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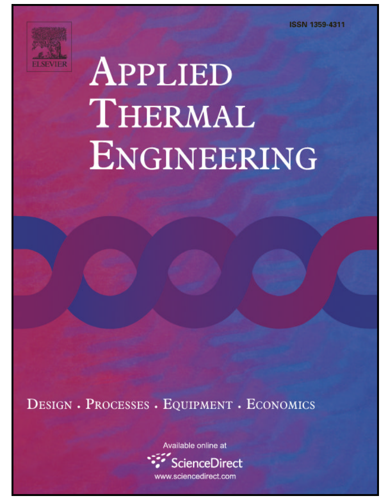

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Direct Numerical Simulation of Conjugated Heat Transfer between a Spherical Particle Rolling over a Planar Surface

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The heat transfer between particles and walls occurs in several industrial processes. Simplified models are applicable within their range of validity and give satisfactory results for known systems. On the other hand, for developing innovative apparatus with Process Intensification and energy efficiency in mind, e.g. a heat recovery system for biogas plants, it is crucial to understand the basic mechanisms. This work aims at reaching a fundamental understanding of the occurring transport phenomena both qualitatively and quantitatively under the presence of turbulence, since turbulence is known for enhancing transport phenomena. A highly resolved finite volume method is applied carrying out Direct Numerical Simulation (DNS) of fluid dynamics and heat transfer simultaneously. The performed simulations, for the first time, describe all involved physical phenomena of a solid particle moving within a fluid phase across a fixed solid phase on continuum level, where all involved phases (particle, gas phase and plate) are resolved with finite volumes. Global and local heat transfer coefficients are presented for spherical particles in a diameter range of 1 to 2 mm. Global heat transfer coefficients between sphere and plate lie in a range between 531 to 807 W/m²K, whereas local values of up to 40,000 W/m²K are observed. The particle Reynolds Number is varied in a range from 3 to 500 and covers flow regimes from laminar state up to transition to turbulent flow. Influence of turbulence on heat transfer mechanisms is discussed in this paper and it is demonstrated that the conductive mechanism is mainly responsible for heat transfer between sphere and plate, whereas the conductive mechanism dominates transport between sphere and gas phase.

Heat transfer; particle; sphere; Direct Numerical Simulation; turbulence

1. Introduction

Heat transfer between spherical particles and walls on the one hand and solely between particles on the other is relevant in several industrial apparatus, e.g. fixed-bed reactors, fluidised beds, tube dryers and rotary kilns. Up to now, different approaches were published, which describe only parts of the occurring phenomena. They can be grouped into approaches with and without explicitly resolved particle velocity. To begin with, approaches not resolving the particle velocity explicitly are discussed.

Yagi and Kunii [1] investigated the heat transfer on the wall of fixed beds for small Reyonlds numbers and formed a new correlation. They showed that neither the theory of penetration, nor the film theory, can adequately describe the real case. Kunii and Levenspiel [2] published a universal equation for the calculation of heat transfer coefficients on gas/particle contacts, covering the largest possible range of a regime (up to Re = 2000), thus reducing the number of special cases. In [3] extensive research results are combined into a detailed theoretical model. The model initially refers to a single static particle. Based on this, the influences of the particle bed and the movement are taken into account successively. Simplifying in this model, the temperature of the gas phase surrounding the particles is assumed to be constant, and the movement of the gas phase is neglected completely. Derkx and Dixon [4] investigated the heat transfer of fixed beds near the wall using CFD. The focus was on the use of detailed fluid dynamics information in the design of fixed bed reactors. By a finer, three-dimensional resolution of the CFD, the heat transfer could be simulated together with the chemical reaction and different influencing variables such as different catalyst particles and particle interactions could be depicted in detail [5]. The heat transfer in these simulations was modelled via Nusselt correlations for bodies in a flow. Feng et. al. [6] introduced a three-dimensional mathematical model for the gas solid heat transfer in sinter bed layers. Several macroscopic influence parameters such as height and diameter of the cooling section as well as particle diameter were investigated.

The next paragraph gives an overview of the approaches explicitly modelling the particle velocity.

Feng [7] carried out Direct Numerical Simulations of a rotating sphere with the Immersed Boundary Method in laminar flows for Reynolds numbers ranging from 0 to 1000. The particle was described by a Lagrangian grid