

Batch RAM Mixing of Pastes



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Outline



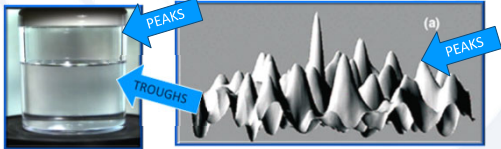
- Fundamentals of RAM Mixing
- Fundamentals of Pastes
- RAM Mixing of Pastes
- Mixing Parameters
- Scaling RAM Batch Mixing
- 2.75 Warhead Example



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Faraday Waves

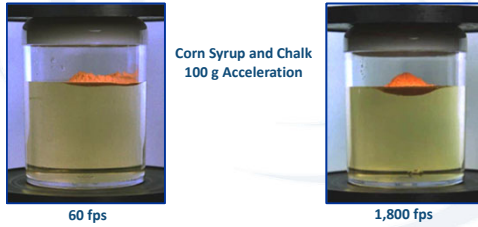
• At the Onset of Movement Across a Liquid – Gas Boundary Layer, Faraday Waves are Formed



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Faraday Waves and Acoustic Energy

- Increasing Acceleration Creates a Vigorous Mix Regime
- High Speed and Real Time Comparison of Mixing



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Batch Mixing and Mix Regimes

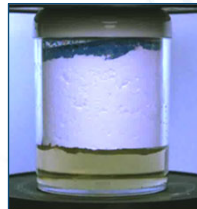
- Traditionally, Three Distinct Mix Regimes are Observed when Processing Raw Materials into a Paste
 - Wetting
 - Incorporation
 - Mixing

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Wetting

- Encapsulation Takes Place Very Briefly at the Onset of Wetting
- Wetting is the Process of Combining Liquids and Solids, which begins with Encapsulation

Wetting Phase



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Incorporation

- Incorporation Takes Place when Wetted Components begin to Agglomerate and form a Larger Mass

Incorporation Phase



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Mixing

- After all Materials are Incorporated, the Material begins to Exhibit Bulk Mixing

Mixing Phase



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RAM Technology Performance Attributes

- Mixing Vessel Alone is the Mixer (no impellers, baffles, etc.)
- Mixer is Easy to Clean
- Single Mixing Vessel Suitable for a Broad Range of Materials
- Rapid Mixing
- Thorough Mixing
- Repeatable Mixing
- Excels in Difficult to Mix Materials

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Mixing Control Variables

- RAM Control Parameters Include
 - Acceleration
 - Pressure (Vacuum Pump)
 - Temperature (Jacketed Vessel)
 - Vessel Fill Percentage
 - Material Order of Addition
 - Time



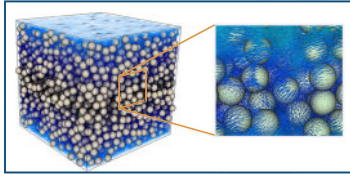

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Paste Basics

- Paste Definition
 - Solid particles encapsulated or suspended in a fluid matrix
 - The weight percentage of solid material within a mass of paste is known as 'Solids Loading'
 - The volume fraction is called the 'Phase Volume'
 - Pastes can be illustrated by the following image

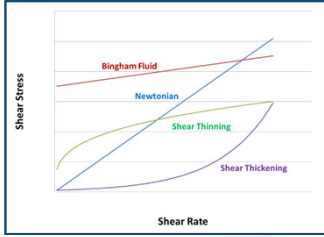

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Rheology of Paste

- Forces Acting on Suspended Solids
 - Brownian Motion
 - Viscous Forces
 - Particle Interactions
- Pastes can Exhibit Several Types of Behavior
 - Bingham Plastic
 - Shear Thinning
 - Newtonian
 - Shear Thickening

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Newtonian Paste

- Suspended Particles Raise the Viscosity of the Fluid Phase
- Particles do not Interact with Each Other
- Viscosity is Independent of Shear Rate
- Newtonian paste does not change its viscosity no matter how much shear occurs



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Acceleration's Effect on Mixing

- As Acceleration is Increased, Velocity (Shear Rate) is Increased
- This Results in More Power Imparted to the Materials
- And Faster Mixing



50 gm of Corn Syrup
2 gm of Chalk

80 g of acceleration

95 g of acceleration

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Shear Thinning and Bingham Plastic Paste

- Particle Structures (Caused by Particle Interactions) are Disrupted Under Flow Thereby Reducing Viscosity
- Higher Shear Rates Result in Lower Viscosities
- Fluids become thinner as the rate of shear increases



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Shear Thinning Liquid Mixing

- Generally, Shear Thinning Pastes Mix Easily in a RAM Environment

- Acceleration and Shear Thinning Synergistically Combine for Faster Mixing at Higher Acceleration



40 g acceleration

3% Solution of Hydroxypropylmethyl Cellulose (HPC) with Chalk



80 g acceleration



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Shear Thickening Paste

- Particle Order at Rest (Dominated by Brownian Motion) is Disrupted Under Flow (Viscous Forces)
- At Higher Flow Rates, Inter-Particle Forces Dominate Causing Clusters that Increase Viscosity
- Fluid exhibits an increase in apparent viscosity with an increase in shear rate



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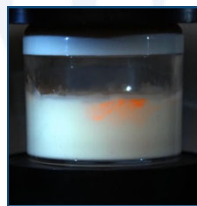


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Shear Thickening Liquid Mixing

- Generally, Shear Thickening Pastes Need Additional Consideration for RAM processing

- High acceleration still mixes, but the increasing viscosity with acceleration (shear rate) needs to be considered



60 g Acceleration

Aqueous Cornstarch with Chalk



100 g Acceleration



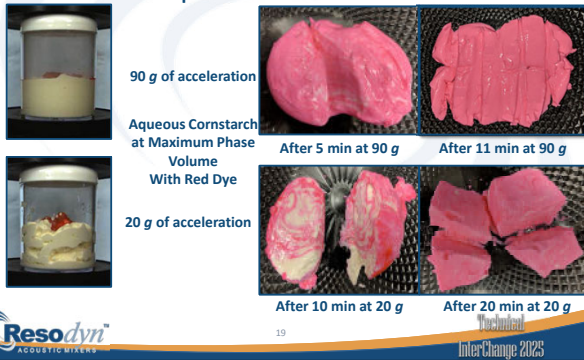
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Shear Thickening Liquid Mixing

- Higher Acceleration Dominates Higher Viscosity even when Material is Decoupled



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Effect of Pressure on RAM Mixing

- Utilizing the RAM Vacuum can help with Processing Inside a Vessel for Several Reasons
 - Reduced Pressure Changes the Force Balance on the Surface of a Paste, and Allows Material to be Processed at Lower Accelerations
 - Vacuum can be Used to Degas Processed Samples, Whether During Processing or in a Post Mixing Step



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Vacuum Uses for Liquid – Solid Mixing

- Low Pressure (<10 Torr) Before Mixing
 - Minimize Gas Incorporation into the Mix
 - Keep Powders from Coming in Contact with the Vessel Lid and Vacuum Ports



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Vacuum Uses for Liquid – Solid Mixing

- Considerations When Lowering the Pressure
 - Don't Pull Vacuum too Fast



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Effect of Temperature on RAM Mixing

- Uncontrolled – Mixing causes temperature to increase thus lowering the viscosity and aiding in mixing
- Controlled – The mix temperature can be controlled using a jacketed mixing vessel
 - The RAM mixing mechanism provides equivalently fast and effective heat transfer



LabRAM II



OmniRAM



RAM 5

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Vessel Fill Percentage – Using the Lid

- Additional Power Imparted by the Lid Breaks up Agglomerations and Speeds Mixing



100 gm corn syrup
4 grams chalk

90g and 60 fps



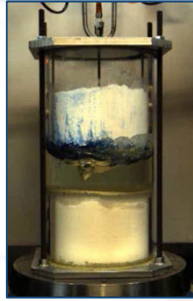
260 gm corn syrup
10 grams chalk

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Scaling from 16 fl. oz. to 5 Gallons



16 fl. oz. Vessel



5-gallon Vessel



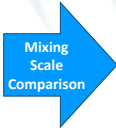
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Process Scale-up

83% Solids Loaded Paste



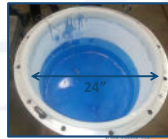
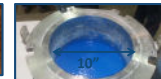
0.24 kg
10 min



21 kg
12 min



204 kg
14 min



Platform	Mass	Power	Power/kg	End temp
LabRAM II	0.24 kg	0.034 kW	145 W/kg	140° F
RsAM 5	21 kg	4.3 kW	150 W/kg	145° F
RAM 55	204 kg	36.5 kW	135 W/kg	124° F



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Bringing it All Together

War Head
2.75" Diameter, 13" Length

19% Powdered Sugar
58% Granulated Sugar
23% HTPB R45

Mixed at:
~40 Torr of Pressure
80 g of Acceleration

Powdered Sugar & Blue dye

Granulated Sugar

HTPB R45



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Bringing it All Together

War Head
2.75" Diameter, 13" Length

19% Powdered Sugar
 58% Granulated Sugar
 23% HTPB R45

Mixed at:
 ~40 Torr of Pressure
 80 g of Acceleration



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Summary

- o RAM mixing is
 - Faster
 - More uniformly distributed throughout the mix vessel
 - Universally applicable to a broad range of materials and processes
 - Scales 1:1 with power density and Mix regime
- o Mixing Pastes with RAM Depends on
 - Material viscosity behavior
 - Acceleration
 - Pressure
 - Temperature
 - Vessel fill percentage

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Thank you for your time and attention.




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