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HYDRODYNAMIC BEHAVIOR OF QUINOA SEEDS IN A ROTARY DRUM USING THE DISCRETE ELEMENT METHOD (DEM)

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1 - Introduction

Rotary drums

- particulate systems + fluids
- isothermal or non-isothermal
- a large number of industrial processes: rotary kilns, dryers, mills, etc
- **But lack of simple tools for the industry**

Experimental



Modeling

- Dimensioning of process variables
- Materials properties

- Understanding the flow material behavior with more details
- Overcoming industrial safety limitations

Discrete Element Method (DEM):

Requires the specification of input parameters related to the particle properties and particle-particle (PP) and particle-wall (PW) interactions.

CALIBRATION STEP: varying the parameters until the model response corresponds to the equivalent experimental responses.

Problem in this approach:

Possibility of non-unicity in the set of parameters.

2 - Goals

- ❖ To study the influence of static friction (SF) and rolling friction (RF) coefficients in both interactions particle-particle (PP) and particle-wall (PW) on the dynamic repose angle of quinoa seeds in a rotary drum in rolling regime.
- ❖ To develop a Central Composite Design to combine the friction parameters of DEM input used in the calibration procedure.
- ❖ To obtain the regression models of the response surface methodology, which allows analyzing the interaction between the parameters and their significance.

Figure 1:



Rolling regime



Quinoa seeds

3 - Methodology

3.1. DIRECT COMPUTATION

Lagrangian Method or Discrete Element Method (DEM):

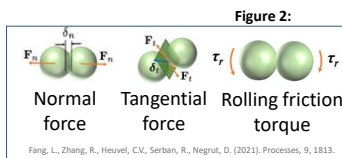
- All the particles trajectories are tracked
- Temporal integration is applied to each of them using Newton's laws:

$$\text{Translation: } m_i \frac{dv_i}{dt} = \sum_j (F_{ij}^n + F_{ij}^t) + m_i g$$

$$\text{Rotation: } I_i \frac{d\omega_i}{dt} = \sum_j (R_i \times F_{ij}^t) + \tau_{ij}$$

$$\text{Normal force: } F_N = \lambda_{AN} v_{Nij} - k_N \delta_N$$

$$\text{Tangential force: } F_T = \begin{cases} \mu_p F_N, & \text{se } |F_T| \leq \mu |F_N| \\ \lambda_{AT} v_T - k_T \delta_T, & \text{se } |F_T| > \mu |F_N| \end{cases}$$



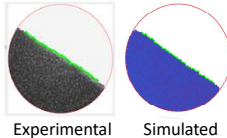
$$\text{Torque: } \vec{\tau}_{ij} = -\mu_R \vec{F}_N \times R_i \vec{\omega}_i$$

μ_p : Static friction coefficient (SF)
 μ_R : Rolling friction coefficient (RF)

3.2. MODEL PARAMETERS

- Drum: diameter 0.084m and length 0.020m
- Quinoa seeds: $d = 0.0017\text{m}$, $\rho = 1058\text{ kg/m}^3$
- Speed rotation: 12 rpm (rolling regime)
- Froude number: $Fr = 0.0068$
- Time-step = $8.6 \times 10^{-6}\text{ s}$ (5% of Rayleigh time)

Figure 3:



Experimental Simulated

- **Linear regression in the mean interface of 200 images of the bed drum, implemented by a MatLab code.**

3.3. PARAMETERS IDENTIFICATION

Response: dynamic repose angle: θ

1st step:

Analysis with 2 variables and interactions PP = PW

Static friction: 0.1, 0.3, 0.5, 0.7, 0.9
Rolling friction: 0.1, 0.3, 0.5, 0.7, 0.9

All the combinations

2nd step:

Analysis with 4 variables and interactions PP \neq PW

Varying: Static friction: 0.1, 0.3, 0.5, 0.7, 0.9
Rolling friction: 0.1, 0.3, 0.5, 0.7, 0.9
Other parameters are fixed.

3rd step:

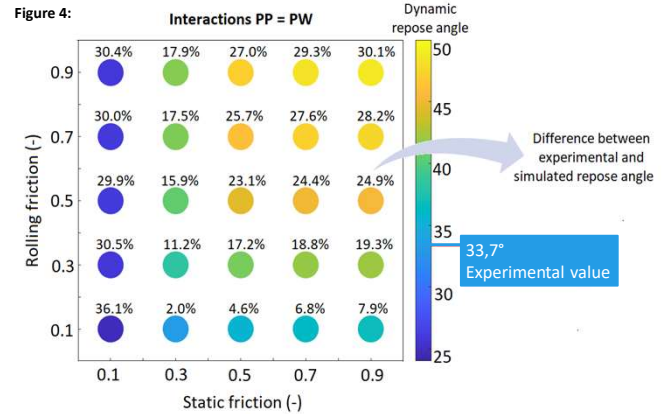
Central Composite Design (CCD) + Response Surface Method

Dynamic repose angle as a function of metamodel:

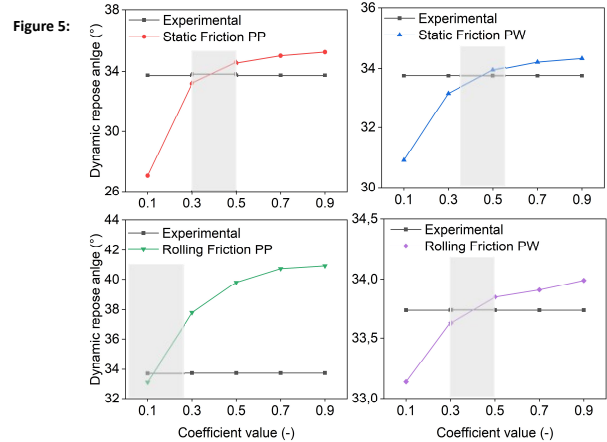
$$\theta = f(\text{SFPP}, \text{SFPW}, \text{RFPP}, \text{RFPW})$$

4 - Simulation results

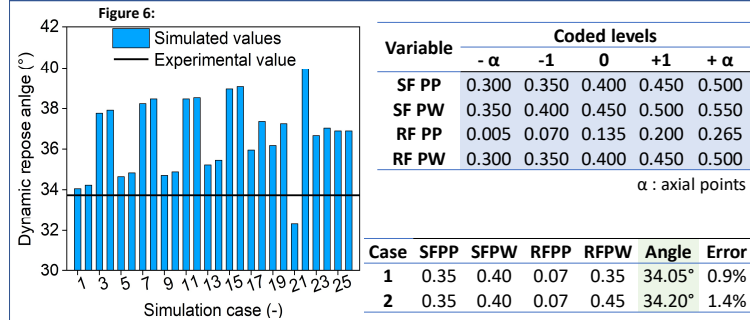
4.1. Parameter analysis with 2 variables: static and rolling friction



4.2. Parameter analysis with 4 variables: static and rolling friction, in each interaction particle-particle and particle-wall



4.3. Central Composite Design and Response Surface Method with 4 variables:



Metamodel of the dynamic repose angle (°) at 12 rpm:

$R^2 = 0,999..$

$$\theta = 20,13 + x_1 a_1 + x_2 A_1 x_2$$

$$a_1 = \begin{bmatrix} 23.08 \\ 18.98 \\ 39.95 \\ 1.68 \end{bmatrix}, A_1 = \begin{bmatrix} -20.61 & 0 & 0 & 0 \\ 0 & -15.11 & 0 & 0 \\ 0 & 0 & -41.78 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, x = \begin{bmatrix} \text{SFPP} \\ \text{SFPW} \\ \text{RFPP} \\ \text{RFPW} \end{bmatrix}$$

5 - Conclusions & perspectives

- ❖ The DEM provides a good representation of the phenomenon, allowing a satisfactory visualization, in Figure 3 (experimental and simulation comparison);
- ❖ The same methodology to measure the dynamic repose angle was used (implemented by MatLab code) for both experimental and simulated pictures;
- ❖ The Response Surface Method can satisfactorily represent static and rolling friction interaction parameters.
- ❖ Quantitatively, the simulation can represent the bed flow so that the dynamic repose angle simulated is very close to the experimental (Figure 4).
- ❖ **ONGOING WORK:** to analyze the influence of parameters in the bed flow of quinoa in other speed rotations using the metamodels.
- ❖ **NEXT STEPS:** to validate a set of parameters from the mixing assessment.

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