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隧道内阻塞物对流淌火火焰形态和流场分布的影响

摘要

在高速公路隧道内，石化产品在运输过程中发生的各种紧急情况可能导致液体持续泄漏流淌火灾。本文旨在通过实验和模拟方法，探讨滞留车辆导致的堵塞对隧道火灾中流淌火灾燃烧和火焰行为的影响。在阻塞比为 12%/20%/30% 的隧道内进行了一系列流淌火灾实验。改变了泄漏点与阻塞物之间的距离 (d=0m，流淌火在阻塞物下方蔓延，火焰接触阻塞物；d=0.3m，流淌火火焰未接触阻塞物)，并采用了五种泄漏速率：100/150/200/250/300 mL/min。测量了火焰高度、燃烧面积和天花板温度。使用 FDS 模拟进一步揭示了典型的速度、温度、涡度场和涡旋结构。结果显示，d=0m 时火焰高度比 d=0.3m 时更高。当阻塞比从 12% 增加到 30% 时，d=0m 处的最大火焰高度约上升 10%。相比之下，火焰振荡频率在 d=0.3m 时更高，且随着阻塞率从 12% 增加到 30%，其最大值在该位置会增加约 6%。通过分析流淌火的扩散燃烧过程，提出了一种计算瞬时燃烧速率的方法。此外，与火焰接触的阻塞物会显著改变火焰周围的流场和空气的卷吸。基于阻塞物对火焰表面和上层火焰卷吸的限制，修正了卷吸边界和燃烧速率，引入了卷吸修正系数，并建立了不同燃烧阶段流淌火的火焰高度和振荡频率预测模型。

关键词

流淌火；阻塞物；涡旋动力学；火焰高度；振荡频率

Abstract

Within highway tunnels, various emergencies during the transportation of petrochemical products may lead to liquid spills and fires, forming spill fires in the tunnel. This paper aims to investigate the effects of blockage caused by stranded vehicles on the combustion and flame behavior of spill fires during tunnel fires through experimental and simulation methods. A series of spill fire experiments were conducted in a tunnel with blockage ratios of 12%/20%/30%. The tests varied the distance between the leak location and the blockage (spill fire spreads beneath the blockage and the flame contacting the blockage d=0m; spill fire does not contact the blockage d=0.3m) and employed five discharge rates: 100/150/200/250/300mL/min. Flame height, burning area, and ceiling temperature were measured. FDS simulations further revealed typical velocity, temperature, vorticity fields, and vortex structures. The results indicate that the flame height is greater at d=0 m than at d=0.3 m. When the blockage ratio increases from 12% to 30%, the maximum flame height at d=0 m rises by approximately 10%. In contrast, the flame oscillation frequency is higher at d=0.3 m; similarly, its maximum value at this position increases by around 6% as the blockage ratio increases from 12% to 30%. Blockage in contact with the flame significantly changes the flow field around the flame and air entrainment. By analyzing the spreading combustion process of spill fires, this study proposes a method for calculating the instantaneous combustion rate. Based on the limitations imposed by blockage on both flame surface and upper flame entrainment, this study revised the entrainment boundary and combustion rate, introduced an entrainment limitation coefficient, and established predictive models for the flame height and oscillation frequency of spill fires during different combustion stages.

Keywords

Spill fire, Blockage, Vortex dynamics,Flame height, Oscillation frequency

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