Prediction of Particle Agglomeration and Deposition by Reduced Particle Stiffness Discrete Element Simulations

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Prediction of Particle Agglomeration and Deposition by Reduced Particle Stiffness Discrete Element Simulations

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Introduction

- The collisions of small particles ($d_p < 10$ µm) in dry air are typically dominated by van der Waals attractive forces.
- Discrete element method (DEM) simulations combined with the analytical JKR adhesive model [1] is a promising mechanistic-based approach to accurately predict agglomeration and deposition of micron-sized particles [2].
- The general applicability and relevance in scientific fields ranging from particle fouling prediction [3] to early stages of planet formation in outer space [4] make the JKR model increasingly popular [5].
- However, resolving collisions of micron-sizes particles typically requires time step sizes in the order of nano seconds (10^{-9} s).

Purpose of study

- To provide a criterion on how to introduce softer particles with the same adhesive behaviour in DEM.
- Using softer particles (lower Young's modulus) allows for an increased time step size and thereby lower computational cost.

Main conclusions

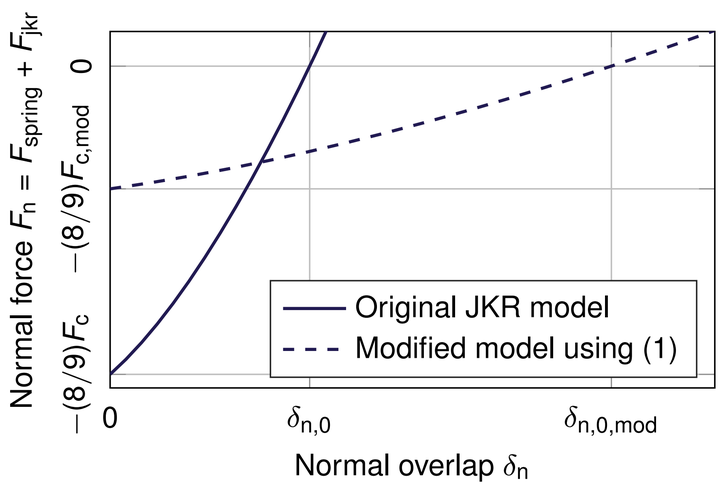
- Simulation time can be reduced several orders of magnitude by reducing Young's modulus from E to E_{mod} while modifying the surface energy density γ as:

$$\gamma_{mod} = \gamma \left(\frac{E_{mod}}{E} \right)^{2/5} \quad (1)$$

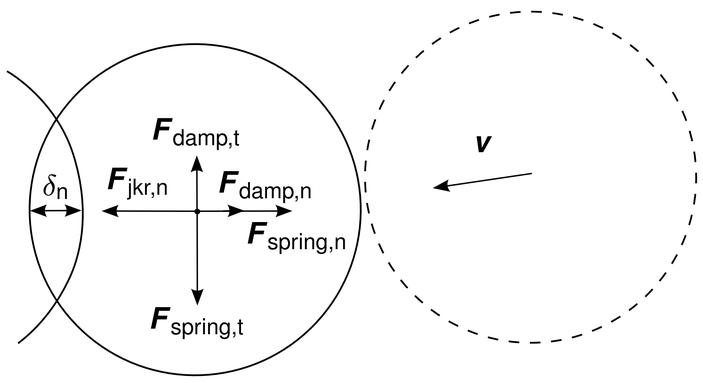
- Simulations that would take **years** can now be done in **hours** or **days**.

Overview of modified model

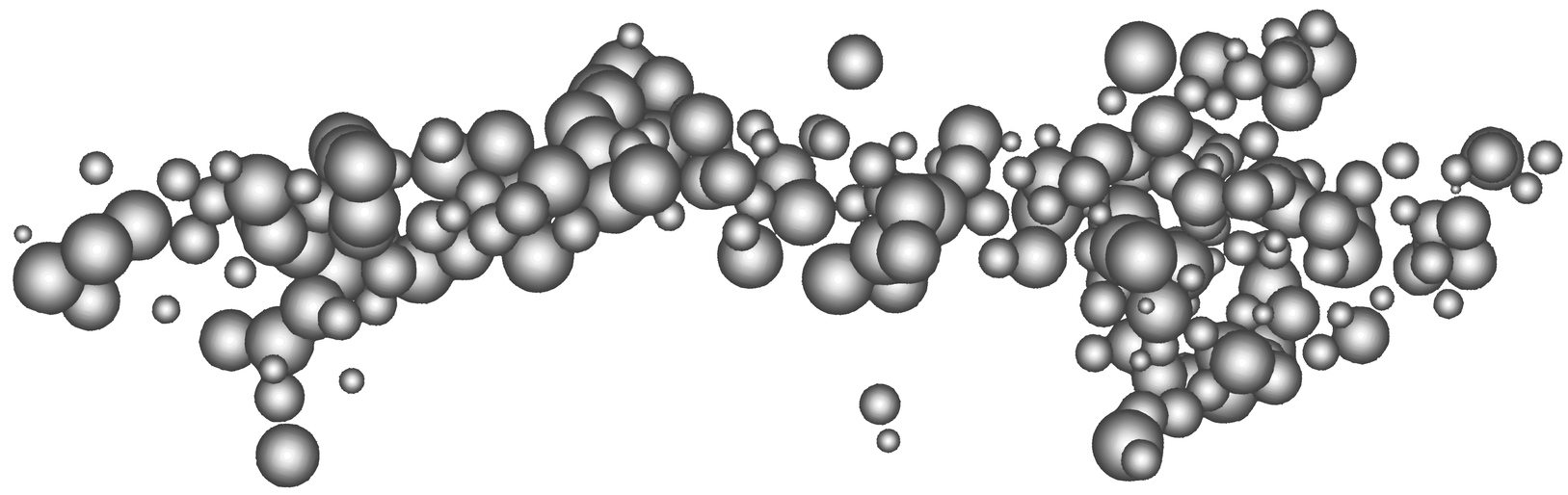
- Figure gives an overview of the force-overlap relation of the JKR model and modified model based on eq. (1):



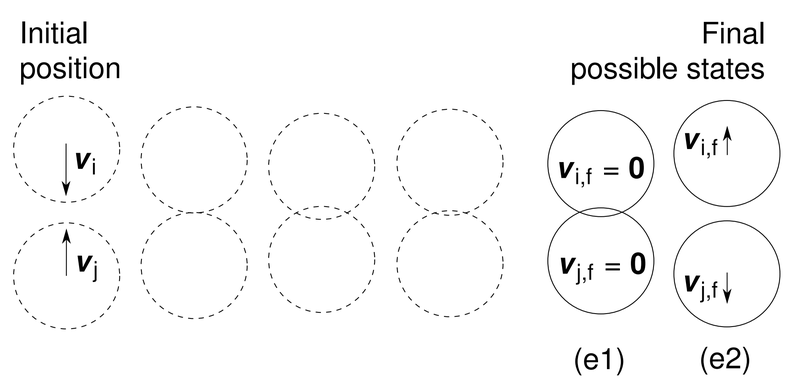
- Where $F_c = 3\pi\gamma R$ is the critical pull-off force to separate particles and $\delta_{n,0} = \left(3\pi^2\gamma^2 R/E^2\right)^{1/3}$ is the equilibrium normal overlap. Graphical overview of DEM forces:

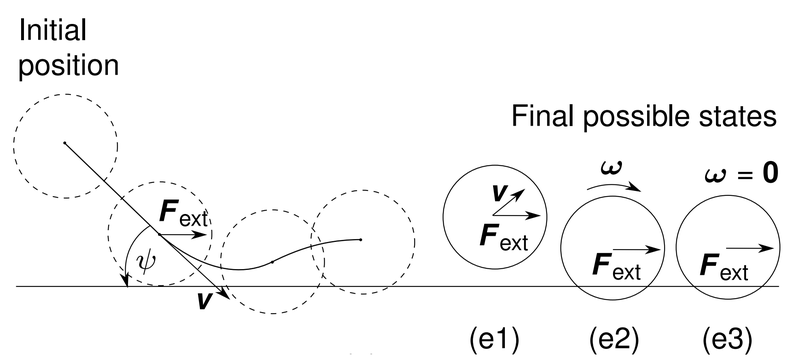


Agglomerate formed by van der Waals attractive forces



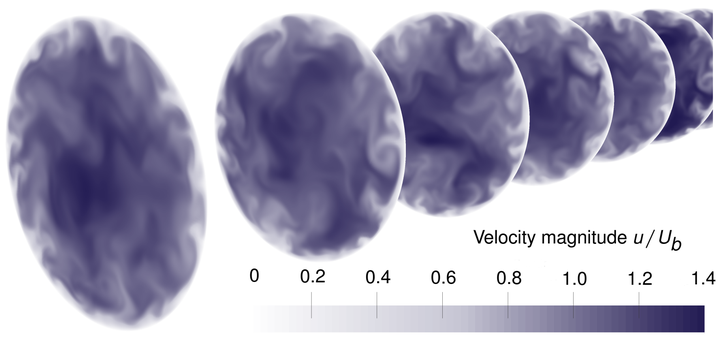
Validation cases





Coupling to turbulent flow

- Coupling DEM to large eddy simulations (LES) is a promising approach to investigate particle agglomeration and deposition mechanisms in details.
- Information is passed between fluid and particle phase by momentum exchange terms. Fluid drag takes local particle volume fraction into account.



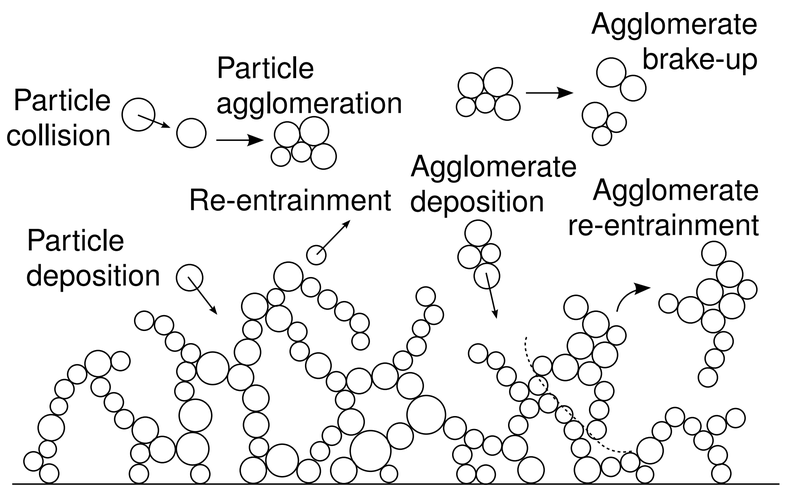
- Example of pipe flow at $Re_b = 10,000$ in a periodic domain with length $L/D = 4$.

Collaborating partners

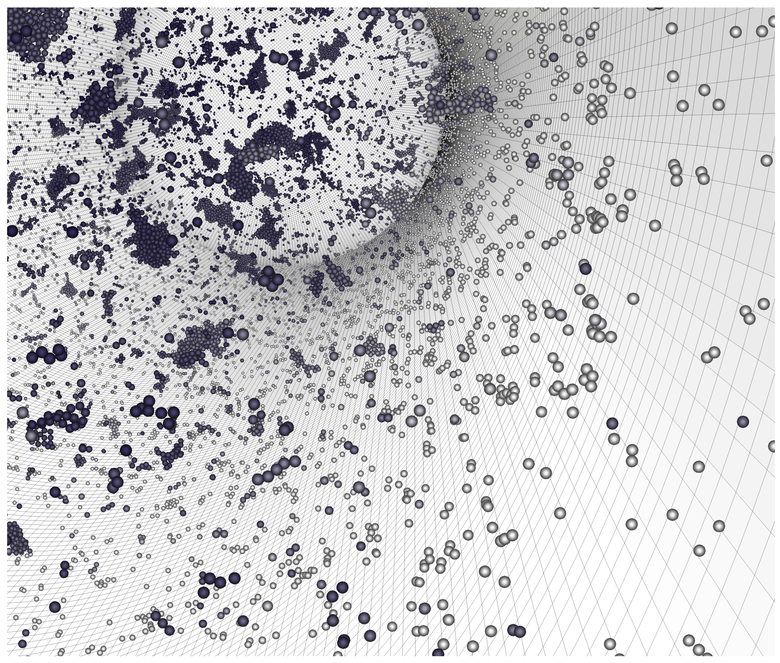
Technische Universität München · TU Delft Delft University of Technology · DTU Technical University of Denmark · Aalborg University Denmark · Alfa Laval · MAN · Maersk · Danfoss · Arla · Danish Technological Institute · viegand maagøe energy people

Outlook

- Particulate fouling in heat exchanger pipes is a major problem with high associated costs. The particulate fouling process can be decomposed up into the following sub-processes:



- Full-scale simulation using OpenFOAM and LIGGGHTS shows early stages of particulate fouling. Larger agglomerates are being formed in the centre of the pipe:



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