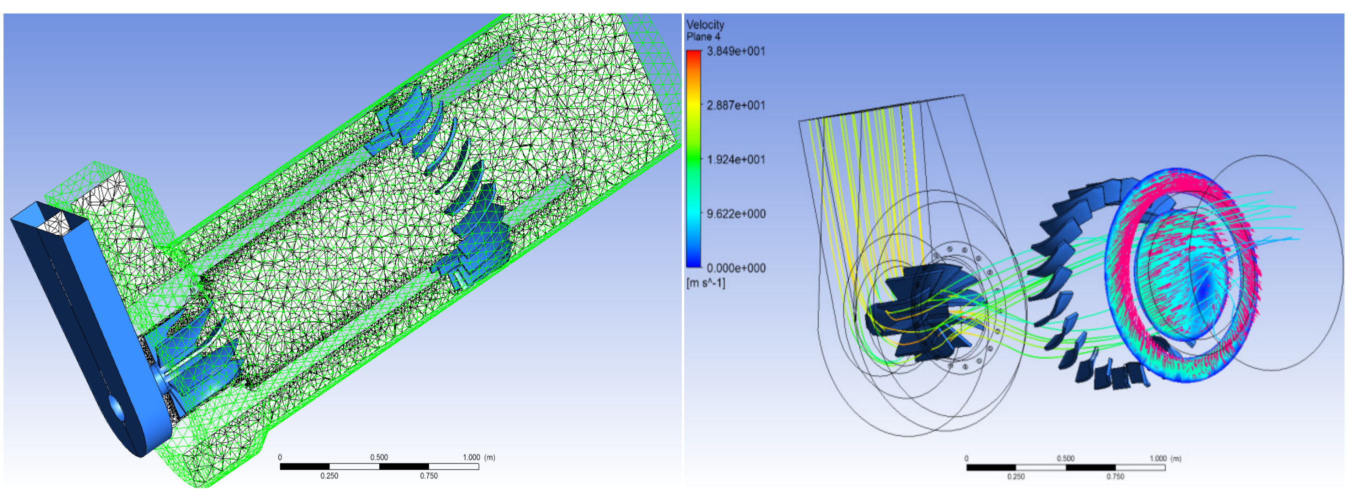

Figure-4
The particles' tracks in the burner coloured on velocities during TCP

Taking into account the design studies and the computer simulation, conceptual design was formulated and the detailed design of the PTCP-70 burner was developed. The burner was manufactured and assembled at the TPP-210A boiler unit station number No. 3A of 300 MW unit of the Trypilska TPP (PJSC "Centrenergo", Figure-5).

Material and Methods

The burner has been in industrial operation since November, 27, 2010 to April, 17, 2012 that was 11500 hours of accident-free operation at different load regimes[12]. At the time of investigation operation, the burner was in operation in different regimes depending on coal quality – both with TCP using and without it. At all regimes the burner provided steady torch in the furnace, absence of the slag adhesion under the burner and slagging of the muffle chamber.

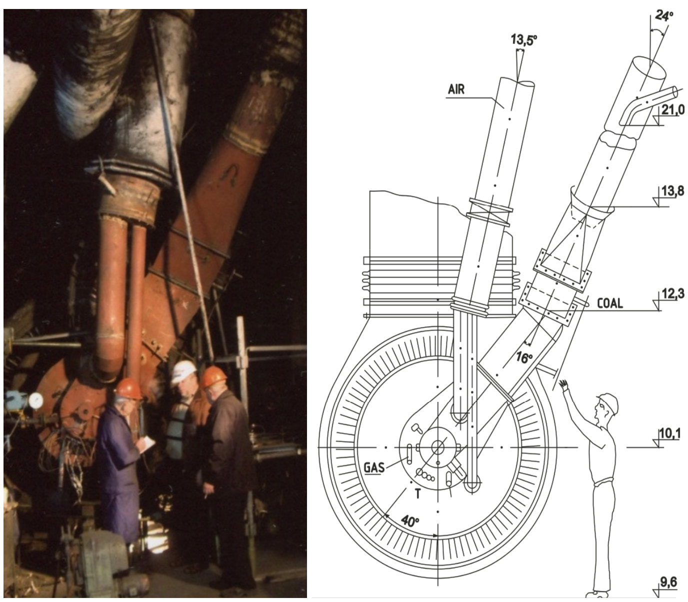

Figure-5
PTCP-70 burner for boiler TPP-210 A St. No. 3 of Trypilska TPP

Experimentally, two possible regimes have been studied: i. The thermochemical coal preparation regime (TCP) at which particles' pyrolysis take place in the burner (gas analysis is evidenced about this) from which hot coke, combustion products of natural gas and submicron coal particles and gaseous combustible gases of pyrolysis go into the furnace. For this, it is necessary to heat anthracite to 900-950°C (for 50-100°C lower ash-fusion temperature) with gas consumption 70-180 Nm^3/h that less than estimated. ii. The regime of previous thermal coal preparation at which particles pyrolysis take place in the furnace and from the burner coal is fed heated to 700-800°C with gas consumption ~60 Nm^3/h.

During anthracite combustion with V^{daf}=3-6%, the regime (a) is used. For Anthracite+Lean coal blends with V^{daf}=6-9% - the regime (b) is used and during combustion of lean coal or A+L blends with V^{daf}=9-14%, the thermal preparation became redundant and burner could steady work with system of TCP shutdown.

The chemical composition of gases in the muffle has been measured under the tests. The results of analyses shown that the natural gas burns mostly at the beginning of the muffle and along its length the devolatilization of combustible gases from coal take place and due to its combustion in residual oxygen rise the air-and-fuel mixture temperature. Experimentally determined, that oxygen concentration near muffle's wall lower than near its axle – this corresponds to theoretic model since coal due to swirling is impressed to walls and namely there the devolatilization take place.

Results and Discussion

The temperature measurement of the shell's metal shown that their maximal levels at different loads and rates not exceed 400-450°C. Two-phase flow temperature measurement shown the influence of coal consumption and natural gas flow rates on the TCP intensity under gas combustion in air-and-fuel mixture. In the range of coal consumption rates for burner 9-11 t/h that correspond to temperatures of primary air-fuel mixture 193-219°C, changes of gas flow rates for TCP (from 50 to 200 Nm^3/h) at constant coal consumption rate are not significantly influenced on temperature of the two-phase flow both out of the muffle and out of the burner ($\Delta t < 100$°C).

It was noted, that the significant impact on gas rate makes also the level of the combustible volatile matter yield in the coal. With increase of V^{daf} to 12 % (anthracite and lean coal blend) the required natural gas flow rate is reduced to ~30-50 Nm^3/h, i.e. in this event the gas is needed for ignition of air-and-fuel mixture only.

Much greater effect on the temperature in the muffle and behind the burner makes air flow rate to the muffle. Experiments shown that gas burning in air-and-fuel mixture significantly differ from burning in air. It runs slower due to heat absorption by coal particles. At high loads coal concentration reaches 1-1,2 kg/Nm^3 or 0,6 kg/m^3 at t = 200°C.

The gas flows from the gas collector during a short time of staying in a burner (~0,1 sec) can not completely burn out. Therefore, increasing of the gas consumption at high loads becomes ineffective. The coal concentration decrease in the muffle's air-and-fuel mixture allows natural gas to burn out even at its beginning causing pyrolysis of the coal particles and volatile matter burning which are released during this. This greatly increases the TCP process intensity bringing it to autothermal process.

In total, the studies shown the burner's performance capacity and the operation efficiency at coal of different grades and different quality (anthracite, anthracite and lean coal blends, lean coal, with volatile matter content: V^{daf} from 6,0 до 13,3% and ash content: A^r from 26,2 to 29,0%) and at different power unit's loads. To determine the effect of one burner's operation for operation of A casing and burner as a whole, the boiler's st. No 3 balance tests at different loads have been carried out.

In most regimes, the reliable slag yield has been provided temperature of which during burner's operation with TCP was 50-80^{o}C above. Average monthly indices of combustibles' content in fly ash during burner's operation with TCP in that half of the boiler where burner with TCP is installed) were for 0,5 – 0,8 % lower. While ensuring temperature at the muffle's outlet 900-950^{o}C, the level of the nitrogen oxide in burner was 100-400 ppm, and during the reconstruction of all boiler's burners the overall NO_x reduction could be expected.

After shutdown of the boiler for medium repair, the burner has been dismantled, and ultrasonic examination of erosion wear of its details was conducted. The most heat-stressed details – the muffle, the peripheral swirler, the gas burner were manufactured of the 12H18N9T steel and practically did not have erosive wear: local abrasions 0,2-0,4 mm at thickness of 10 mm. Erosion on armoured sheets thickness of 10 mm reached 4-5 mm and required their replacement. The highest erosion was marked on side walls of coal box in places of flow sharp turn (at 90°). The experimental test of the burner's operation shown not only the reliability of its structure but the cheapening possibility of further burners' manufacturing due to replacement of high alloyed steel 12H18N9T for less alloyed heat-resistant steel, as well as burner's lining of the corundum concrete for the standard curved chamotte heat-resistant bricks.

Conclusion

The burner operation is reliable in all load ranges of the boiler, in which tests were conducted.

The tests carried out in a wide range of coal consumption per burner (6-14 tons of coal per hour). In all specific range of the loads the burner had shown the reliable operation as with application of the thermochemical preparation of the coal as without it.

Ensuring the temperature at the muffle outlet of 900-950°C, the level of the nitrogen oxide is 100-400 ppm and providing TCP burners' installation the total reduction of the NO_x could be expected to 20%.

In most regimes the reliable slag yield is provided the temperature of which on the side of TCP burner was for 50-80°C above. The average monthly indices of the combustibles' content in fly ash on the side of the TCP burner's operation were for 0,5-0,8 % lower.

The cheapening of further TCP burners' is possible due to replacement of high alloyed steel for heat-resistant steel, as well as burner's lining of the corundum concrete for the standard curved chamotte heat-resistant brick.

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