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烧结作用对高温堆石墨粉尘重悬浮行为的影响

摘要

高温气冷堆的石墨粉尘重悬浮特性对其源项估计意义重大。颗粒的重悬浮行为与颗粒-颗粒和颗粒-壁面的相互作用密切相关。反应堆内高温高压的环境会促使已沉积的石墨颗粒发生烧结，显著影响颗粒与颗粒间及颗粒与壁面间的粘附力，但是这种效应在已有的研究中很少被考虑。忽视高温烧结历史的影响可能会导致高估事故中石墨粉尘的重悬浮率，也会影响重悬浮颗粒的特性。本文对沉积石墨颗粒经不同温度和时长烧结后的重悬浮特性进行了实验研究，并结合 Rock 'n' Roll（R 'n' R）重悬浮模型开展了理论分析。同时，用高速摄像机记录重悬浮过程。结果表明，与未烧结的颗粒相比，烧结颗粒在重悬浮时表现出更高的摩擦速度阈值，烧结温度和持续时间的增加会放大这种效应，尤其是对于较大的颗粒。烧结 9 小时后，摩擦速度明显增加（达约 80%）。通过调整等效表面能，新的重悬浮曲线仍可与 Rock'n'Roll 模型相匹配，等效表面能与烧结温度呈阿伦尼乌斯型关系。这项初步研究表明，纳入烧结效应可以显著降低高温堆气溶胶源项的估算值。

关键词

高温气冷堆；石墨粉尘；烧结；重悬浮；R 'n' R 模型

Abstract

The resuspension of deposited graphite particles in high-temperature gas-cooled reactors (HTGRs) under specific accident conditions has attracted considerable attention due to its critical connection with source terms. However, nearly all related studies have overlooked the effects of long-term high-temperature sintering after particle deposition, which could have a significant impact by changing the strength of particle-particle and particle-wall connections and lead to an overestimation of graphite dust resuspension in accident scenarios. In this work, we conduct an experimental study to quantitatively evaluate the effect of sintering on the resuspension behavior of graphite particles, and combined with the Rock 'n' Roll (R 'n' R) model for theoretical analysis. Meanwhile, the resuspension process is recorded with a high-speed camera. The results show that sintered particles exhibit a higher friction velocity threshold for resuspension compared to their un-sintered counterparts, with the effect amplified by increased sintering temperature and duration, particularly for larger particles. The friction velocity significantly increases (up to ~80%) after 9 h sintering. The new resuspension curve can still be fitted to Rock'n'Roll model by adjusting the effective surface energy which shows an Arrhenius-type dependence on the sintering temperature. This preliminary study suggests that incorporating the sintering effect could significantly lower the estimated aerosol source term for HTGRs.

Keywords

High-temperature gas-cooled reactor; Graphite dust; Sintering; Resuspension; Rock 'n' Roll model

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