Chapter 7 Mixing and Granulation

7.1 Mixing and Segregation (Chapter 9)

Mixing vs. segregation

(1) Types of Mixture

* *Perfect mixing*

Random mixing

Segregating mixing

Figure 9.1

(2) Segregation

1) Causes and Consequences of Segregation

- *Particles with the same physical property (**size**, density and shape) collect together in one part of the mixture.*
- *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 $$s = \frac{\rho_p x^2 U}{18\mu}$$

- *Percolation of fine particles - Figure 9.3*

Rise of coarse particles on vibration - Figure 9.4

- *Elutriation segregation*

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}

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

  Add a small amount of liquid (Use of liquid-bridge force)
- *Make one of the components very fine (less than 5 μm)*

  *Ordered mixing**

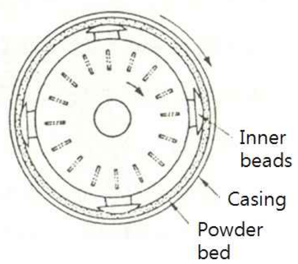
  Figure 9.5
- *Avoid to promote the segregation*
- *Use continuous mixing for very segregating materials*

4) Equipment for Particulate Mixing

- *Mechanisms of Mixing and Types of Mixer (9.5.1 and 9.5.2)*

Diffusive mixing	*- Random walk phenomenon* *- Essential for microscopic homogenization* *- Not suitable for segregating particles*	*Tumbling mixers, Figure 9.6*
Shear mixing	*- Induced by the momentum exchange of powders having different velocities* *- Semi-microscopic mixing*	*High-velocity rotating blade* *Low velocity-high compression rollers,*
Convective mixing	*- Circulation of powders by rotating blades* *- Beneficial for batch mode, not for continuous mixing* *- Suitable for segregating particles*	*Ribbon blender, Figures 9.7,9.8* *Fluidized-bed mixer*

** Ordered mixture by dry impact blending method*



5) 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,

<u>Sample mean</u>

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

* *True mean?*

<u>Standard deviation, σ</u> (standard variance, σ^2)

- *Estimated standard variance(S^2)*

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

- *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

<u>Degree of Mixing (Mixing indices)</u>

The ratio of mixing achieved to mixing possible

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

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

Worked Example 9.1, 9.2, 9.3

7.2 Size Enlargement - Granulation (Chapter 11)

* *Size enlargement - agglomeration of particles*

cf. coagulation

* *Why enlarge the particles?*

- *To reduce dust hazard*
- *To reduce cake and lump formation*
- *To increase flow properties*
- *To increase bulk density for storage*
- *To increase nonsegregating mixtures*
- *To provide defined metered quantity of active ingredients*
- *To control surface-to-volume ratio*

* *How enlarge the particles?*

- *Granulation: agglomeration by agitation (relative motion of particles)*
- *Machine granulation :compaction(tabletting), extrusion*
- *Sintering: thermal, final densification*
- *Spray drying: starting from droplets followed by its drying*
- *Prilling (freeze drying)*

(1) Interparticle Forces (11.2)

1) Van der Waals Forces

- *Between two spheres*

$$W = -\frac{A}{12z}\frac{x_1 x_2}{x_1 + x_2}$$

where A : *Hamaker constant*

z : *separation*

2) Forces due to Adsorbed Liquid Layers

- *Overlapping of adsorbed layers*
- *Dependent on area of contact and tensile strength of the adsorbed layers*

3) Forces due to Liquid Bridges

For pendular state Figure 11.1

$$F = 2\ r_2\ +\ r_2^2 \left[\frac{1}{r_1} - \frac{1}{r_2} \right]$$

* Strong granules in which the quantity of liquid is not critical...

* Granule strength continuously decreases in funicular, capillary and droplet states.

4) Electrostatic Forces

* Contact electrification:

- Friction caused by interparticle collision → Transfer of electrons between bodies

5) Solid bridges

- Crystalline bridges
- Liquid binder bridges
- Solid binder bridges

6) Comparison and Interaction between Forces

- Humidity vs. van der Waals forces, interparticle friction, liquid bridges and electrostatic forces

Figure 11.2 Tensile strength for various bonding mechanisms

(2) Granulation (11.3)

- Agitation: distribute liquid binder and impart energy to particles and granules for relative motion to meet together...

1) Granulation Rate Process (11.3.2)

i) Wetting

- Rate of penetration of liquid

θ γ μ

$$\frac{dz}{dt} = \frac{R_p \cos}{4 \ z}$$

Washburn equation

where R_p*: average pore radius, depending on particle size and packing density ☞ packing..*

θ *: dynamic contact angle*

μ *: viscosity of liquid, depending on the binder concentration*

ii) Growth Figure 11.3

- *Nucleation - shatter*
- *Coalescence - breakage*
- *Layering - attrition*
- *Abrasive transfer*

ρ μ

Define $Stk \equiv \frac{_{gr} V_{app} x}{16}$ *☞Box on p274 Ennis and Litster(1997)*

$$Stk^{*} = \left(1 + \frac{1}{e}\right) \ln\left(\frac{h}{h_a}\right)$$

where e *: coefficient of restitution*

h_a*: surface roughness of granules*

- *Noninertial regime:* $Stk < Stk^{*}$
  - · *all collisions effective for coalescence*
  - · *rate of wetting controls*
  - · *independent of liquid viscosity, granule size and kinetic energy of collision*
- *Inertial regime: some* Stk *exceeds* Stk^{*}
  - · *the proportion of successful collision decreases*
  - · *dependent on viscosity, granule size and kinetic energy*
- *Coating regime: average* Stk *exceeds* Stk^{*}
  - · *granule growth is balanced by breakage*
  - · *growth continues by coating of primary particles onto existing granules*

iii) Granule consolidation

- *increase in granule density by closer packing density*
- *squeeze out liquid*

2) Simulation of Granule Growth (11.3.3)

Rate of increase of number of granules in size interval v to v+dv	=	Rate of inflow of granules in size interval v to v+dv	-	Rate of outflow of granules in size interval v to v+dv	+	Rate at which granules enter size range v to v+dv by growth	-	Rate at which granules leave size range v to v+dv by breakage
(11.7)		(11.8)				(11.9) +(11.10)+(11.11)		

$$\frac{\partial n(v,t)}{\partial t} = \frac{Q_{in}}{V} n_{in}(v) - \frac{Q_{out}}{V} n_{out(v)} + \frac{\partial G(v) n(v,t)}{\partial v} + B_{nuc}(v)$$

$$+ \frac{1}{2}\int_0^v \beta(u, v-u,t) n(u,t) n(v-u,t) du - \int_0^\infty \beta(u,v,t) n(u,t) n(v,t) du$$

$$- \frac{\partial A(v) n(v,t)}{\partial v}$$

3) Granulation Equipments (11.3.4) *Table 11.1*

- *Tumbling granulator   Figure 11.4*
  - *Tumbling inclined drum and pan*
  - *Operate in continuous mode*

- *Mixer granulator*
  - *Rotating agitator*
  - *From 50 rpm(horizontal pug mixer-fertilizer) to 3000 rpm(vertical Schugi high shear continuous granulator-detergent, agricultural chemicals)*

- *Fluidized bed granulators*

- *Bubbling or spouted bed Figure 11.5*
- *Operate in batch or continuous mode*
- *Good heat and mass transfer*
- *Mechanical simplicity*
- *Combine drying stage with granulation*
- *Produce small granules*
- *Running cost and attrition rates : higher*