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各向同性湍流内颗粒碰撞率的直接模拟研究

李瑞霞, 柳朝晖, 贺铸, 陈胤密, 郑楚光

华中科技大学煤燃烧国家重点实验室，430074

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摘要 对 Re_{\lambda } 约为51均匀各向同性湍流内 St_{k}(=\tau_{p}/\tau_{k}) 为 0 ~10.0 的有限惯性颗粒的碰撞行为进行了直接数值模拟，以研究湍流对有限惯性颗粒碰撞的影响. 结果表明，具有一定惯性颗粒的湍流碰撞率完全不同于零惯性的轻颗粒 (St_{k}=0) 和可忽略湍流作用的重颗粒 (St{k} \to \infty) , 其变化趋势极其复杂：在Stk为 0~1.0 之间，颗粒的碰撞率随 St 的增加而近乎线性地剧烈增长，在 Stk≈1.0 3.0(对应的StE=τp/Te≈0.5)附近，颗粒碰撞率出现两个峰值，在Stk>3.0以后，颗粒的碰撞率随惯性增大而逐渐趋向于重颗粒极限；在峰值处，有限惯性颗粒的平均碰撞率的峰值较轻颗粒增强了 30倍左右. 为进一步分析湍流作用下颗粒碰撞率的影响因素，分别使用可能发生碰撞的颗粒对的径向分布函数和径向相对速度来量化颗粒的局部富集效应和湍流掺混效应，表明 St_{k} \approx 1.0 时局部富集效应最为强烈，使得颗粒的碰撞率出现第1个峰值；湍流掺混效应则随着颗粒Stk的增大而渐近增大；局部富集和湍流掺混联合作用的结果，使得颗粒碰撞率在 St_{k} \approx 3.0 附近出现另一个峰值.

关键词 各向同性湍流,惯性颗粒,碰撞率,湍流掺混效应,直接数值模拟

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Direct Numerical Simulation of Finite-Inertia Particle Collision in Isotropic Turbulent Flow

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华中科技大学煤燃烧国家重点实验室，430074

Abstract

In this paper, direct numerical simulations (DNS) were conducted to study particle collisions in a stationary isotropic homogeneous turbulent flow, with the aim to investigate the influence of turbulence on particle collision rates of various finite-inertia particles. It is found that the behavior of finite-inertial particle collision is very complicated, both the Saffman & Turner theory(Stk=τp/τk =0) and kinetic theory(Stk=￥) can't correctly predict it. For particles of Stk <1 the collision rate increases sharply as Stk increases; at Stk ~1, collision rate reaches a peak value; As Stk continues to increase, collision rate slowly decreases at first and then increases to reach another peak at Stk ~3 (corresponding to Eulerian integral time scale). As particle inertia continues to increase, collision rate begins to decrease slowly to reach the kinetic theory. Both of the peak value is about 30 times of zero inertia limit. To further understand the mechanism of finite-inertia particle collision in isotropic turbulence, two major effects of turbulent flow on particle collision, namely turbulent transport effect and preferential concentration effect, are investigated and are represent qualitatively using radial relative velocity <|wr|> and radial distribution function g(R) of colliding particle pairs respectively. Both effects tend to increase collision rates, leading to the observed complex behavior. The results showed that preferential concentration effect is the main contribution factor for the peak of particle collision rate near Stk~1, while both preferential concentration effect and turbulent transport effect contributing to the peak near Stk~3, with much stronger turbulent transport effect herein. Statistical analysis of the data also showed that the probability density function(pdf) of relative radial velocity between two colliding particles does not fit for Gaussian distribution for different Stokes number. Instead, due to the effect of different scales of motions in turbulent flow, the shape of the pdf appears to belong to a family of exponential distributions with powers in the exponent that vary with the Stokes number. Keywords: Isotropic Turbulence, DNS, Finite Inertia, Particle Collision Rate, Preferential Concentration Effect, Turbulent Transport Effect

Key words isotropic turbulence particle collision rate preferential concentration turbulent mixing effect DNS

DOI:

通讯作者 hustlrx@163.com