Batch Mixing of Solids and Scaling Considerations

Presented By:
Stephanie Trant

Resodyn Acoustic Mixers — Technical InterChange 2025

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Outline

- Fundamentals of RAM Mixing
- Conventional Mixers Compared
- Powder Properties
- Batch Powder Mixing
  - Free Flowing
    - Defined
    - Mix regime in RAM
  - Cohesive
    - Defined
    - Mix regimes in RAM
      - Banding
- Batch Scaling

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RAM Mixing Video

- Salient Features of RAM Mixing
  - Rapid mixing
  - Well mixed
  - No paddles, ribbons, or complex geometries to clean
  - Eliminates de-mixing

60 fps

35 gm Avicel (~50 micron)
20 gm Blue Chalk
Acceleration: 100 *g*

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RAM Movement

- ResonantAcoustic® Mixers Create Up to 0.55 Inch Oscillating Displacements at ~60 Hz (Up to 100 *g* of Acceleration)

Empty container at 100 *g* of acceleration
3,600 fps

0.55 inch

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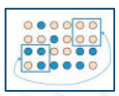
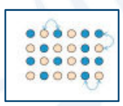
Mechanisms of Powder Mixing-Conventional Mixers

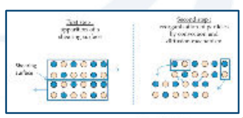
- Convective Mixing – Involves the Bulk Movement of Large Amounts of Particles From One Part of the Powder Bed to Another



- Diffusion Mixing – Mixing Occurs During Random Movement of Individual Particles



- Shear Mixing – Mixing Caused by Particle Movement From One Shear Zone to an Adjacent Shear Zone



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Blender/Mixer	Mixing Mechanism	Limitations
Tumble Mixers 	Diffusion Convective	Mixer footprint and head height Segregation during mixing and emptying Axial Mixing
Paddle or Ribbon Mixers 	Convective Shear	Difficult to Clean Axial mixing Not recommended for fragile materials
Auger Mixers 	Convective Shear	Difficult to Clean Mixer Head Height Not recommended for fragile materials

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RAM Versus Conventional Mixing

		
Diffusion Mixing	Uses gravity (1 *g*) as the restoring force to drive small scale random particle motion	Uses up to 100 *g* to drive random particle motion to mix
Convective Mixing	Uses rotational movement at ~30 rpm to split and combine material systematically	Uses vessel movement at 60 Hz (~3,600 cycles per minute) to impart high energy chaotic motion
De-mixing	The systematic motion of the v-blender can cause de-mixing	Random and chaotic motion of RAM prevents de-mixing

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RAM Attributes

- Rapid Mixing – Up to 100 *g* of Acceleration at 60 Hz Provides Much Higher Rates of Mixing Than Conventional Mixers
- Eliminates De-Mixing – The Rate of Mixing Is Much Higher Than Segregation Rates
- Well Mixed – Collisions Are Being Propagated Throughout the Entire Mixture and Are Not Localized Creating Uniform Homogeneity
- Repeatable – Completely Random Mixing Gives the Same Results Mix to Mix
- One Platform – Mixes a Wide Variety of Powders on One Mixer

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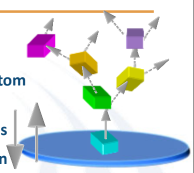
ResonantAcoustic® Solids Mixing

- Vertical Vessel Movement Sets the Particles in Motion When They Collide with the Vessel Bottom
- The Primary Mixing Mechanism Is Particle Redistribution Driven by Inter-Particle Collisions
- Mixing Occurs Through Random Particle Motion



High-Speed Video 3,000 fps

Real-Time Video 60 fps

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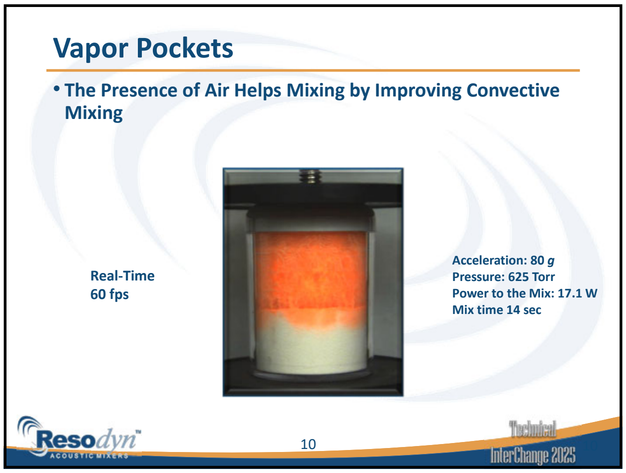
Vapor Pockets
• The Presence of Air Helps Mixing by Improving Convective Mixing
Real-Time
60 fps
Acceleration: 80 g
Pressure: 625 Torr
Power to the Mix: 17.1 W
Mix time 14 sec
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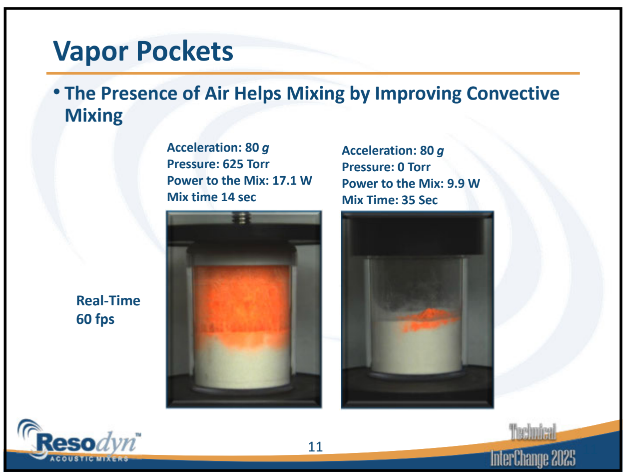
Vapor Pockets
• The Presence of Air Helps Mixing by Improving Convective Mixing
Acceleration: 80 g
Pressure: 625 Torr
Power to the Mix: 17.1 W
Mix time 14 sec
Acceleration: 80 g
Pressure: 0 Torr
Power to the Mix: 9.9 W
Mix Time: 35 Sec
Real-Time
60 fps
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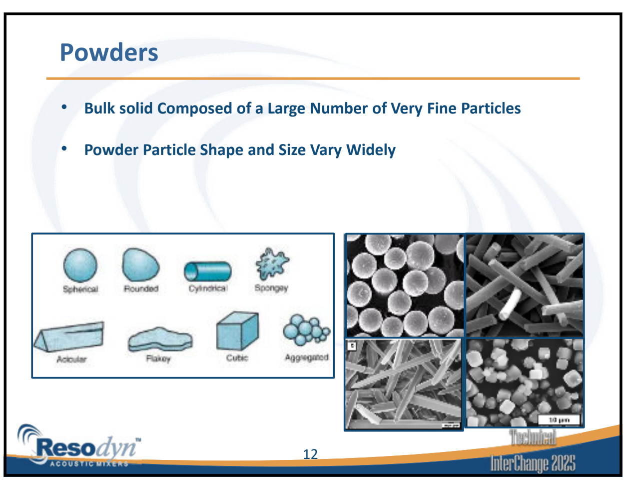
Powders
• Bulk solid Composed of a Large Number of Very Fine Particles
• Powder Particle Shape and Size Vary Widely
Spherical
Rounded
Cylindrical
Spongey
Acicular
Flakey
Cubic
Aggregated
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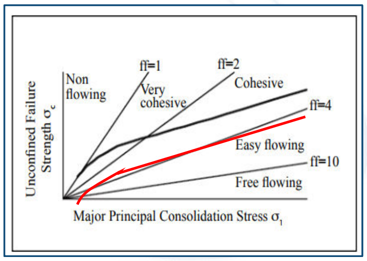
Flowability of Powders

- Powders are Described by How Well They Move or Flow.
- Powder Flow Tester Measures the Flowability of Powders.



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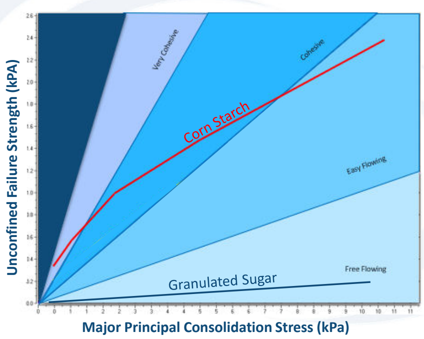
Powder Followability



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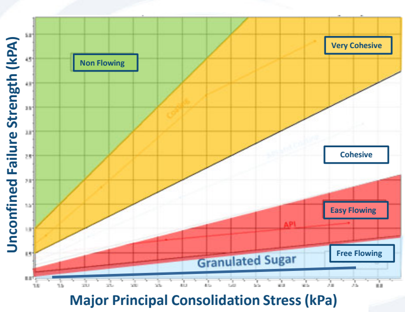
Free-Flowing Powders



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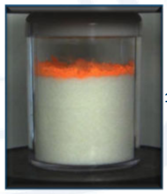
Free Flowing Powder

- **Mixing Through Random Particle Collisions**
- **Vapor Pockets are** Created by the Acoustic Field **Causing Energized** Mixing **in the Powder** Bed
- **Powders Mix Rapidly**

60 fps

200 gm Sugar
5 gm Orange Chalk
Acceleration: 100 *g*



1,800 fps

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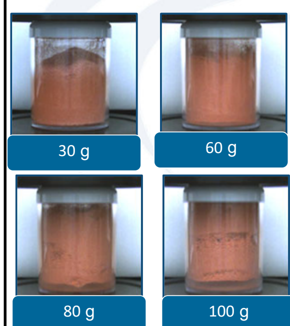
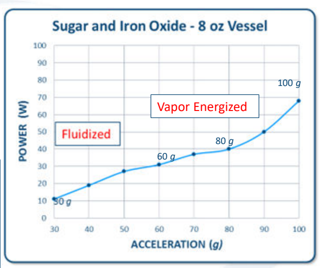
Free Flowing Powder Mix Regimes





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Granular Powder Mixing Regimes Compared

Sugar and Iron Oxide
Acceleration: 30g
Mix Time: 56 sec.

Sugar and Iron Oxide
Acceleration: 80g
Mix Time: 16 sec

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Granular Powder Example-Sugar and Blue Tracer

Sugar and Blue Tracer
Acceleration: 30g
Mix Time: 50 sec.

Sugar and Blue Tracer
Acceleration: 80g
Mix Time: 50 sec.

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Results

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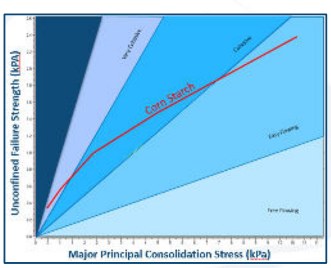
Cohesive Powders

- Illustrations and Examples
- Interparticle Forces
- Banding



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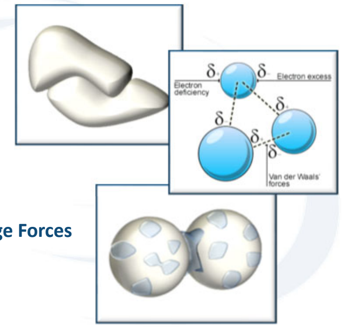
Interparticle Forces

- Electrostatic Forces
- Interlocking Forces
- Van der Waals Forces
- Solid Bridge Forces
- Capillary or Liquid Bridge Forces
- Magnetic Forces



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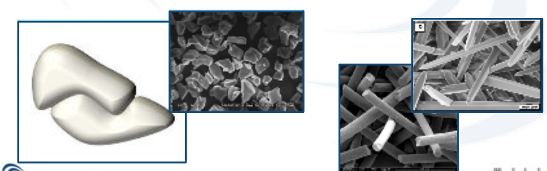
Interlocking Force

- Geometric Property of Particles Which May Orient in a Specific Direction to Lock With One Another
- The Interlocking of the Particles With Each Other Increases the Cohesiveness of the Material
- Rounded, Acicular, and Cylindrical Particles



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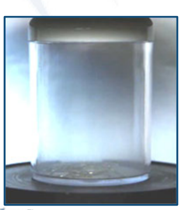
Cohesive Powder Illustration

- Staples are Straightened to Represent a Powder with Rod-like Particle Shape
- Rod-like Particle Shapes Tend to Align and Interlock with One Another
- Interparticle Forces Result in Cohesiveness of a Material

20 Staples
100 *g* Acceleration



500 Staples
100 *g* Acceleration

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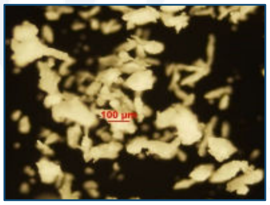
Avicel

- Particle Shape: Acicular and Rounded



Avicel: 167 gm
Chalk: 12 gm
Acceleration: 60 *g*

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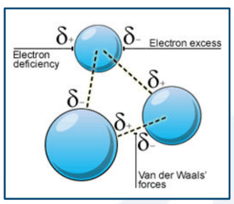
Van der Waals Force

- Induced Charge Between Two Particles Creates an Electrical Attraction
- No intrinsic polarity, but develop Instantaneous polarity
- Instantaneous Polarity Cause Neighboring Molecules to Polarize.
- Domino Effect of Polarization Throughout the Material Results in Cohesion
- More Dominant with particles less than 20 µm



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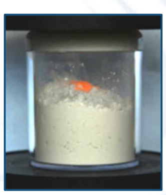
Glass Sphere Comparison

- Hollow Glass Spheres Are Lighter and Smaller Than Solid Glass Spheres
- Van der Waals Force Dominance Increases as Particles Size Decreases

Acceleration: 70 *g*



Solid Glass Spheres: 20 gm
Particle Size: 70 µm
Chalk: 2 gm
Mix Time: 5 Seconds

Hollow Glass Spheres: 47 gm
Particle Size: 10 µm
Chalk: 2 gm
Mix Time: 12 Seconds

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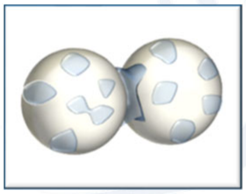
Capillary or Liquid Bridging Force

- Induced by Liquid Bridges Between Two Solid Bodies
- Causes Particles to "Stick" to Each Other and Greatly Changes Particle Behavior
- Example: Sand Castle



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Liquid Coated Hollow Glass Spheres

- Addition of 4 wt. % Liquid Coats the Hollow Glass Spheres and Enables Liquid Bridging Forces in the Powder

Hollow Glass Spheres: 47 gm
Chalk: 2 gm
Mix Time: 12 Seconds

Acceleration: 70 *g*

Hollow Glass Spheres and 4 wt. % Liquid: 47 gm
Chalk: 2 gm
Mix Time: 18 Seconds

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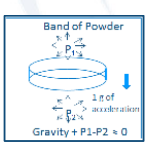
Banding

- Banding is a Result of Cohesive Forces Preventing Air from Moving Through the Powder
- The Result Is Stable Air Cushions Above and Below the Band



- Banding Can Be Disturbed
  - Change the Fill Ratio
  - Change the Pressure

Avicel 60% Fill
Acceleration: 80 *g*

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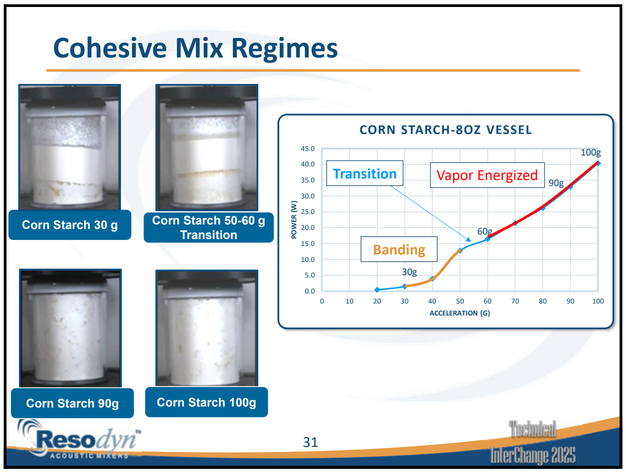
Cohesive Mix Regimes
Corn Starch 30 g
Corn Starch 50-60 g Transition
Corn Starch 90g
Corn Starch 100g
CORN STARCH-8OZ VESSEL
Transition
Vapor Energized
Banding
30g
60g
90g
100g
POWER (W)
ACCELERATION (G)
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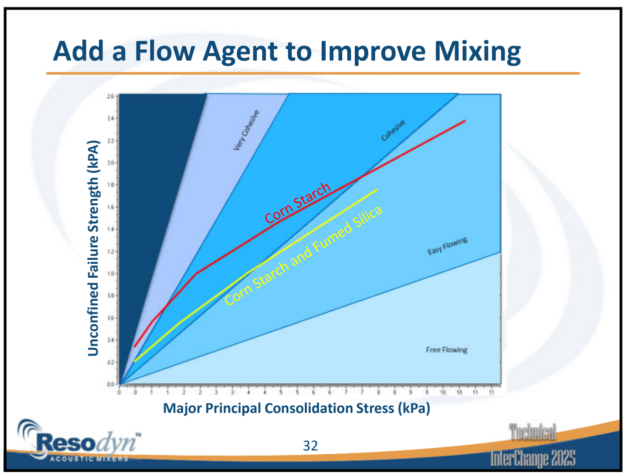
Add a Flow Agent to Improve Mixing
Unconfined Failure Strength (kPA)
Very Cohesive
Cohesive
Easy Flowing
Free Flowing
Corn Starch
Corn Starch and Fumed Silica
Major Principal Consolidation Stress (kPa)
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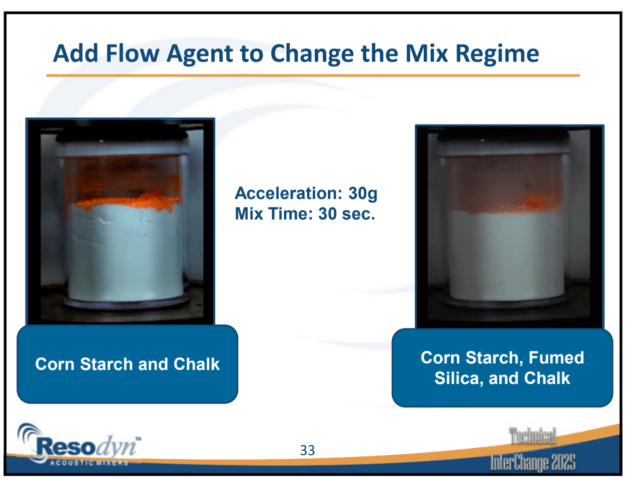
Add Flow Agent to Change the Mix Regime
Acceleration: 30g
Mix Time: 30 sec.
Corn Starch and Chalk
Corn Starch, Fumed Silica, and Chalk
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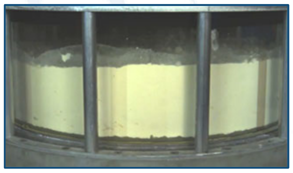
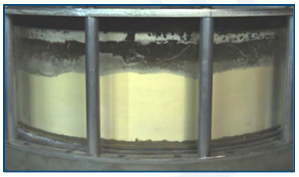
Use of Vacuum to Disrupt Band

- Proprietary Powders Mixed on the RAM5 at 95 *g* of Acceleration
- Vessel Dimensions: 24 in. Wide x 6 in. Tall, 40 Liter



Vessel Pressure: 620 torr



Vessel Pressure: 200 torr

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Scaling LabRAM to RAM5

Avicel : ~40gm
Acceleration: 80 *g*
8 fl oz Vessel

Avicel: 4,000 gm
Acceleration: 90 *g*
5 gal Vessel

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Scaling to RAM55

- Scaling to the RAM55 Presents further Challenges:
  - Increased Bed Height and Weight
  - Less Energetic Collisions
  - Reduction in Vapor Pockets
  - Reduction in 2nd Transducer Impacts

8 fl oz Vessel

5 gal Vessel

90 gal Vessel

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Summary

- RAM Mixing is Efficient at Mixing Powders
- Powder Characteristics Affect Mixing
- Challenges Can Be Overcome
  - Acceleration
  - Add a Flow Agent
  - Vessel Pressure
- Scalable

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