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Influence of Bar Motion on Heat-up and Temperature Dispersion of a Wooden Bed on a Forward Acting Grate

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The objective of this contribution is to investigate numerically into the impact of bar motion such as amplitude and frequency of a forward acting grate on the rate of heat-up and dispersion of particle temperature of a moving bed. The latter consists of wooden particles subject to a radiation heat flux form from the furnace walls on the particles that form the surface of the moving bed. While transported to over the forward acting grate each particle experiences a convective heat transfer by primary air in contact with the surface of the particles.
The recently developed Discrete Particle Method (DPM) as an advanced numerical simulation tool is employed to describe both heating and motion of a moving bed. Contrary to a continuum mechanics approach that spatially averages over an ensemble of particles, the Discrete Particle Method considers a moving bed as composed of individual particles with different sizes, shapes or material properties. The temperature distribution of each particle is described by a one-dimensional and transient differential conservation equation for energy with appropriate convective boundary conditions. Motion of particles is characterised by the motion of a rigid body through six degrees of freedom for translation along the three directions in space and rotation about the centre-of-mass. By describing these degrees of freedom for each particle its motion is entirely determined by Newton's Second Law.

1. Numerical Approach

As mentioned above, conversion and motion of individual particles are predicted by the conversion and motion module of the Discrete Particle Method (DPM).

1.1 Conversion Module

An individual particle is considered to consist of a gas, liquid, solid and inert phase whereby the inert, solid and liquid species are considered as immobile. The gas phase represents the porous structure e.g. porosity of a particle and is assumed to behave as an ideal gas. Each of the phases may undergo various conversions by homogeneous, heterogeneous or intrinsic reactions whereby the products may experience a phase change such as encountered during drying i.e. evaporation. The need for heterogeneous reactions was pointed out by Chapman (1996), while intrinsic rate modelling was

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emphasised by Rogers et al. (1975) and Hellwig (1988) to capture accurately the nature of various reaction processes. Furthermore, local thermal equilibrium between the phases is assumed. It is based on the assessment of the ratio of heat transfer by conduction to the rate of heat transfer by convection expressed by the Peclet number as described by Peters and Kansa et al. According to Man and Byeong (1994) one-dimensional differential conservation equations for mass, momentum and energy are sufficiently accurate. The importance of a transient behaviour is stressed by Lee et al. (1996). Transport through diffusion has to be augmented by convection as stated by Rattea et al. (2009) and Chan et al. (1985). In general, the inertial term of the momentum equation is negligible due to a small pore diameter and a low Reynolds number as pointed out by Kansa et al. However, for generality, the inertial terms may be taken into account by the current formulation.

Thus, the Discrete Particle Model (DPM) offers a high level of detailed information and, therefore, is assumed to omit empirical correlations, which makes it independent of particular experimental conditions for both a single particle and a packed bed of particles. Such a model covers a larger spectrum of validity than an integral approach and considerably contributes to the detailed understanding of the process.

1.2 Motion Module

The movement of particles is characterised by the motion of a rigid body through six degrees of freedom for translation along the three directions in space and rotation about the centre-of-mass. By describing these degrees of freedom for each particle its motion is entirely determined. Newton's Second Law for conservation of linear and angular momentum describes position and orientation of a particle depending on the forces and torques acting on it. Both forces and torques of a particle depend on position, velocity, orientation and angular velocity of neighbour particles that undergo impact with the respective particle. The contact forces comprise all forces as a result of material contacts between a particle and its neighbours. External forces may include forces due to gravity, fluid drag, and bounding moving or non-moving walls e.g. grate bars.

Applying both conversion and motion to each particle of a packed bed defines the entire particle processes so that the sum of a particle processes constitutes the all over global process symbolised by the following formula:

Entire Process = Σ Particle Processes

The gaseous flow such as primary air through the void space between particles of a packed bed is described by well established Computational Fluid Dynamics (CFD) - methods. Thus, each particle exchanges both mass and heat via its surface with the local state of the gas phase. Heat and mass transfer rates are described by empirical correlations for porous media. This concept offers a large degree of detail on both motion and heat-up that allow statistical analysis to compare the temperature distribution versus time dependent on motion of the grate bars.

For a detailed description including relevant conservation equations the reader is referred to Peter (2003).

2. Results

A packed bed consisting of 400 fir wood particles with a radius of 6 mm was chosen for the predictions. The particles' properties are summarized in the following table:

Table 1: Properties of fir wood

Property	Value	Property	Value
Density ρ	350.0 kg/m^3	Porosity ε	0.6
Specific heat c_p	1733.0 J/kg K	Pore diameter d	50.0 10^{-6} m
Conductivity λ_{fir}	0.2 W/mK	Tortuosity τ	1.0
Conductivity λ_{char}	0.1 W/mK	Radius	6.0 mm

The bar motion was set to a constant amplitude of 0.1238 m, while the frequency i.e. the time period for a complete forward and backward stroke was varied between 1 s and 10 s. A specific radiation flux of 30 kW/m^2 was employed to heat the packed bed. Only particles that have been moved to the top of the bed have been exposed to the radiation wall flux until they were moved to the inner part of the packed bed, and thus, shielded by newly emerging surface particles. In order to exclude effects of a spatially changing gas temperature all particles are exposed to a convective heat transfer with an ambient temperature of 300 K. The simulation time accounted to 600 s with periodic boundary conditions of which the temperature distribution is shown in fig. 1.

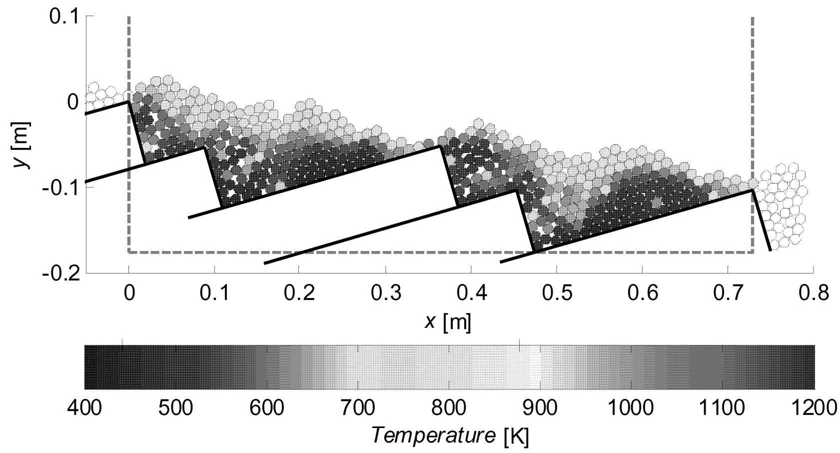

Figure 1: Temperature distribution of individual particles of a packed bed subject to a specific radiation flux of 30 kW/m^2 at a time of 600 s

Maximum temperatures of app. 900 K are reached, whereby particles at the bottom of the packed bed remain app. at their initial temperature of 400 K. Due to mixing of the forward acting grate during motion a redistribution of heated particles form the surface of the packed bed to its interior takes place, so that no strictly layered temperature profile develops.

Since temperatures of each particle at all times are known and in order to compare the influence of different bar velocities to the heat-up of a moving bed statistics has been employed to the temperature distribution. It yields a mean temperature including its standard deviation and naturally minimum and maximum temperatures. The statistics versus time are shown in fig. 2 and fig. 3 for a bar cycle period of 10s and 1 s. The maximum temperature of app. 900 K in fig. 2 for a cycle period of 10 s is reached after a period of app. 100 s and experiences hereafter only minor fluctuations. The same steady state value is reached for a faster bar motion in fig. 3 after a period of app. 200 s, however. Large differences are to be seen for the mean and minimum temperature in fig. 2 and fig. 3. Whereas a slow bar motion yields a mean temperature of app. 600 K, a faster bar motion increases the mean temperature by app. 200 K approaching the maximum temperature. Similarly, the minimum temperature is increased by app. 300 K from 400 K for a higher bar velocity. Thus, the temperatures of all particles vary over a range of 200 K only between 700 K and 900 K for faster bar motion. This is also manifested by the standard deviation of app. 40 K for faster bar motion as opposed to app. 100 K for a cycle period of 10 s. Hence, the results indicate that a faster bar motion leads to a more intensive mixing of particles on a forward acting grate, so that particles appear more frequently on the surface of the moving bed. This increases the heat transferred into the packed bed, and therefore, leads to a more homogeneous temperature distribution among the particles.

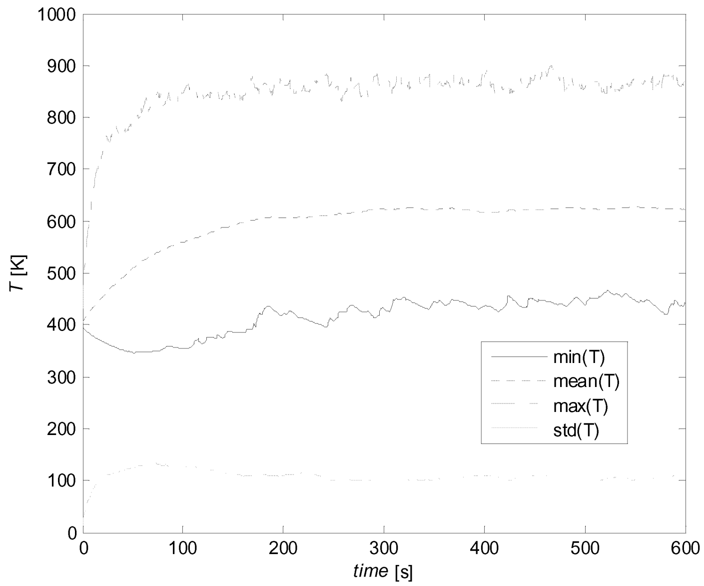

Figure 2: Evolution of mean temperature, its deviation, minimum and maximum temperature of a moving bed under a bar cycle period of 10 s

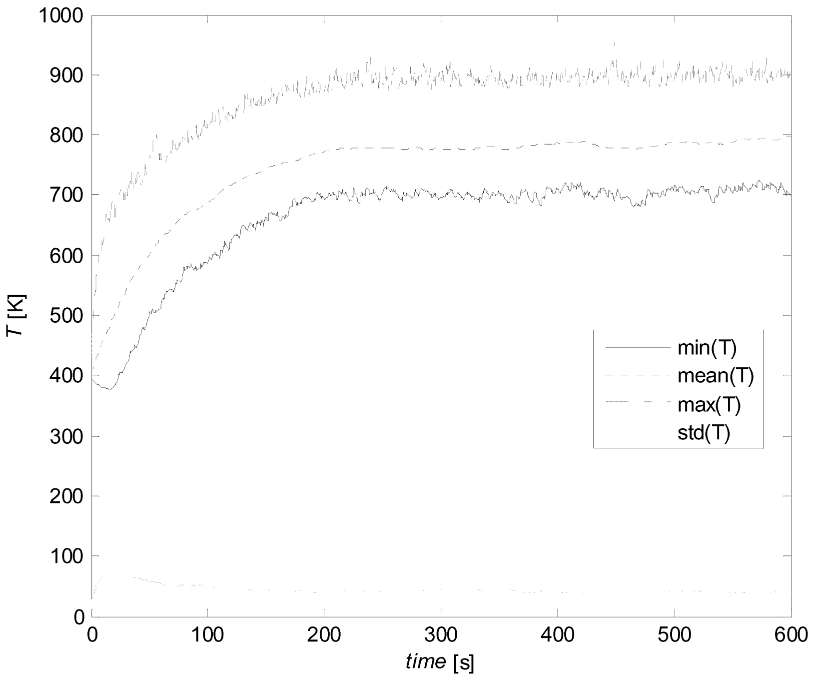

Figure 3: Evolution of mean temperature, its deviation, minimum and maximum temperature of a moving bed under a bar cycle period of 1 s

3. Conclusion

Within this study the effect of bar velocity of a forward acting grate on the heat-up of a moving bed has been investigated numerically that is not possible under experimental conditions. Therefore, the current approach is ideally suited to investigate into processes of particulate material and deepens the knowledge of thermal conversion of packed beds on forward acting grate or similar engineering devices. The results for a cycle period of 10 s and 1 s show that a higher bar velocity increases the mean temperature by 200 K due to an increased mixing of the bed. This contributes also to a smaller deviation of app. 40 K for an increased bar velocity as compared to a value of app. 100 K for slow bar velocities. In general it may be concluded that a higher bar velocity leads to an increased mixing rate of the particles, and therefore, to a more homogeneous temperature distribution. These results may be used to assess conversion of solid particles and to adjust temperature for a control of reaction progress.

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