Ultra-fast calculation of conductive heat transfer in a moving granular medium

Institut Mines-Télécom

Parties prenantes

MINES Saint-Étienne

Une école de l'IMT

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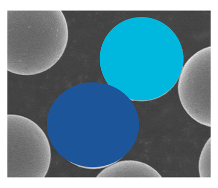
UNION EUROPÉENNE

1. Introduction

❑ **Particle-fluid systems can be found:**
- industries (fluidized beds, rotary kilns, …)
- natural phenomena (avalanches, pyroclastic flows, …)

❑ **Numerically:** Discrete Element Method (DEM) for particles



Microscopic level
- Contact Forces
- Transfers

Numerical simulations

Obstacle: CPU time

Industrial level
- Zillions of particles

2. Scientific challenge

How to accelerate the simulations of the processes at an industrial time scale?

3. Objectives

❑ **Develop models for pseudo-periodic systems to extrapolate DEM results from one period of time over a longer period**
- Application to conductive heat transfer in rotary drum

Standard DEM In one week

One million of particles

For one minute of real time

Extrapolated DEM In one minute

4. Proposed numerical method

Step 1

DEM simulation for one period

$$\frac{d\mathbf{x_i}}{dt} = \mathbf{v_i}$$

$$\frac{d\boldsymbol{\theta}_\mathbf{i}}{dt} = \boldsymbol{\omega}_\mathbf{i}$$

$$m_p \frac{d\mathbf{x_i}}{dt} = \sum(\mathbf{f_{ij}^t} + \mathbf{f_{ij}^n})$$

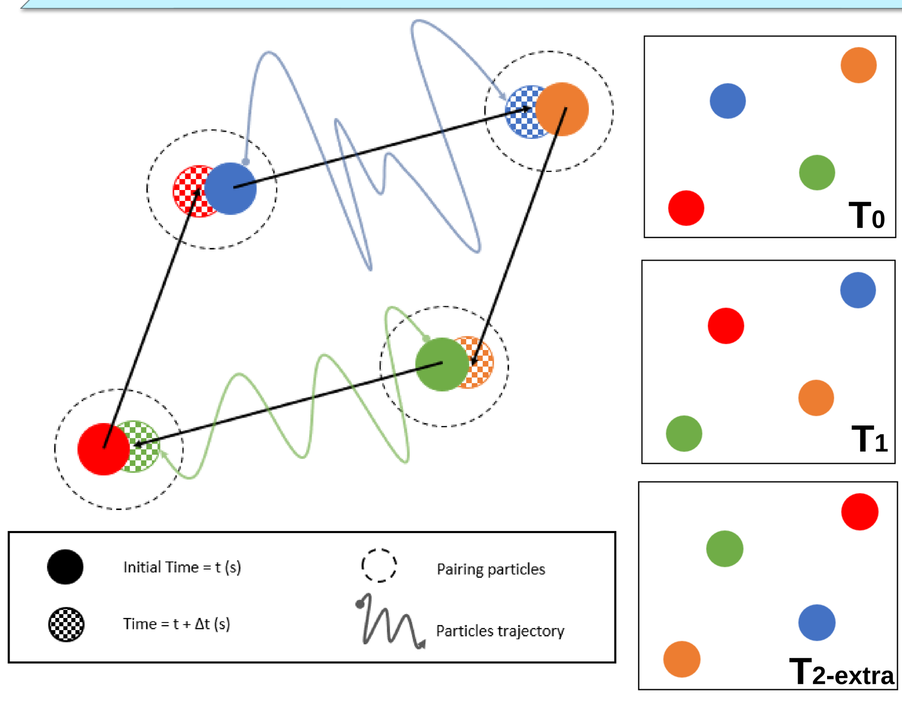
$$I_i \frac{d\omega_\mathbf{i}}{dt} = \sum(\mathbf{f_{ij}^t} \times \mathbf{r_{ij}})$$

❑ **Input:** Physical properties of the particles

❑ **Output:** Positions, temperatures and collisions list

Step 2

Granular motion extrapolation: Pairing algorithm[1]



Output

Red → Blue
Blue → Orange
Orange → Green
Green → Red

Scan for pairing algorithm video

Step 3: This work

Ultra-fast simulation for heat transfer in granular media

using the heat conduction equation [2]

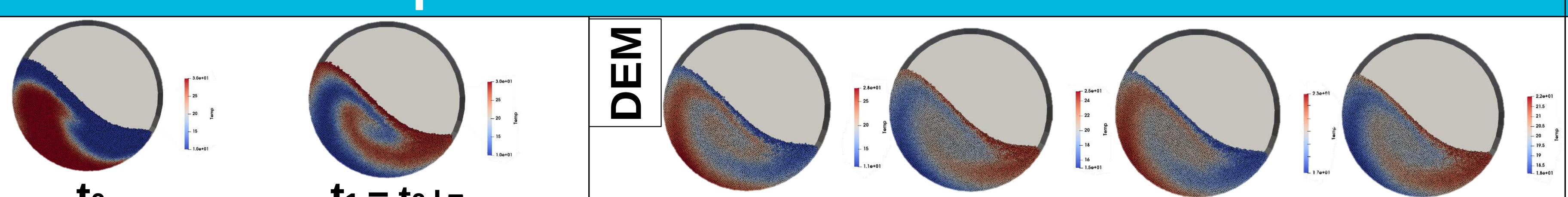
$$\dot{Q_{ij}} = K_s(T_i - T_j)$$

$$m_p C_i \frac{dT_i}{dt} = \sum(\dot{Q}_{ij_{contacts}})$$

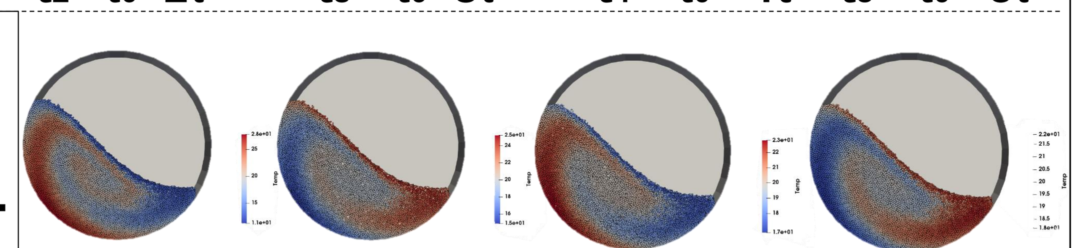
❑ **Output:** Extrapolated temperature of the particles

5. Results//Temperature field

DEM



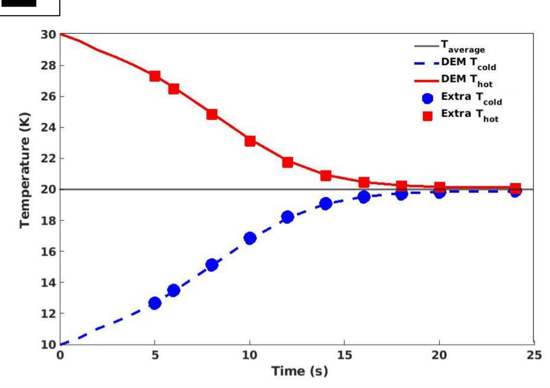
Extrapolated



Simulation properties

100 000 particles
- Half cold/ half hot
- Adiabatic wall
- Biot < 1
- Restitution coefficient= 0.2
- Rotation speed of drum ω = 5 s
- τ = 10 s = 2 ω

Scan to see the video of the temperature profile over time



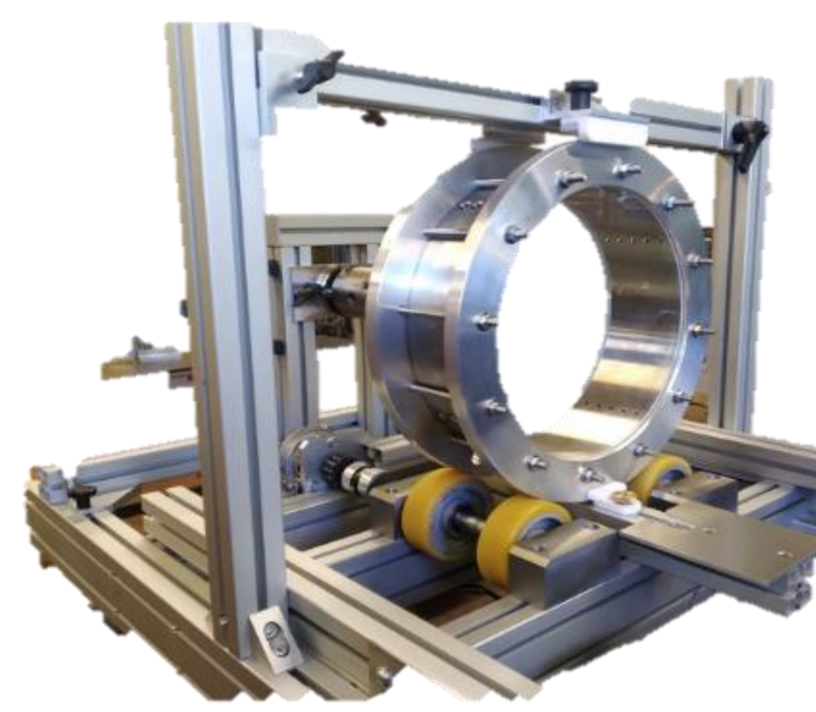
DEM: CPU time = 3900 s / τ

vs.

Extrapolated: CPU time = 6 s / τ

- **Temperature profiles are in agreement.**
- **Error is less than 2% with a gain factor of 650.**

Experimental Validation



Rotary drum constructed in SPIN centre at Ecole des Mines de Saint-Etienne.

Coming soon for experimental validation

6. Conclusions

Work Done/Novelty

❑ **DEM simulation for rotary kiln**
- Standard DEM and extrapolated DEM simulation with pairing algorithm

❑ **Ultra-fast simulation for conductive heat transfer**
- Extrapolation of the heat transport in granular media (massive reduction of CPU time)

Perspectives

❑ **Adaptation of the algorithm for fluid (convective heat transfer)**
- Extrapolation of results from a coupled CFD-DEM simulation

❑ **Validation of numerical results with experimental setup**
- Setting up experiments on the constructed rotary kiln for validation purpose

7. References

[1] Bednarek, X., Martin, S., Ndiaye, A., Peres, V., & Bonnefoy, O. (2019). Extrapolation of DEM simulations to large time scale. Application to the mixing of powder in a conical screw mixer. Chemical Engineering Science, 197, 223–234.

[2] Chaudhuri, B., Muzzio, F. J., & Tomassone, M. S. (2006). Modeling of heat transfer in granular flow in rotating vessels. Chemical Engineering Science, 61(19), 6348 - 6360.

[3] Kloss, C., Goniva, C., Hager, A., Amberger, S., & Pirker, S. (2012). Models, algorithms and validation for opensource DEM and CFD-DEM. Progress in Computational Fluid Dynamics, An International Journal, 12(2/3), 140.

[4] Lichtenegger, T., & Pirker, S. (2016). Recurrence CFD – A novel approach to simulate multiphase flows with strongly separated time scales. Chemical Engineering Science, 153, 394–410.

[5] Siegmann, E., Enzinger, S., Toson, P., Doshi, P., Khinast, J., & Jajcevic, D. (2021). Massively speeding up DEM simulations of continuous processes using a DEM extrapolation. Powder Technology.

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