PROBLEMS OF ECOLOGY

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ENVIRONMENTAL PROBLEMS OF THE FLAME COMBUSTION OF FUEL IN GLASS-MELTING FURNACES

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The environmental characteristics of the flame in glass-melting furnaces are provided. The main harmful emissions released with combustion products and the mechanisms of the formation of some gaseous oxides and dust in the flame are considered. Recommendations for reducing the harmful emissions are supplied.

The main environment-related parameters of glass-melting furnaces are total and harmful emissions released with fuel combustion products, which, on the one hand, are determined by the operating specifics of the furnaces, and on the other hand, by the parameters of flame evolution in the working space of the furnace. The principal harmful emissions released with combustion products are nitrogen oxides, carbon oxide, and dust, and in the case of using fuel oil, sulfur oxides as well. The nature of formation of the above listed oxides is different. It is related to various mechanisms, and in each case the emission concentration in specific conditions is determined by its own regularities. The maximum permissible concentration (MPC) standards for a number of chemicals contained in combustion product emissions from glass-melting furnaces are presented in Table 1 [1].

It should be noted that the environmental regulations for carbon and nitrogen oxides in Russia are considerably stricter than the world standards, the EU and USA regulations, and the norms for sulfur oxides in Russia virtually coincide with the world standards.

The unit value of harmful emissions \( \varepsilon_h \) is closely related to the fuel rate \( b_f \) and the thermal efficiency of the furnace \( \eta_h \) and can be calculated from the following formula:

\[
\varepsilon_h = \Psi_h \frac{\Delta q_h}{\eta_h Q_n^P}
\]

where \( \Delta q_h \) is the effective heat rate, kJ/ton; \( Q_n^P \) is the fuel combustion heat, kJ/m³ or kJ/kg; \( V_a \) is the volume of the products resulting from combustion of a unit of fuel, m³/m³; or m³/ton; \( \Psi_h \) is the concentration of harmful emissions in the combustion products, kg/m³; \( \varepsilon_h \) is the specific value of the total emission, m³/ton

Hence obviously

\[
b_f = \frac{\Delta q_f}{\eta_h Q_n^P} \quad \text{and} \quad \varepsilon_h = b_f V_a.
\]

Nowadays, in the case of harmful emissions into the atmosphere, the environmental damage is calculated, and the companies are charged payments for environmental pollution based on this calculation. The methods used for evaluation of environmental damage and payments due for that damage involve the value of the total harmful emissions per quarter of year (tons/quarter (year))

\[
M_i = \varepsilon_h P_i 10^3,
\]

where \( P_i \) is the quarterly or annual production volume, and the index \( i \) corresponds to a particular emission component.

In assessing the environmental damage and the payment due for environmental pollution, the value of reduced emission mass \( M_n \) is used, which is equal to the product of the ac-

<table>
<thead>
<tr>
<th>Compound</th>
<th>World standard</th>
<th>EU</th>
<th>USA</th>
<th>Russia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon oxide, mg/m³</td>
<td>10 – 20</td>
<td>–</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Nitrogen oxides, mg/m³</td>
<td>0.15 – 0.200</td>
<td>0.10</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Sulfur anhydride, mg/m³</td>
<td>0.05 – 0.06</td>
<td>0.08</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

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The equilibrium concentration of nitric oxides in combustion products on the air rate coefficient (1) and the temperature in the combustion chamber (2).

The value \( A_i \) is estimated with respect to the average daily aggressiveness of carbon monoxide taken as one. Thus, for example, the relative aggressiveness factor of sulfur anhydride is 22, and that of nitrogen oxides is 41.

Let us consider the specifics of formation of harmful emissions in the furnace flame and analyze ways to reduce them.

Proceeding from the available experience of operation of different thermal plants and furnaces, the state standard of the Russian Federation for the maximum permissible concentration of \( \text{NO}_x \) in combustion products was adopted (GOST 50591–93). Table 2 gives the maximum permissible concentration values for \( \text{NO}_x \) in the natural gas combustion products at \( \alpha = 1.0 \) for regenerative tank glass-melting furnaces heated with natural gas, compared to some other thermal plants.

As can be seen, the maximum standards of \( \text{NO}_x \) concentration for glass-making furnaces are several times greater than the similar standards for other thermal plants. On the one hand, it suggests that the operating conditions of glass-melting furnaces facilitate the formation of substantial quantities of \( \text{NO}_x \), and on the other hand, it is indicative of significant reserves for a possible decrease in the level of this type of emissions. It should be noted that the amendments to the GOST 50591–93 standards developed by the JSC Promgaz suggest a decrease in the MPC of \( \text{NO}_x \) to 2000 mg/m³ for the newly designed glass-melting furnaces.

The studies performed in recent years [2, 3] established that there are three possible ways of \( \text{NO} \) formation in a hydrocarbon flame: prompt and thermal formation, and formation including intermediate \( \text{N}_2\text{O} \).

The third way of \( \text{NO} \) formation is possible only at high pressures. The prompt formation is absent in carbon flame, and its mechanism is not yet sufficiently studied. Therefore, scientists focus their attention on the best studied thermal mechanism of \( \text{NO} \) formation which was first investigated by Ya. B. Zel’dovich [4]. According to this mechanism, the summary reaction of molecular nitrogen oxidation \( (\text{N}_2 + \text{O}_2 = 2\text{NO} + 186.6 \text{ kJ}) \) proceeds by the chain mechanism:

\[
\begin{align*}
\text{N}_2 + \text{O} &= \text{NO} + \text{N}; \\
\text{N} + \text{O}_2 &= \text{NO} + \text{O}; \\
\text{N} + \text{OH} &= \text{NO} + \text{H}.
\end{align*}
\]

The transition of \( \text{NO} \) to \( \text{NO}_2 \) begins at a temperature below 650°C.

\[
2\text{NO} + \text{O}_2 \rightleftharpoons 2\text{NO}_2.
\]

The analysis revealed that the conditions facilitating the formation and preservation of nitric oxides include high temperatures, high initial concentration of nitrogen and free oxygen in the gas mixture, an increase in the time of exposing the mixture to a high temperature, and prompt cooling of the mixture. Figure 1 shows equilibrium concentrations of \( \text{NO}_x \) in the combustion products of a methane-air mixture at different combustion temperatures and different air rate coefficients [5]. It can be seen that an increase in the enthalpy of the initial mixture produces an increase in the combustion product temperature and, accordingly, the yield of nitric oxides. Combustion of the fuel mixture with the air rate coefficient significantly greater than 1, as well as a decrease in the combustion temperature brought about by other methods, produce a decrease in the yield of nitric oxides.

**TABLE 2**

<table>
<thead>
<tr>
<th>Thermal plants</th>
<th>Rated heat power, MW</th>
<th>Air preheating temperature, °C</th>
<th>Maximum permissible concentration of ( \text{NO}_x ), mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regenerative tank glass-melting furnaces</td>
<td>7.0 – 40.0</td>
<td>930 – 1100</td>
<td>2500</td>
</tr>
<tr>
<td>Continuous heating furnace</td>
<td>7.0 – 65.0</td>
<td>250 – 350</td>
<td>760</td>
</tr>
<tr>
<td>Hip roof tube furnaces</td>
<td>3.0 – 80.0</td>
<td>No preheating</td>
<td>600</td>
</tr>
<tr>
<td>Hot-water boilers of PTMV type</td>
<td>58.2; 116.3; 209</td>
<td>The same</td>
<td>390</td>
</tr>
</tbody>
</table>