The 57th International October Conference on Mining and Metallurgy
05 - 07 October 2026, Bor Lake, Serbia
https://ioc.irmbor.co.rs

DOI: 10.5937/IOC26293S Original Scientific Paper-Chemistry

ASH CHEMISTRY AND FUSION BEHAVIOUR OF COAL BLENDS FOR THERMAL POWER PLANTS

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Abstract

This study investigates the relationship between ash chemical composition and ash fusion behavior of three parent coals and two laboratory-prepared blends for thermal power plant application. Ash composition was determined by ICP-OES according to ASTM D6349-21, and ash fusion temperatures according to ISO 540:2008. Parent coals with higher CaO content and B/A ratios exhibited lower fusion temperatures, while the S/A ratio alone did not describe the observed behavior. Coal blending produced different fusion responses, with Blend 1 showing a lower flow temperature than either parent coal. The results highlight the importance of ash chemistry in evaluating coal blending behavior.

***Keywords**: coal blending, ash chemistry, ash fusion temperature, ash fusion behavior*

1. INTRODUCTION

Coal remains an important fuel for thermal power generation, while the behavior of its inorganic constituents represents one of the major factors affecting reliable boiler operation. During combustion, mineral matter undergoes complex physical and chemical transformations, forming ash that may partially melt, sinter and deposit on heat-transfer surfaces. Depending on the temperature and deposition mechanism, these processes may contribute to slagging and fouling, resulting in reduced heat transfer efficiency and operational problems in combustion systems [1,2].

Ash fusion temperatures (AFTs) are widely used for assessing the high-temperature behavior of coal ash. The conventional ash fusion test identifies characteristic temperatures associated with progressive deformation and melting of ash, including the deformation temperature (DT), softening temperature (ST), hemispherical temperature (HT), and flow temperature (FT). Although AFTs do not provide a complete description of the melting process, they remain useful practical indicators for coal selection and for evaluating the tendency of ash to soften and form deposits under elevated-temperature conditions [1,3].

Ash fusion behavior is strongly related to its chemical and mineralogical composition. Coal ash can generally be considered a complex aluminosilicate system in which SiO_2, Al_2O_3 and TiO_2 predominantly behave as refractory components, whereas Fe_2O_3, CaO, MgO and alkali oxides may act as fluxing components. Consequently, compositional parameters such as the SiO_2/ Al_2O_3 ratio and the relative proportions of acidic and basic oxides have frequently been used to interpret variations in ash fusibility. However, the relationships between individual oxide concentrations and AFTs are complex and may be nonlinear because ash melting involves interactions between multiple components and the formation of different mineral and eutectic phases [1-3].

Coal blending provides a practical approach for modifying fuel properties without changing the individual coal sources. However, the ash fusion behavior of a blend cannot necessarily be predicted by simple interpolation between the properties of the parent coals. Previous studies have demonstrated that blending may cause nonlinear changes in AFTs as a consequence of interactions and mineral transformations occurring between the inorganic constituents during heating [4,5].

Therefore, the aim of this study was to investigate the relationship between ash chemical composition and ash fusion behavior of three different coals and two laboratory-prepared coal blends intended for thermal power plant application. Particular attention was given to the influence of major ash-forming oxides and selected compositional ratios on the experimentally determined ash fusion temperatures.

2. EXPERIMENTAL

Three commercially available coals of different origin and rank were investigated in this study. The samples included a bituminous coal of US origin (Coal 1), a second imported US coal (Coal 2), and lignite from the Gacko coal mine, Bosnia and Herzegovina (Coal 3). In addition to the individual coals, two laboratory-prepared coal blends were investigated. Blend 1 consisted of Coal 1 and Coal 3, while Blend 2 consisted of Coal 2 and Coal 3. Both blends were prepared at a 1:7 mass ratio on a dry basis, with correction for the analytical moisture content of the parent coals.

The chemical composition of coal ash was determined in accordance with ASTM D6349-21 using inductively coupled plasma optical emission spectrometry (ICP-OES). The concentrations of the major ash-forming oxides, including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O and TiO_2, were considered in the present study. Ash fusion behavior was evaluated according to ISO 540:2008 under a reducing atmosphere. Four characteristic ash fusion temperatures were determined: deformation temperature (DT), softening temperature (ST), hemispherical temperature (HT), and flow temperature (FT).

To further evaluate the relationship between ash chemistry and fusion behavior, two compositional indices were calculated for the parent coal ashes. The silica-to-alumina ratio (S/A) was calculated as SiO_2/Al_2O_3, while the base-to-acid ratio (B/A) was calculated as bellow in equation 1:

$$B/A = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2} \quad (1)$$

These compositional indices, commonly used for interpreting coal ash fusibility, were calculated according to relationships reported in the literature [3,6].

3. RESULTS AND DISCUSSION

3.1. Ash chemistry and fusion behavior of parent coals

The major ash-forming oxide contents calculated compositional indices, and characteristic ash fusion temperatures of the parent coals, are presented in Table 1.

Table 1. *Major ash-forming oxides, compositional indices, and ash fusion temperatures of parent coals*

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	Na_2O+K_2O (%)	S/A	B/A	DT (°C)	FT (°C)
Coal 1	54.21	19.78	15.63	1.97	0.82	3.33	2.74	0.29	1338	1396
Coal 2	31.25	14.54	4.06	23.08	4.02	1.02	2.15	0.69	1180	1230
Coal 3	29.04	12.08	6.57	30.41	1.26	0.90	2.40	0.94	1212	1234

As can be concluded from the Table 1, the parent coals exhibited distinctly different ash chemical compositions and fusion characteristics. Coal 1 is characterized by the highest contents of SiO_2 (54.21%) and Al_2O_3 (19.78%) and a comparatively low CaO content (1.97%). In contrast, Coal 2 and Coal 3 contain considerably more CaO, 23.08% and 30.41%, respectively, accompanied by lower SiO_2 and Al_2O_3 contents. These compositional differences reflect in the calculated B/A ratios, which increased from 0.29 for Coal 1 to 0.69 and 0.93 for Coal 2 and Coal 3, respectively.

Coal 1 also indicates substantially higher ash fusion temperatures, with DT and FT of 1338 °C and 1396 °C, respectively. In comparison, Coal 2 showed DT/FT values of 1180/1230 °C, while the corresponding values for Coal 3 are 1212/1234 °C. The observed behavior is consistent with the general influence of the balance between refractory and fluxing constituents on ash fusibility. SiO_2 and Al_2O_3 are important constituents of the aluminosilicate ash system, whereas CaO, Fe_2O_3, MgO and alkali oxides can participate in the formation of lower-melting phases. Previous studies have shown that AFTs may reach relatively low values when the B/A ratio approaches unity, although the actual fusion behavior depends on interactions between the individual ash constituents and the mineral phases formed during heating [2,6].

The calculated S/A ratios are 2.74, 2.15 and 2.40 for Coal 1, Coal 2 and Coal 3, respectively. The measured AFTs did not show a consistent trend with changes in the S/A ratio. For example, Coal 3 had a higher S/A than Coal 2, while their FT values were very similar (1234 and 1230 °C, respectively). This supports previous findings that the

influence of S/A on ash fusion is nonlinear and strongly dependent on the overall ash composition and high-temperature mineral transformations [1,3].

Therefore, the present results indicate that the high fusion temperatures of Coal 1 and the considerably lower values obtained for Coal 2 and Coal 3 are better interpreted through the combined balance of refractory and fluxing constituents rather than through the S/A ratio alone.

3.2. Effect of coal blending on ash fusion behavior

Coal blending resulted in different ash fusion responses depending on the parent coals used, which is presented in Figure 1. Blend 1, prepared from Coal 1 and Coal 3 at a 1:7 dry-basis mass ratio, exhibited DT and FT values of 1206°C and 1220°C, respectively. Despite the considerably higher FT of Coal 1 (1396 °C), the FT of Blend 1 was 14 °C lower than that of Coal 3 (1234°C), which constituted the major component of the blend.

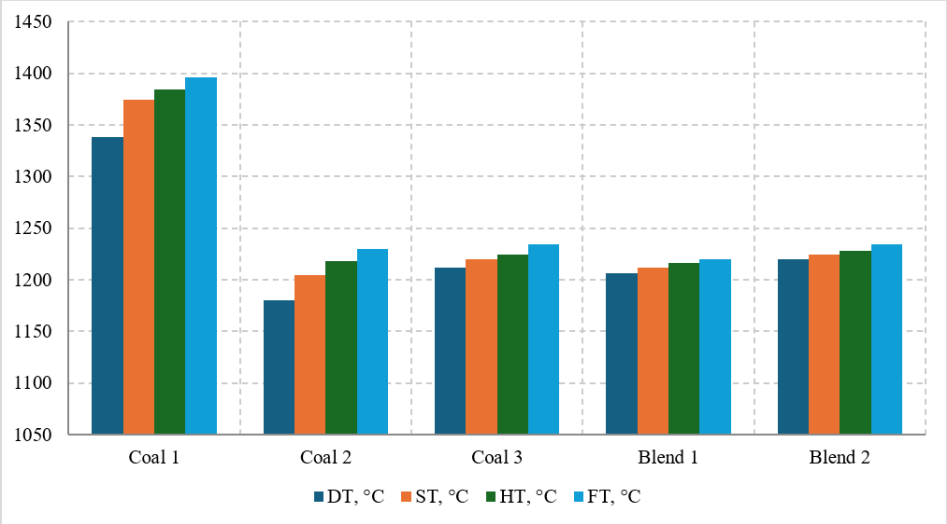


Figure 1. *Ash fusion temperatures of the parent coals and laboratory-prepared-coal blends*

Thus, the fusion behavior of Blend 1 did not follow a simple intermediate trend between the corresponding values of its parent coals. In contrast, Blend 2 exhibited DT and FT values of 1220 °C and 1234 °C, respectively, with its FT remaining within the narrow range defined by Coal 2 (1230 °C) and Coal 3 (1234 °C).

The non-intermediate behavior observed for Blend 1 is consistent with previous studies showing that ash fusion temperatures of coal blends may exhibit nonlinear changes with blending ratio. Such behavior has been associated with interactions

between ash-forming constituents during heating and the formation of new mineral and eutectic phases, rather than with a simple additive contribution of the parent coal ashes [4,5].

However, since the chemical and mineralogical compositions of the blend ashes were not directly determined in the present study, the specific phase transformations responsible for the observed behavior cannot be identified.

An additional difference was observed in the fusion temperature range, expressed as $\Delta T = FT - DT$. The parent coals exhibited ΔT values of 58, 50 and 22°C for Coal 1, Coal 2 and Coal 3, respectively, whereas both blends exhibited a considerably narrower range of only 14 (°C). This indicates that, under the applied test conditions, once deformation of the blend ashes began, progression to the flow state occurred over a relatively narrow temperature interval. The fusion range provides complementary information to individual AFT values, as differences in the interval between deformation and flow may reflect differences in the progression of ash melting [3].

4. CONCLUSION

The results obtained in this paper demonstrated a clear relationship between ash chemical composition and fusion behavior of the investigated parent coals. Coal 1, characterized by a Si-Al-rich and Ca-poor ash and the lowest B/A ratio (0.29), exhibited the highest fusion temperature (FT = 1396 °C), whereas the Ca-rich ashes of Coal 2 and Coal 3 showed considerably lower FT values of 1230 and 1234 °C, respectively. The S/A ratio alone was insufficient to explain the observed differences, indicating the importance of the overall balance between refractory and fluxing constituents. Coal blending further modified ash fusion behavior, particularly for Blend 1, whose FT (1220 °C) was lower than those of both parent coals. Both blends also exhibited a narrow FT-DT interval of 14 °C. These findings indicate that ash fusion behavior of coal blends cannot always be interpreted as a simple intermediate response of the parent coals.

ACKNOWLEDGEMENTS

The authors are grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for financial support in 2026 according to the contract with registration No. 451-03-33/2026-03/200052.

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