P a r t 1

AIR PROTECTION FROM POWER INDUSTRY EMISSIONS

1.5. Technologies of organic fuel combustion at TPPs with the lowered level of harmful emissions into atmosphere

1.5.5. Efficient reduction of nitrogen oxide emissions in the boiler furnaces by means of aerodynamic optimization of the staged fuel combustion

1.5.5.8. Complex solution of combustion problems at hot water boilers of KVGM-180 type

A.M. Arkhipov, MPEI (TU); A.A. Vagner, OJSC "RAO UES of Russia"; N.I. Solovyev, OJSC CKB "Energoremont"; V.V. Abramov, OJSC "Zapadno-Sibirskaya TPP"

Hot water boilers of KVGM-180 type have several advantages in comparison with PTVM boilers. They include: high altitude of the furnace with a lifting flow of water in the screen pipes at two-flow circulation scheme; arrangement of convective packages in the downtaking ducts; ensuring shot-blast cleaning of pipes; installation of two-speed fan blowing and exhauster, as well as equipping the boiler with the gas recirculation exhauster.

At the same time, fault in construction of KVGM-180 boiler is a high thermal stress of the furnace cross-section (q_f = 5,28 Gcal/(m^2·h)). This is the reason for the increased levels of maximum heat flow at the belt of burner arrangement that, in turn, causes an intense accumulation of salts, such as hardness, at the inner surface of furnace tubes because of the negative coefficient of solubility of these salts in water. According to [27], the intensity of deposits of hardness salts is roughly proportional to the heat flow squared.

In this connection the staff of Boiler Plants and Ecology in Power Engineering Department of MPEI according to the task of the JSC "Mosenergo" developed a diagram of direct-flow burner installation in the KVGM-180 boiler furnace [12], which provides a significant reduction in the maximum incident heat flux in the high-temperature zone of the furnace at gas combustion and, most importantly, in case of oil combustion. In process of development, requirement for reduction of specific NO_x emissions was taken into account.

A layout diagram of direct-flow burners, shown in Fig. 1.91, was proposed for introduction. A basic design of the burner is shown in Fig. 1.92.

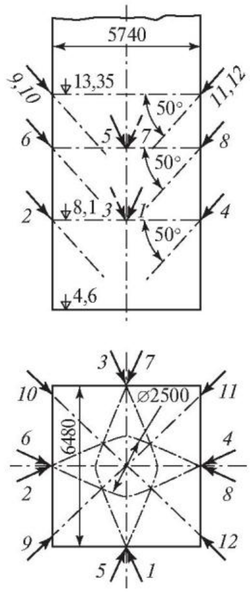


Fig. 1.91. The layout diagram of direct-flow burners at the reconstructed KVGM-180 boiler

Before developing the assembly scheme of burners, multivariate modeling studies of the furnace aerodynamics were conducted. The main problems were the following: dispersing of burner flames throughout the height and cross section of the furnace, excluding intensive collision of jets and their large dynamic pressure on the furnace walls. Thus, the greatest difficulties were related to the provision of a relatively low position of burner flames of the third tier, which have a strong effect of pushing out from a side of flue gases, formed from the flames of downstream burners, due to a high heat stress of the furnace cross-section.

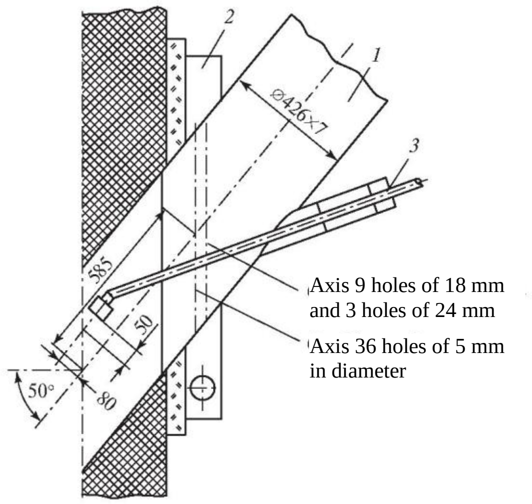
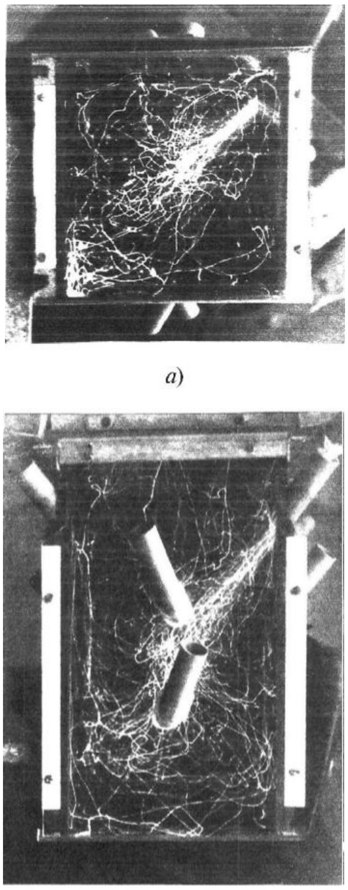


Fig. 1.92. The basic design of direct-flow burner:
1 - body, 2 - gas distribution collector, 3 – steam-and-mechanical oil nozzle

A tangential direction of burner jets of the first and second layers relative to the surface of conventional cylinder of 2,5 m in diameter at the opposite direction of tangential swirl was proposed. It freed the axial furnace zone from the lifting motion of gases, formed from the flames of the mentioned burner tiers. Due to concentration of jets in the axial zone, flowing from the highly inclined down burners of the third tier, their penetration into the furnace bottom was managed. This is well illustrated in Fig. 1.93, where a character of jet flow of the 12th burner of the upper tier is shown as an example.

The studies have shown that in the furnace with the burner layout diagram according to Fig. 1.94 under conditions of high-speed jet flow (to 45 m/s) there is a significant internal recirculation of gases into fresh burner jets, making 35 ... 40 % of their initial weight, and a high degree of turbulence in the flame. This predetermined a high efficiency of the furnace even at the staged combustion of oil due to the low level of critical excess air.



a)

б)

Fig. 1.93. A character of jet flow of the 12th burner:
a – bottom view, б – a view through the model side wall

MPEI staff conducted the comparative tests at the reconstructed boiler # 7 at CHPP-25 and at the typical KVGM-180 boiler at CHPP-21 of the JSC "Mosenergo", equipped with six vortex burners, set in three tiers – by three at the side walls of the furnace. The test results are presented in Tab. 1.36. These results were obtained at the reconstructed boiler №7 at the staged combustion, when secondary air was fed through the turned off burners (at gas burning - through the burners № 2, 4, 5, 7, and at oil burning - through the burners № 5, 7).

Below the main achieved results are described.

The maximum level of incident heat flux is fixed at both boilers near a vertical axis of the front and back walls of the furnace. A nature of heat flow changes throughout the height of these walls is shown in Fig. 1.94. The level of maximum downdrafts at the reconstructed boiler is reduced by 28% in case of oil burning. A degree of non-uniformity of incident heat flux in the active zone of oil combustion (all screens, below 15,15 m inclusive), calculated by the ratio $(q_{\max} - q_{\min})/q_{\max}$, was reduced from 0,62 to 0,26.

The maximum incident flux at oil burning at the reconstructed boiler even without GRE was by 4% less than its maximum value, fixed at the standard boiler with application of GRE. It should be noted that in case of GRE application, a degree of gas recirculation was about 16% for both boilers.

Flue gas temperature at the reconstructed boiler has not increased, despite of the fact that the gas temperature at the furnace top raised. This is due to the increased temperature gradient in convective packages, primarily, by reducing a temperature of water at their inlet, since the increase in water temperature in the furnace screens reduced by 20 ... 25%.

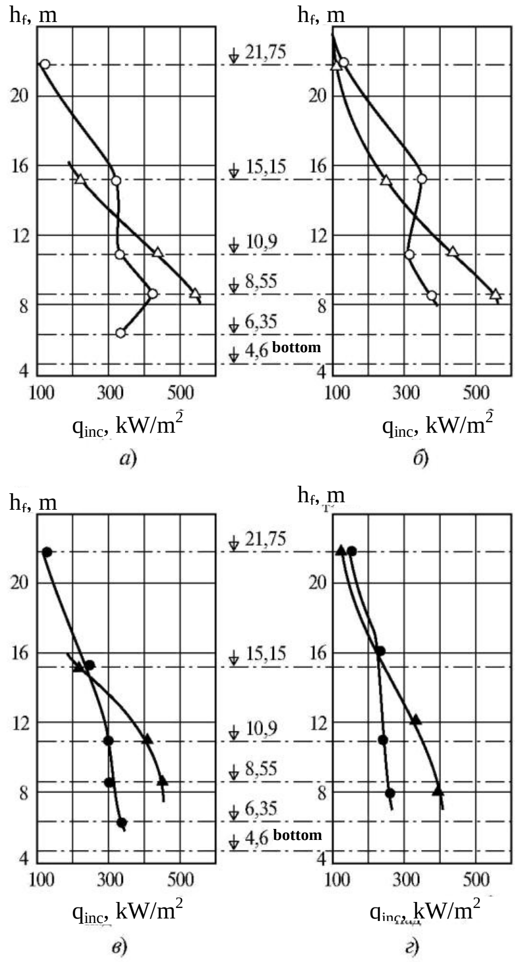


Fig. 1.94. Change in the incident heat flux throughout the height of front *(a, в)* and back *(б, г)* screens, *в* and *г* – with gas recycling exhauster (GRE)

When using GRE, flue gas temperature increases, but at the reconstructed boiler –the difference is smaller (10 vs. 13 ° C) due to an additional reduction of conventional core of the flame due to the increased vertical velocity component at the output of the down sloping burners.

Specific emissions of nitrogen oxides at gas burning without GRE application at the reconstructed boiler are more than 3 times less and made about 55 mg/m^3. In case of oil combustion this index also improved (although to a lesser extent) and was about 150 ... 155 mg/m^3.

Parameters, characterizing sulfuric aggressiveness of flue gases at the reconstructed KVGM-180 boiler, are significantly lower. For example, in case of operation of boilers without GRE, SO_3 concentration reduced to $0{,}4 \cdot 10^{-3}$ %. Decrease in dew point temperature by 40 and 30°C corresponds to the indicated reduction of SO_3 concentration and its absolute values.

Table 1.36. **Performance of the typical and reconstructed KVGM-180 boiler**

Index of the boiler operation at the rated power	Typical boiler	Reconstructed boiler	Notes
The maximum incident flux without GRE at gas/oil burning, kW/m^2	365/550	282/397	Three-tiered arrangement of direct-flow burners at four walls, a high placement of the upper tier burners, a large internal recirculation of gases into fresh jets
The same at oil burning with GRE, kW/m^2	415	300	The same
A degree of non-uniformity n_q of the incident heat flux at oil burning without GRE	0,62	0,26	$n_q = (q_{max} - q_{min})/q_{max}$ in the active combustion zone (marks of 8.55 ... 15.15 m)
Critical excess air in flue gases at gas/oil burning	1,095/1,09	1,055/1,04	A high degree of the flame turbulence, a large internal recirculation of gases with products of incomplete burning into fresh jets, a low position of the flame tail part of the burner upper tier
Flue gas temperature reduced to t '= 110°C at gas/oil burning without GRE (at clean convective surfaces), °C	179/185	177/185	Increase in the temperature difference in the convective surfaces, especially by reducing the temperature of water at their inlet
Raising flue gas temperature due to GRE application at oil combustion, °C	13	10	Increasing the vertical component of velocity of fresh jets
Specific NO_x emissions at gas burning without GRE, mg/m^3	185	55	Staged combustion at α_{bur} = 0,73, large internal recirculation of gases with products of incomplete burning into fresh jets
The same at oil burning without/with GRE application, mg/m	240/165	150/155	Staged combustion in α_{bur} = 0,9, large internal recirculation of gases with products of incomplete burning into fresh jets
SO_3 concentration in flue gases at oil burning without/with GRE application, mg/m	$1{,}2 \cdot 10^{-3}$/ $0{,}75 \cdot 10^{-3}$	$0{,}45 \cdot 10^{-3}$/ $0{,}4 \cdot 10^{-3}$	The same. Low position in the furnace tail part of the flame
Dew point temperature $t_{d,p}$ under the same conditions, °C	125/110	85/80	Dew point temperature, taken from the graphic dependence $t_{d,p} = f(SO_3)$, received by MPEI employees at PTVM boilers

In the heart of reducing the sulfuric aggressiveness of flue gases lays application of direct-flow burners. The burners are strongly inclined downwards, which eliminates an ingress of the tail part of oil flame into the upper furnace zone. According to [28] in this case, a large mass of SO_3 formed in the tail part of the flame (due to SO_2 oxidation) has time to decompose with reduction of less aggressive SO_2. This process is only possible at high temperatures - up to the inlet to the convective heating surfaces, where the remaining amount of SO_3 is "frozen".

Thus, combustion of natural gas and oil, in particular, in the staged direct-flow vortex flame provides solution of a complex of the furnace problems at the reconstructed KVGM-180 boilers at CHPP-25 of the JSC "Mosenergo" without application of GRE. Operation of the reconstructed boilers without GRE provides additional benefits: reduction of flue gas temperature and decrease in energy consumption for drafting and blasting, including due to possible blow fan operation at the first rotation speed in the whole loading range.

Instead of ring gas distributors, having the damaged welded joints, gas is reasonable to be supplied into the outlet burner section using from six to eight pipes, equipped with the gas exhaust nozzles, which must be made of heat resistant steel.

A shut-control slide valve, set at the beginning of burner body of 412 mm in diameter, does not provide a smooth control of the air flow in process of firing of the reconstructed boilers. At the inaccuracy of the fully open gate (for example, by 5 ... 10%), a pressure drop on it can vary greatly at application of different burners, especially at the rated load, when the average air velocity at burner outlet is about 45 m/s. This leads to different values of air flow through the different burners (secondary air nozzles), so the dampers must be located in the supply ducts where air velocity should not exceed 10 ... 12 m/s.

To ensure more reliable operation of the concrete section of burner embrasures and the required direction of jets is expedient to increase the body of burners to the surface of screens, manufacturing the outlet body sections of the heat-resistant steel.