



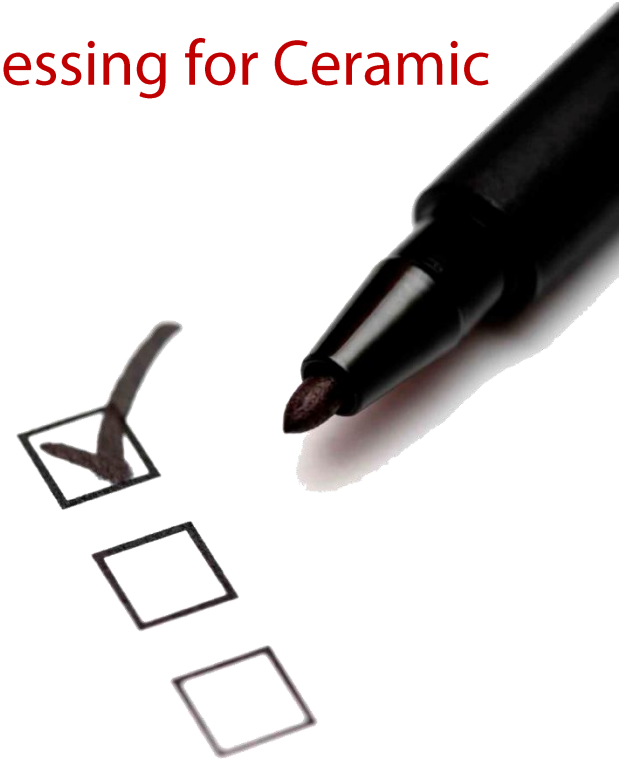
Holistic Design of Thermochemical
Processing for Ceramic Production

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Today's Agenda

“Holistic Design of Thermochemical Processing for Ceramic Production”

- About Harper
- Scale Up Objectives, Challenges & Risks
- Scale Up Success Factors
- Case Study
- Conclusion



About Harper

- > Established Leader in Thermochemical Processing Systems
- > Precision High Volume Net Shape Sintering Systems
- > Key Partner in Carbon & Ceramic Fiber Pilot and Production Plants

Primary Technical Focus:

- New / Challenging / Advanced Material Processing
 - 300°C – 3000°C
 - Batch and Continuous processing
 - Precise atmospheric controls
 - High purity requirements
 - Complex gas-solid interactions



Challenges in Scale-Up of Emerging Materials

Technical Success

- Product quality
- Transition from 1 → 100's kg/hr
- Yield of in-spec. product
- Handling of products and wastes

OPEX Appropriate for return

- Input materials cost
- Labor
- Utility consumption
- CAPEX depreciation

Time for Deployment



Objectives in Thermal Processing Scale-Up

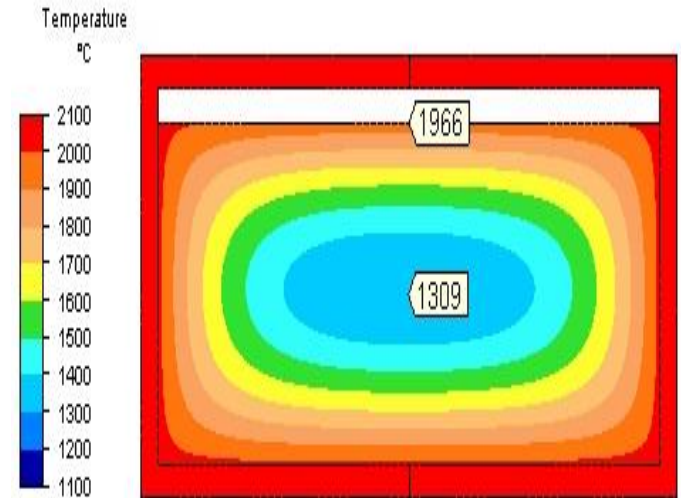
- ✓ Define the "process window"
 - ✓ Stable zone
 - ✓ Push to failure
- ✓ Reduce & Retire risks
- ✓ Validate data for OPEX model
- ✓ Develop a safe process that will meet environmental regulations
- ✓ Innovate and Optimize
- ✓ Model and validate under industrial conditions



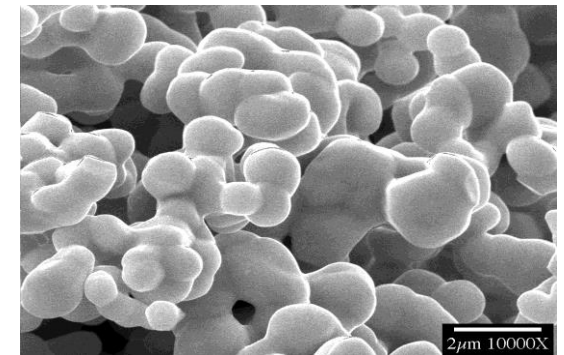
An alignment problem

Challenges in Thermal Processing Scale-Up

- Rate limiting reaction kinetics
- Gas - solid contact
- Thermal uniformity within process material vs time
- Techniques for -
 - Suppressing entrainment
 - Minimizing contamination
 - Avoiding condensation/recycling from exhaust gases
 - Raw material feeding and product discharge and collection
- Handling of exhaust gases
- Benefits of co-current or countercurrent flow
- Entrainment



Temp vs time inside carrier and product



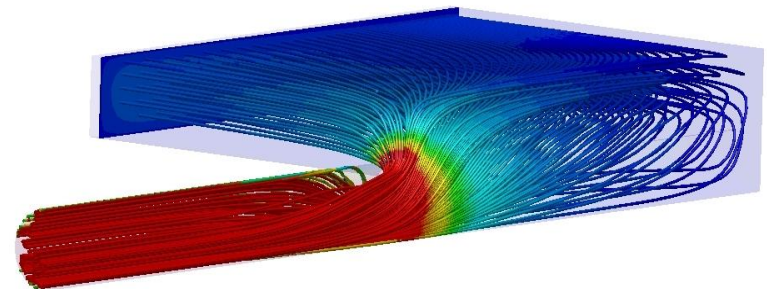
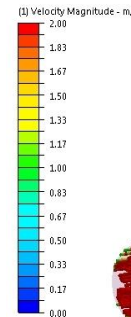
Scale Up Success - Data Analysis and Equipment Design

Data from pilot plant designed experiments will:

- ✓ Define the processing window
- ✓ Develop process flow and P&ID diagrams
- ✓ Provide scale up information for commercial production
- ✓ "Production like" materials for product validation

Rigorous Engineering Analysis:

- ✓ Equipment size scale up
- ✓ Thermal and stress modeling
- ✓ Determine gas handling systems
- ✓ Define feed and product collection systems
- ✓ Determine OPEX and CAPEX



FEA CFD of process gas flow in reactor

Scale Up Success - Data Analysis and Equipment Design

- **OPEX Estimation**

- ~70-90% of total cost over lifetime
- Process cost models
- Economics of increased production capacity with current and future technologies
- Analysis of best-suited thermal process technology system
- Identification of opportunities for improved product quality and cost reduction

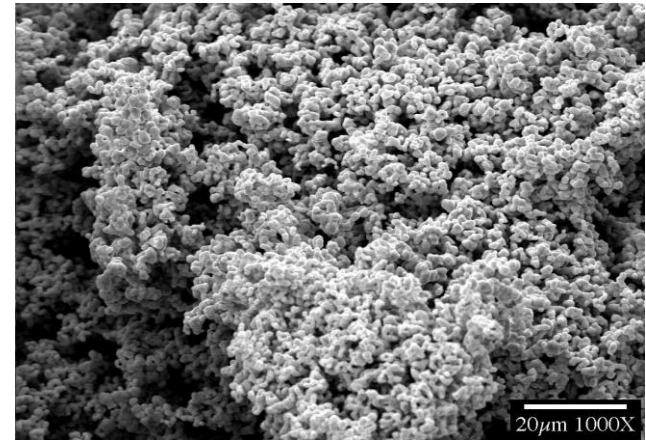
- **CAPEX Definition**

- ~10-30% of total cost over lifetime
- Based on scale-up from trial data collected
- Scale up of processing equipment to meet desired production targets
- Design integration to handle feeding, product handling, gas systems and effluent mgmt
- Prepare a capital cost estimate

Challenge

Continuous Reactor for fine powders

- Desired 1200 kg/hr scale → Current State Piloted on 10 kg/hr scale
- Micron sized powders, morphology important
- Need high degree of Gas - Solid contact in reducing atmosphere
- Highly Exothermic Reaction
 - Alters morphology and causes sticking
- Entrainment <1wt%
- Maintain high purity of product <3ppm



Ignite™

The Ignite™ program aims to help the progression of a discovery, an invention or a concept from a small, batch scale to a commercial stage.

- Helping customers turn the next generation of material innovations into profitable new markets
 - Utilizes our depth and breadth of experience in thermal processing
-
- ✓ Reduce Risk
 - ✓ Scaling factor 1:10, 1:100, 1:1000
 - ✓ Control OPEX
 - ✓ Parallel Development
 - ✓ Controlled Scale-up
 - ✓ Successful Commercialization



Challenge

Continuous Reactor for fine powders



- Industrial pilot on 200 kg/hr scale
- Validated Concepts
- Demonstrated Automation in 24/7 production
- Retired Risk
- Confirmed OPEX data to impose on full sale plant model

Solution: Riffle Flight Reactor



- High Degree of mixing
 - Back mixing neutralized exotherm
 - Energy recovery >30%
- Gas Solid contact without entrainment increase

Subject to US and International Patents

- ~ 1.2 meter diameter reactor
- ~ 12 meter heated length
- 500 – 1000 C in H₂



Thank you for your time!



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