The Impact of Granular Segregation on Heat Transfer in a Rotary Kiln

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GPS Génie par la simulation / SBES Simulation - Based Engineering Science

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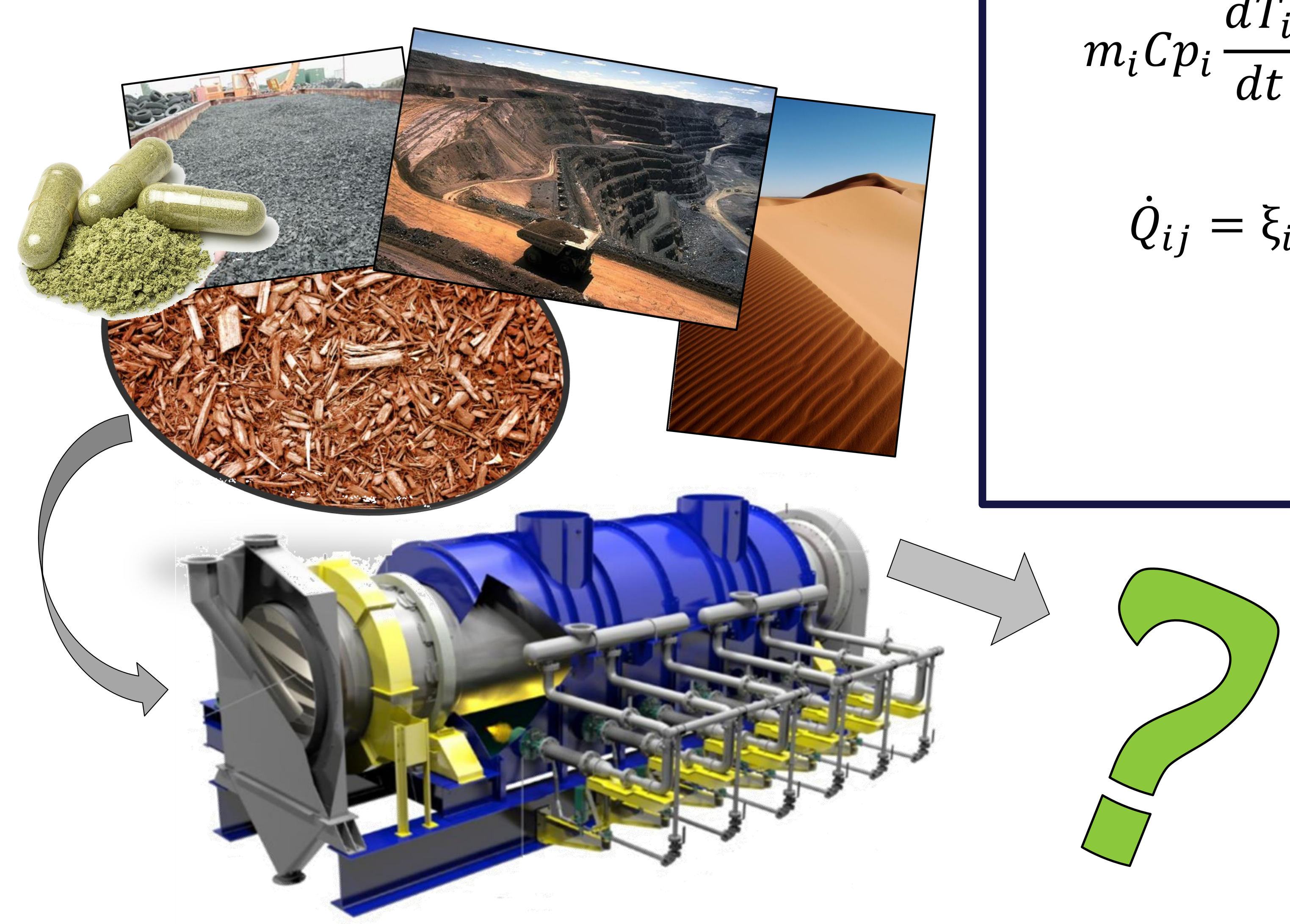
BRAZIL NUT EFFECT AND CEREALS

Granular Segregation : The small ones go on one side and the big ones on the other side! *No fighting!*

PROBLEM



Rotary kilns are versatile equipment often used in industry to heat, mix, coat, dry or transport different types of granular material. However, granular segregation taking place inside makes the unit temperature control challenging.

OBJECTIVE

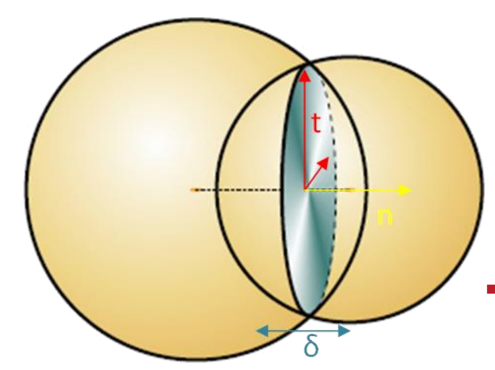
Quantify the impact of **granular segregation** on **heat transfer** in a **rotary kiln** to optimize granular processes.

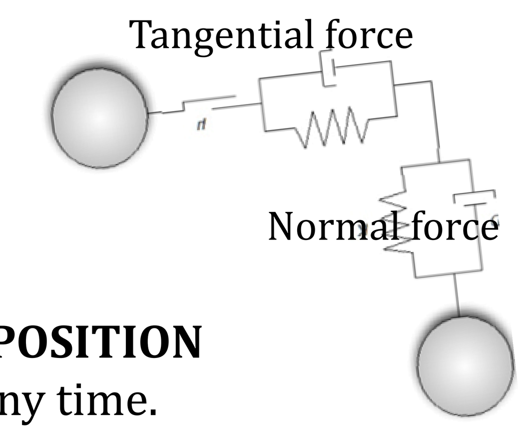
NUMERICAL MODEL IMPLEMENTED IN *LIGGGHTS*

Discrete Element Method (DEM)

Translation : $m_i \frac{d\mathbf{v}_i}{dt} = \sum_j \mathbf{F}_{c,ij} + \sum_k \mathbf{F}_{nc,ik} + \mathbf{F}_{g,i} + \mathbf{F}_{f,i}$

Rotation : $I_i \frac{d\boldsymbol{\omega}_i}{dt} = \sum_j \mathbf{T}_{ij}$





Momentum conservation gives us the **POSITION** and **VELOCITY** of every particle at any time.

Heat Transfer

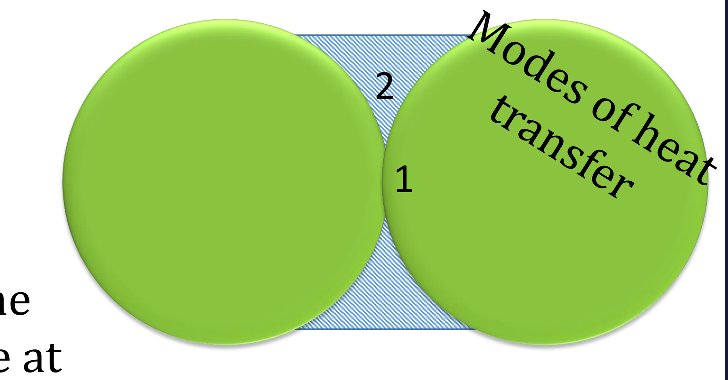
$$m_i Cp_i \frac{dT_i}{dt} = \sum_j \dot{Q}_{ij} + \dot{Q}_{i,source}$$

$$\dot{Q}_{ij} = \xi_{ij}(T_i - T_j)$$

Energy conservation gives us the **TEMPERATURE** of every particle at any time.

$$\xi_{ij} = \underbrace{\frac{4k_i k_j}{k_i + k_j}\left(A_{c,ij}\right)^{1/2}}_{\text{1. Solid conduction}} + \underbrace{\frac{k_f A_f}{L_f}}_{\text{2. Fluid conduction}}$$

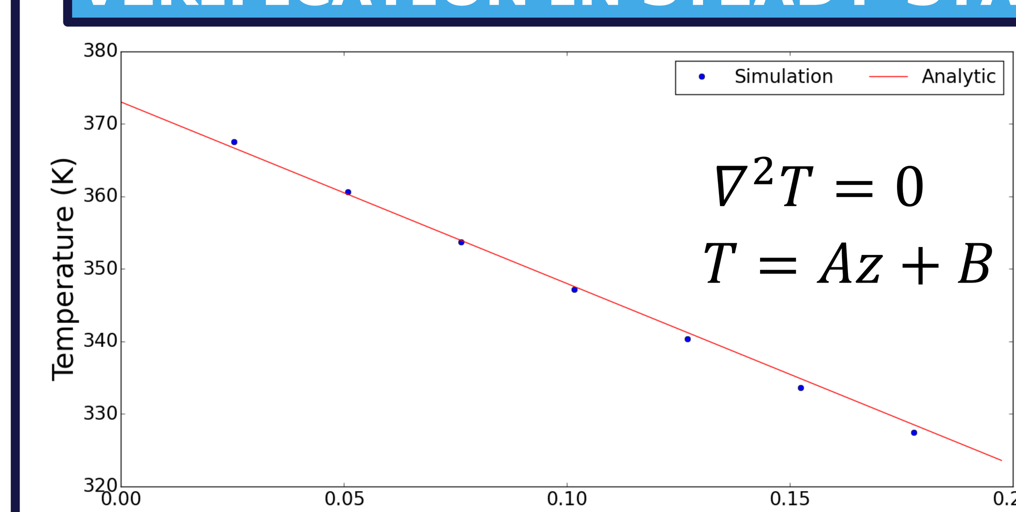
$$A_{c,ij} = (\pi \bar{r}_{ij})\delta_{ij}$$



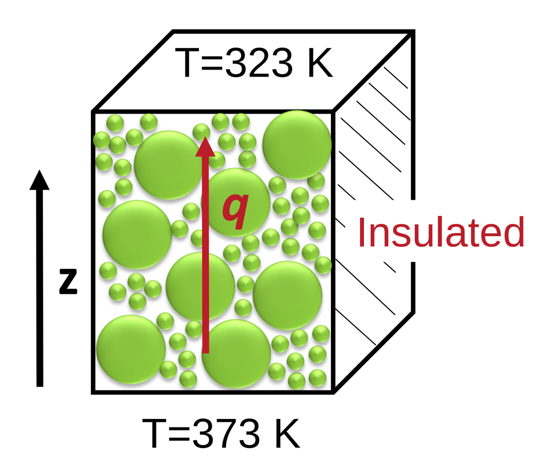
1. Solid conduction : at the contact point
2. Gas conduction : in the stagnant gas around the contact point

How to download LIGGGHTS : *cfdem.com*

VERIFICATION IN STEADY-STATE

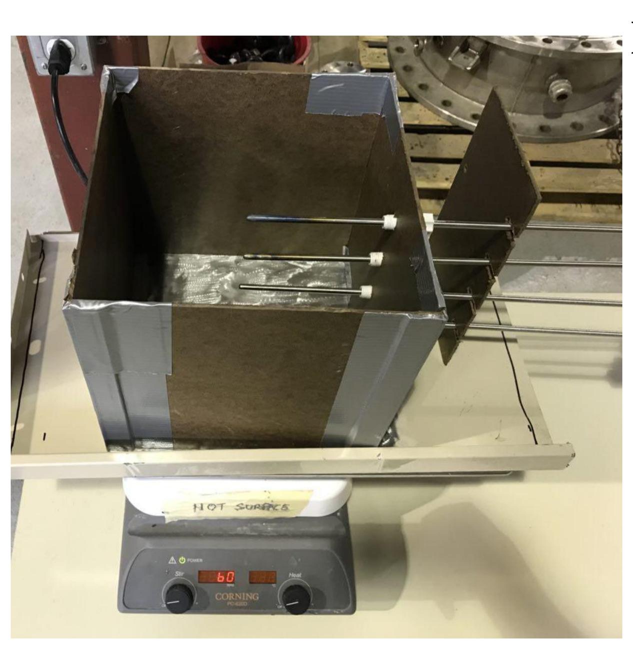


$$\nabla^2 T = 0$$
$$T = Az + B$$



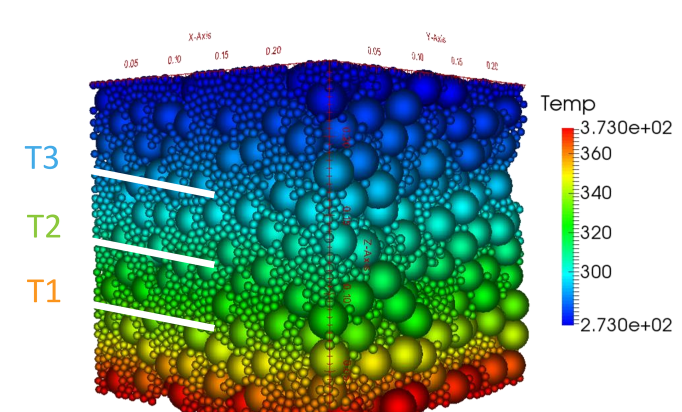
At steady-state, with constant temperatures as boundary conditions, we obtain the theoretical linear profile for the temperature against the height.

VALIDATION



T=373 K

Experiment with steel beads of 1" and ¼" in diameter.



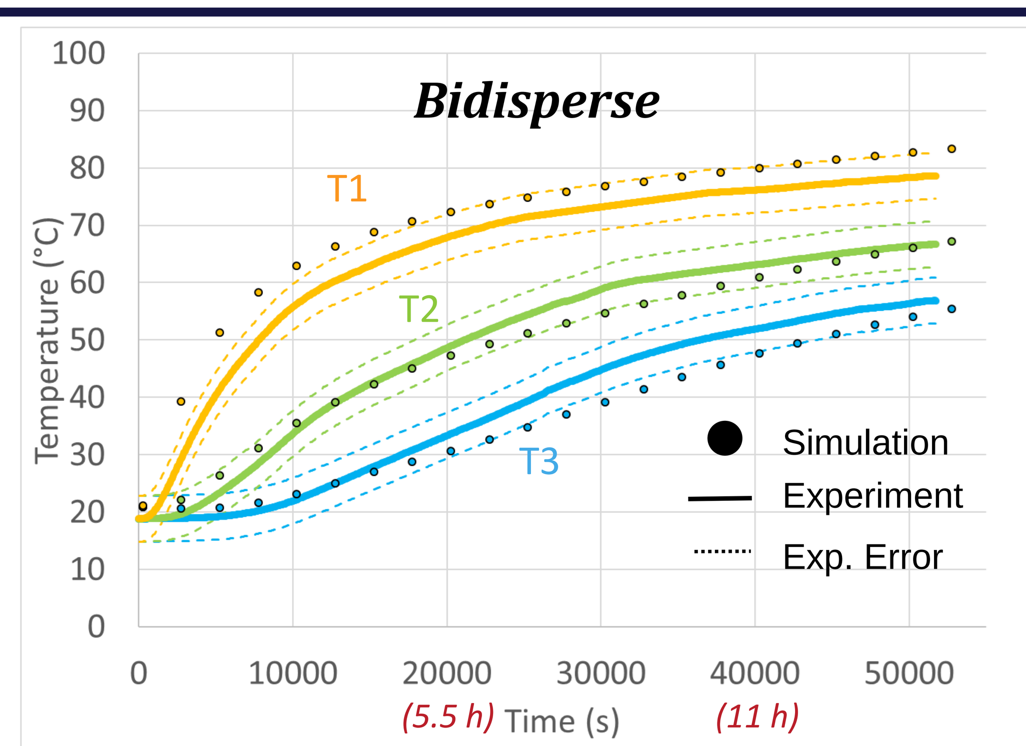
$k_{steel} = 17\ W/_{m.K}$

$k_{air} = 0.026\ W/_{m.K}$

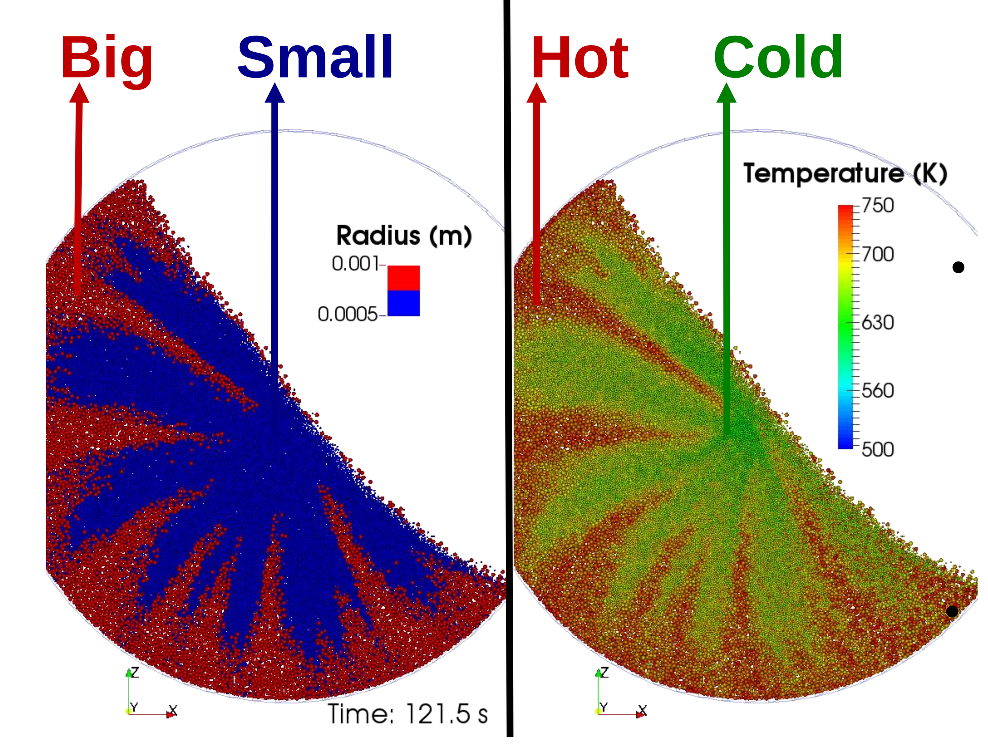
Our model is able to predict the temperature increase in a bed of steel beads of 2 different sizes.

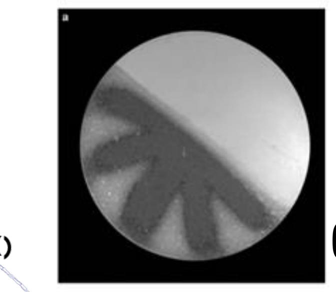
Ongoing work

- Validation with a mix of steel and glass beads
- Validation in dynamic based on literature data



RESULTS AND HIGHLIGHTS

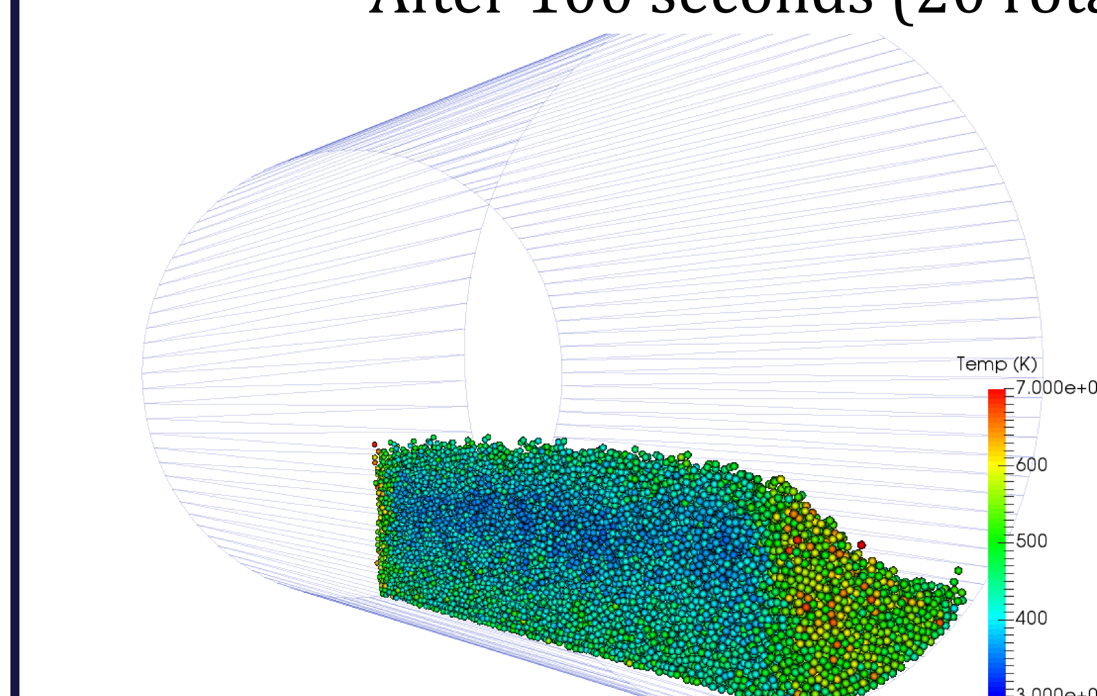




(Jain, 2005)

- The temperature profile in a drum filled with 2 types of particles matches the segregation profile, even with peculiar star-shape patterns.
- These segregation patterns are also obtained experimentally.

After 100 seconds (20 rotations at 12 RPM)

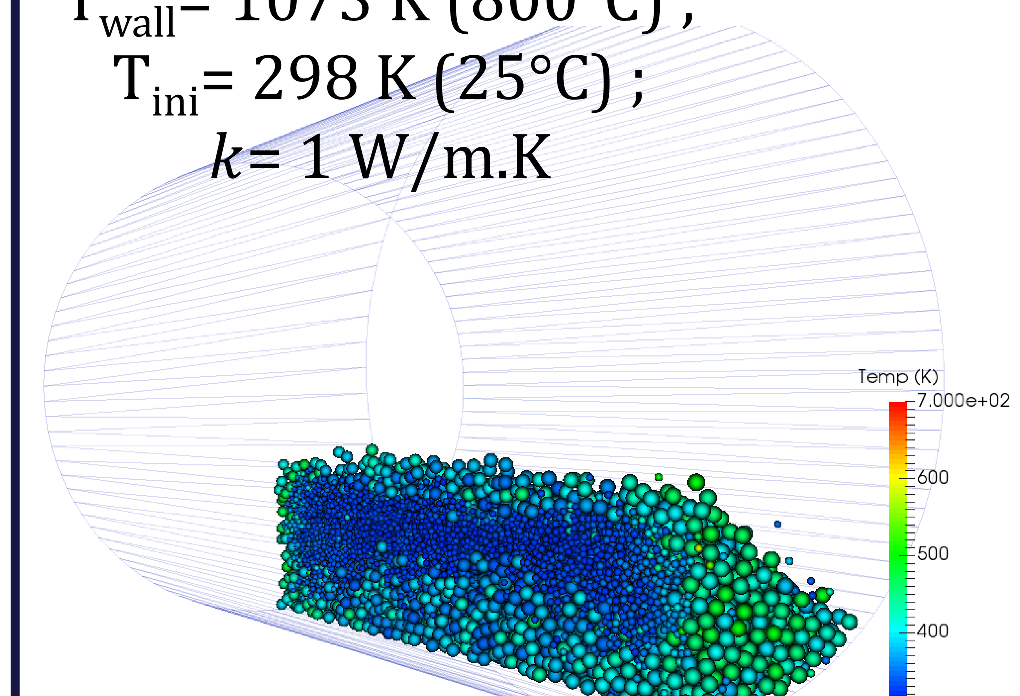


Monodisperse (d$_p$=3 mm)

T_{mean}= 430 K

T_{wall}= 1073 K (800°C) ;
T_{ini}= 298 K (25°C) ;
k= 1 W/m.K

- The formation of a core of smaller particles slows down the general heating of the drum when it is heated by the walls.



Bidisperse (d$_p$=3 mm and 6 mm)

T_{mean}= 350 K

30%vol of fines

NOMENCLATURE

m_i: mass of the particle *i* (kg)
v_i: velocity of the particle *i* (m/s)
$F_{c,ij}$: contact force between particles *i* and *j* (N)
$F_{nc,ik}$: non-contact force between particles *i* and *k* (N) *(neglected here)*
$F_{g,i}$: gravity force acting on particle *i* (N)
$F_{f,i}$: fluid force acting on particle *i* *(neglected here)*
I_i: moment of inertia of particle *i* (kg/m²)
ω_i: angular velocity of particle *i* (rad/s)
T_{ij}: torque acting on particle *i* in contact with particle *j* (N)
Cp_i: specific heat of particle *i* (J/kg.K)
T_i: temperature of particle *i* (K)
$\dot{Q}$: heat transfer rate (W)
ξ_{ij}: heat transfer coefficient between particles i and *j* (W/K)
k_i: heat conductivity of particle *i* (W/m.K)
$A_{c,ij}$: contact area between particles *i* and *j* (m²)
k_f: heat conductivity of the fluid (W/m.K)
A_f: conductive area for the fluid heat transfer (m²)
L_f: conductive length for the fluid heat transfer (m)
$\bar{r}_{ij}$: average radius of particles *i* and *j* (m)
δ_{ij} : overlap between particles *i* and *j* (m)

ACKNOWLEDGMENTS

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