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Introduction

In various industries such as petrochemicals, food, and pharmaceutical, wet granulation figures prominently in the production of intermediate or final products. Various phenomena are expected to occur in such systems: i) deposition of droplets on the particle surface due to particle-droplet collisions, ii) evaporation of liquid attached to the particle surface, and iii) particle agglomeration due to the collision of wet particles.

We use a numerical approach based on the Computational Fluid Dynamics – Discrete Element Method (CFD-DEM) to study particle-droplet-fluid interaction. To do so, additional modules for the simulation tool CFDEM[®] were developed to simulate particle-droplet-fluid interaction in a heated fluidized bed that features a spray injection region.

Methods and Materials

- Simulations were performed after substantial extension of the CFDEM[®] code [1]. The momentum equation for the gas phase is solved based on the Navier-Stokes equation, and particles follow Newton's equation of motion [2].

- The droplet deposition rate is calculated using the model of Kolakaluri [3]:

$$\dot{S}_d = -\lambda |\mathbf{u}_d - \mathbf{u}_p| \mu_{liq} \varphi_f \rho_f \quad (1)$$

- We solely focus on the so-called first drying period, and assume that the critical moisture content of the particles is zero (i.e., particles are non-porous). Then, the rate of droplet evaporation from the particle surface can be calculated based on the driving force for water vapor transport between particle and gas phase

$$\dot{S}_{evap,p} = |\rho_{w,sat} - \rho_g \mu_{vap}| a_{dp} \beta \quad (2)$$

- The rate of evaporation from the spray is calculated using the same methodology

$$\dot{S}_{evap} = |\rho_{w,sat} - \rho_g \mu_{vap}| \varphi_f a_d \beta \quad (3)$$

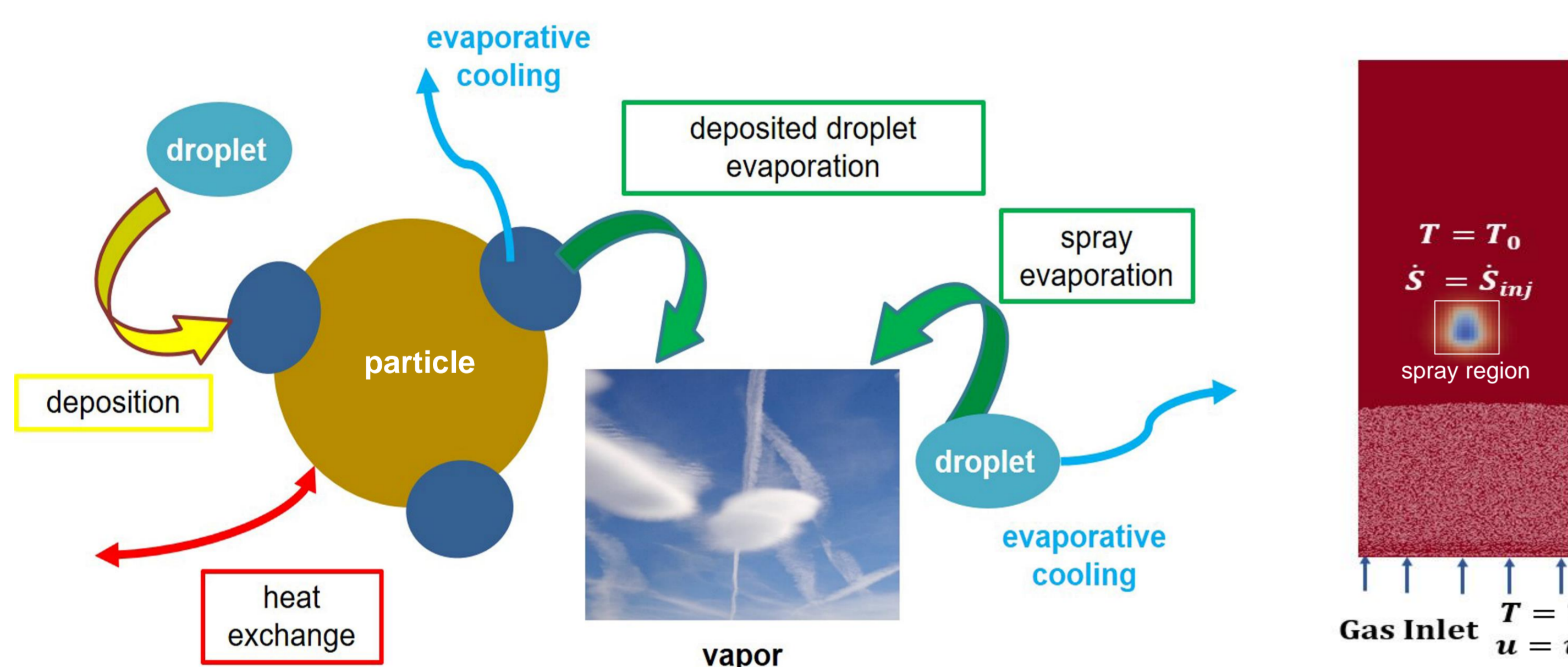


Figure 1. Illustration of various phenomena taking place in a wet fluidized bed.

Figure 2. Simulation setup (60,000 particles, $d_p = 140 \mu\text{m}$, fluidized with air).

Results

- The accuracy of the implemented model was examined through various verification studies for evaporation, deposition, and heat exchange. For example, the transient temperature profiles in a fixed bed (without evaporation, as well as considering a constant evaporation rate from the particle surface) were compared with analytical solutions (see Fig. 3 and 4).

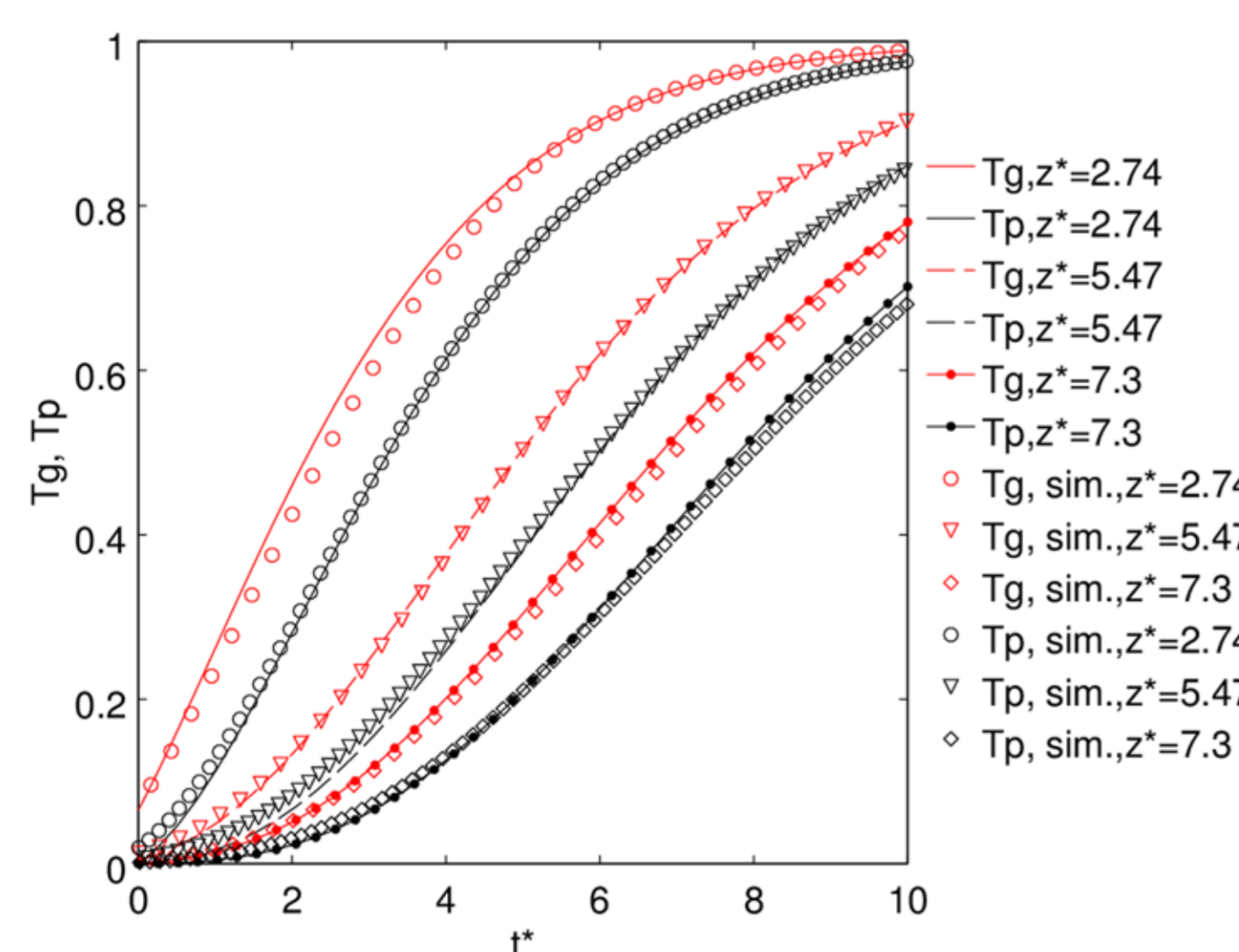


Figure 3. Comparison of the normalized gas and particle temperature between simulation and the corresponding analytical solution for gas-particle heat exchange.

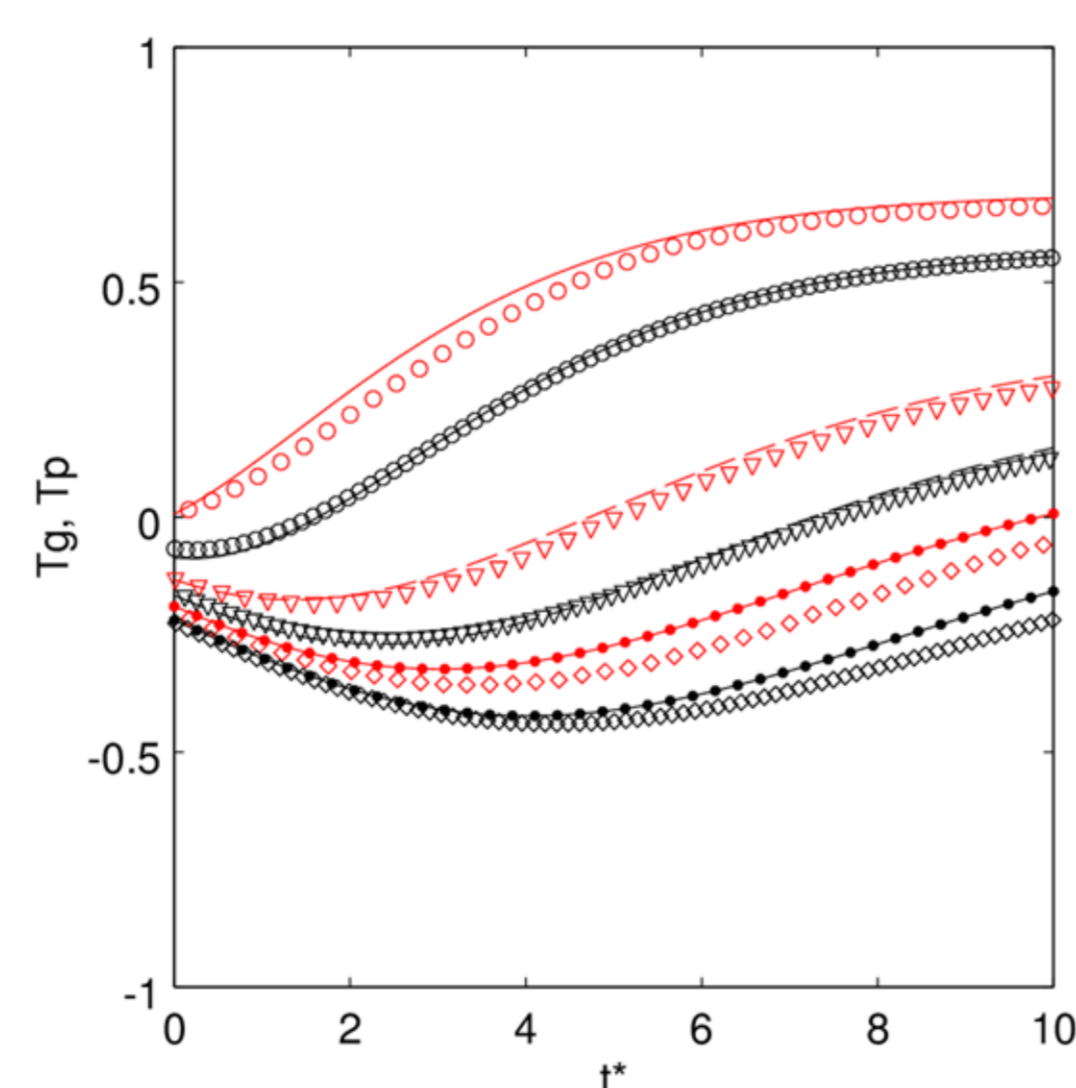
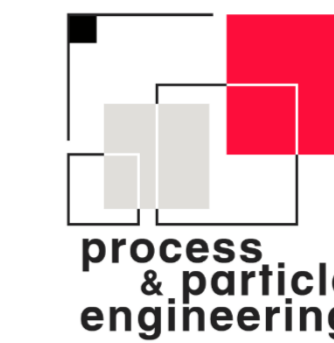


Figure 4. Comparison of the normalized gas and particle temperature between simulation and the corresponding analytical solution for gas-particle heat exchange and evaporation from the particle surface.

References

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- The contribution of involved phenomena has been investigated through simulation of various cases. The results of simulations for cases with and without spray evaporation are shown in Figure 5. Comparing the exchange rates in Figures 5a, the rate of spray evaporation is two orders of magnitude larger than the rates of the droplet deposition and evaporation from the particles' surface.
- In case of no spray evaporation (Figure 5b), the deposition rate is two orders of magnitude higher in comparison to its rate in the case with spray evaporation. Upon neglecting spray evaporation, the rate of evaporation from the particles increases. This is due to a lower vapor mass loading, and consequently the driving force for the evaporation is higher.

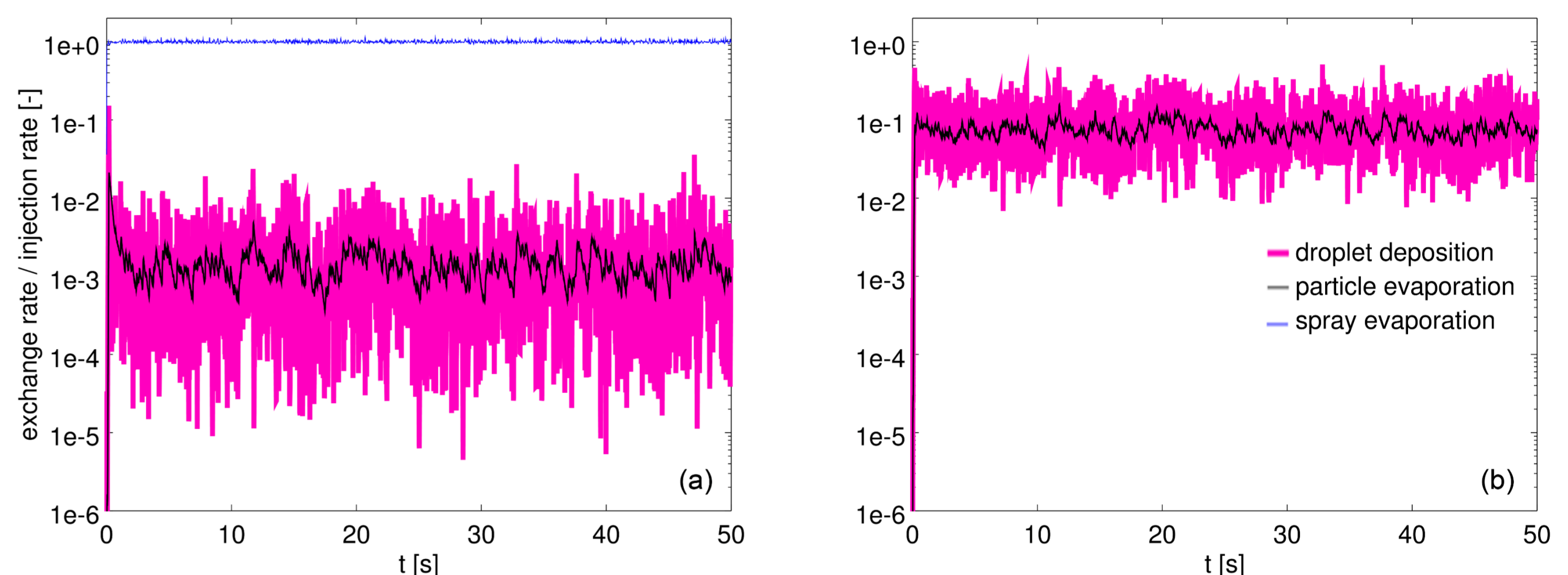


Figure 5. Exchange rates for the cases a) with all model, and b) without spray evaporation.

- The predicted mass loadings, temperatures, and LoD have been plotted in Figure 6. In the case with droplet evaporation, the gas temperature drops drastically within a few seconds. In contrast, the particle temperature decreases very slowly. This is due to the fact that evaporation cools the gas above the dense bed, and the higher heat capacity of the particle bed.
- Considering spray evaporation results in lower LoD because a lower amount of liquid is available for droplet deposition.

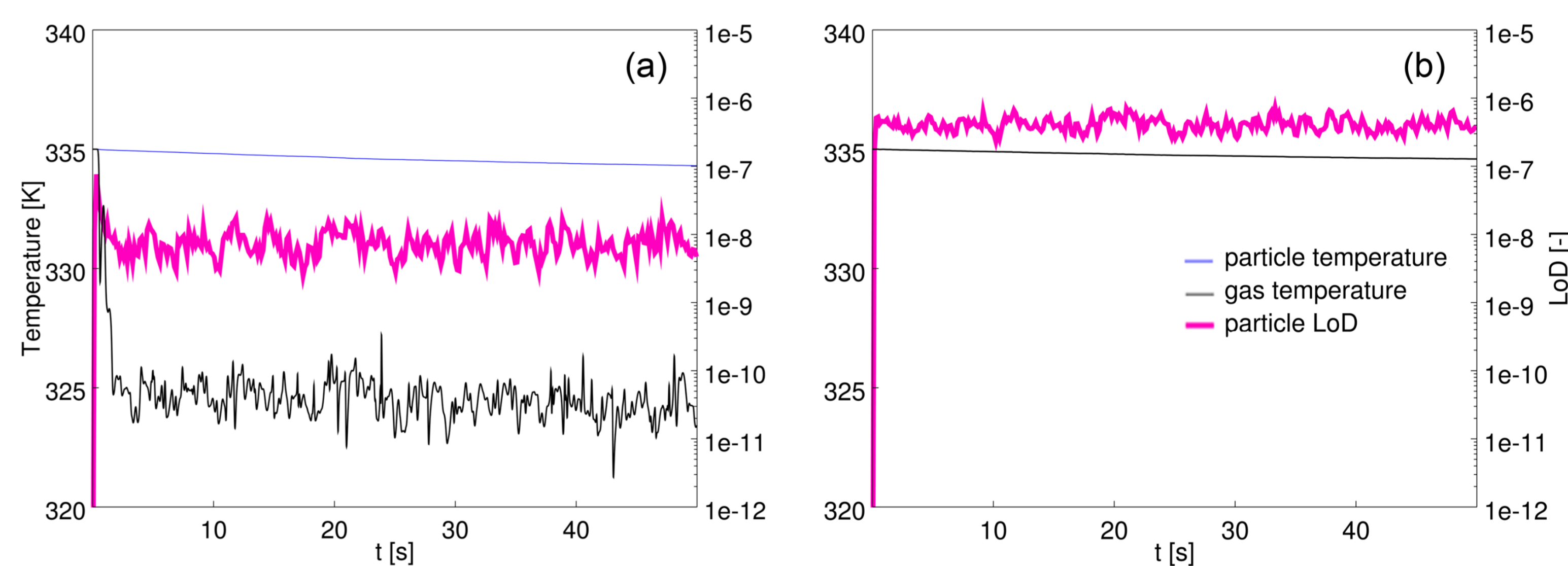


Figure 6. Temperatures and LoD for the cases a) with all model, and b) without spray evaporation.

- The gas temperature is approximately constant along the dense bed for both cases. However, the temperature dramatically decreases up to the spray zone center for the case with the droplet evaporation (see Figure 7).

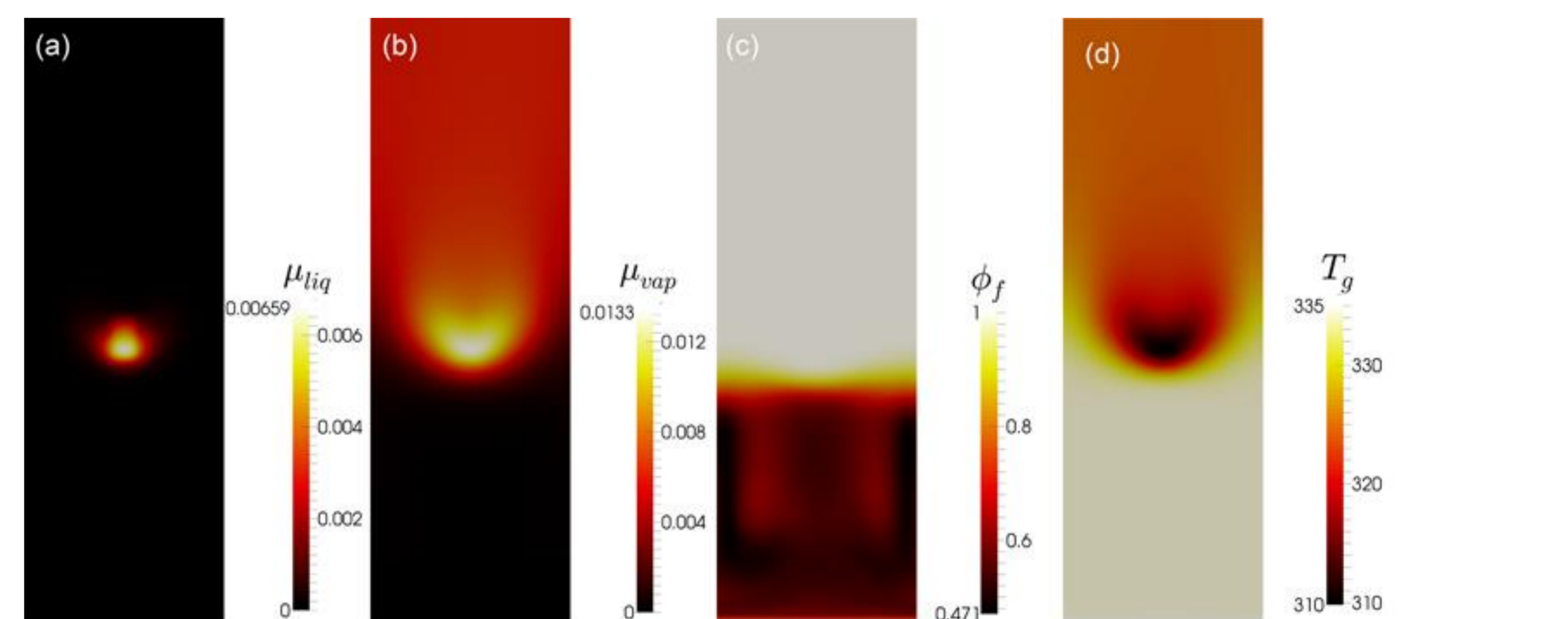


Figure 7. Time-averaged data for a) liquid mass loading, b) vapor mass loading, c) bed voidage, and d) gas temperature.

Nomenclature

a	1/m	Specific surface area	λ	1/m	Filtration coefficient
$\dot{S}_{evap,p}$	kg/s/m ³	Rate of evaporation from particle surface	μ_{liq}	kg/kg	Mass loading of liquid water in gas phase
\dot{S}_{evap}	kg/s/m ³	Rate of evaporation from spray	μ_{vap}	kg/kg	Mass loading of water vapour in gas phase
\mathbf{u}	m/s	Velocity	φ_f	m ³ /m ³	Fluid volume fraction
β	m/s	Mass transfer coefficient			