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Part 4

COMPLEX TECHNOLOGIES OF ENVIRONMENTAL POLLUTION FROM THERMAL POWER PLANTS

4.3. Combustion of solid fuel

4.3.1. Complex solution of issues on increasing of the economic efficiency, ecological safety and beneficiation of ash and slag at pulverized coal combustion in power boilers at TPPs in Russia

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ABSTRACT

Influence of the pulverized coal combustion technologies in power boilers on NOx emissions and loss on ignition (L.O.I.) in fly ash is considered. The special attention in the paper is given to the issues concerning combustion of Kuznetsky coal of the main ranks in different boilers of capacity from 210 to 950 t/h. At combustion of the rated Kyznetsky coal at TPPs, specific nitrogen oxide emissions make 1200…1500 mg/m^3 that is from 2 to 4 times higher than the normative values depending on the boiler capacity. Thus, L.O.I. in fly ash can reach 25 %, that is also 5 times more than in the specifications on ash use in spite of the fact that requirements on the unburnt carbon are in most cases satisfied. The basic technical solutions on arrangement of the staged combustion of Kuznetsky coal in order to achieve specific emissions of nitrogen oxides below the normative values without implementation of expensive DeNOx measures and maximum decrease in combustibles in fly ash are resulted. Recommendations on combustible content in ash and slag below the standard requirements are resulted.

Recently increase in efficiency of pulverized combustion of the rated and non-rated coal in the furnaces of power boilers becomes more and more actual. Burning Kuznetsky lean coal in slag-tap boilers the standard values of the unburnt carbon are usually provided, but L.O.I. in fly ash in specific cases can reach 25 % that exceeds specifications on ash use by 5 times. By this, specific NOx emissions make 1500…1600 mg/m^3 due to considerable contribution of both fuel and thermal NOx in their total formation. It should be mentioned, that burning the rated and non-rated coal of the worsened quality, intermediate products and sludge from coal cleaning plants results in essential decrease in ecological indices of the boiler operation and increase in combustibles in ash and slag, and also decreased reliability of the boiler operation in connection with the sharp growth of a probability of the furnace slagging, especially at the lowered loadings.

Building and operation of DeNOx installations is an expensive measure. Besides, by this in connection with saturation of fly ash with the products containing, for example, ammonia, leads to significant decrease in its commodity value [1].

According to the data resulted in [2], fluidased bed combustion technologies have an essential disadvantage: commodity value of ash is decreased because of its saturation with sulfur components.

Evacuation of bottom ash from the furnace throat results in the possible application of 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 %. Advantages of the pneumomechanical bottom ash removal technology are given in [3].

Therefore, transferring slag-tap boilers for dry bottom ones is becoming more and more actual using new technical solutions on arrangement of the staged coal combustion as at traditional staged combustion, for example, of Kuznetsky lean coal in dry bottom boilers not only the unburnt carbon exceeds the standard level by several times, but also specific NOx emissions are 1,5 times higher than in the set norms. These data on efficiency of burning Kuznetsk TR coal using traditional technologies are resulted in [4] and concern as to the modified, and not modified boilers of PC 10 type introduced at Yuzhno-Kuzbasskaya State District Power Plant. After analyzing the data in [5] it is offered to raise the efficiency of burning the lean Kuznetsky coal in PK-10 boilers by optimization of aerodynamics of the flame due to rearrangement of configuration and design of the tangentially-directed burners and nozzles. The main principle of optimization is to increase the intensity of washing fresh burner jets with the tangential flow of flue gases for the purpose of maintenance of early warming up and ignition of the coal dust. In order to achieve this purpose, displacement of inlet points of highly concentrated dust into the burner closer to their lateral generatrix — towards to tangential flow of flue gases was considered to be reasonable. Besides, in [5] it was offered to eliminate the cooling impact of the discharged air from dust preparation systems influencing the burner jets of the second level to accelerate a process of coal dust ignition.

As a result of analyzing operation indicators of the modified boilers of several types with their switching to the staged combustion of Kuznetsky GR coal [6, 7], the basic condition on minimum fuel oxide formation was defined: ignition and burning of volatiles should take place at the primary air excess making less than a part of volatiles in the burnt coal, counted up on its working mass. At performance of this condition, fuel nitrogen oxides are formed significantly less due to reduction of molecular nitrogen from nitrogen-containing compounds presenting in the coal dust. By this, the earlier and more complete burning of volatiles without oxygen excess before adding the secondary air into the the flame is organised, the more effective a process of reduction of molecular nitrogen in a zone of coal dust ignition is.

Intensive warming up of the coal dust and its stable ignition due to early ignition and maintenance of burning of volatiles in the environment close to reductive, and also due to compulsory ejection admixing of high-temperature inert furnace gases, containing unburnt carbon products, to the roots of the burner jets can provide a complex efficiency of the furnace operation. Under the complex efficiency of a burning process conformity to specifications of the two basic parameters: specific NOx emissions and unburned carbon is meant. The last one can certainly correspond to the specification not only thanks to early coal dust ignition, but also due to optimization of aerodynamics of the flame in zones of core burning and afterburning of the coal dust.

Increase in initial perimeter of contacting the air and fuel jets with furnace gases contributes in reliable and early character of volatile burning, that can be reached, for example, at the expense of increase in the relation of height to width of the outlet cross-section of dust-air burners (DABs). Thus, a big role is played by creation of aerodynamic conditions for the forced ejection supply of the high-temperature furnace gases to the roots of DAB jets. Besides, feeding a rather small part of primary air into DABs leads to the growth of volume concentration of volatiles that is rather important for maintenance of the early ignition of such types of solid fuel with the lowered reactivity as a lean coal, intermediate products or sludge from coal cleaning plants, and, as consequence, for decrease in the unburnt carbon.

Introduction of regime and constructive actions concerning DABs and a new organization of the staged combustion should provide a satisfactory solution of issues on increase in the complex efficiency of burning the rated hard coal with the lowered volatile formation, and also non-rated coal and ones of the worsened quality.

Positive influence of early volatile ignition both on ecological and economical efficiency of the combustion processes was confirmed after analyzing the results of introduction of various technical solutions on burning Kuznetsky coal with different volatile content in the boilers of several types. To estimate an efficiency of the coal dust ignition it was offered to use is a constructive and regime parameter of ignition Kz, defined as follows:

$$K_z = P_{DAB}/P_{HFC} \cdot v^W/v^W_f \;\; 1/\alpha_{DAB},$$

P_{DAB}/P_{HFC} – a perimeter of contacting of jet roots of the air and fuel mixture (at CDB outlet) with the furnace gases firing it, referred to the perimeter of horizontal furnace cross-section P_{HFC}; v^w/v^w_f – volatile content in the coal burnt, calculated on its working mass, %, referred to the volatile content on the working mass of the lean oxygenized Kuznetsky TR coal, v^w_f = 9,6, % [8]; α_{CDB} – air excess at the CDB outlet.

A determining influence on the process of coal dust ignition makes a temperature of the furnace gases in a zone of their direct contacting with the jets of air and fuel mixture leaving the CDB. Besides, additional influence on a process of warming up and ignition of the coal dust has the radiating factor defined by the temperatures of the flame and surfaces of screen pipes taking into account their pollution. For estimating the quantitative relationships describing influence of the radiating factor on the considered process, carrying out additional special researches is required.

Finally, the complex efficiency of coal burning $E_к$ is determined by the specific content of nitrogen oxides in flue gases at the furnace outlet and the unburnt carbon. $E_к$ is defined as follows:

$$E_к = \frac{NO_x^n}{NO_x^a}\,\frac{q_4^n}{q_4^a},$$

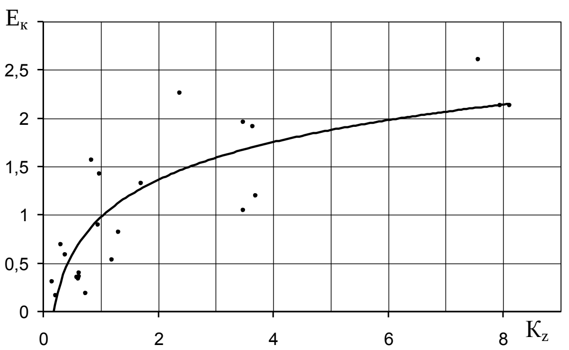

Fig. Complex efficiency of coal combustion $E_к$ versus parameter of ignition K_z

NO_x^n/NO_x^a и q_4^n/q_4^a – ratio normative and actual specific nitrogen oxide emissions to the unburnt carbon. For the newly introduced dry bottom boiler plants NO_x^n make 470 and 350 mg/m^3 at D_n less 420 t/h and 420 t/h and more accordingly [9]. For GR and TR coal q_4^n is 1,5 and 2 % accordingly [8].

In the table efficiency estimation of burning Kuznetsky and Donetsky coal in dry bottom and slag-tap boilers is given. In accordance with the test and calculated data, presented in the table, a graph indicating dependence of constructive and regime parameter of ignition K_z on the factor of the complex efficiency of coal burning $E_к$ is built and shown in the picture.

Brief comments on the table.

About specific nitrogen oxide emissions. For P-50 boiler estimating $E_К$ standard specific nitrogen oxide emissions make are accepted to be 350 mg/m^3 as for newly introduced boiler plants, and for other operating boilers disregarding their capacity make 470 mg/m^3. Such a decision was accepted by because of the following reasons:

- •nature protection specifications, as a rule, become tougher;
- the best available technologies are those which application allows to get the best results;
- boiler plants at TPPs are mostly outweared and out of date, in this connection their replacement is required.

About combustible content in ash and slag. In case of pulverized lignite combustion L.O.I. in bottom ash/slag is almost absent, and in fly ash, as a rule, are below 5 % by mass. At pulverized hard coal burning in slag-tap boilers, the unburnt carbon in boiler slag is almost absent, but in fly ash can be much more than 5 %. After analyzing the actual and expected results of introduction of MPEI recommendation on the pulverized staged hard coal combustion, presented in the table, it is possible to conclude significant decrease in combustibles in fly ash. However, exceeding the normative value of L.O.I. making 5 % is possible; that is a very important limiting factor, preventing from the beneficial use of fly ash.

Table. **Complex efficiency of the pulverized staged hard coal combustion and volatile content in dry ash at different options of the burning process arrangement in dry bottom and slag-tap boilers**

Boiler type, unit #, Power Plant	Coal rank	Boiler condition	D_{nom}/D_{min} t/h	NO_x, mg/m^3	q_4, %	P_{CDB}/P_{HFC}	V_w/V_w^f	α_{CDB}	K_z	$E_{к}$	Q_m^w, kcal/kg	A^w, %	W^w, %	L.O.I., % by mass
PK-10, #7, Yuzhno-Kuzbasskaya PP, dry bottom boilers (DBBs)	TR	After modification of the boiler under technical solutions of Yuzhno-Kuzbasskaya SDPP [4]	230 / 165	1030	5,4	0,139	1,000	0,63	0,221	0,169	5500	17,5	9,5	18,66
PK-10, Yuzhno-Kuzbasskaya PP, DBBs	TR	MPEI recommendation on the boiler modification	230 / 150	425	3,2	0,198	1,000	0,64	0,309	0,691	5900	16,2	10,0	13,61
BKZ-210-140F, #5, Zapadno-Sibirskaya PP, DBBs	GR	After modification of the boiler under VTI recommendations [4]	210 / 160	900	2,3	0,198	2,930	0,95	0,611	0,341	4985	26,0	6,9	5,63
	Int.Prod.	After the 1st stage of the boiler modifications under MPEI recommendations	210 / 150	260	14,3	0,294	1,500	0,60	0,735	0,190	3715	44,6	6,2	13,87
	GCOC*		210 / 150	250	5,3	0,294	2,440	0,60	1,196	0,532	4400	21,8	15,4	12,63
	GCOC*	After the 2nd stage of the boiler modifications under MPEI recommendations [10]	210 / 140	335	1,1	0,403	2,430	0,30	3,264	1,913	4755	20,2	14,2	3,38
BKZ-210-140F, #6, Zapadno-Sibirskaya PP, DBBs	GR	After modification of the boiler under VTI recommendations [4]	210 / 160	900	2,2	0,198	2,910	0,98	0,588	0,356	4847	18,0	14,3	7,41
		After modification of the boiler under MPEI recommendations [11]	210 / 150	450	1,1	0,198	2,950	0,60	0,974	1,424	4900	18,5	14,0	3,79
BKZ-220-100F, #17, Kuznetskaya PP, DBBs	GR	Initial option	220 / 160	1065	2,15	0,05	3,076	1,02	0,151	0,308	5602	13,6	12,0	10,69
		After modification of the boiler under MPEI recommendations [7]		785	2,5	0,162	2,880	0,75	0,622	0,359	5217	19,7	9,9	8,21
TP-10, #7, Tom-Usinskaya PP, DBBs	GR	Initial option	220 / 170	560	1,4	0,308	3,100	1,00	0,955	0,899	5000	17,0	15,0	5,27
		After modification of the boiler under MPEI recommendations [7]		380	1,4	0,42	2,900	0,70	1,740	1,325	5050	17,5	13,0	5,18
K-50-14-250, #2, boiler-house, city Tashtagol, DBBs	GR	Initial option	50 / 30	800	3,0	0,135	2,800	1,00	0,378	0,588	4900	18,5	14,0	9,70
		After modification of the boiler under MPEI recommendations	50 / 15	470	2,5	0,41	3,150	0,35	3,690	1,200	4900	18,5	14,0	8,22
TP-87,#9, Zapadno-Sibirskaya PP, slag-tap boilers (STBs)	GR	Initial option	420 / 320	1175	0,5	0,175	3,000	0,85	0,618	0,400	4900	18,5	14,0	1,96
		After the 1st stage of the boiler modifications under MPEI recommendations	420 / 210	570	0,5	0,175	3,000	0,40	1,313	0,825	4900	18,5	14,0	1,96
		MPEI recommendation on the boiler modification	420 / 200	500	0,3	0,335	3,000	0,12	0,838	1,567	4900	18,5	14,0	1,19
TP-87, STBs	TR	MPEI recommendation on the CDB modification similar to [6]	420 / 310	500	0,9	0,383	1,000	0,11	3,482	1,044	6000	14,6	7,0	5,29
TP-87, DBBs	TR	MPEI recommendation on the boiler modification	420 / 300	320	1,5	0,383	1,000	0,11	3,482	1,958	6000	14,6	7,0	7,69
	GR		420 / 270	300	1,1	0,636	3,1870	0,25	8,108	2,136	5630	16,9	8,5	4,72
P-50, DBBs (NO_x^n = 350 mg/m^3)	TR	MPEI recommendation on the boiler modification	475 / 350	320	1,3	0,593	1,000	0,25	2,372	2,260	5900	16,2	10,0	6,02
	GR		475 / 320	300	0,9	0,593	3,187	0,25	7,560	2,611	5450	14,0	9,5	4,52
TPP-312A, DBBs	GR	MPEI recommendation on the boiler modification	1000 / 700	330	1,0	0,769	2,584	0,25	7,944	2,136	4509	28,5	11,0	2,09

*Gas cleek oxygenized coal

At the most large TPPs in Russia electrostatic precipitators as ash catching facilities are applied. In case of exceeding the L.O.I. normative value the best way of the unburnt carbon decrease up to the level of 2…3 % is application of technology developed by the company STI [1]. As a rule, at traditional burning of Kuznetsky, Vorkutinsky and other coal types at TPPs in Russia L.O.I. in fly ash makes 10…20 %, and at burning of Donetsky coal L.O.I. can make 30 %.

About bottom ash removal technologies. At all the mentioned above modified boilers, wet bottom ash removal installations are applied. Unfortunately, at the Russian TPPs the most effective pneumomechanical bottom ash removal technology is not applied now which have been used in power sector of the developed countries worldwide for about 30 years. Advantages and disadvantages of the applied bottom ash removal technologies are described in detail in [3]. It should be briefly mentioned that introduction of the bottom ash removal technology allows to raise the fuel utilization factor due to reduction of combustibles in bottom ash to the level below the standard and almost complete elimination of loss with bottom ash heat. The technology provides a reliable mechanical crushing of even large (to 500…700 mm) botom ash lumps and their cooling to 70°C. As a result one ton of bottom ash can be sold at the price of 35 euros and more (in the prices of 2009). Besides, it is necessary to state that application of pneumomechanical bottom ash removal technology results in elimination of water as the carrying medium. Non-use of reliable and economically effective waterless bottom ash removal technologies in Russia was and is an objective brake for introduction of "dry" ash removal technologies at TPPs as a whole whereas technologies of dry fly ash removal are widely enough applied for a long time.

As a result of analyzing the trends of power sector development in the countries of the world it has been established that the total expenses for ash and slag handling considering investments, operational costs and ecological payments for dry ash removal systems are half of the expenses in comparison with the traditional wet ash removal systems [12].

Since the key disadvantage of the staged pulverized coal combustion in dry bottom boilers is increase in probability of the unburnt carbon growth in bottom ash, but application of pneumomechanical bottom ash removal technology leads to decrease in combustibles in bottom ash and thermal loss with it, these technologies should be applied together.

Aerodynamic feature of the offered staged combustion technology is a drop flow of the burning flame in the axial zone of the furnace, but without excessive penetration into the boiler throat. Scheme optimization is possible due to selection of a slope angle of tertiary air jets downwards, speed of the air efflux and diameter of a conditional body of rotation in the furnace centre concerning which tangentional primary and discharge burners are directed. In case of applying pneumomechanical bottom ash removal plant, products from afterburning the combustibles in bottom ash coming from the plant and rising upwards will slightly obstruct to the free flow of bottom ash particles and conglomerates downwards. Thus, afterburning of the unburnt fuel will occur both in the extractor of pneumomechanical bottom ash removal plant, and in the boiler throat, at the certain presence of oxygen.

CONCLUSIONS

1. Introduction of technologies of the staged coal combustion in dry bottom boilers under MPEI recommendations allows to burn both the rated and non-rated types of coal of the worsened quality effectively, and also non-rated solid fuel, including intermediate products and sludge from coal cleaning plants.
2. Replacing slag-tap boilers with dry bottom ones with arrangement of the staged combustion of different coal ranks under MPEI recommendations allows not only to provide specific nitrogen oxide emissions below the standard values set both for the operating and the newly introduced boilers, without realization of the expensive DeNOx measures, and also to lower the unburnt carbon in ash.
3. Applying pneumomechanical bottom ash removal technology results not only in the guaranteed reduction of combustibles in bottom ash below the normative values and raising the fuel utilization factor at TPPs, but also creates a possibility for discharging dry bottom ash of the required consumer properties having minimum expenses.
4. Exceeding the specifications on combustible content in dry ash it is recommended to apply the electromagnetic separation technology.

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