A phenomenological model for predicting segregation in particulate mixtures

Development of multivariable coefficients through statistical analysis

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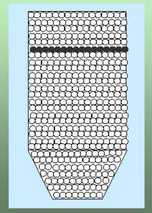
Proposed Way to Study Segregation

- Bench Scale Silo of 16 kg (≈ 30L & 1:20)
- Use of a thin layer of an "active" ingredient in the silo. Similar to the method of the pulse used in reaction engineering
- Taking samples to measure the *conc.* at the outlet



A Typical Example of a DOE

- Dry granular system, spherical and non cohesive
- 2^3, partially replicated
- Apparatus : transport and the compression machine hopper
- Conditions
  - Two size ratio : ≈2:1 and ≈4:1
  - Two density ratio : ≈1.5:1 and ≈2.5:1
  - Two types of flow « Mass » and « Funnel »
  - Measurement : C% vs $t_{equivalent}$

The "Excipients"

- Cohesive systems
  - Foremost Farm # 310 : 93 µm (average size), angular
  - Foremost Farm # 312 : 31 µm (average size), angular
  - Foremost Farm #316 (Fast Flo) : 93µm (average size), spherical
- Non Cohesive Systems
  - Sugar spheres
  - Sphericity: ~0,98
  - Size ranges
    - 500-600µm
    - 600-710µm
    - 710-850µm
    - 850-1000µm
    - 850-1180µm
    - 1000-1180µm
    - 1000-1400µm

The "Active" ingredients

- The "active" ingredients
  - Zeospheres
    - G-200, 5µm, 2.5g/cc, spherical
  - ZrO
    - 200-300µm, 3.8g/cc, spherical
  - Glass Beads
    - 200-300µm, 2.5g/cc, spherical
    - 400-600µm, 2.5g/cc, spherical
  - Silica Sand
    - 400-600µm, 2.5g/cc, sphericity ≈ 0.9

Classification of materials tested

- Based on literature and observations
  - Type of flow
  - Type of inter-particular forces

Mass Flow + Cohesive	Mass Flow + Non Cohesive
Funnel Flow + Cohesive	Funnel Flow + Non Cohesive

Definition of N_{SAS}

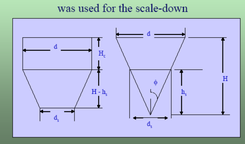
Expression of the tendency to segregation

- Non-dimensional number that allow to compare the segregation tendency of different systems

$$N_{SAS} = \frac{\left[d_{p_1} - d_{p_2}\right]^{\alpha} * \left[\frac{\rho_{a_1}}{1-\varepsilon_1} - \frac{\rho_{a_2}}{1-\varepsilon_2}\right] * \left[\frac{1}{w}\right]^{\delta} * \left[\psi_1 - \psi_2\right]^{\gamma} * \left[\frac{M_1}{M_2}\right]^{\lambda} * [\nu] * [\mu]}{\rho g \left[\frac{6\tan(\phi) d^2 H_{cyl} + \left[d^3 - d_s^3\right]}{\left[6\tan(\phi) d_s^2\right]}\right]}$$

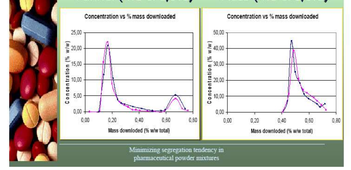
Use of N_{SAS} for the scale-down

The principle of geometric and dynamic similarity was used for the scale-down



Typical readings

- Funnel (4:1 & 1,5:1)
- Mass (4:1 & 1,5:1)



Usefulness of method and models

Analysis of Non-Cohesive Systems

Statistically significant parameters

Average time, t_m	Variance σ
✓ Type of flow	✓ Type of flow
✓ Size Ratio	✓ Size Ratio
✓ Density Ratio	✓ Bin Geometry

Storage Time and Components Conc. were not proven conclusive at the range tested

Modeling for t_m

$$t_m = \frac{E}{(D*d)^{0.2}} = E*(D*d)^{-0.2}$$

- E : Flow factor (=18 for Funnel Flow and 30 for Mass Flow)
- D : Ratio of diameters of the two components
- d : Ratio of densities of the two components

Modeling for σ

$$\sigma = EG * D^{0.2}$$

- EG : Form factor

Geometry	Flow: Funnel	Flow: Mass
Prismatic	80	8
Cylindro-conic	8	6

Analysis of Cohesive Systems

Statistically significant parameters

Average time, t_m	Variance σ
✓ Type of flow	✓ Type of flow
✓ Size Ratio	✓ Size Ratio
✓ Density Ratio	✓ Bin Geometry

Storage Time and Components Conc. were not proven conclusive at the range tested

Statistically significant parameters

Average time, t_m	Variance σ
– Size Ratio	– Concentration
– Concentration	

All other parameters were not proven significant but due to high level variability in the experimental observations definite conclusions are not possible

Modeling for Cohesive Systems

$$t_m = 40*D^{-0.5}*C\%^{0.2}$$

$$\sigma = 250*D^{0.5}$$

- D : Ratio of diameters of the two components
- C% : Concentration of Active component

Comparison Table

If	and	Then:
T_m↗	σ↘	Dispersion speed and propagation are lower. The system is more stable and segregation tendency is lower
	σ↗	Dispersion speed is lower but propagation is faster. The system is less stable and segregation tendency increases
T_m↘	σ↘	Dispersion speed is faster but propagation is lower. Our conclusion is uncertain. More work is needed by playing with variables
	σ↗	Dispersion speed and propagation are faster. The system is less stable and segregation tendency is higher

How to apply the method

- Take a granular system which gives a marginally "acceptable" RSD of its product and apply the method
- Take the new system under study and apply the method
- Compare results (in terms of t_m and σ)
- Use the "Comparison Table" to decide whether the system under study has a higher or lower tendency to segregation

50 ans L'audace porte fruit

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