

Integrated solutions on providing the consumer properties of ash and improvement of environmental and economic characteristics of power plant operation at burning hard coal of the unsteady quality in power boilers

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Abstract. Influence of technologies of pulverized coal combustion in power boilers on loss on ignition (L.O.I.) in fly ash and NO_x emissions is considered. In the paper attention is paid to burning of Kuznetsky coal of the main ranks in different boilers of steam capacity of 50 to 950 t/h. At combustion of design Kuznetsky coal at these power plants L.O.I. in fly ash can reach 25 % that exceeds the standards for using fly ash by 5 times despite of the fact the standards for unburnt carbon are mostly met. By that, specific emissions of nitrogen oxides without implementation of expensive DeNO_x measures make up to 1600 mg/m^3 that is also several times more than the normative values. The paper contains the basic technical solutions and recommendations on arrangement of effective pulverized staged combustion of Kuznetsky coal of unsteady quality for maximum reduction of L.O.I. in fly and bottom ash as well as for achievement of specific nitrogen oxides emissions below the norms without constructing the costly DeNO_x installations.

KEYWORDS: power plant, slag-tap boiler, dry-bottom boiler, fly ash, L.O.I., hard coal, Kuznetsky coal, NO_x emissions

1. Introduction

In power boilers at the Russian thermal power plants (TPPs) more than 100 coal ranks are totally burnt, but the main coals are taken from the following fields: Kuznetsky, Kansko-Achinsky, Ekibastuzsky. Berezovsky and Irsha-Borodinsky coals belong to Kansko-Achinsky coals. In European countries, stringent requirements for the quality of coal delivered are set; therefore, the same coal has a rather constant chemical composition. But in Russia the characteristics of delivered coals of the same rank can vary significantly depending on the mine (quarry) of coal deposits and the occurrence depth of coal beds. Coal preparation plants work only for supplying coal to the Russian coke plants and ensuring the export contracts but not for supplying coal to the Russian power stations. Therefore, the Russian power operators have to burn coal of the varying quality. There are known the cases of burning wastes from coal preparation plants (intermediate products). In this regard, consumer ash properties (primarily, it is – L.O.I. as well as chemical and mineralogical composition) are also unstable, which affects the level of their beneficial use in various industries.

A problem of improving the environmental and economic efficiency of pulverized fuel combustion boilers operation at the Russian TPPs is becoming more important not only due to burning of

coal of the design and worsened quality, but also non-standard coal ranks, including intermediate products and sludge. The situation becomes sharper owing to a tendency of tightening environmental legislation and the need for introduction of new coal-fired power boilers. At the same time the Russian power operators faced the problem of achieving the integrated efficiency at combustion of coal with low volatiles and increased content of fuel nitrogen.

2. Application of dry-bottom and slag-tap boilers

At the Russian thermal power plants coal is burnt in power dry bottom and slag-tap boilers [1]. Circulating fluidized-bed boilers are currently not applied at the thermal power plants of Russia. In Figs. 1, 2 configurations of dry-bottom and slag-tap furnaces are shown [2].

In dry-bottom boilers the maximum temperature in a core of the flame is up to 1600°C. By that, nitrogen oxides are formed, mainly, from nitrogen-containing components of the organic mass of

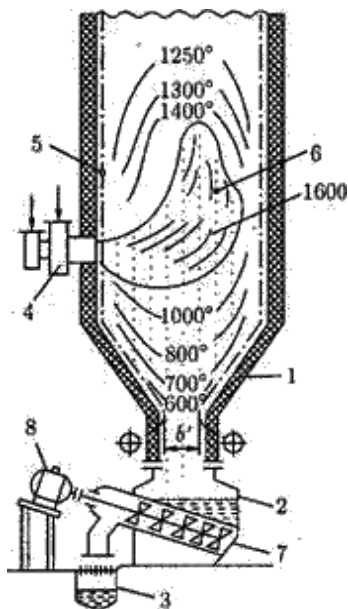


Fig.1. Dry-bottom furnace:

1 – boiler throat; 2 – bottom ash water bath; 3 – wet ash removal channel; 4 - burner; 5 – wall screens; 6 – a core of the flame; 7 – boiler slag removal screw.

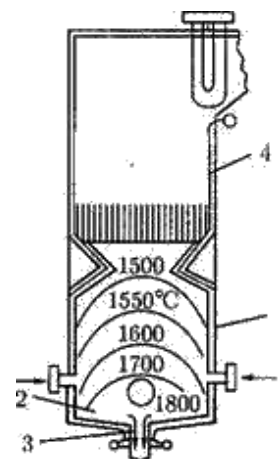


Fig.2. Slag-tap furnace:

1 – combustion chamber; 2 — furnace bottom; 3 — boiler slag tap; 4 — cooling chamber

the fuel. In slag-tap

boilers the maximum temperature in the furnace can reach 1800°C. In such furnaces burning, for example, Kuznetsky lean coal of the standard quality a normative level of the unburnt carbon is usually provided, but L.O.I. can exceed 5%. However, due to a significant contribution of both fuel and thermal NO_x into the total level of NO_x emissions, specific NO_x emissions reach 1500 ... 1600 mg/m³, exceeding NO_x concentration by 2,5 ... 3 times in case of coal combustion in dry-bottom boilers. It should be noted that burning the coal of the worsened quality, intermediate product and sludge is accompanied by a decrease in the safe operation of slag-tap boilers.

Consequently, application of dry-bottom boilers is rather than slag-tap ones in terms of evacuation of bottom ash/boiler slag from the furnace, reliability and environmental performance of the boiler. In addition, an important ecological and economic advantages of dry-bottom boilers are gained due to possible reduction of NO_x emissions by 2,5 ... 3 times without implementing the costly measures and preserving the value of marketable fly and bottom ash.

In case of pulverized coal combustion slag-tap boilers it's rather difficult to achieve normative contents of nitrogen oxides in flue gases using the furnace methods while maintaining the efficiency of combustion, but purifying flue gases from nitrogen oxides is a very costly measure in terms of both investment and operating costs. Moreover, in this case saturation of fly ash with ammonia-containing products to a large extent reduces its commodity value [3].

According to reports presented at the II International Scientific and Practical Workshop "Ashes from TPPs - removal, transport, processing, landfilling", fluidized bed technology has a major drawback: the ash commodity value is reduced due to its saturation with sulfur components [4].

In the nearest future, Russia will tighten environmental requirements for power plants in part of setting the lower standard levels of specific NO_x emissions and severization of requirements for beneficial use of ash and slag. Under these conditions the conversion to combustion of coal in power dry-bottom boilers is most appropriate from both the environmental and the economic points of view.

In case of evacuation of bottom ash from the furnace throat it's possible to apply a pneumomechanical bottom ash removal technology that allows to produce bottom ash with high consumer properties without any L.O.I. limitations and raise the boiler efficiency by about 0,4 % [5]. It should be noted that introduction of pneumomechanical bottom ash removal technology would increase the fuel utilization factor due to reduction of combustibles in bottom ash below the normative level and almost complete exclusion of bottom ash heat losses.

It should be mentioned that maintaining the efficient and reliable flaring of coal dust in dry-bottom boilers at possible increase in moisture and ash content of coal dust at decrease in the volatile content by working mass, as well as at decrease in the melting temperature of bottom ash is a serious problem. This is determined by risks of deterioration of efficiency and reliability of combustion, mill equipment slowdown and local slagging of furnace screens [5].

3. Application of the new staged coal combustion technology

NO_x emissions reduction can be achieved using conventional staged combustion, for example, of Kuznetsky lean coal in dry-bottom boilers. However, in this case the unburnt carbon in fly ash is several times higher than the standard level, and specific emissions of NO_x exceed the established standards by 1.5 times or even more.

Application of a new technology of the staged combustion of coal with a low volatile content, developed by MPEI staff, together with the bottom ash removal technology result in reduction of the unburnt carbon in bottom ash and NO_x emissions below the standards without construction of costly DeNO_x plants [6]. An essence of the staged combustion technology consists in optimization

of the flame aerodynamics by changing the layout and design of tangentially directed burners and nozzles (Fig. 3).

The primary optimization tool is increasing the intensity of washing fresh burner jets by tangential flow of flue gases in order to ensure an early warm-up and ignition of coal dust. To achieve this purpose displacement of high concentration dust feeding points to the burners closer to their lateral forming — from the opposite direction to tangential flow of the furnace gases has

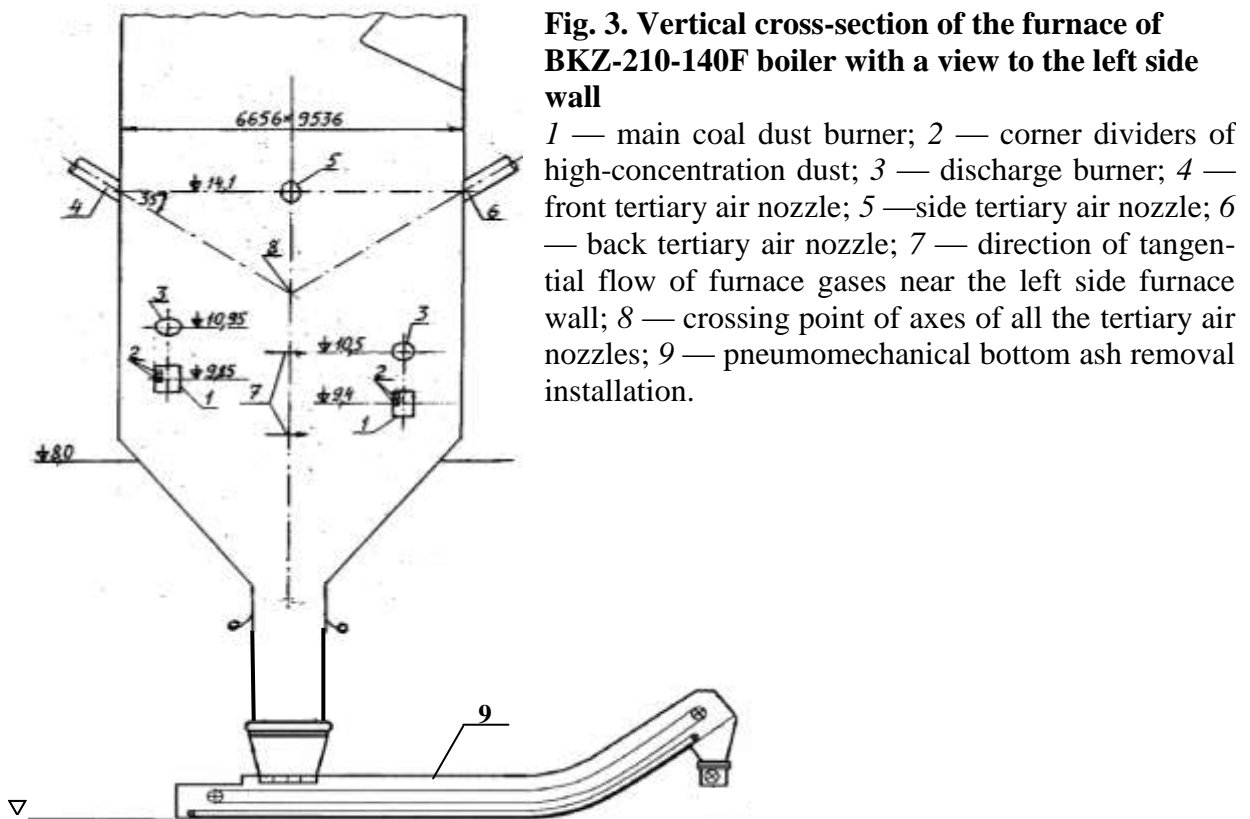


Fig. 3. Vertical cross-section of the furnace of BKZ-210-140F boiler with a view to the left side wall

1 — main coal dust burner; 2 — corner dividers of high-concentration dust; 3 — discharge burner; 4 — front tertiary air nozzle; 5 — side tertiary air nozzle; 6 — back tertiary air nozzle; 7 — direction of tangential flow of furnace gases near the left side furnace wall; 8 — crossing point of axes of all the tertiary air nozzles; 9 — pneumomechanical bottom ash removal installation.

been recognized to be justified. Besides, in [7] it was proposed to release the jets of the second circle burners from cooling waste air of coal-pulverization system to accelerate a process of the coal dust ignition.

In accordance with [8] analyzing the results of introduction at power boilers of the schemes of staged combustion of Kuznetsky coal with high volatile content, developed in MPEI, it was found that the level of NO_x emission reduction depends on the following major factors: primary air excess, total air excess at the burners outlet and a probability of direct contact of coal dust particles with furnace gases at the root of burner jets. In turn, these factors have a significant impact on reliable coal dust ignition and unburnt carbon, especially in case of significant increase in moisture and ash content in the fuel source.

In the table evaluation of combustion effectiveness of Kuznetsky and Donetsk hard coals in dry bottom and slag-tap boilers us shown.

Table. Integrated effectiveness of the staged hard coal combustion and combustible content in dry ashes in case of arranging different options of the burning process in dry bottom boilers and slag-tap boilers

Boiler mark, unit #, Power Plant, dry bottom/slag-tap boiler	Coal rank	Boiler condition, year of introduction, source of information	D_{nom}/D_{min} t/h	$NO_{x,3}$ mg/m ³	Q_m^w , ccal/kg	Ash content A^w , %	Moisture W^w , %	Unburnt carbon q_4 , %	L.O.I., % by mass
PK-10, #7, Yuzhno-Kuzbasskaya SDPP, dry bottom boilers (DBBs)	TR*	After modification of the boiler under technical solutions of Yuzhno-Kuzbasskaya SDPP [9]	230/165	1030	5500	17,5	9,5	5,4	18,66
PK-10, Yuzhno-Kuzbasskaya SDPP, DBBs	TR	MPEI recommendation on the boiler modification	230/150	425	5900	16,2	10,0	3,2	13,61
BKZ-210-140F, #5, Zapadno-Sibirskaya CHPP, DBBs	GR*	After modification of the boiler under VTI recommendations [9]	210/160	900	4985	26,0	6,9	2,3	5,63
	Int. Prod.	After the 1st stage of the boiler modifications under MPEI recommendations, 2002	210/150	260	3715	44,6	6,2	14,3	13,87
	GCOC*	After the 1st stage of the boiler modifications under MPEI recommendations, 2002	210/150	250	4400	21,8	15,4	5,3	12,63
	GCOC*	After the 2nd stage of the boiler modifications under MPEI recommendations, 2003 [10]	210/140	335	4755	20,2	14,2	1,1	3,38
BKZ-210-140F, #6, Zapadno-Sibirskaya CHPP, DBBs	GR*	After modification of the boiler under VTI recommendations [9]	210/160	900	4847	18,0	14,3	2,2	7,41
		After modification of the boiler under MPEI recommendations, 2003 [11]	210/150	450	4900	18,5	14,0	1,1	3,79
BKZ-220-100F, #17, Kuznetskaya CHPP, DBBs	GR	Initial option	220/160	1065	5602	13,6	12,0	2,15	10,69
		After modification of the boiler under MPEI recommendations, 2004 [8]		785	5217	19,7	9,9	2,5	8,21
TP-10, #7, Tom-Usinskaya SDPP, DBBs	GR	Initial option	220/170	560	5000	17,0	15,0	1,4	5,27
		After modification of the boiler under MPEI recommendations, 2003 [8]		380	5050	17,5	13,0	1,4	5,18
K-50-14-250, ##2-5, boiler-house, city Tashtagol, DBBs	GR	Initial option	50/30	800	4900	18,5	14,0	3,0	9,70
		After modification of the boiler under MPEI recommendations, 2008-2011	50/(15...20)	450...490	4700...4900	18...20	14...16	2...3	6...8
TP-87, #9, Zapadno-Sibirskaya CHPP, slag-tap boilers (STBs)	GR	Initial option	420/320	1175	4900	18,5	14,0	0,5	1,96
		After the 1st stage of the boiler modifications under MPEI recommendations, 2005	420/210	570	4900	18,5	14,0	0,5	1,96
		MPEI proposals on the boiler modification, project	420/200	500	4900	18,5	14,0	0,3	1,19
TP-87, #9, Zapadno-Sibirskaya CHPP, STBs	TR	MPEI proposals on the boiler modification similar to [5], project	420/310	500	6000	14,6	7,0	0,9	5,29
TP-87, DBBs	TR	MPEI proposals on the	420/300	320	6000	14,6	7,0	1,5	7,69

	GR	boiler modification, project	420/270	300	5630	16,9	8,5	1,1	4,72
P-50, DBBs	TR	MPEI proposals on the boiler modification, project	475/350	320	5900	16,2	10,0	1,3	6,02
	GR	boiler modification, project	475/320	300	5450	14,0	9,5	0,9	4,52
TPP-312A, DBBs	GR	MPEI proposals on the boiler modif., project	1000/700	330	4509	28,5	11,0	1,0	2,09

*TR – lean cleek coal; GR – gas cleek coal; GCOC - gas cleek oxygenized coal

$\text{NO}_x^n = 350 \text{ mg/m}^3$ — normative specific NO_x emissions for the newly-introduced boiler plants

Brief comments on the table

On specific NO_x emissions. For P-50 boiler the standard specific emissions of nitrogen oxides are assumed to be 350 mg/m^3 for the newly-introduced boiler plants, but for other operating boilers, regardless of their steam productivity they are 470 mg/m^3 . We made this decision because of the following considerations:

- ecological standards, generally, become stricter;
- best available technologies are considered to be those, application of which gives the best results;
- boilers installed at power plants are mostly outdated and worn out, therefore, they need to be replaced.

On combustibles in ash and slag. At pulverized brown coal combustion L.O.I. in bottom ash is almost absent, and in fly ash it is usually less than 5% by mass. At pulverized hard coal combustion in slag-tap boilers the unburnt carbon is negligible, but in fly ash L.O.I. can significantly exceed 5%. Analyzing actual and expected results of implementing MPEI recommendations on staged hard coal combustion, presented in the Table, we can conclude about the significant reduction of combustibles in fly ash. However, exceeding the L.O.I. standard of 5% is possible. That is a very important limiting factor that prevents beneficial use of fly ash. At the majority of large thermal power plants of Russia ESPs are applied as ash collecting installations. In case of exceeding the L.O.I. standard the best way to reduce the unburnt carbon to a level of 2 ... 4% is application of STI technology [3]. As a rule, at traditional combustion of Kuznetsky, Vorkutinsky and other types of hard coal at the Russian power plants, L.O.I. in fly ash makes 10 ... 20%, and at combustion of Donetsk coal L.O.I. can reach 30%.

On technologies of evacuation of bottom ash from boiler furnaces. At all the above-mentioned re-designed boilers wet bottom ash removal plants are applied. Unfortunately, at the Russian power plants the pneumomechanical bottom ash removal technology, being the most effective at present, applied about 30 years in the energy sector of industrialized countries of the world, is not yet introduced. Advantages and disadvantages of bottom ash removal technologies applied in power sector are considered in [12] in details. It could be briefly noted that introduction of pneumomechanical bottom ash removal technology would increase a fuel utilization factor by reducing combustibles in bottom ash below the normative level and the almost complete exclusion of bottom ash heat losses. The technology provides a reliable mechanical crushing of even large pieces (up to 500 ... 700 mm) of bottom ash and its cooling to 70°C . This would result in selling bot-

tom ash at a price of not less than 45 euros per ton (in 2012 prices). Furthermore, it should be noted that application of pneumomechanical bottom ash removal technology allows to eliminate the use of water as a carrier medium. Non-use of reliable and cost-effective dry bottom ash removal technologies in Russia was and is now an objective obstacle to introduction of “dry” bottom ash removal technologies at TPPs as a whole, whereas dry fly ash handling technologies are applied at the Russian power plants since the early 1960-ties.

Analyzing the energy development trends in countries all over the world it was established that the total costs for ash and slag handling including investments, operating costs and ecological payments for "dry" ash and slag removal systems are about two times lower than for traditional wet systems [13].

Conclusion

1. Interaction of experts in the field of coal combustion in power boilers, as well as addressing ash and slag handling issues allows to solve as a whole the problems on improvement of economic and environmental performance of coal-fired power plants and consumer properties of ash and slag in order to increase their level of beneficial use.
2. Implementation of MPEI technical solutions on arrangement of three-stage combustion of low-reactive hard coal in coal-fired dry bottom boilers at the Russian thermal power plants results in the following:
 - leads to a significant reduction of combustibles in fly and bottom ash, increasing their market value;
 - provides technological conditions for creating environmentally friendly dry ash handling systems;
 - allows to reduce nitrogen oxides below the standard level without construction of the costly DeNOx plants;
 - contributes in significant improvement of the boiler operation reliability.
3. Since after introducing MPEI technical solutions on three-stage combustion of low-reactive coal in coal-fired dry bottom boilers at the Russian thermal power plants, combustibles in fly and bottom ash is greatly reduced, but L.O.I. is not provided less than 5%, these solutions should be applied in conjunction with pneumomechanical bottom ash removal technologies and separation of the unburnt carbon from fly and bottom ash.

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