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The investigation of free radicals in flaming and smoldering smoke particle

摘要

火灾烟雾颗粒中的环境持久性自由基可诱导氧化应激并增强颗粒毒性，但明火与阴燃烟雾颗粒的自由基状态差异仍不明晰。本研究采集 7 种典型样品，结合 EPR、Raman 光谱和 OC/EC 分析，比较其自由基特性、碳结构及组成。结果表明，明火颗粒具有更高自由基浓度、更低 g 值、更宽 FWHM 和更高 $P_{1/2}$，呈现自由基富集、碳中心和芳香缩合特征。Raman 和 OC/EC 结果显示，明火颗粒富含 D1 型芳香边缘/纳米石墨化碳和 EC/soot-EC，有利于碳中心自由基稳定；阴燃颗粒富含 D3/D4 型无定形碳和 OC/char-EC，对应低自由基负载和强氧相关电子扰动。燃烧模式主导自由基丰度与电子特征，碳结构和组成调控自由基宿主环境。

关键词

明火烟雾，阴燃烟雾，自由基，EPR 光谱，碳烟颗粒

Abstract

Environmentally persistent free radicals in fire smoke particles can induce oxidative stress and enhance particle toxicity, yet the radical-state differences between flaming and smoldering smoke particles remain unclear. In this study, seven representative smoke particle samples were analyzed using electron paramagnetic resonance spectroscopy, Raman spectroscopy, and OC/EC analysis to link radical properties with carbon structure and carbonaceous composition. The results showed that flaming smoke particles had markedly higher radical concentrations, lower g values, broader FWHM, and higher $P_{1/2}$ than smoldering smoke particles, indicating a radical-rich, carbon-centered, and aromatically condensed radical state. Raman and OC/EC results further showed that flaming particles were enriched in D1-type aromatic-edge/nanographitic carbon and EC/soot-EC, which favored the stabilization of carbon-centered radicals. In contrast, smoldering particles were characterized by D3/D4-rich amorphous carbon and OC/char-EC, corresponding to lower radical loading and stronger oxygen-related electronic perturbation. These findings demonstrate that combustion mode governs radical abundance and electronic character, while carbon structure and composition regulate the radical-hosting environment.

Keywords

Flaming smoke, Smoldering smoke, Free radical, EPR spectroscopy, Soot particles

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