

双碳目标下生物质-煤耦合燃烧的腐蚀悖论：气-固多组分协同侵袭机理

摘要

在“双碳”目标驱动下，燃煤机组掺烧生物质是实现存量煤电低碳化转型的关键路径。然而，生物质引入的氯、碱金属与煤中硫分共存，导致高温受热面面临复杂的气-固多相协同腐蚀，成为制约掺烧比例与机组安全运行的技术瓶颈。本研究针对此关键科学问题，以锅炉典型用钢 12Cr1MoV 为对象，构建了多组分协同腐蚀模拟实验系统，系统探究了 450-600°C 范围内 HCl、SO₂、H₂O 及模拟灰分的耦合腐蚀行为与机理。研究揭示了 HCl 主导的“活性氧化”与 SO₂ 的竞争吸附抑制之间的动态平衡机制：HCl 通过破坏 Cr₂O₃ 保护膜引发剧烈腐蚀，而 SO₂ 因较低的反应临界分压可优先占据表面活性位点，部分抑制 Cl⁻ 的侵蚀。首次发现水蒸气（10 vol%）在混合气氛中的“双向调节”作用：其通过促进更致密 Cr₂O₃ 膜的形成并改变 Cl/S 迁移路径，在所有测试工况下均表现出显著的腐蚀抑制效果。在模拟 20% 能量掺比的固-气耦合工况下，混合灰与酸性气体协同作用导致腐蚀速率高达 42.60 mm/a，量化了多相耦合的极值风险。本研究阐明了灰-气多相协同腐蚀机理，相关成果为燃煤掺烧生物质锅炉的材料选型、运行优化与腐蚀防控提供了直接的理论依据与技术支撑。

关键词

煤电低碳化改造；气-固耦合腐蚀；HCl/SO₂ 协同机制；安全控制；保护层失效

Abstract

Driven by the “dual carbon” goals, co-firing biomass in coal-fired power units is a critical pathway for the low-carbon transformation of existing coal power capacity. However, the coexistence of chlorine and alkali metals introduced by biomass with the sulfur inherent in coal leads to complex multi-phase gas-solid synergistic corrosion on high-temperature heating surfaces, posing a significant technical bottleneck that limits co-firing ratios and compromises unit safety. To address this key scientific challenge, this study focuses on the typical boiler steel 12Cr1MoV and establishes a multi-component synergistic corrosion simulation experimental system. The coupling corrosion behavior and mechanisms involving HCl, SO₂, H₂O, and simulated ash deposits were systematically investigated within the temperature range of 450–600°C. The study reveals a dynamic equilibrium mechanism between the HCl-dominated “active oxidation” and the competitive adsorption inhibition by SO₂: HCl triggers severe corrosion by destroying the protective Cr₂O₃ scale, whereas SO₂ preferentially occupies active surface sites due to its lower critical reaction partial pressure, thereby partially mitigating Cl⁻ ingress. For the first time, the “dual regulatory” role of water vapor (10 vol%) in mixed atmospheres was identified: it exhibits a significant corrosion inhibition effect under all tested conditions by promoting the formation of a denser, more stable Cr₂O₃-rich scale and altering the migration pathways of Cl/S species. Under simulated 20% energy-input co-firing conditions with combined ash and gas exposure, the synergistic effect of mixed ash and acid gases results in an extreme corrosion rate of 42.60 mm/a, quantifying the peak risk of multi-phase coupling. This work elucidates the mechanisms of multi-phase ash-gas synergistic corrosion, and the findings provide a direct theoretical basis and technical support for material selection, operational optimization, and corrosion mitigation strategies in coal-biomass co-firing boilers.

Keywords

Coal power low-carbon retrofit; Gas-solid coupling corrosion; HCl/SO₂ synergistic mechanism; Safety control; Protective layer failure

Author: 泽熙, 赵 (东北大学)

Presenter: 泽熙, 赵 (东北大学)

Session Classification: 安全科学与技术

Track Classification: 口头报告: 安全科学与技术