

Effect of the Composition of Additive Ash on the Thermal Behavior of Petroleum Coke Ash during Gasification

Wei Li, Ben Wang,* Jun Nie, Wu Yang, Lushi Sun, Deepak Pudasainee, and Rajender Gupta*

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ABSTRACT: The behavior of ash fusion at high temperatures plays a key role in the stable operation of gasifiers. This study investigated the effect of synthetic mineral compounds on the transformation and ash fusion temperatures (AFTs) of petroleum coke (petcoke) ash in a steam atmosphere with the variation of the $\text{SiO}_2/\text{Al}_2\text{O}_3$ (Si/Al), $\text{Fe}_2\text{O}_3/\text{CaO}$ (Fe/Ca), and $\text{V}_2\text{O}_5/\text{NiO}$ (V/Ni) ratios and temperature. Thermodynamic equilibrium calculation was also applied to simulate the ash-melting process in petcoke gasification. The results show that the dominant crystalline phases in petcoke ash at high temperature are $\text{CaAl}_2\text{Si}_2\text{O}_7$, FeAl_2O_6 , and FeV_2O_6 . The increase of temperature is conducive to the formation of low-melting minerals, such as, $\text{CaAl}_2\text{Si}_2\text{O}_7$ and FeAl_2O_6 . High Si/Al is beneficial for the reduction of AFTs because high melting point minerals partly convert into slag and the low melting point mineral phase of $\text{CaAl}_2\text{Si}_2\text{O}_7$ transforms largely into slag. AFTs could be reduced at an Fe/Ca ratio of 0.5 when the content of slag in the ash reaches maximum and there are plenty of the low-melting minerals ($\text{CaAl}_2\text{Si}_2\text{O}_7$). A high V/Ni ratio was not conducive to the suppression of AFTs. The effect of Si/Al and Fe/Ca could effectively improve the AFTs of petcoke ash. A high ratio of Si/Al and the ratio of Fe/Ca at 0.5 were beneficial to the ash fusibility. AFTs under gasification atmosphere conditions have been predicted by FactSage.

1. INTRODUCTION

Petroleum coke (petcoke) has been rapidly produced with the continuous consumption of heavy crudes in refineries.^{1,2} As a fuel for combustion, petcoke causes undesirable pollution to the environment because of the high content of sulfur and other trace elements such as vanadium and nickel.^{3,4} The special advantages of petcoke including cheap price, high heating value, and low ash content make it an alternative fuel, which is preferred for entrained flow gasifiers because of economic and technical reasons.^{5–7} Entrained flow gasifiers operated at high temperatures have been steadily becoming a promising gasification technology with the advantages of high carbon-conversion efficiency.^{8–10} However, ash mobility issues have become one of the major challenges faced by entrained flow gasifiers for the mineral matter-related problems.^{11–13} Continuous discharge of slag is essential for maintaining the smooth operation of a gasifier, which is beneficial for the lifetime of equipment.^{14–16} Therefore, it is significant to understand the mineral matters contributing to the thermal behavior of petcoke ash for the application of petcoke gasification.

Ash fusibility, being an important operation parameter as it determines the operating temperature of the entrained flow gasifier, has been investigated by numerous researchers. Establishing the relationship between ash fusion temperatures and ash components is widely considered as an effective method to understand issues related to ash mobility. Nieng et al.¹⁷ investigated ash fusion characteristics during co-gasification of biomass and petcoke. The high melting temperature of petcoke ash including Ca_2SiO_6 , V_2O_5 , and FeV_2O_6 can be effectively reduced by blending with biomass ash. Li et al.¹⁸

studied a high V petcoke ash fusibility at reducing atmosphere by coal blending and flux addition, which could effectively decrease the ash fusion temperature. The addition of flux calcium oxide decreased the ash fusion temperature (AFT) when low-melting $\text{Ca}_2\text{V}_2\text{O}_7$ and $\text{Ca}_2\text{Fe}_2\text{Si}_2\text{O}_{12}$ formed and high-melting V_2O_5 and FeV_2O_6 decreased under a reducing atmosphere. Li et al.¹⁹ also investigated the effects of $\text{SiO}_2/\text{Al}_2\text{O}_3$ and $(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ ratios on the synthetic petcoke ash fusibility at an oxidizing atmosphere. The decline of high-melting $\text{Al}_2\text{Si}_2\text{O}_{11}$ might cause a sharp decrease in AFTs of synthetic ashes with different $\text{SiO}_2/\text{Al}_2\text{O}_3$. Wang et al.²⁰ showed that a small amount of coal ash additive could reduce the ash melting temperature when the total content of V and Ni in the ash exceeded 30%. Although the effect of coal, biomass, and other flux additions on the mineral transformation and AFTs of petcoke is extensively studied, little has been investigated on the connection between systematic mineral matters and AFTs of petcoke under a reducing atmosphere.

AFTs are also associated with thermodynamic equilibrium simulation by FactSage. Jak²¹ performed a research of the processes taking place during the AFT test from perspective of the phase equilibrium of the ash slag system. It was reported

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