

清华大学高通量反应堆两相热力学特性研究

摘要

清华高通量反应堆（THFR）燃料元件的窄流道及局部堵塞事故是影响堆芯安全的核心问题之一。本研究采用计算流体力学（CFD）方法，分析了高通量反应堆内局部流道堵塞引发的热工水力现象。研究表明：堵塞物尾迹区的热量积聚贡献了开启核态沸腾（ONB）所需过热度的 90% 以上，其影响远超压力降效应。研究识别出一种关键的“涡旋捕获”机制：蒸汽团被截留在再循环涡流中，形成持久的蒸汽包覆层。这种热屏蔽效应将包壳与过冷主流隔离，从而急剧增加了偏离核态沸腾（DNB）的风险。研究结论认为，决定堵塞期间反应堆安全裕度的是微观尺度下的多相动力学特征，而非宏观的压力波动。本研究揭示的物理机制可为高通量反应堆的堵塞事故监测报警系统提供理论支撑，并为先进燃料组件的流道优化设计提供参考依据。

关键词

窄流道, 局部流道堵塞, 多相动力学

Abstract

The narrow flow channel and local blockage accidents in the fuel elements of the Tsinghua High-Flux Reactor are one of the key issues affecting core safety. This study uses CFD to analyze thermal-hydraulic phenomena induced by local flow blockages in a high-flux reactor. Results show that heat accumulation in the blockage wake contributes over 90% of the superheat required for Onset of Nucleate Boiling, far outweighing pressure-drop effects. A critical “vortex trapping” mechanism was identified, where vapor clusters are sequestered in recirculating eddies, forming a persistent vapor blanket. This thermal-shielding effect isolates the cladding from the subcooled mainstream, drastically increasing Departure from Nucleate Boiling (DNB) risks. The study concludes that micro-scale multiphase dynamics, not macroscopic pressure fluctuations, govern reactor safety margins during blockages. The physical mechanisms revealed in this study provide a theoretical foundation for monitoring and alarm systems for blockage accidents in high-flux reactors and offer a reference for the optimized channel design of advanced fuel assemblies.

Keywords

Narrow flow channel, Local flow blockage, Multiphase flow dynamics

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