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基于 CFD 的球形燃料元件气力抽吸行为数值研究

摘要

球形燃料元件装入贮罐后，如需要从贮罐内取出，需要通过乏燃料气力输送子系统，用负压抽吸的方式，通过抽吸软管将元件从贮罐内抽吸取出，输送到下游的输球管道。本文采用计算流体力学（CFD）方法，针对球形元件在不同初始位置下的可抽吸性进行了数值模拟，界定了在最高抽吸流速（300 m3/h）条件下的有效抽吸区域，并分析了相应的流场特征。结果表明，球形元件在抽吸过程中所受的曳力与其位置密切相关。随着元件进入抽吸口，其受到非对称的流场作用，呈现向抽吸管轴线趋近的运动趋势，有利于后续稳定输送。在上升阶段，元件所受曳力虽存在小幅波动，但始终大于其重力，确保了持续的输送能力。总体而言，当球形元件位于 45° 斜角管嘴外约 15 mm 范围内时，可实现稳定抽吸。本研究结果不仅可为乏燃料输送系统的设计与优化提供参考，也可为其他领域中球形物体的气力抽吸问题提供理论支持。

关键词

数值模拟；气力输送；抽吸；球形燃料元件

Abstract

After spherical fuel elements are loaded into the storage tank, they must be extracted via the spent fuel pneumatic conveying subsystem when needed. This process relies on negative pressure suction, where the elements are drawn out of the tank through a suction hose and transported to the downstream conveying pipeline. In this study, computational fluid dynamics (CFD) simulations are conducted to investigate the suction feasibility of spherical elements positioned at various initial locations. The effective suction region under a maximum airflow rate of 300 m^3/h is identified, and the associated flow field characteristics are analyzed. The results indicate that the drag force acting on the spherical element during suction is closely related to its position. As the element approaches the suction inlet, it experiences an asymmetric flow field, resulting in a movement trend toward the central axis of the suction pipe, which facilitates subsequent stable transport. During the ascent, although the drag force exhibits slight fluctuations, it consistently exceeds the gravitational force of the element, ensuring continuous transport. Overall, stable suction can be achieved when the spherical element is located within approximately 15 mm outside the 45° inclined suction nozzle. These findings provide valuable guidance for the design and optimization of spent fuel conveying systems and offer theoretical support for pneumatic suction of spherical objects in other engineering applications.

Keywords

Numerical simulation; Pneumatic conveying; Suction; Spherical fuel element

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