

THERMAL POWER PLANTS

EFFECT OF THE ASH CONTENT ON THE SLAGGING PROPERTIES OF COALS AND THE SLAGGING OF PULVERIZED COAL-FIRED BOILERS

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The slagging rate in high-temperature zones and the furnace exhaust temperature in boilers firing high-ash coals increase with the ash content of coal. However, the slagging situation in pulverized-coal-fired boilers often improves with increase in the ash content of coal. This is because of the different effects of increase in the ash content on the slagging in different boiler zones and for different types of coal ash. The ash content affects the temperature of flue gas and the slagging properties; the effect of these factors can be either of the same or of opposite signs.

Keywords: boiler; boilers slagging; flame temperature; furnace exhaust temperature; coal; ash content; type of coal ash; slagging properties; initial slagging temperature; deposit strength; strong sulfate-calcium deposits; strong ferrous deposits.

As the ash content of coal increases, the efficiency of pulverized-coal-fired TPPs decreases, the environmental performance reduces, and the wear of the equipment intensifies. With increase in the ash content \( A_d \) (Fig. 1), the slagging rate in high-temperature zones increases (if the temperature exceeds the actual slagging point \( \theta_{as} \)), which, in some cases, aggravates the slagging situation in boilers. However, this is not always so—the operational personnel of TPPs and researchers know that the slagging of pulverized-coal-fired boilers often slows down with increase in the ash content of coal. There were cases where recommendations to fire coal of higher ash content appeared sufficient to improve the slagging situation substantially or even prevent slagging. The above-mentioned contradiction reflects different effects of increase in the ash content on the slagging in different boiler zones and for different coals.

The dependence of the slagging situation in pulverized-coal-fired boilers on the ash content and the other characteristics of coal and the combustion process (including operating conditions) is due to changes in the local and maximum flame temperatures and possible change in the slagging properties of the ash. The effects of these factors can be either of the same or of opposite signs. The magnitude and sign of the effects of change in the temperature and slagging properties depend on the type of coal and, for specific coal, depend on the area of the gas path of the boiler.

Effect of the Ash Content on the Flame Temperature. The adiabatic flame temperature and the flame core temperature decrease with increase in the ash content. However, the flame temperature varies ambiguously along the flame, including at the furnace exit. When coals of low ash content are fired in relatively small boilers, the gas temperature decreases along the entire height of the furnace, including its entry. When coals of high ash content are fired in large furnaces, the gas temperature \( \theta_{fr} \) at the furnace exit increases (Fig. 2), despite its lower value in the flame core.

The temperature \( \theta_{fr} \) depends on the flame emissivity factor, radiant flux diffusion, thermal efficiency of waterwalls, and fuel burnout. With increase in the ash content, the flame emissivity increases, and so does the radiant flux diffusion. This factor is accounted for in the standard furnace design method [3] by using the Burei number Bu instead of the emissivity factor \( a_{fr} \) and in the VTI’s zonal furnace model [4]. Figure 3a – d show the variation in the calculated flame temperatures with the ash content of Borodino and Ekbastuz coals. These results are based on the assumption that the thermal efficiency of the waterwalls remains constant, which reduces the reliability of the results. However, there are still no reliable algorithms for describing the
thermal resistance of slags depending on the ash content for an arbitrary boiler and coal in furnace heat-transfer models.

The decrease in the adiabatic flame temperature and the flame core temperature with increase in the ash content is due mainly to the increase in the hydrate moisture content of coal, which depends on the mineral composition, primarily on the type of clay minerals. Figure 3e compares the adiabatic flame temperatures for dry ash-free coal (C_{daf}, H_{daf}, S_{daf}, N_{daf}, O_{daf}) of varying chemical composition and for coal of constant chemical composition and varying ash content.

It is obvious and confirmed experimentally that among fuels with the same composition and same amount of minerals, those that produce flame of higher temperature increase the probability of slagging of the waterwalls. With increase in the ash content, the amount of fly ash and possible change in the slagging properties come into play too. If the change in the slagging properties is disregarded, an increase in the ash content causes the slagging rate to increase approximately proportionally to the normalized ash content \( n = \frac{A}{\text{value of as-received fuel}} \). However, the decrease in the gas temperature slows down or stops the increase of the slagging rate. Figure 4a illustrates the total effect of two factors of opposite signs that depend on the rate of increase in the slagging rate with increasing temperature in the temperature range \( \Delta g/\Delta t \) of interest and on the magnitude of decrease \( \Delta \theta \) in the temperature with increasing ash content.

The magnitude of decrease \( \Delta \theta \) in the flame temperature with increasing ash content is relatively small and similar for different coals. Contrastingly, the change in the slagging rate with temperature \( \Delta g/\Delta t \) depends considerably on the temperature difference \( \theta - \theta_{as} \) and the type of coal. This is illustrated in Fig. 4b, which shows the variation in the slagging ratio \( k_{sl} \) for coals tested in the UralVTI combustion testing facility (\( k_{sl} = g/\mu \) is the ratio of deposition flux to ash flux or, in other terms, the ratio of deposited ash particles to particles passing through the transverse midsection of the probe).

The curve of the slagging rate \( g \) versus temperature is S-shaped (logistic) over a wide temperature range. It is characterized by relatively slow increase in \( g \) at temperatures slightly higher than the initial slagging temperature, followed by a fast increase in the temperature increment and, then, by a decrease in the gain gradient. Figure 4a shows that for specific coal, the gain \( dg \) in the slagging rate at low values of \( \theta - \theta_{as} \) can be insignificant (compare \( dg1 \) with \( dg2 \) and \( dg3 \)). As will be shown below, for coals with the high concentration of components of acid or base composition, the initial slagging temperature (\( \theta_{as}, t_{sl} \)) can change with increase in the ash content. As the initial slagging temperature for coals with acid ash increases, the line of slagging rate of coal with

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**Fig. 1.** Variation in the slagging rate of uncooled probes [1, 2] with ash content and gas temperature (a) and with the ash content and probe penetration depth (b) and variation in normalized ash content with ash content (c): 1, slagging rate of uncooled probe in BKZ-420 boiler firing Borodino coal of different ash contents at gas temperature \( \theta = 1100°C \); 2, same at \( \theta = 1200°C \); 3, slagging rate depending on probe penetration depth in BKZ-160 boiler firing Ekibastuz coal with ash content \( A = 42.7\% \); 4, same with \( A = 53.2\% \); 5 and 6, normalized ash contents of Borodino and Ekibastuz coals, respectively.

**Fig. 2.** Variation in the furnace exhaust temperature with ash content: 1, regression line for experimental data (boiler PK-39, Ekibastuz coal); 2, 2’, calculation by the standard method for Ekibastuz-coal-fired PK-39 boiler and Borodino-coal-fired E-500 boiler; 3, 3’, calculation by the VTI’s zonal model for the same boilers; 4, 5, experimental value and regression line of experimental data (boilers PK-57 of different TPPs, Ekibastuz coal); 6, regression line for experimental data (boiler PK-57, Kuznetsk gas coal).