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泄爆压力对氨-氢-空气爆炸动力学的影响

摘要

掺氢是改善氨燃烧性能的有效途径之一，但同时也提高了爆炸危险性。泄爆能够有效降低腔体内部压力，进而减轻爆炸损害。然而，泄爆压力（Pstat）对氨-氢-空气爆炸动力学的影响仍然不清晰。为此，本文通过实验与数值模拟，研究了不同泄爆压力下氨-氢-空气混合物爆炸过程中的超压发展与火焰形态演化。结果表明，提高 Pstat 增强了火焰-压力波相互作用的强度，促使火焰裙边接触管道侧壁的时刻由泄爆后提前至泄爆前，进而影响火焰表面积的增长过程。因此，泄爆膜破裂导致的超压峰值 P1 由线性增长转变为非线性增长。此外，当 Pstat 较低时，火焰形态仅表现为球形和指尖形，表明火焰裙边接触管道侧壁产生的稀疏波不足以诱发郁金香火焰。当 Pstat 增加至 60.14 kPa 时，观察到典型的郁金香火焰。数值模拟结果表明，随着 Pstat 增加，火焰与从泄爆膜反射的压缩波之间的碰撞增强，在火焰前锋前方诱导出郁金香形轴向速度分布。这种轴向速度分布最终导致郁金香火焰的形成。

关键词

泄爆压力；氨-氢混合物；郁金香火焰；火焰-压力波相互作用；泄爆

Abstract

Blending ammonia with hydrogen is an effective way to improve the combustion performance of ammonia, but it also increases the explosion risk. Venting can effectively reduce the internal overpressure of the enclosure, thereby mitigating explosion damage. However, the influence of vent burst pressure (Pstat) on the explosion dynamics of ammonia–hydrogen–air mixtures remains unclear. To address this problem, the present study experimentally and numerically investigates the overpressure development and flame morphology evolution during the explosion of ammonia–hydrogen–air mixtures under different vent burst pressures. The results show that increasing Pstat enhances the intensity of flame–pressure wave interaction, advancing the timing of flame skirt contact with the duct sidewall from post-venting to pre-venting, thereby affecting the growth of flame surface area. Consequently, the peak overpressure P1 generated by vent cover rupture transitions from a linear to a nonlinear increase. Furthermore, at low Pstat, only spherical and fingertip flames are observed, indicating that the rarefaction wave generated by flame–wall contact is too weak to induce a tulip flame. When Pstat increases to 60.14 kPa, a typical tulip flame is observed.Numerical simulation results show that with increasing Pstat, the collision between the flame and the compression wave reflected from the vent cover intensifies, inducing a tulip-shaped axial velocity profile ahead of the flame front. This axial velocity distribution ultimately leads to the formation of the tulip flame.

Keywords

Venr burst pressure; Ammonia-hydrogen; Tulip flame; Flame-pressure wave interaction; Vented explosions

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