ULTRA-FAST CALCULATION OF HEAT TRANSFER IN A MOVING GRANULAR MEDIA

Clara HAYDAR [1,2], Sylvain MARTIN [2], Olivier BONNEFOY [2] and Bruno BLAIS [1]

1. URPEI – Dept. of Chemical Engineering - Polytechnique Montréal, C.P. 6079, succ. Centre-Ville, Montréal, Québec, H3C 3A7, Canada

2. Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5307 LGF, Centre SPIN, F-42023 Saint-Etienne, France

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

Industrial level
- Millions of particles

Obstacle: CPU time

2. Scientific challenge

How to simulate the process of interest at an industrial time scale?

3. Objectives

- Develop models to extrapolate DEM results over a long period

Application to conductive heat transfer in rotary drum

Standard DEM	Extrapolated DEM
In one week	In one minute

One million of particles over 40 threads [1]

4. Proposed numerical method

First Step
DEM simulation for one period

Second Step
Pairing Algorithm [2]

Third Step: This work
Scaled up simulation for heat transfer in granular media
Low Computational Time!

$$\frac{d\mathbf{x}_i}{dt} = \mathbf{v}_i$$

$$m\frac{d\mathbf{v}_i}{dt} = \sum_j (\mathbf{f}^t_{ij} + \mathbf{f}^n_{ij})$$

$$I_i\frac{d\boldsymbol{\omega}_i}{dt} = \sum_i \mathbf{f}^t_{ij} \times \mathbf{r}_{ij}$$

Assumptions
- Pseudo-periodic system
- Identical particles
- Dense system

- **Step 1 :** Simulation to reach periodic state
- **Step 2 :** Define t_0 and t_1
- **Step 3 :** Associate particles by pairs
- **Step 4 :** Extrapolate the results to t_2

$$\dot{Q}_{pi-pj} = h_{c,i-j}\,\Delta T_{pi-pj}$$

$$h_{c,i-j} = \frac{4k_{pi}k_{pj}}{k_{pi}+k_{pj}}\left(A_{contact\,i-j}\right)^{\frac{1}{2}}$$

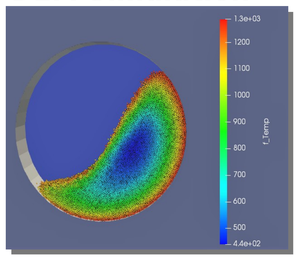
$$m_p c_p \frac{dT_{p,i}}{dt} = \underbrace{\sum_{contacts\,i-j}\dot{Q}_{pi-pj}}_{\text{heat conduction by contacts}} + \underbrace{\dot{Q}_{pi,source}}_{\text{heat generation due to sources, e.g. reactions}}$$

- **Input:** Physical properties of the particles
- **Output:** Positions, velocities and stresses

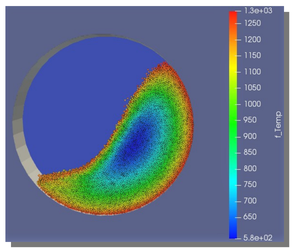
Scan for pairing algorithm video

5. Results//Temperature field

DEM Simulation

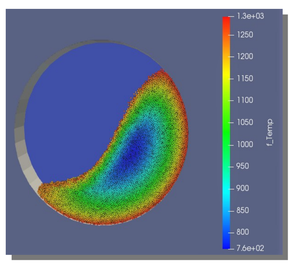


t_0

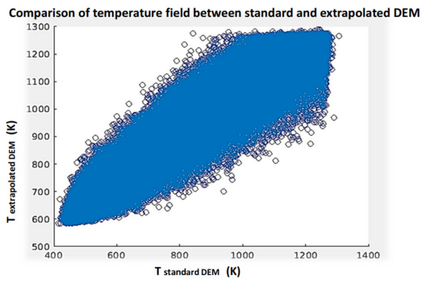


$t_1 = t_0 + 10s$

Extrapolated DEM Simulation



t_2(Standard DEM)



t_2(Preliminary/extrapolated DEM)

Scan to see the video of the temperature profile over time

Difference in results:
- Paring grid
- Small number of particles
- Order of collision in time

5. Results (Cont'd)

Experimental Setup

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

Coming soon for experimental validation!

6. Conclusions

Work Done

DEM simulation for rotary kiln
- Full simulation
- Extrapolated with pairing algorithm

Novelty

Scalar transport:
- Extrapolation of the heat transport in granular media

Perspectives

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

Adaptation of pairing algorithm for fluid
- Extrapolation of results from a coupled CFD-DEM simulation

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.

8. Acknowlegments

MINES Saint-Étienne – Une école de l'IMT
LGF UMR 5307
cnrs
SIS SCIENCES INGÉNIERIE SANTÉ – UNIVERSITÉ DE LYON – ÉCOLE DOCTORALE 488