AVEKA Group

Challenges and Opportunities in Particle Processing: An Industrial Perspective

May 24, 2023

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Particle Processing Services
Toll Manufacturing
Research & Development
Innovative Solutions

WCPT9

IFPRI

Presentation Outline

- Overview of *AVEKA* & How Did I Get Here?
- Why Do We Care About Particle Processing?
- General Challenges for Industrial Particle Processing
- The Economics of Particle Processing & Examples
- Technology Readiness Level, The Valley of Death & Your Experience
- Examples
- Future Directions
- Conclusions

AVEKA Group Overview

- Particle technology company focused on contract manufacturing
- Spin-off of 3M in 1994
- Comprised of 5 Manufacturing Sites in Minnesota and Iowa
- ISO certifications / food-grade certifications
- Currently 280 employees

The *AVEKA* Group – A Different Type of CMO

- Broad Range of Unit Operations & Industry Areas
- Active Research & Development Group
- Extreme Technical and Collaborative Business Model

2000+	**600+**	**300+**
Inquires Per Year	Project Proposals Per Year	Customers Per Year

Particle Characterization

Particle Size Analysis

- Particles 1 nm to 2+ mm
- Particle size distribution (PSD)
- Sonic sieving
- Rototap

Electronic Imaging

- Optical microscopy
- Scanning electron microscopy (SEM)

Surface Area Analysis

True Density Analysis

- Helium pycnometry

Formulation Analysis

- High performance liquid chromatography (HPLC)
- Thermogravimetric analysis (TGA)
- Spectrophotometer
- Differential scanning calorimetry (DSC)

Flow Characteristics

- Freeman FT4
- Zeta potential analysis (ZP)
- Rheological analysis
- Moisture and solids analysis (MSA)
- Karl Fisher

How Did I Get Here?

Age

- 2 — Sandcastles

- 5 — Aggregate & Sand Digging, Concrete Mixing & Pouring

- 9 — Visited Taconite Plant
- 12 — Animal Feed Grinding

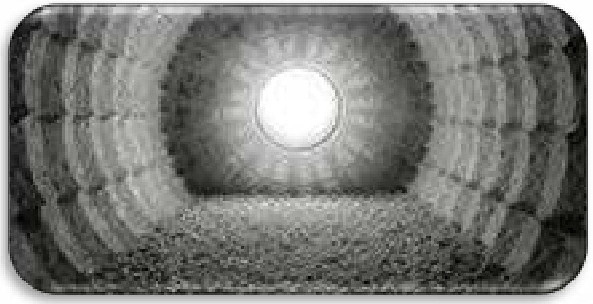
- 14 — First Chemistry Set i.e., Gunpowder

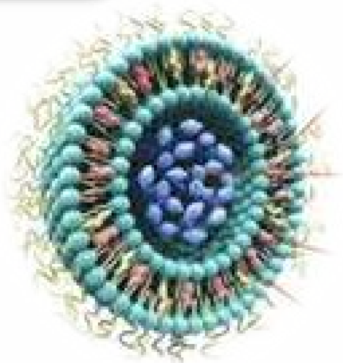
- 22 — Crystallization in Graduate School
- 27 — Xerography at 3M
- 31 — Bread Baking

- 34 — Set Up and Managed Particle Group at 3M
- 35 — Joined IFPRI
- 41 — Started *AVEKA*
- 61 — President of IFPRI

Who Cares About Particle Processing?

- 1930’s Taconite Processing and its Effects
- Cement Manufacturing and Energy Costs
- Xerography and the Information Age
- COVID-19 and the Pandemic





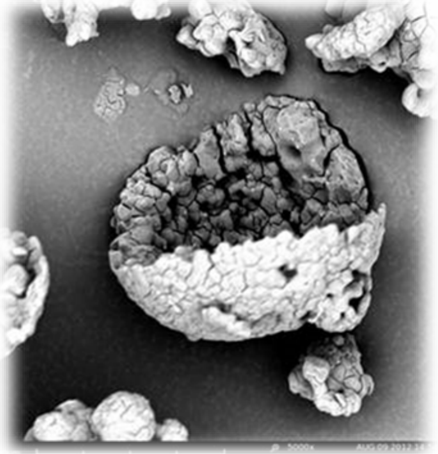
Big Challenges in Industrial Particle Processing

Operations

- Economics
- Technology Readiness Levels

Technology

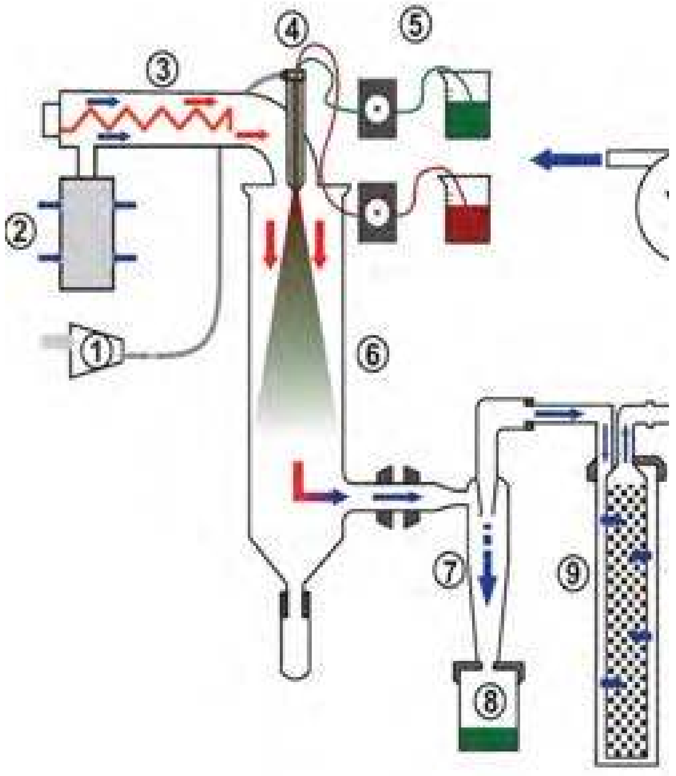
- Water
- Powder Flow
- Grinding Efficiency



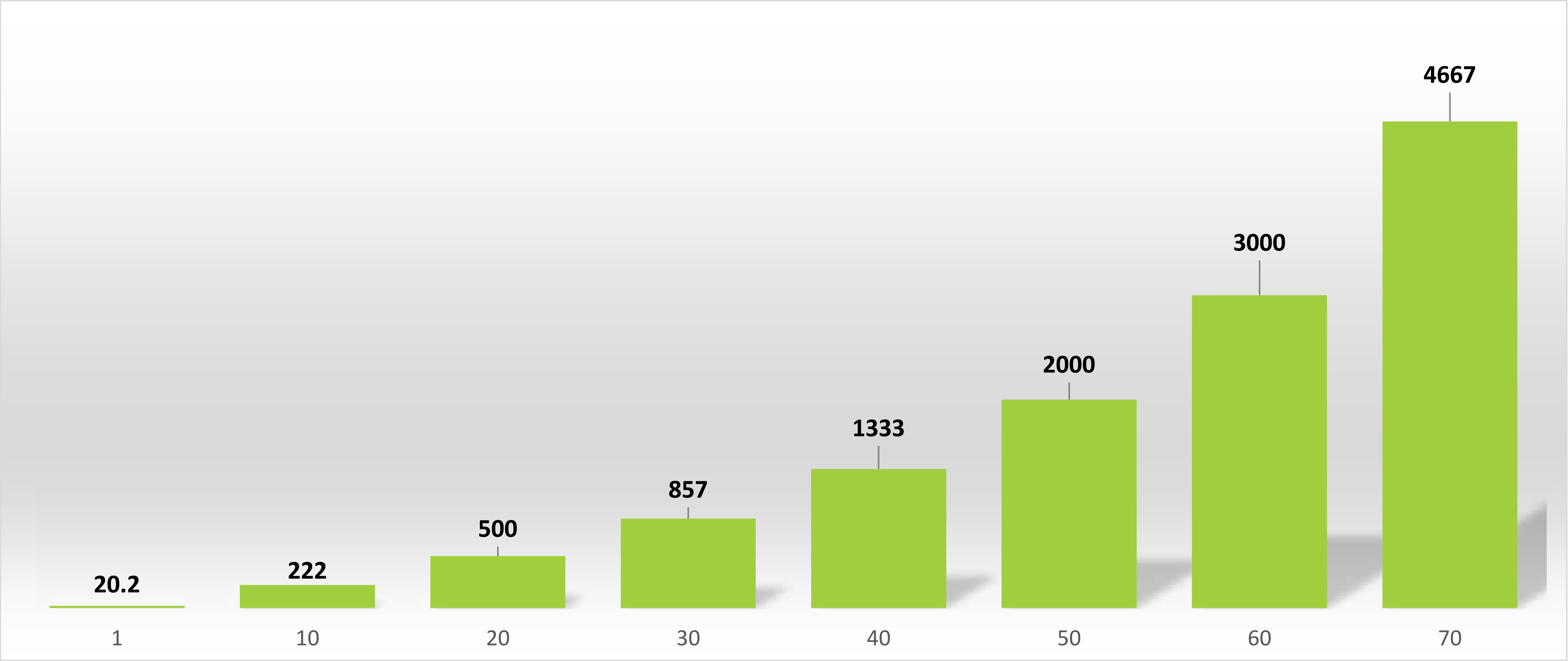
Economics of Particle Processing
Spray Drying - an Illustrative Example

Cost of Spray Drying Equipment: $30,000,000

- Process Parameters:
  - Input Solids
  - Drying Rate
- Yields: 98-99%
- Operating Income: $500-700/hour



Spray Drying Economics I



Output kg/hr

% Solids of Solution

Spray Drying Economics II

Assumptions

- 19%, 20%, and 21% solids
- 80%, 90%, and 95% Operational Time
- 2000 kg/hr Water Evaporation Rate

% Solids	Dried Product kg/hr	80% (7008 hr/yr)	90% (7884 hr/yr)	95% (8322 hr/yr)
19	469	3,286,752	3,697,596	3,903,018
20	500	3,504,000	3,942,000	4,161,000
21	532	3,728,256	4,194,288	4,427,304

Spray Drying Economics III

Assumptions

- 19%, 20%, and 21% solids
- 80% Operational Time
- 1900, 2000, 2100 kg/hr Water Evaporation Rate

% Solids	1900 kg/hr kg/hr Product	2000 kg/hr kg/hr Product	2100 kg/hr kg/hr Product
19	446	469	499
20	475	500	525
21	505	532	558

Spray Drying Economics IV

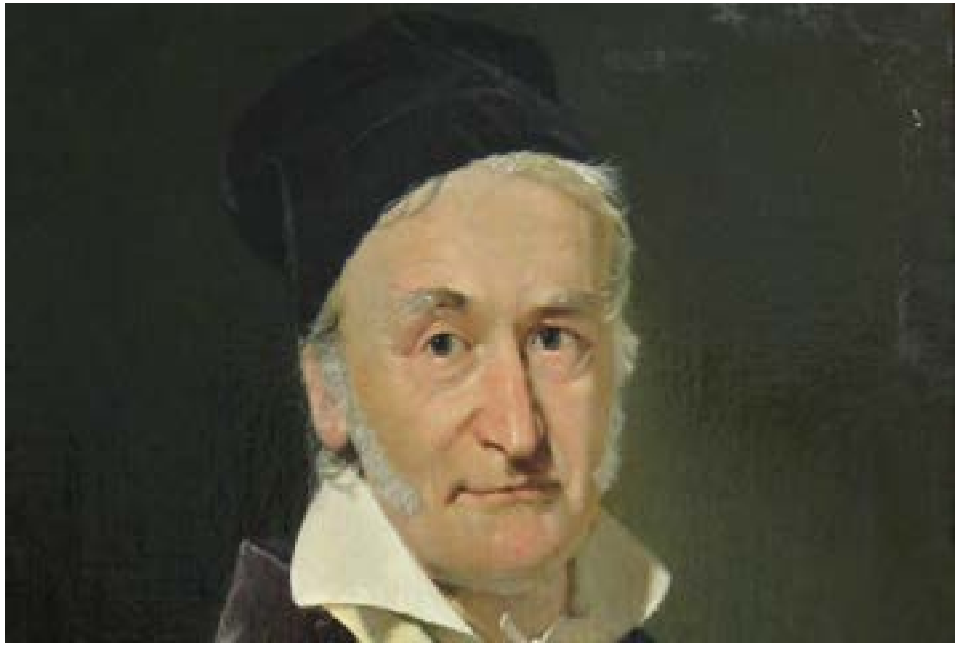
- Assume the Yield is 98%
- Therefore, at 2000 kg/hr evaporation rate the actual output is 490 kg/hr not 500 kg/hr
- However, product typically has 8% retained water or an actual theoretical yield of 543 kg/hr (but the yield is calculated on 500 kg/hr not 543 kg/hr)
- Where is the lost 53 kg/hr product?

Economic Overview

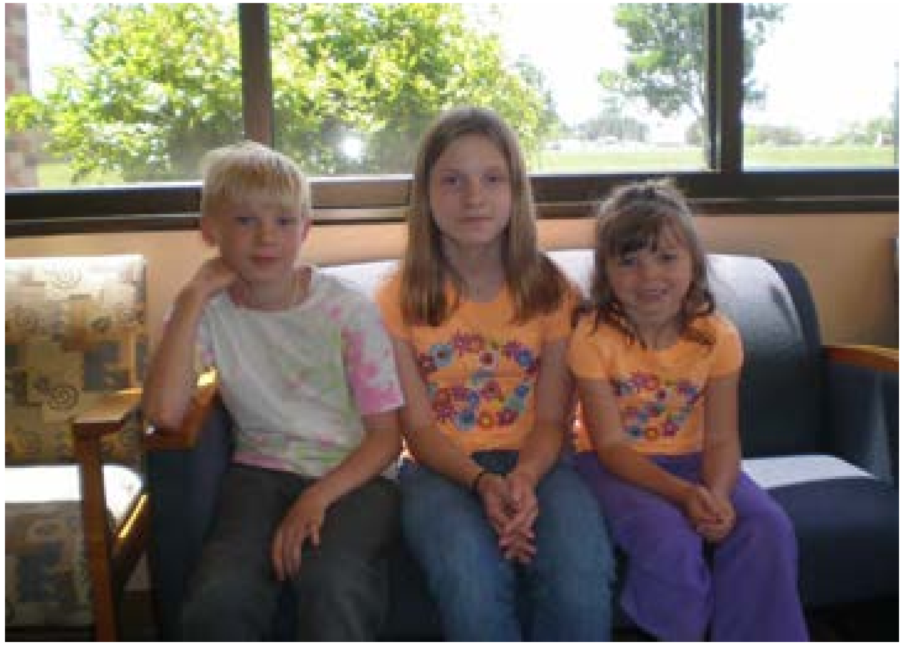
CHALLENGES	OPPORTUNITIES
Water Evaporation Rate	% Relative Humidity Preventative Maintenance
% Solids on Solutions	Atomization Assists Viscosity of Solution
Yields	Poor Collection Wall Sticking and Pneumatic Conveying
Operation Time	Cleaning Cycle Times Preventative Maintenance

It's All About Knowing the Trick

Carl Friedrich Gauss



Orrin, Nora, Laina Yates

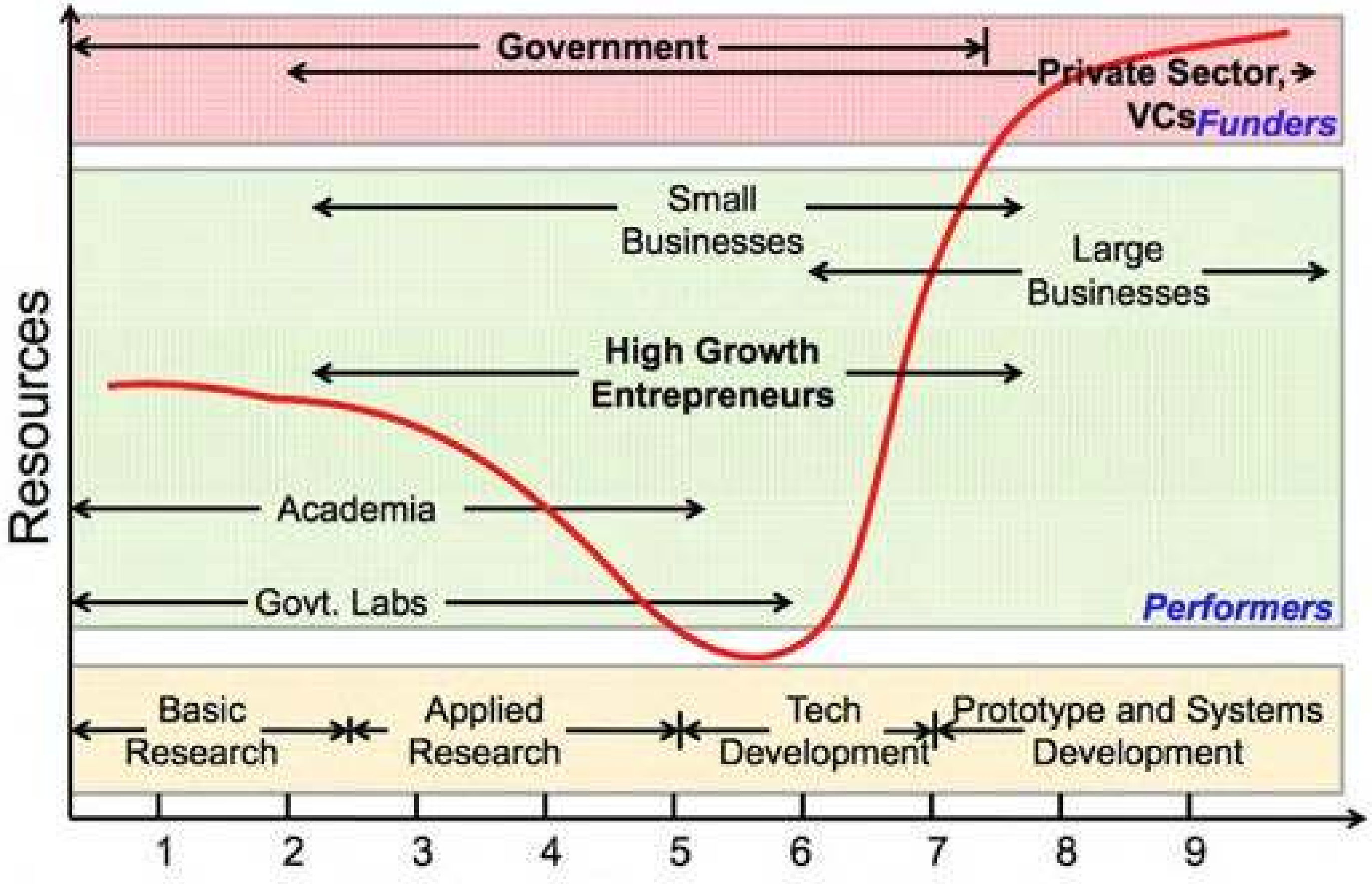


Particle Technology Tricks (examples)

Technology Readiness Levels and the Valley of Death

TRL		
	9	Commercialized
	8	Pre-production
	7	Field Test
	6	Prototype
	5	Bench / Lab Testing
	4	Detailed Design
	3	Preliminary Design
	2	Conceptual Design
	1	Basic Concept

Concept to grams to kilograms to metric tons



What is the Valley of Death?

Answers to questions and the mitigation of risk

The Valley of Death is the Answers to:

What process should be used?

What is my cost per unit?

How much do I need/can make?

What is my yield?

What are the product specifications?

How do I get rid of the waste?

What are the raw material risks?

Can I make this product in blue?

Can I rework the product?

What are the quality issues I will have to solve?

Plus 12,457 other questions.

Processing Dilemmas

- Available equipment dilemma
  - Coffee Grinder
- Volume/Scalability dilemma
  - Pozarnsky Numbers
- Mass balance dilemma
- Optimization dilemma

Why is scaling up so difficult?

Preparation is all done with small scale processing – one becomes immune to:

- Inefficiencies
- Not understanding alternative processes
- Bad choices of equipment
- Poor to no mass balances
- Not enough money

Acceptance of a new product or process needs to fit within current understandings of:

- Process standards
- Equipment modifications
- Trained operators
- Safety considerations
- Internal vs. external IP

The Examples…Finally

Blending Consistency

Classification Efficiency

Multistep Grinding

Monodisperse Particles

Cellulose Fiber Separation

Particle Coating

Water Addition

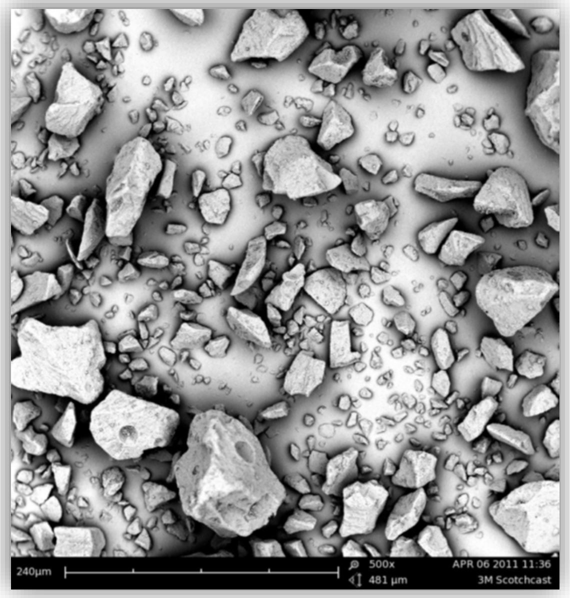
Maximizing Yields

Controlled D_{50}

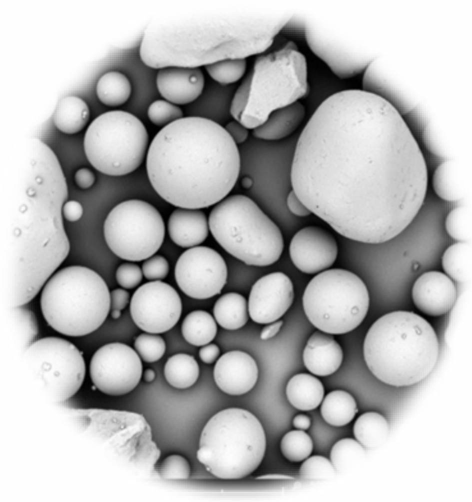
Medical Device Testing

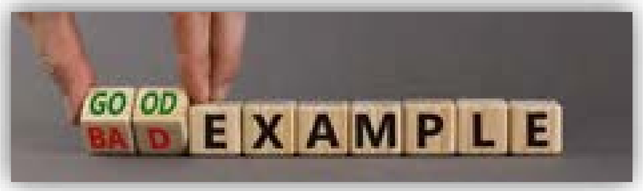
Water Holding Enhancement

Enhanced Powder Flow



- **Statement of Need**
- **How We Approached the Problem**
- **What Went Right (or Wrong)**
- **Opportunities**





Blending Gone Bad

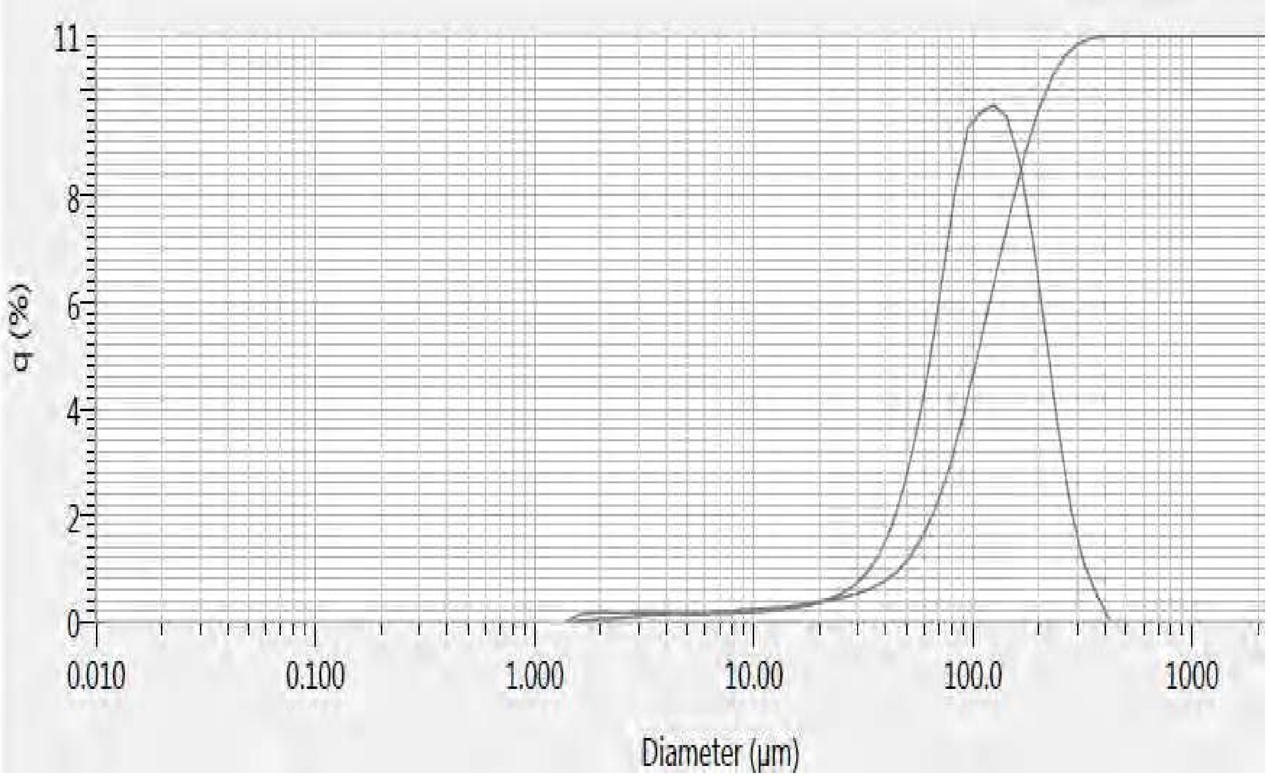
Statement of challenge

Uniformly add water to dry food product

- % moisture <1% to 5%
- Ribbon blender and spray atomization

The Result

PSD changed slightly due to water absorption and particle swelling

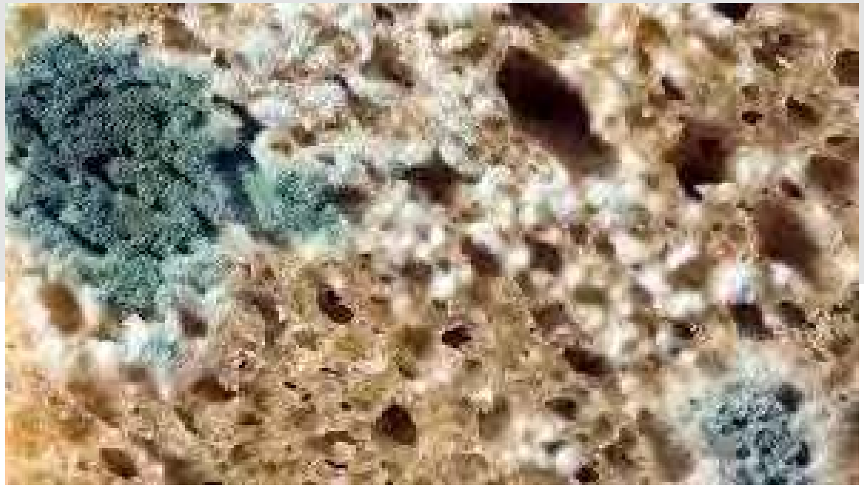


What Went Wrong?

- Nothing - blending was straight forward
- Everything - incredible micro growth

The Reality

- Water was not uniformly distributed - wet spots allowed bacterial growth



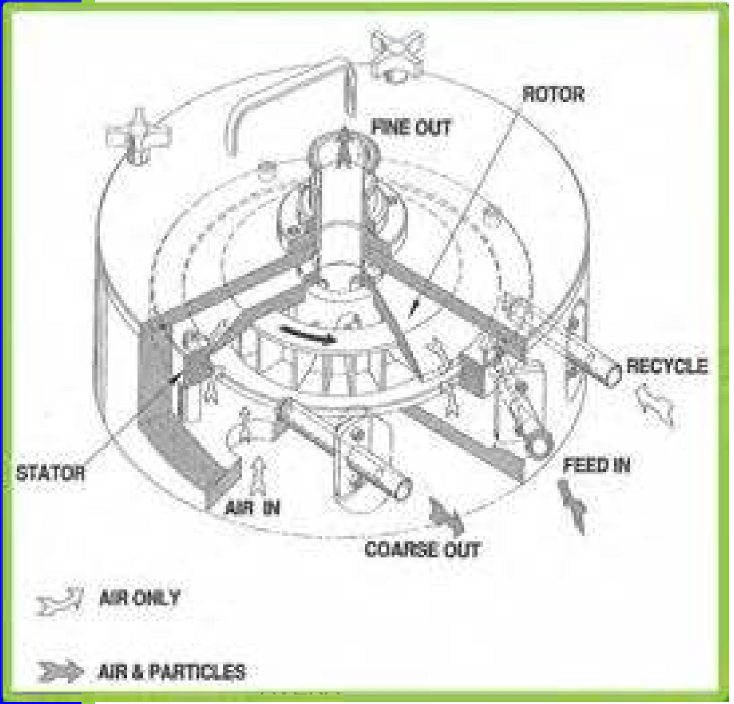
Opportunity: New characterization method to determine powder uniformity

Classification Optimization

Statement of challenge

Maximize Yields during classification

- Glass beads
- Air classified

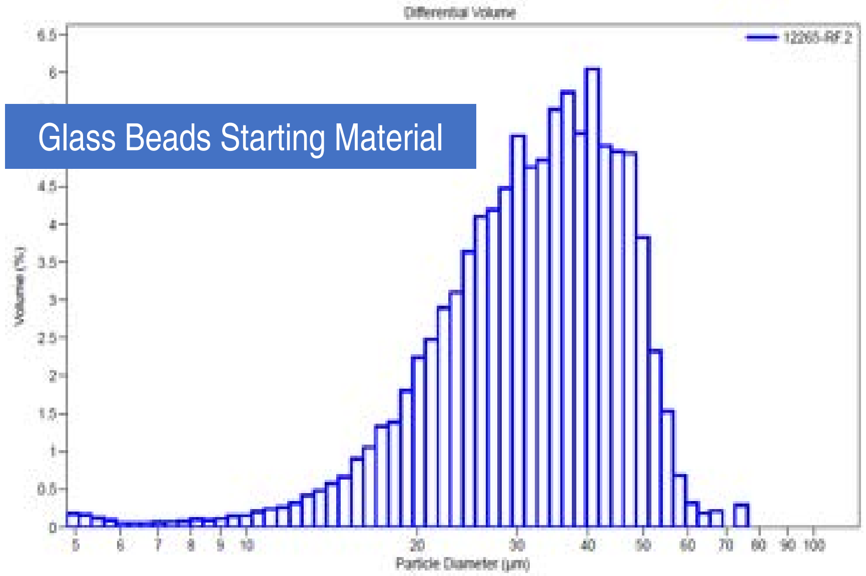


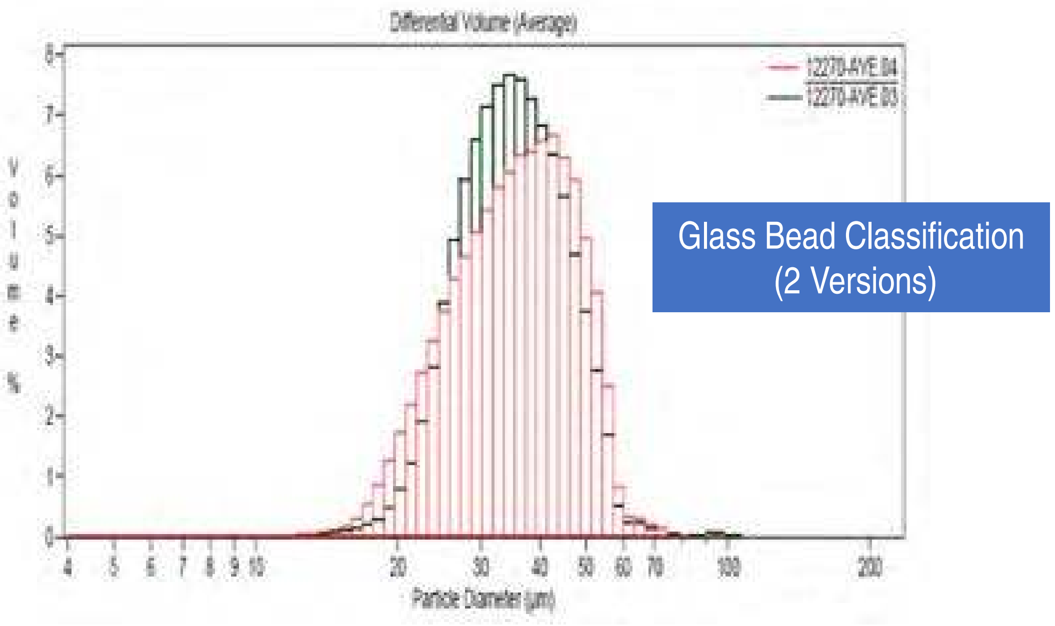
The Result

Small cut points had huge yield results

Glass Bead Classifications & Yields

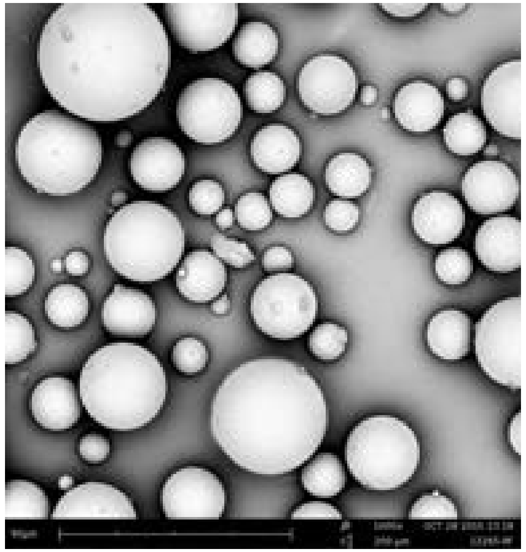
Objective: Increase yield after classification





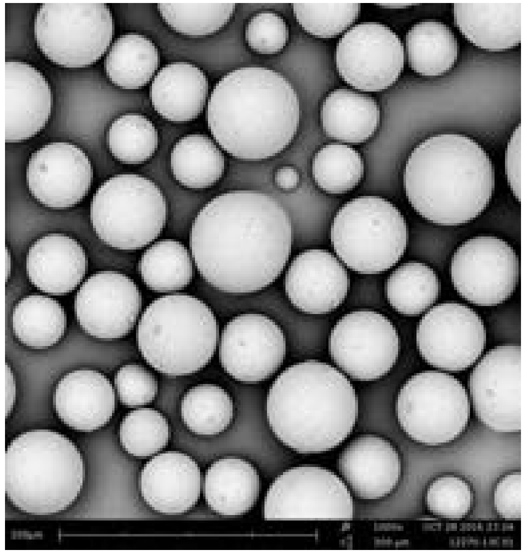
	<10%	<25%	<50%	<75%	<90%
Starting Glass	19.01 μm	25.08 μm	33.10 μm	41.56 μm	48.29 μm
Classification (red)	23.95 μm	28.22 μm	35.82 μm	43.94 μm	50.41 μm
Classification (green)	24.95 μm	29.05 μm	34.89 μm	41.96 μm	48.47 μm

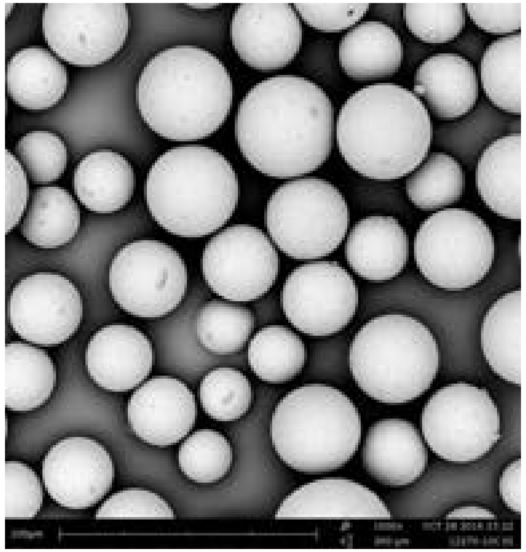
Glass Bead Classification & Yields



Starting Beads

Broad Cut (24-50 μm)
73% Yield





Narrow Cut (25-48 μm)
43% Yield

Opportunity: Models for Separation Prediction

Grinding Optimization

Statement of challenge

Tighten Distribution and Reduce Processing Time of Ceramic Substrates

- Multi-step grinding
- Grinding aid addition

The Result

3x reduction in grinding time

D_{50} tightened from 15-35 µm to 17-19 µm

Multi-Step Grinding Line

- Tote Tipper Feeder
- Komar Industries auger crusher
- Pneumatic conveying to screener
- Ball Mill and final screening

Multi-Step Grinding Line

2003	D_{50} = 15-35µm	Crushing and Ball Milling
2006	D_{50} = 18-24µm	Hammer and Ball Milling
2013	D_{50} = 16-19µm	Crushing, Hammer Milling and Ball Milling
2015	D_{50} = 17-19µm	Added Grinding Aid

Opportunity: New Grinding Aids for Non-Ceramic Materials

Monodisperse Particles

Statement of challenge

Produce a 4mm Spherical Wax Bead Within 1%

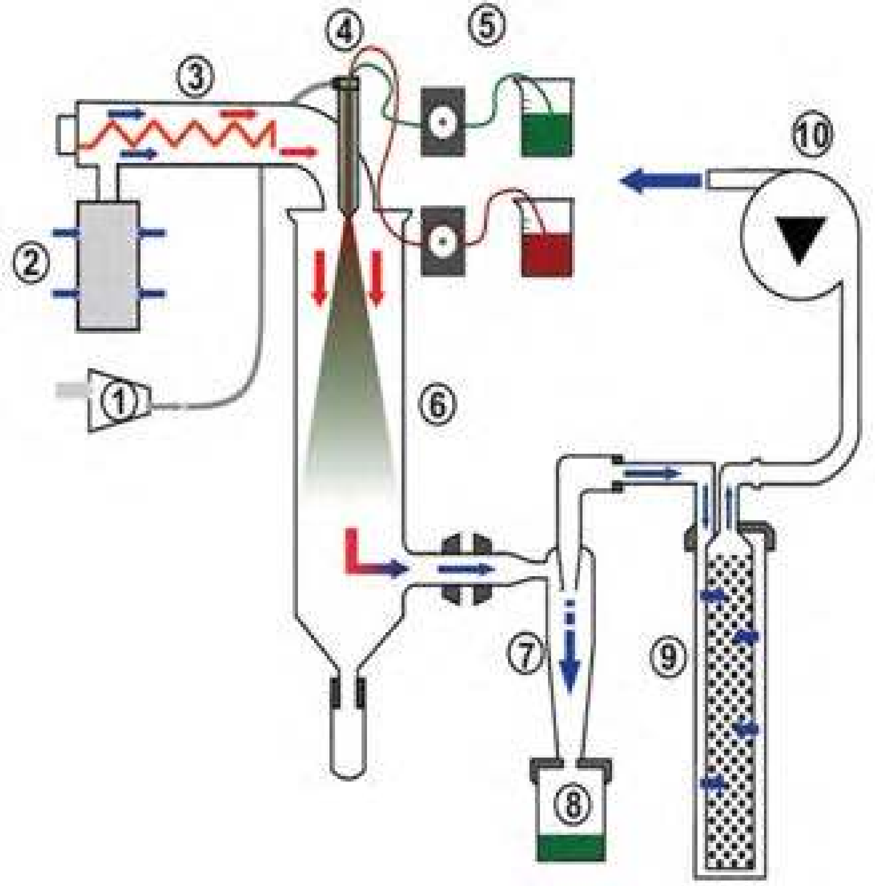
- Prilling
- Novel atomization method

The Result

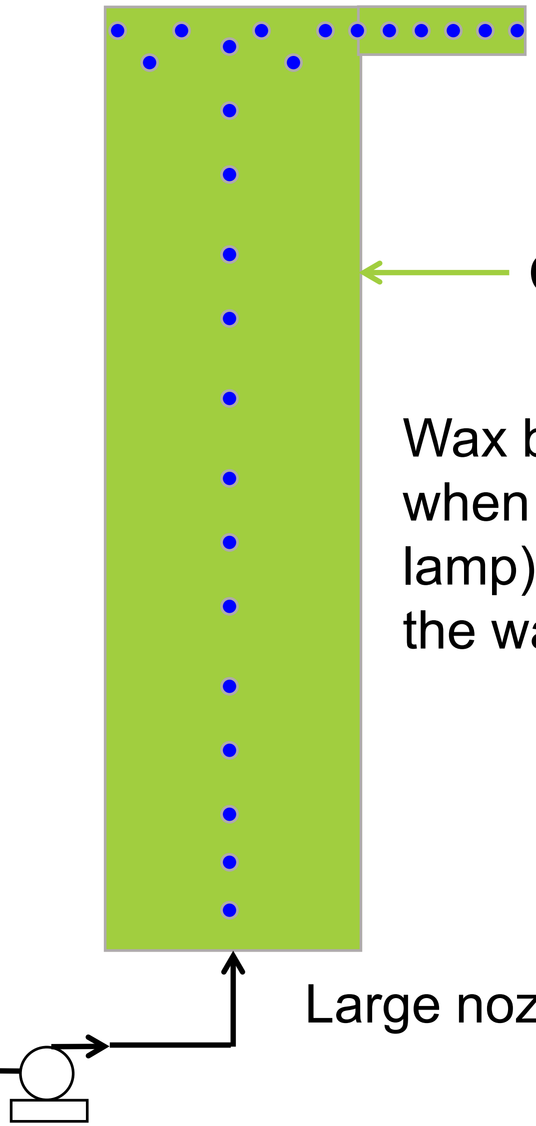
Prilled underwater (shortened tower from 3000 cm to 30 cm)

4 mm beads produced

Entrained water



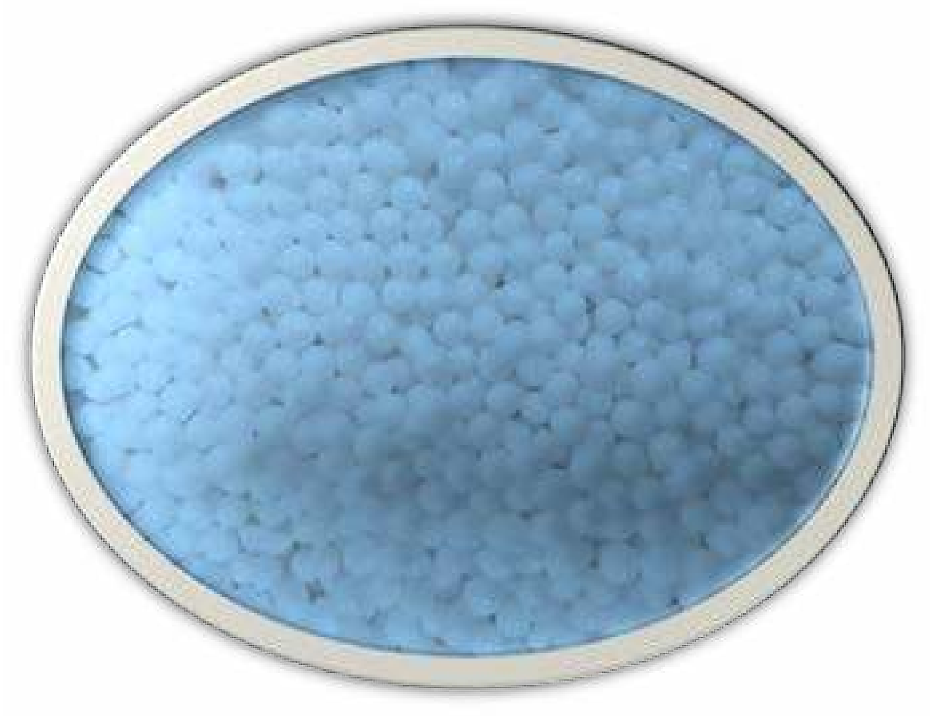
Underwater Prilling



Wax beads cool and form spheres when floating up in the water (~lava lamp) since they are less dense than the water

Underwater Prilling Process

Underwater Prilling Results



Opportunity: Entrainment Mechanism and Atomization Methods

Plasma Cutters, Spray Dryers & Metal Detectors

While spray drying in plant, plasma cutting was being done in same building 100 meters away and behind 3 doors.

Powder set off metal detector during and after plasma cutting.

Plasma Cutters, Spray Dryers & Metal Detectors

What is happening?

- No Metal Contamination was found by ICP analysis
- Charge contamination is known to trigger metal detector
- Charge did not dissipate after 3 months

Thoughts and the Merrow Report

It's always the economics

Small changes in processing can have profound effects on profitability

Processing tricks (wide base of processing and material knowledge) is critical

New opportunities abound

- Characterization methods
- Atomization
- Grinding aids
- Dry powder flow

E. W. Merrow Chem Eng 24, 89-92, 1988

"Estimating Startup Times for Solids-Processing Plants"

Does industrial, academic, and funding management understand the critical value of particle processing in profitability?

Where is the Forum for Industrial Concerns and Needs?

World Congress on Particle Technology

AIChE Particle Technology Forum

Equipment and Modeling Vendors

International Fine Particle Research Institute (IFPRI)

- New Merrow Report Commissioned by IFPRI
- Current and Past Projects on Most Opportunities Mentioned in this Talk
- Forum for Learning Best Practices from Some of the Best Practitioners

Summary

- We are in the broadest and most exciting field in the world
- This is a challenging field, but rich with both industrial and academic opportunities
- Reach out to others for help

Contact Information:

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