Chapter 9 Mixing and Segregation

9.1 Introduction

☞http://sol.rutgers.edu/~shinbrot/Group_Index.html

9.2 Types of Mixture

* *Perfect mixing*

Random mixing

Segregating mixing

Figure 9.1

9.3 Segregation

(1) Causes and Consequences of Segregation

- The phenomena by which the particles with *the same* physical property (size, density and shape) *collect together* in one part of the mixture. Among them *particle size* is *most important* cause for segregation mechanisms
- Usually it occurs during *moving, pouring, conveying, processing*
- Its degree depends on *particle-particle interaction**

* *Free-flowing* powder or *coarse* particles → *segregating* rather than mixing

Cohesive powder or *fine* particles → mixing rather than segregating but easily *aggregating*

(2) Mechanisms of Separation   Figure 9-2

- *Trajectory* segregation

From Chapter 3 in lecture note,

Stop distance $s = \tau U = \frac{\rho_p d_p^2 U}{18\mu}$, 큰 입자가 멀리 간다.

- *Percolation* of fine particles - Figure 9.3

  작은 입자가 큰입자의 사이를 파고 들고 큰입자가 겉, 작은 입자가 속을 차지한다.

  Rise of coarse particles on vibration - Figure 9.4

- *Elutriation* segregation

  기체는 침강속도가 작은 입자를 들어올리나 침강속도가 큰 입자는 그대로 내려 오게 한다.

(3) Reduction of Segregation

Make *the sizes* of the components as *close* as possible

Reduce the absolute size of the particles

(< 30 μm with density about ρ_p= 2000-3000kg/m^3)

- Use of interparticulate forces
  - Critical diameter lowered as the density increases.

Add a small amount of *liquid*.

- Use of liquid-bridge force

Make *one of the components very fine* (less than 5 μm)

- *Ordered mixing**

Figure 9.5

Avoid to promote the segregation

e.g. use mass flow instead of core flow

Use continuous mixing for very segregating materials

9.5 Equipment for Particulate Mixing

(1) Mechanisms of Mixing

Diffusive mixing: random walk phenomenon

- Essential for microscopic homogenization

- Not suitable for segregating particles

e.g. Tumbling mixers : Figure 9.6

Shear mixing: induced by the momentum exchange of powders having different velocities

- Semimicroscopic mixing

e.g. High-velocity rotating blade

Low velocity-high compression rollers

☞ Chapter 10

Convective mixing: circulation of powders

- Beneficial for batch mode, not for continuous mixing
- Suitable for segregating particles

e.g. Ribbon blender : Figures 9.7, 9.8

Fluidized-bed mixer

Effect of particle size on mixing patterns

(2) Types of Mixers

Tumbling mixers, Figure 9.6

- Closed vessel rotating about axis
- dominant in *diffusive* mixing
- makes segregation for free flowing particles
- baffle installed has little effect

Convective mixers, Figures 9.7, 9.8

- static shell by *rotating blades or paddles*, < 1rps
- accompanied by some diffusive and shear mixing

Fluidized mixers

- largely *convective* by bubble motion
- mixing, reaction coating, drying etc.:carried out in the same vessel

High shear mixers

- high shear created by high velocity rotating blades low velocity-high compression rollers

- breaking down agglomerates of cohesive powders

※ *Ordered mixture*

- Dry impact blending method
- Mechanofusion method

(3) Power Requirement for Mixing

$$P = 2\pi N_s T$$

where N_s: rotation speed(rps)

T ?

- Horizontal Cylinder Mixer

$$\frac{T}{R^3 L \rho_b g} = A + B\frac{N_s^2 R}{g}$$

where R : radius of rotation

A and B : depend on powder properties

- V-Type Mixer

$$\frac{T_j}{R_{\max}^4 \rho_b g} = A_j + B_j \frac{N_s^2 R_{\max}}{g}$$

where A and B : depend on powder properties

- Stationary Vessel Mixer-ribbon and paddle impeller

$$T = K d_p^{\alpha_1} \rho_b^{\alpha_2} \mu_s^{\alpha_3} Z^{\alpha_4} D^{\alpha_5} \left(\frac{S}{D}\right)^{\alpha_6} b^{\alpha_7} f^{\alpha_8}, \ (\mathrm{N \cdot m})$$

where d_p: particle diameter(m)

ρ_b: bulk density(kg/m^3)

μ_0: internal friction coefficient

S: pitch of ribbon impeller(m)

b: width of impeller(m)

D: diameter of impeller(m)

f: charge ratio

Z: height of powder bed(m)

K, α_i's: depend on the type of mixers

9.6 Assessing the Mixture

For Binary mixture(2 components)

If y_i(i=1,2,……N): composition of the key component in the i-th sample,

Sample mean

$$\bar{y} = \frac{1}{N} \sum_{i=1}^{N} y_i$$

True mean

$$\mu = \bar{y} \pm \frac{tS}{\sqrt{N}}$$

where t : percentile value for *student's t distribution*

☞ Shaum's-Mathematical handbook

depends on *the level of confidence and the number of freedom(N)*

e.g. for 97.5% confidence and $N = 60$

$$t = 2.00$$

S : the *estimated* standard deviation

Standard deviation, σ and standard variance, σ^2

- *Estimated* standard variance(S^2)

$$S^2 = \frac{1}{N} \sum_{i=1}^{N} (y_i - \mu)^2$$

if true mean is known, otherwise

$$S^2 = \frac{1}{N} \sum_{i=1}^{N} (y_i - \bar{y})^2$$

- *Theoretical* Limits of variance

Upper limit: true standard deviation for a completely unmixed system, σ_0

$$\sigma_0^2 = p(1-p)$$

Lower limit: true standard deviation of random binary mixture, σ_r

$$\sigma_R^2 = \frac{p(1-p)}{n}$$

where p, $1-p$: fractions of two components in the whole mixture

- *True variance,* σ

when $N > 50$

$$\sigma^2 = S^2 \pm [t \times E(S^2)]$$

where $E(S^2) = S^2\sqrt{\frac{2}{N}}$

When $N < 50$

Lower limit: $\sigma_L = \frac{S^2(N-1)}{\chi_\alpha^2}$

Upper limit: $\sigma_U = \frac{S^2(N-1)}{\chi_{1-\alpha}^2}$

where χ_α: *chi-squared distribution* for significance level, α

$\alpha = 0.5(1-c)$ where c: confidence range

e.g. $c = 0.9 \rightarrow \alpha = 0.05 \rightarrow \chi_{0.05}^2 = 34.8$ for $N = 50$

- *Degree of Mixing*(Mixing indices)

the ratio of mixing achieved to mixing possible

Lacey : $\frac{\sigma_0^2 - \sigma^2}{\sigma_0^2 - \sigma_r^2}$

Poole : $\frac{\sigma}{\sigma_r}$

Worked Example 9.1, 9.2, 9.3