P a r t 1

AIR POOL PROTECTION FROM EMISSIONS OF THE POWER INDUSTRY

1.1. Reducing nitrogen oxides emissions

1.1.2. Technological methods to reduce nitrogen oxide formation in the boilers during combustion of different types of organic fuel

1.1.2.1. Regime and commissioning activities to reduce nitrogen oxide emissions

1.1.2.1.2. Biased Burner Firing — BBF

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As usually power boilers have several circle of the burners or a few burners in one circle at least. This allows no additional costs to implement the method of non-stoichiometric combustion.

Non-stoichiometric combustion – it is an unconventional way of fuel combustion with the organization of separate recovery ($\alpha < 1$) and oxidation ($\alpha > 1,2…1,25$) combustion zones in the combustion chamber while maintaining the traditional excesses air of the outlet from the chamber. In this case in the regenerative zone is suppressed formation of the thermal and fuel nitrogen oxides for lack of oxygen (this shows a shift mode from point A to point B′ in Fig. 1.2), and in an oxidizing zone of the thermal NO_x formation are constrained as a result of decrease the combustion temperature due to high excess volumes of air (this shows a shift mode from point A to point B″ in Fig. 1.2). In the regenerative zone the CO concentration raises, but in the oxidizing zone is “over” oxygen, which oxidizes CO to CO_2.

In a practice, the non-stoichiometric fuel combustion is implemented by the imbalance of fuel-air ration in the burners or tiers of burners [6].For this purpose three scheme imbalance (Fig. 1.5):

- air imbalance;
- fuel imbalance;
- combined imbalance.

The air imbalance is carried out by redistribution of giving of air on burner units by partial cover air sliding shutter before a part of burners at uniform distribution of fuel. Partial closing of the individual air sliding before corresponding burners provides an overflow of additional quantity of air on the others burner units, the air sliding shutters before which remain completely opened. The total air flow to the boiler remains unchanged, which can be controlled under the oxygen content in the exhaust gases behind a chamber.

This method of imbalance is quite universal and can be used in non-stoichiometric combustion of any fuels, as well as their co-combustion. Its implementation is simple and requires only a preliminary inspection of the actuator drive air sliding shutters. Changing of the boiler loading is carried out by regulation of the fuel rate to the boiler and the air pressure in the general box.

The fuel imbalance is carried out by redistribution of the fuel rate to the burners at uniform distribution of air on all burner units. For this all the air sliding shutters are fully open before the burners. This kind of imbalance is recommended for non-stoichiometric combustion of natural gas and in some cases by coal combustion. During non-stoichiometric combustion of natural gas the fuel imbalance can be fixed by changing of the flow area in the gas-distribution tubes of the burners of upper and lower tiers. This low-costs insures against possible errors of the unskilled operation personnel which may be infringement of an optimum excess air ratio in the burners of the different tiers. The character of aerodynamics of a combustion chamber, conditions of ignition and fuel depletion practically don't change in the implementing of the fuel imbalance. During the non-stoichiometric oil combustion the fuel imbalance is not recommended because of the deteriorating quality of the spray and separation of the hot button oil from the air stream, which leads to the chemical underburning (incomplete combustion) and contamination of the surface heating in the boiler flues.

The combined method of the imbalance is consist in the redistribution of the air and fuel in the burner units in order to create a strongly pronounced regenerative and oxidizing zones of burning in the combustion chamber. For this purpose through one burner are provide lower fuel consumption, and through others are reduced air consumption. The combined imbalance can be recommended in cases where a simple redistribution of burners or fuel, or air cannot provide the optimal values of the excess air in the oxidizing $\alpha_{ок}$ and reducing $\alpha_{в}$ flames. This method of the fuel-air ratio imbalance is recommended for non-stoichiometric combustion of the natural gas, coals, as well as co-combustion of different fuels. The efficiency of nitrogen oxide suppression in the non-stoichiometric fuels combustion significantly depend on the operation conditions. During combustion of the natural gas a minimum output of the nitrogen oxide is observed when excess air in recovery and oxidizing zones respectively α_{rec}/α_{ox} = 0,75/1,35. In turn, the greatest reduction of NO_x emissions at non-stoichiometric oil combustion take place when excess air in the recovery and oxidizing flames α_{rec}/α_{ox} = 0,8…0,85/1,3…1,25 [6]. Simultaneously provide very favorable temperature and concentration (by O_2) conditions for reburning fuel with almost no increase of chemical underburning, which does not exceed the allowable values for oil-gas boilers ($q_3 \leq 0,15$ %).

Obviously, the non-stoichiometric combustion is more effective to reduce NO_x emission during operating on natural gas, than when working on oil and especially coal. The reason of it is fuel nitrogen oxides, whose formation is suppressed to a lesser extent than thermal NO_x.

In practice, there are a large variety of possible schemes for the organization of non-stoichiometric combustion, the choice of which depends on the overall dimensions of the chamber, the type and number of burners. Thus, the non-stoichiometric combustion can be organized “horizontally” for a simple-tiered counter arrangement of burners in the boiler chamber (Fig. 1.). If the boiler has a two-tiered arrangement of the burners, it is possible to organize a large number of combinations of non-stoichiometric combustion by “vertical” (Fig. 1.7).

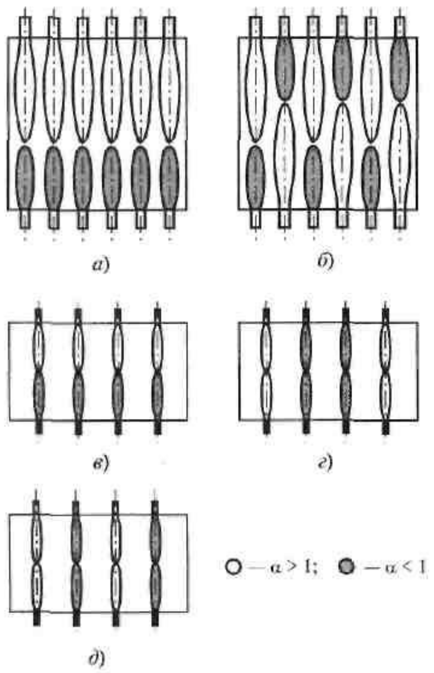

Fig. 1.6. Schemes of non-stoichiometric combustion by "horizontally" in single-tiered arrangement of burners:
а — oncoming (the boiler PTVM-100); *б* — chess (the boiler PTVM-100); *в* — oncoming (the boiler TPE-430); *г* — central (boiler TPE-430); *д* — alternate(the boiler TPE-430)

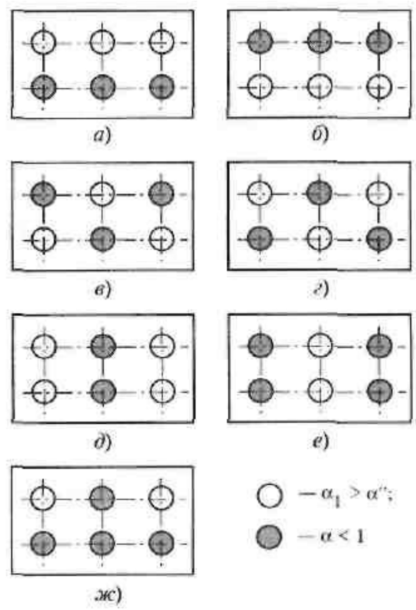

Fig. 1.7. Schemes of non-stoichiometric combustion by "vertical" in two-tiered arrangement of burners:
а — air from the top; *б* — air from below; *в* — a triangle upwards; *г* — a triangle downwards; *д* — air along the edges; *е* — air on the center; *ж* — air from the top along the edges

A characteristic property of non-stoichiometric combustion is the weak dependence of the NO_x emission from the boiler loading (Fig. 1.8, a). The degree of the output reduction of nitrogen oxides in reducing pressure drops from 30…55 % at nominal loading up to 10…15 % at D = 0,5 $D_{ном}$ (Fig. 1.8, b). This is explained by the constant position of control valves in the entire operating load range, which is determined at a nominal loading of the boiler. In this case during reducing the load is not provide required air/fuel imbalance, as it occurred at maximum load, so the effect of non-stoichiometric combustion becomes less pronounced, and the effect of reducing the NO_x emission is less significant.

Through only non-stoichiometric combustion is not always possible to ensure the reduction of NO_x emissions to normative values. Additional entry of moisture and recirculation of gases in non-stoichiometric combustion of fuels are lead to a reduction of the maximum flame temperature, which suppresses the formation of the thermal nitrogen oxides, but virtually no effect on the output of the fast and the fuel NO_x, so the entry of moisture and gas recirculation as an additional event is especially helpful during non-stoichiometric combustion of natural gas and oil.

So output of the nitrogen oxides is 410 mg/m^3 (600 mg/m^3 at the general combustion) at the nominal loan on the boiler BKZ-320-140GM of the Komtchatskaya TPP-2 during non-stoichiometric combustion of oil, and at the join implementation of non-stoichiometric combustion with the introduction of the gas recirculation in the box if hot air of 20 % content of NO_x in combustion productswas reduced to 210…240 mg/m^3.

The introduction of non-stoichiometric combustion in the boiler does not lead to a deterioration of the technical and economic indicators at corresponding adjustment. At the organization of non-stoichiometric combustion of fuels by the scheme of the air above (Fig. 1.7, a) most of the fuel supplied through the lower tier of burners, which leads to some lowering of the flame core throughout the height of chamber. The result is a decrease of the gas temperature at the outlet of the chamber. In turn, the gas temperature in the rotary chamber is reduced to 10…30 °C, and the temperature of exhaust gases decreased on 2…5 °C, i.e. no increase in heat loss from the exhaust gases. During the implementing of the optimal scheme the transition on non-stoichiometric combustion does not lead to significantly higher concentrations if Co in the exhaust gases and does not cause a significant increase in operational values of excess air at the outlet of the chamber. In this case, the boiler efficiency remains almost the same.

Non –stoichiometric combustion of natural gas and oil (both individually and collectively) is recommended for implementation on the hot-water boilers with thermal load more than 35 MW (30 Gcal/h), as well as for subcritical pressure steam boilers with steam production – not exceeding 400 t/h.

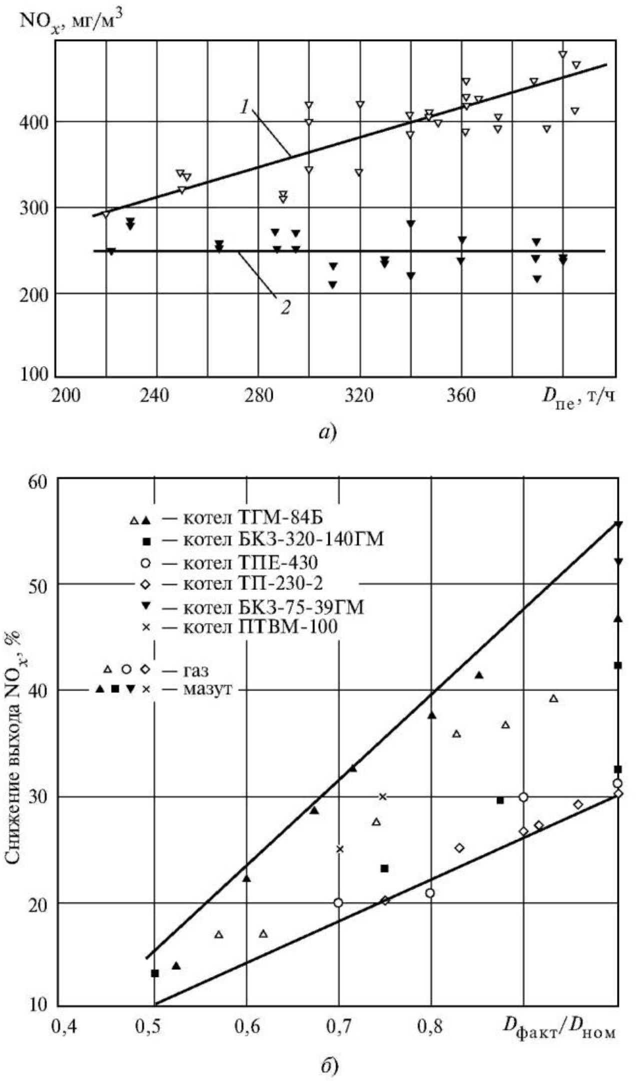

Fig. 1.8. effect of boiler loading on the output of nitrogen oxides with non-stoichiometric combustion at:

а — the boiler TGM-84B, *1* — at uniform distribution of fuel and air to burner, *2* — non-stoichiometric combustion; *б* — degree of decrease in output of nitrogen oxides to different types of the boilers

Shifting of the boiler from traditional to non-stoichiometric combustion should include a several stages. The first (preparatory) stage should be to verify the sealing of combustion chamber and flues of the boiler and eliminate the causes of the deviant suction of cold air. In accordance with “The Rules of technical operation of electric power stations and networks” should be ensured the uniformity of air distribution between burners, made verification of oil nozzles on a water stand in order to ensure their equal performance and a satisfactory quality if spray. Checks the isolation and controlling valves in front burners of the boiler and the fuel channel. Finally, verification is performed and if necessary adjustment of measuring equipment, which ensuring control of technical condition and operating modes of the boiler plant. For a period of adjustment tests (and if possible at all the next working period) on the boiler must be installed the instrumental control of the flue gases (NO_x, CO, O_2). These activities are necessary in order to eliminate or at least significantly reduce the well-known effect of increasing the critical excess air ratio in the transition to non-traditional ways of fuel combustion.

In the second stage depending on the type of fuel combustion and design features of the boiler are determined by way of imbalance of the fuel-air ratio in burners and scheme of the non-stoichiometric combustion.

In the third (final) stage are carried out practical introduction of a way of non-stoichiometric combustion and calibration tests. As part of this stage the boiler checked the chosen method of fuel imbalance ratio in burners and implementation schemes of non-stoichiometric combustion. The ratio of excess air in the recovery α_{rec} and α_{ox} oxidative flames should be selected so that the total numbers of organized fed into the chamber of hot air are remained the same, i.e. as in ordinary combustion. Real values of α_{rec} and α_{ox} as possible should be maximum approach to recommended for the respective type of fuel values.

During the calibration tests determined the optimum operating conditions of non-stoichiometric fuel combustion in the entire operating range of loads and developed operational regulations of the boiler. For maintenance of the high efficiency of suppression of nitrogen oxides emission at low loads provides for a transition from non-stoichiometric combustion (for large and medium loads) to a two-stage combustion (at low loads) by shutting down a number of the burner fuel.

During the implementation of non-stoichiometric combustion the performance of the proposed recommendations will provide decrease of nitrogen oxide emissions on 35…50 % and reliable work of the boiler at preservation of its basic technical and economic indicators.

The advantages of this combustion method are:

Преимуществами данного способа сжигания являются:

- the possibility of implementation the majority of serial steam and water-heating boilers irrespective of designs of chamber and burner units;
- flexibility of fuel;
- ease of implementation on the exiting boilers without their reconstruction and replacement of draft machines;

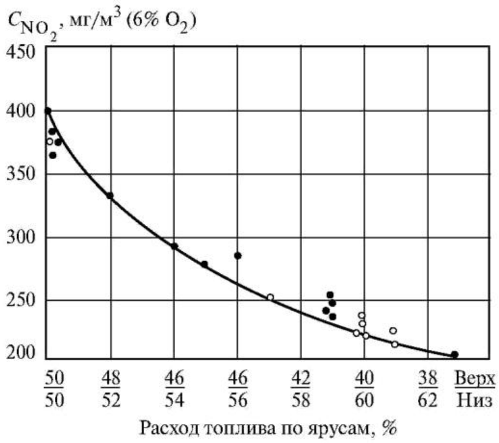

Fig. 1.9. Dependence of concentration NO_x on degree of gas redistribution on tiers of burners of the boilers TGME-464:

D = 500...510 t/h; $a''_{эк}$ = 1,04... 1,06; • — the first stage of testing;

o — the second stage of testing

- absence of necessity of additional capital and operational expenses for realization;
- fast adaptation of the operating personnel to this non-traditional fuel combustion.

Table 1.5. shows the results if the introduction of non-stoichiometric combustion at various boilers.

To further reduce of the output of NO_x (if during the implementation of non-stoichiometric combustion the reduction will be less than 40 %) can be further applied to recycle of combustion products in the overall box of the hot air or post-combustion zone (the upper tier of the burners) in the number of 10…20 % of the fuel gas or entry of moisture into the flame core in number of 5…8 % of the mass of fuel combustion.

In the boilers TGME-464 at natural gas combustion the organization of a fixed non-stoichiometric combustion has lowered concentration of NO_x from 400 to 200 mg/m^3 at the loading close to nominal (Fig. 1.9). On the boiler TGME-464 of Lipetskaya TPP-2 at non-stoichiometric combustion combined with exhaust gases recirculation and with over fire air concentration of NO_x was reduced to 80…90 mg/m^3 [8].

Table 1.5. **The effectiveness of reducing nitrogen oxide emissions at the implementation of the non-stoichiometric combustion method [6, 7]**

Type of the boiler, TPP	Fuel	NO_x emission, mg/m^3		Reducing of NO_x emissions %
		at the normal combustion	at the non-stoichiometric combustion	
PTVM-100, TPP, Glazova city	Oil	250	170...175	30 ... 32
TGME-464, Lipetskaya TPP-2	Natural gas	400	200	50
BKZ-320-140GM, Kamtchatskaya TPP-2	Oil	510...530	280...300	43...45
TGM-151, Salavatskaya TPP	Natural gas	330	260	20
TGM-84B, Kazanskaya TPP-3	Oil	430	260	40
	Natural gas	250	135	45
	Gas/oil	340	220	35
БКЗ-75-35ГМ, ТЭЦ г. Глазова	Oil	330...350	150...155	50...55
ТП-230-2, Безымянская ТЭЦ	Natural gas	460...485	310...350	28... 32
ЦКТИ-75-39Ф, ТЭЦ г. Глазова	Kizelovsky coal	390...400	290...310	22... 34