Designing for Energy Efficiency in Thermal Processing

Webinar 1 in Harper’s Series on Maximizing Production Economics
Welcome!

Meet your Presenters:

- Robert Blackmon, VP of Integrated Systems
  Chemical Engineering, Northwestern University
  Leads Carbon Fiber Systems Division

- Doug Armstrong, Process Technology Engineer
  Mechanical Engineering, University at Buffalo
  Senior Engineer for Integrated Projects

Designing for Energy Efficiency in Thermal Processing
Agenda

- About this Webinar Series
- Introduction to Harper
- Keys to an Energy Efficient Design
  - Moving from batch to continuous
  - Considerations in furnace selection
  - Mitigating risk in scale up
  - Practical solutions for existing systems
- Case Study Example
- Wrap-Up / Question & Answer
About This Webinar Series

Maximizing the Production Economics of Your Thermal Processing System

- Your inside access to Harper's deep technical expertise
- Recording of the event will be available on demand for 60 days after the event
- Future Events in this Series
  - Planning for Success: Sensibly Scaling Up Production – August 2012
  - Thermal Processing Research: Designing Flexibility & Performance – October 2012
  - Maintenance Optimization – Planning Downtime Efficiently – December 2012
Introduction to Harper

- Headquartered outside of Buffalo, NY
- Decades of thermal processing experience
- Dedicated Technology Centers for customer process development & testing
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration
Introduction to Harper

We work with developers & producers of advanced materials to provide innovative technologies:

– 200°C – 3000°C
– Batch to continuous processing
– Precise atmospheric controls
– High purity requirements
– High temperature GSL reactions

- Refinement
- Scale Up
- Optimization
Introduction to Harper

Focus on Processing System Solutions for…

Advanced Materials:
- Fibers & Filaments
- Metal Oxides & Powders
- Technical Ceramics
- Energy Materials
- Nano Materials
- Rare Earths
- Graphene

Processes:
- Sintering
- Drying
- Calcination
- Reduction
- Oxidation
- Carbonization
- Carburization
- Solid-solid reaction
- Gas-solid reaction
- Purification
- Metalizing
- Debinding
- Parts processing
- Phase transformation
Introduction to Harper

Whether in refinement, scale up or optimization…
…we solve challenges that no one else can.

Helping customers turn the next generation of material innovations into profitable new markets.
Keys to Energy Efficient Design
Deeply considering energy efficiency when scaling advanced materials processing can directly impact commercial viability…
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…and must start at the Pilot Phase of scaling.

- **Unit Cost**\(^*\) of an Advanced Material
- **Energy Cost**\(^*\) per Unit of an Advanced Material

Stair step due to shift from batch to continuous processing.

*Fully burdened cost*
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*Unit Cost* of an Advanced Material

*Energy Cost* per Unit of an Advanced Material

Log Scale

Lab Scale  | Pilot Scale  | Production Scale

Stair step due to shift from batch to continuous processing.

Typical 25-30% Slope

Energy cost can equal 1/5 or more of total unit cost

*Fully burdened cost*
Keys to Energy Efficient Design

The largest gain in efficiency comes from transitioning from Batch to Continuous – WHY?
The largest gain in efficiency comes from transitioning from Batch to Continuous – WHY?

Three key design aspects to consider:
- Refractory design & heat cycling
- Process gas management
- Effluent / Off gas processing
Energy Efficiency – Refractory Design
Energy Efficiency – Refractory Design

**Batch**

- Balance thermal containment vs. heating / cooling rates
Energy Efficiency – Refractory Design

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- Balance thermal containment vs. heating / cooling rates
  - More efficient designs provide energy savings, but extended cycle time
Energy Efficiency – Refractory Design

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Energy Efficiency – Refractory Design

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**Continuous**

- Heating, soak, and cooling processes are decoupled
Energy Efficiency – Refractory Design

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- Energy recovery possible
Energy Efficiency – Process Gas Mgmt

**Batch**

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  - Energy content
Energy Efficiency – Off Gas Processing

Abatement vs. Clean and Recycle

**Abatement**
- Commonly viewed as a cost center
- Generally does not relate to or enhance production quality
- Exhaust is considered a byproduct requiring treatment and disposal
- High temperature thermal process that creates opportunity for energy reutilization, if needed

**Clean and Recycle**
- Involves investment of capital equipment to achieve recycle needs to be weighed against cost for producing the gas
Energy Efficiency – Off Gas Processing

Key Decisions in Abatement vs. Clean and Recycle
Energy Efficiency – Off Gas Processing

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Energy Efficiency – Off Gas Processing

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- ROI must make sense. Larger scale, more continuous processing,
  and elevated temperatures yield an economic advantage.
- Identify auxiliary process or utilities
  to use recovered energy
Selecting an Energy Efficient Reactor Process

Energy Cost per Unit of an Advanced Material

Batch Processing

Continuous Processing
Selecting an Energy Efficient Reactor Process

Energy Cost per Unit of an Advanced Material

- Elevator Furnace
- Box Furnace
- Autoclave

Batch Processing  | Continuous Processing
Selecting an Energy Efficient Reactor Process

- Elevator Furnace
- Box Furnace
- Autoclave
- Rotary Tube
- Pusher/Roller Hearth
- Horizontal Slot
- Mesh/Strip Belt
- Vertical Tube/Slot

Energy Cost per Unit of an Advanced Material

Batch Processing
Continuous Processing
Selecting an Energy Efficient Reactor Process

Transitioning from batch to continuous processing create a step function reduction in energy cost.

- Rotary Tube
- Pusher/Roller Hearth
- Horizontal Slot
- Mesh/Strip Belt
- Vertical Tube/Slot

Energy Cost per Unit of an Advanced Material

- Elevator Furnace
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Batch Processing vs. Continuous Processing
# Keys to an Energy Efficient Design – Furnace Selection

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<th>Reactor Type</th>
<th>Typical Material Profile</th>
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#### Energy Efficiency Considerations:

- Requires saggers to go through heating and cooling cycle
- Recovered heat from product carriers can be used to minimize impact on system efficiencies
- Material flows can be engineered so that exiting material is directly cooled by association with cool, incoming reactants, which are concurrently preheated
### Furnace Selection - Rotary Tube

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### Energy Efficiency Considerations:

- No need for containers; conveyance is energy efficient. Only reactant powder is heated and cooled, not the conveying system.

- Built in stirring action
  - Enhances thermal transfer to the bed
  - Improves removal of product gases
  - Increases solid/gas exchange in cases where the furnace gas is also a reactant

However, process heterogeneity increases (variance of time at temperature)
Energy use is primarily related to heating the product and reaction, and is thus relatively efficient. Opportunity for highest volumetric utilization.

Design allows for minimal interaction with the furnace wall, thereby providing improved options where contamination is an issue.

### Furnace Selection – Vertical Tube / Slot

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#### Energy Efficiency Considerations:

- No container required but belt must be heated and cooled
- Choice in open weave or uniform plate – difference in heat load and gas interactions
- With open weave, more targeted gas solid interaction as gas can flow through the belt
- Scalable within limits
  - Long belt creates of stresses
  - Thermal lag influences time temperature curve for the process material
  - Lower maximum temperatures
Furnace Selection – Horizontal Slot

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**Energy Efficiency Considerations:**

- Represents near ideal design for energy efficiency
  - Minimal or no interactions between reactor and flow of material
  - Low to moderate volumetric utilization of the reactor – lots of empty space
  - Options exist for improving volumetric utilization through mass transport
Keys to an Energy Efficient Design – Furnace Selection

**Ideal state** is:
Keys to an Energy Efficient Design – Furnace Selection

**Ideal state** is:

- ✓ requirements for reaction homogenity are met
  (to achieve product quality)
Keys to an Energy Efficient Design – Furnace Selection

**Ideal state** is:

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- ✓ an entirely container-less and continuous mode, where material itself provides the motive force to move the product through subsequent process steps, and
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No one furnace design perfectly captures these objectives.
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No one furnace design perfectly captures these objectives. Compromises during the design process are common. Hence experimentation/scaling is critical in process optimization.
Keys to an Energy Efficient Design – Scale Up

Scaling thermal processes seldom follows linear extrapolation.
Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up
Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
- Evaluate whether production volumes warrant continuous operation
Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
- Evaluate whether production volumes warrant continuous operation
- Consider if material handling can be automated
Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
- Evaluate whether production volumes warrant continuous operation
- Consider if material handling can be automated
- Consider magnitude of scale up; go stepwise
  1 to 10 Scale Up = Typical
  1 to 100 Scale Up = More Difficult
  1 to 10000 Scale Up = Risky
Keys to an Energy Efficient Design

Practical Solutions for Existing Systems
Keys to an Energy Efficient Design

Practical Solutions for Existing Systems

- Upgrading to more energy efficiency refractories
Keys to an Energy Efficient Design

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- Upgrading to more energy efficiency refractories
- Replacement of heavy belts with lighter weight belts
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- Addition of heat exchangers downstream of installed abatement systems
Keys to an Energy Efficient Design

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- Addition of heat exchangers downstream of installed abatement systems
- Consider the life of your elements and other proper maintenance
- Consider power conditioning and filtering to minimize line losses
- Conduct process audits to optimize consumables such as purge gases and electricity
Case Study Example – Carbon Fiber

A Model of Step-Wise Scale Up
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- 2008 to Today: >12 systems @ 3000mm wide
Important Historical Steps Towards Efficiency that have Supported Carbon Fiber Commercialization:
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5. Movement Towards Sealed Oxidation Oven Design
   -> Oven accounts for 45-65% of the installed electrical power (connected load) of the line and requires further design efficiencies
Case Study Example – Carbon Fiber

Important Historical Steps Towards Efficiency that have Supported Carbon Fiber Commercialization:

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2. Consumer Market Adoption: at higher volumes, a better understanding of environmental impact is required (automotive)
Case Study Example – Carbon Fiber

Specific Cost - Cumulative

USD/kg Carbon Fiber

Production Rate (MTPY CF)

PRECURSOR  CAPEX  INFRASTRUCTURE  TOTAL COST  OPEX

1m Wide
2m Wide
3m Wide
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Case Study Example – Carbon Fiber

Asymptote Indicative of Diminishing Returns
Case Study Example – Carbon Fiber

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Outputs Tailored to Specific Site Conditions and Client Circumstances

- Thermal Losses - kWh of Losses as a function of Scale & Operating Parameters
- Carbon Footprint - kg/hr of CO2 per kg of Material
- Impact of HCN Destruction - CAPEX, OPEX & Environmental Impacts of Achieving Lower Levels of HCN
- Nitrogen Oxides Emissions - kg/hr of Nitrogen Oxides per kg of Material
- CAPEX & OPEX Per Unit Operation for Various Line Configurations
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5. Opportunities for improvement in efficiency need not be limited to new capacity expansions. Audit your process now.
Thank You!

Learn more at harperintl.com and harperbeacon.com