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Part 3

ASH AND SLAG HANDLING

3.2. Ash and slag handling systems at TPPs

3.2.3. Bottom ash/slag removal

3.2.3.1. About reasonability of transferring slag-tap boilers to dry bottom ones at TPP reconstruction

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ABSTRACT

Technical solutions for transferring slag-tap boilers P-50 and TP-87 combusting Kuznetsky lean coal to dry bottom boilers are given. The issues of evaluation of complex efficiency of implementing the suggested technical solutions are considered.

A problem of expediency of transferring slag-tap power boilers to dry bottom ash removal (DBAR) has been recently discussed in the technical literature (see, for example [1]). Technical solutions for transferring the P-50 boilers (Kashirskaya, Cherepetskaya and other TPPs) and TP-87 boilers (CHP-22 of Mosenergo, Tolyatinskaya and other CHPs) for DBAR are presented below. The mentioned boilers were designed for combustion of Donetsky coal of anthracite culm type in the regime of liquid slag removal, but at the present time they are combusting Kuznetsky coal of variable quality, mainly with coal of TR type.

In the nearest years the new pulverized-coal power boilers are mainly intended to put into operation because of the increasing price of natural gas [1]. In connection with that a problem of combusting rated coals with deteriorated quality in power boilers in Russia as well as not rated coals including intermediate products and bottom ash / boiler slag is more and more important. In addition the world trend is hardening of ecological requirements for TPPs concerning the standard levels of specific emissions of nitrogen oxides and rational use of ash and slag. Under these conditions the transfer for coal combustion in power boilers with dry bottom ash removal seems to be optimal both from ecological and economic points of view.

The main advantage of boiler with DBAR is a possibility to reduce the nitrogen oxides emission 2,5…3 times without realizing the expensive measures.

Pneumo-mechanical technology of bottom ash removal can be used when bottom ash is extracted dry from the bottom of the boiler. It allows to have bottom ash with high consuming properties without limitations on loss on ignition and to increase the boiler efficiency approximately by 0.4 %. The advantages of pneumo-mechanical technology of bottom ash removal are described in details in [2].

It should be noted that maintenance of the efficient and reliable pulverized coal combustion in DBAR regime with the possible increase in moisture and ash content in the coal and with decrease in volatiles per working mass is also a serious problem. It is determined by the dangers of deterioration of combustion efficiency and reliability, the reduction of mill equipment output and the local slagging of furnace water walls.

Complex solution of the mentioned problem is possible on the basis of separate arrangement of pulverized coal (PCB) and oil-gas (OGB) burners acting the part of secondary air nozzles for pulverized coal combustion. The both types of burners should be straight-flow. Separate arrangement of pulverized coal and oil-gas burners allows accelerating the warm-up and ignition of air-fuel mixture, because its mass is not ballasted by the secondary air. In this case the velocity of pulverized coal jet outflow can be assumed as a medium one (no more than 24 m/s) for reliability of torch ignition and decreasing its pulsations. At the same time the velocity at the outlet of secondary air nozzle can be raised for providing the reliable ignition of pulverized coal because of intensification of inner recirculation of hot gases in the case, when the jets don’t impede to flame spreading.

The advantage of straight-flow burners is conditioned by the simplicity of their design and the possibility of jets orientation in the necessary direction for providing the required aerodynamics and the flame temperature regime A few variants were considered in working out the possibility of transferring P-50 and TP-87 boilers for DBAR. One of the variants of layout diagram with tangentially directed burners and nozzles as it applies to the boiler P-50 with five swirl flames is presented in figs. 1, 2. The first stage of combustion is realized in three of them. This variant can be also used at the boiler TP-87 with some not principal changes. For the both boilers the pinch is deleted, the dry-bottom ash hopper is fulfilled, whiles the refractory-face and lined water walls of the lower surface part are changed for the plain-tube ones.

The special features of adopted layout diagram with evaluation of its advantages are reflected in table 1.

The calculated air excess / air velocities (m/s) at the output from burners and nozzles of P-50 boiler are pointed out below.

Type of combusted fuel	coal	nat. gas
Oil-gas burners	0,20/40,7	0,23/45,6
Gas burners	0,20/40,7	0,22/45,6
Pulverized coal burners	0,25/21,2	0,15/18,4
Combined nozzles	0,50/45,1	0,45/50,1
incl. discharge pulverized coal pipes	0,25/25,6	0/0

Table 1. **Comparative characteristics of P-50 boiler with dry bottom ash and liquid slag removal**

Name of parameter	Unit of meas	Characteristic of parameter	Advantages of suggested solution
Type of suggested pulverized-coal burners / existing		Straight-flow fantail/swirl	Simplicity, reliability and maintainability of design
Number of pulverized-coal burners	pc	12	Accordingly to a number of feeders. Reduction of burners number is not desirable because of decreasing the ignition reliability and the boiler maneuverability
Initial perimeter of jet ignition for suggested pulverized-coal burners	m	1,8	More than for jet of existing swirl burners approximately by 0,4 m
Aerodynamic characteristic of ignition source for fresh jet in suggested / existing burner		Forced-ejection / ejection	More intensive and high-temperature one than in the upstream zone of swirl burner
Probability of unburned dust separation		Less than for swirl burner	Because of existence of air cushion formed by high-speed jets of oil-gas burners of the 1st layer and side(relatively to eddy zones) jets of gas burners of the second layer
A value of unburned carbon by content of combustibles in fly ash especially for combustion of coal with raised ash content and moisture		It is less than for the boilers with swirl burners with stoichiometric combustion	Early ignition of coal dust; a large share of inner recirculation of high-temperature gases; high mixing rate of torch in the zone of tertiary blast; exclusion of output from the first stage of combustion of the unburned coal dust without mixing with the secondary and tertiary air
Conditions of burning for fine dust in air effluent		Are provided	Because of location of pulverized coal pipes of discharge air in the lower part of combined nozzles and intensive heating of aeromixture by rising flame due to the large slope of nozzles down
Conditions of efficient combined combustion of fuel (gas, oil-fuel) and pulverized coal with high reactivity		Are provided	The burners of high-reaction fuel and the burners for pulverized coal are divided. The combustion products of both fuel types are moving upstream in the vertical segments of furnace volume, where the high-speed are flows are coming in the tiered manner and turbulize the torch
Probability of local slagging of water walls in the zone of PCB location		A probability is small	Two layer arrangement of PCB; technology of staged combustion of pulverized coal with existence of the 2nd stage of combustion below PCB location and the 3rd stage – above it; absence of zones of flame pressure on the furnace walls with their reliable screening by air jets.
Expected (existing) specific emission of nitrogen oxides for combustion of pulverized coal / natural gas	mg/ m^3	No more than 350/125 (1300/700)	Technologies of stage combustion of pulverized coal and natural gas; low (0.25) excess air in outlet of PCB, which doesn't exceed the volatiles content in coal per its working mass
A possibility of boiler operation with the coal of deteriorated quality		exists	Because of special feature of flame flow mechanics and change of boiler over ТШУ regime.
Expected/existing temperature of gases at the furnace top	^{o}C	(1130…1150)/ (1200…1220)	Increasing of mean thermal efficiency of furnace screen, aerodynamic advantages of suggested combustion technology
Commodity properties of fly ash and slaga		Are provided	By means of afterburning below the standard volatiles in fly ash in the upper furnace and using the plant of pneumo-mechanical slag removal

It is suggested to fulfill the straight-flow pulverized coal burners oblong for vertical, because the more is a height and the less is the width of root of jets coming from PCB, the more is the initial perimeter of ejection and the quicker is the heating and ignition of all mass of air-fuel mixture. For example, for the adopted overall dimensions of PCB (700x200 mm) the initial perimeter of ejection for one jet constitutes: 0,7x2 + 0,2x2 = 1,8 m. The dissector diameter for existing swirl burner of P-50 boiler constitutes about 450 mm. Therefore the initial perimeter of ejection (from the side of upstream in the zone near axis, from where the ignition occurs) will be equal to 0.45x3.14 = 1.41 m. The height of flat-slot could be assumed to be 1000 mm, while the width - 140 mm. In this case the initial perimeter of ejection is increased up to 2,28 m, and the ignition reliability is increased. In suggested furnace the tailing volumes of PCB jets of one wall taking into account the inertance of fire particles are forcibly supplied to the roots of PCB jets of opposite wall and are ejected by latter. In this case the share of forced inner circulation, which is typical for aerodynamics of tangentially directed jets, is quite high with taking into account the high velocities of secondary air flow. By estimate calculations the temperature of ejected combustion products will constitute about 1300^{o}C. Thus, the convective source of ignition in the suggested furnace is more developed and stable both for temperature and mass than with combustion of coals of degraded quality in the boilers with swirl burners and liquid slag removal.

For stabilizing the combustion in suggested furnace of P-50 boiler (even with deterioration of coal quality) the fresh torches of each four PCB are concentrated in one of three eddy zones of the first combustion stage. Each similar zone is formed due to the tangential directivity relatively to the conditional surface of vertical figure of axes rotation not only of four PCBs, but also of four axisymmetric burners of fuel with high reactivity. When the coal is burned, the latter burners perform the role of secondary air nozzles. As it is presented in fig.1 and 2, the vapors of oil-gas burners (1, 6; 2, 5 and 3, 4) play in this case the role of lower nozzles of secondary air. Their high-speed air jets will prevent the separation of unburned dust in dry-bottom ash hopper from the right, central and left eddy zones of the first combustion stage, correspondingly. Seemingly, it will be also provided with the certain coarse grinding of coal sometimes the intended one (for decreasing the specific consumption of electricity for milling) and sometimes the forced one (because of deterioration of coal quality).

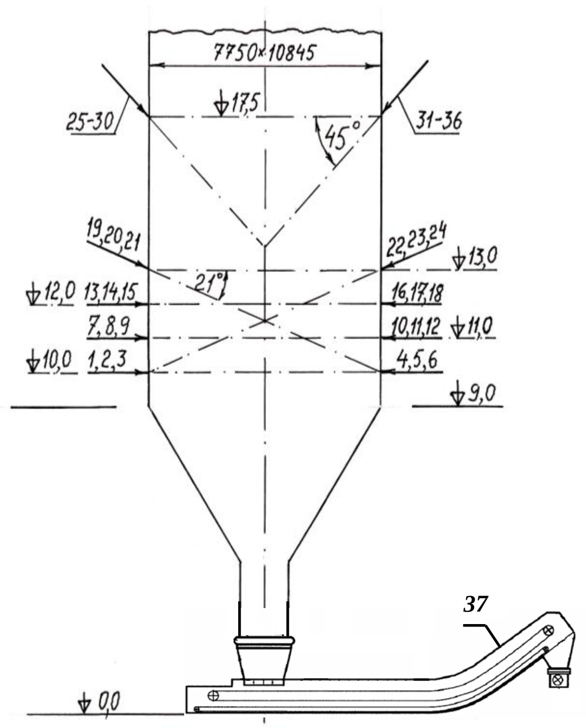

Fig. 1. Diagram of burners and nozzles location along the furnace height of P-50boiler:
1-6 — oil-gas burners (for operation with coal – the lower nozzles of secondary air); 7-12 — pulverized coal burners of lower layer; 13-18 — pulverized cola burners of upper layer; 19-24 — gas burners of upper layer (for operation with coal – the upper nozzles of secondary air); 25-36 — combined nozzles of discharge tertiary air; 37 — installation of pneumo-mechanical bottom ash removal

The vapors of inclined below gas burners of upper layer (*19, 24; 20, 23* и *21, 22*) are also intended for introduction of air jets in the pointed swirl zones. These jets increase the vortex intensity (i.e. the quantity of forced inner recirculation – the source of early ignition), because they are directed tangentially to the conditional surface of larger diameter than dust-coal jets (Fig. 2). In addition, due to the slope down by the angle of about 20^o (Fig. 1), they restrict the swirl torches of the first combustion stage from the sides. First of all, it concentrates the body of flame and is important for the stabilization of combustion, especially with coal quality reduction. Secondly, it prevents the widening of flame with unburned pulverized coal without the interrelation with secondary air jets that results in the reduction of volatiles content in bottom ash and fly ash.

The reduced volatiles content in fly ash is also provided by means of creating the zones of raised air pres-

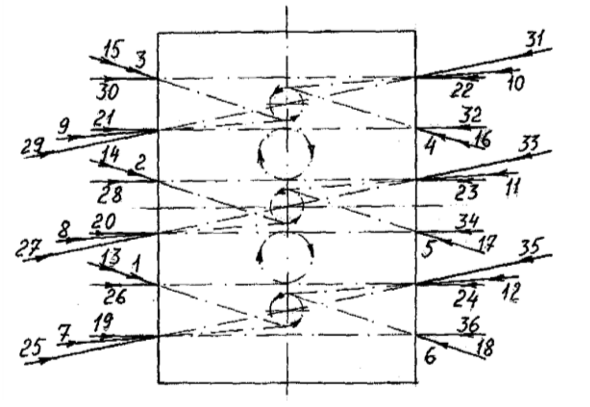

Fig. 2. Diagram of burners and nozzles location projecting on the horizontal cross-section of furnace:
1-6 — oil-gas burners (at coal combustion – the lower nozzles of secondary air); 7-12 — pulverized coal burners of lower layer; 13-18 — pulverized coal burners of upper layer; 19-24 —gas burners of upper layer (at coal combustion – the upper nozzles of secondary air); 25-36 —combined nozzles of discharge tertiary air

sure above the pointed vortex flames. It is provided due to sending in these zones of high-speed jets of discharge and tertiary air flowing out of combined nozzles 25-36 located at the level 17.5 m and inclined down by the angle 45^o (Figs 1, 2). The jets leaving the pairs of combined nozzles *25, 35; 27, 33* and *29, 31* cross the vertical axes of swirl flames preventing to the most probable axial outlet up of unburned pulverized coal. The pairs of combined nozzles *26, 36; 28, 34* и *30, 32* prevent to the dispersed horizontal outlet up of unburned pulverized coal, because they are directed tangentially relatively to the conditional body of rotation with the raised diameter. In this case the direction of tangential spin is inverse than in the vortex ones. It provides the raised turbulization of after-burning flame and promoted to equalizing the velocity fields in the upper part of furnace.

The input of air discharge in furnace through the combined nozzles located in accordance with fig. 1, 2 is more optimal in comparison with the existing one at P-50 boilers and especially at TP-87 boiler. The lateral jets of air discharge at P-50 boilers with the furnace width 10845 mm, which contains the excess air with LSR, penetrates probably in insufficient amount to the zone of furnace that is central by front. It is quite possible to approve that for TP-87 boilers with the wider furnace (14080 mm) these lateral jets of air discharge don't penetrate at all in the pointed zone of furnace. In connection with that the certain increase of total air excess at the furnace outlet is required for providing the standard content of volatiles in fly ash.

The positive experience of reconstructing the boilers NKZ-210-140FD of the West-Siberian CHP [3] was used for the development of layout diagram of combined nozzles. During these works the different types of fuel and air flows were introduced in the furnace in the general vertical layers of furnace volume. Before the reconstruction of these boilers the pointed flows were introduced in the furnace volume in the mutually perpendicular directions that resulted in the considerable unburned carbon and slagging of steam superheater.

The uniform introduction of discharge air through the front and back walls was successfully tested during the first stage of reconstruction of TP-87 boiler (no.9) of the West-Siberian CHP [3]. The pointed input was supplied by installing in the zone near axis and sidewalls of four vertical dividers (by two at each side) providing the going from pipe Ø 630x7 mm to three pipes Ø 325 mm. It is suggested to use this successful experience in realizing the layout diagram of combined nozzles accordingly to fig 1, 2. Taking into account the raised steam-generating capacity of one shell of P-50 boiler (475 in comparison with 420 t/h), the discharge pulverized coal pipes should be fulfilled from the pipes Ø 377x7 mm.

The principal design of axisymmetrical oil-fuel burners 1-6 (Figs.1, 2) and gas burners 19-24 doesn't demand any explanation. The pointed burners were successfully tested at the large number of reconstructed boilers, mainly of Barnaulsky boiler manufacture, which were changed over combustion of gas and oil-fuel in the straight-vortex flame [3] and were certified.

The estimating thermal calculations of furnace chambers of P-50 and TP-87 boilers were fulfilled on the whole. The value of unburned carbon in calculation was assumed by 0.5 % lower than the standard one [4], i.e. the same as for the boilers with liquid slag removal (1.5 %). It is explained by the aerodynamic advantages of suggested technology for combustion of lean coal under DBAR conditions concerning the reliability of ignition and after-burning of pulverized coal.

The model investigations of furnace aerodynamics [3] should be carried out in transferring the boilers for dry bottom ash removal for the concrete TPP, and the results of estimating thermal calculations should be refined taking into account the concrete marks of combustible fuel, the sizes of heating surfaces etc.

Switching boilers for dry bottom ash removal is a positive measure, because in this case the possibility of slagging of steam superheater surfaces is decreased, especially with the possible deterioration of coal quality, the reliability of operating the upper tube plates of air heater is increased and the temperature of flue gases is decreased. For example, the slagging of surfaces and excursions of superheater metal temperature above the legitimate values takes place currently and not infrequently at the boilers TP-87 with liquid slag removal. It occurs even at the boilers, at which the temperature of superheated steam is reduced up to 545^{o}C as a result of growing economizer surface and a cut of the part of steam superheater surface.

The following separate measures or their combinations can be used for providing the designed temperature of superheated steam in transferring TP-87 boilers for DBAR:

1) Increasing level of dry-bottom ash hopper location;
1) Restoration of design heating surface of steam superheater;
2) Decreasing of heating surface of water economizer to the design one;
3) Reduction of angle slope of combined nozzles in accordance of model investigations of furnace aerodynamics;
4) Process extraction of some part of saturated steam from the boiler drum for its use for TPP auxiliaries;
5) Increasing of heating surface of radiant steam superheater.

If to use even all the pointed measures during TP-87 boiler reconstruction transferring for DBAR, they should have undoubtedly less expenditures than the cost of realizing the traditional methods of specific NO_x-emission reduction at the boilers with liquid slag removal. The additional advantage of boiler operation with DBAR on suggested technology of coal combustion is a possibility of using fuels with the raised ash content and moisture and practically the same efficiency.

Some increase of "gross" efficiency could take place mainly due to the reduction of heat losses in bottom ash and reduction of combustibles content in bottom ash, if the outlet of bottom ash from dry-bottom ash hopper is made and the technology of pneumo-mechanical ash removal is used.

The simplier layout drawing of oil-gas and pulverized burners as well as the combined nozzles as they apply to TP-87boiler, at which the pulverized coal is supplied in the furnace by technology of pulverized coal with high concentration (DHC), is presented in fig. 3.

The pointed technology of pulverized coal supply aggravates the problems of its early ignition and mixing with air, because the initial perimeter of ignition is comparatively small in this case. This problem is especially evident at the boilers combusting coal having the reduced reactivity, as the Kuznetsky coal of TR mark [5]. Therefore the presented below justification of suggested combustion technology for TP-87 boiler is mainly directed to providing the intensification pulverized coal ignition and its mixing with air.

In the same time just the pulverized coal supply by technology DHC represents the additional possibilities for reducing excess of primary air to the level 0.1…0.15 that in % is less than the volatiles content per working mass of any mark of Kuznetsky coal. It is a guarantee of substantial reduction of forming the fuel NO_x, as accordingly to [6] the intensity of their formation is proportional the square of excess air in the zone of volatile substances outlet. The preliminary calculations of NO_x formation accordingly to [6] show that the NO_x concentration doesn't exceed 300 mg/m^3 at the outlet from the reconstructed boiler TP-87 with DBAR. Thus, we will have the reduction of specific emission of NO_x in 4…5 times in comparison with boilers working in the regime of liquid slag removal.

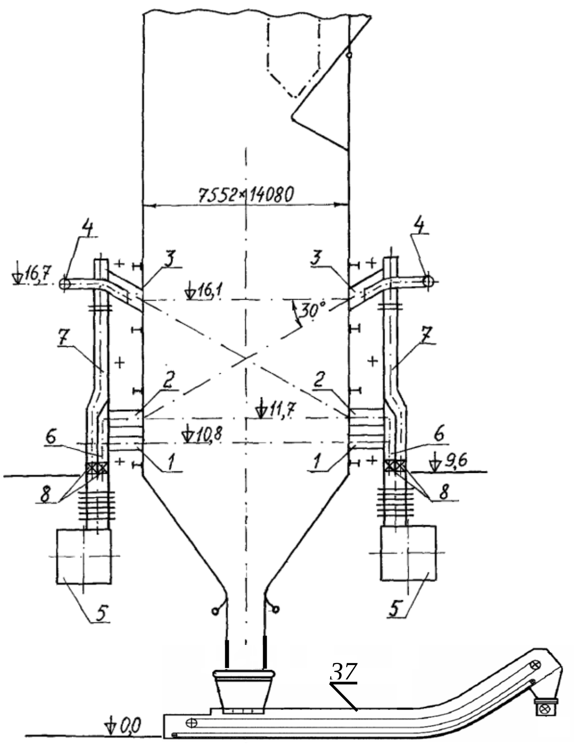

Fig. 3. Longitudinal section of furnace of TP-87 boiler with dry bottom ash removal:
1 — oil-gas burner, 2 — pulverized coal burner, 3 — combined nozzle, 4 — pulverized coal pipe of discharge air Ø 377x7 mm, 5 — existing air collector, 6 — air line to burners, 7— air line to combined nozzles, 8 — air gate, 9 — jet tube, 10 — ring burning collector of natural gas, 11 — pipe of natural gas, 12 — pipe of dust with high concentration, 13 — sparger from sections of angle type, 14 — axis of water-wall tubes, 15 — installation of pneumo-mechanical slag removal; 37 — installation of pneumo-mechanical slag removal

The aerodynamics of counter-displaced burners and nozzles located by six on the frontal and back furnace walls opposite each other with the horizontal spacing about 2200 mm, as for existing burners, was used in the suggested diagram. The optimal aerodynamics of counter-displaced jets is provided by means of rotation of axes of burners and nozzles by 8.3^0 that was well confirmed in the tests of the first and second stages of reconstruction of TP-87 boiler (st. no.9) ZSCHP [3]. Oil-gas *1* and pulverized coal *2* burners were rotated to the left, while the combined nozzles *3* — to the right. The extreme burners and nozzles are mutually directed in parallel to the furnace sidewalls for decreasing the flame impingement on them. The inverse rotation is provided for the better mixing of fuel and air (i.e. for the intensification of coal after-burning in the zone of jet action of combined nozzles *3*) as well as for the equalization of velocity field in the upper part of furnace.

As in case of technology suggested above for P-50boiler, the forced ejection will be carried out in the furnace of TP-87boiler, where the tailing volumes of jets running out the burners of one wall, approach (with accounting the inertance of dust particles) to the roots of jets of burners at the opposite wall, are elected by them and fire them. As to the mixing, it is known from the theory of turbulent jets [7, 8] that its largest intensity is provided with counter-displaced jets movement. The important issue for achieving the desirable effect is the distribution of pulverized coal along the height of straight-flow slot burner. The different variants are possible for solving this problem.

The calculated excess / velocities of air (m/s) at the outlet from burners and nozzles of boiler TP-87 are presented below.

Fuel	Coal	Nat. gas
Gas-oil burners	0.49/39.6	0.41/31.6
Pulverized-coal burners	0.11/33.8	0.09/27.5
Combined nozzles	0.55/47.3	0.50/44.5
incl. discharge pulverized coal pipes	0.25/30.5	0/0

Thus, the examples of suggested technical solutions of transfer for dry bottom ash removal of the boilers of P-50 and TP-87 type have demonstrated the possible approaches for providing their reliable, efficient and ecologically acceptable operation with the moderate reactivity (even with the raised ash content and moisture) and the alternate fuel – natural gas.

When it is necessary to have the boilers operation with the mixture of pointed fuels, the uniform loading of furnace by its width should be carried out by both fuels. At TP-87 boiler it is expedient to connect the discharging pulverized coal pipes from mills A and B to the combined nozzles located opposite each other, while the alternate connection to the nozzles of pulverized coal pipe must be carried out from both mills.

CONCLUSION

1. The reconstruction of furnaces transferring them for the regimes of dry bottom ash removal and stage combustion could be carried out at the P-50 and TP-87 boilers for providing the reduction of nitrogen oxides emission, which is substantially lower than the standard one.
2. The main works on reconstruction are: realization of new layout drawing and design of furnace-burning devices, liquidation of pinch of furnace walls, substitution of refractory-face and lined water walls for plain-tube ones, fulfillment of measures on securing the temperature of superheated vapor, making of dry-bottom ash hopper and application of pneumo-mechanical bottom ash removal.
3. The technology of staged combustion realized by means of separate layout drawing of straight-flow-slot pulverized-coal burners operating with the small

excess air and the moderate flow velocities of aero-mixture, and axisymmetrical oil-gas burners fulfilling the functions of secondary air nozzles for coal combustion is fully efficient. At that the high-speed air jets of oil-gas burners form the air-cushion support preventing to the fall of unburned pulverized coal in dry-bottom ash hopper.

4. It is suggested to carry out the after-burning of combustibles in fly ash in the zone of action of twelve of high-velocity jets moving with large slope down from the combined nozzles located uniformly on the front and back walls by 3.5…4.5 m above PCB. Each combined nozzle consists of two channels, and the lower one is intended for the input of discharge air, while the upper one – of tertiary air.
5. It is suggest to carry out the after-burning of combustibles in bottom ash and its cooling in the unit of pneumo-mechanical bottom ash removal with returning the heat in furnace through the boiler dry-bottom ash hopper. In addition, the unit of pneumo-mechanical bottom ash removal allows not only to cool the slag up to the supply temperature but also to disintegrate it in accordance with consumers' requests.

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