Novel Oxidation Oven Technology for the Next Generation of Carbon Fiber Manufacturing

GOCarbonFiber
July 22, 2015
Presented by: Bill Stry, PhD
About Harper

- Headquartered in Buffalo, NY
- An Employee-Owned Company
- State-of-the-art Technology Center
- Access to carbon fiber piloting facilities
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration
About Harper

-> Established Leader in Thermal Processing Systems
-> Key Partner in Carbon Fiber Scale Up

Primary Technical Focus:

- New / Challenging / Advanced Material Processing
  - 200°C – 3000°C
  - Batch and continuous processing
  - Precise atmospheric controls
  - High purity requirements
  - Complex gas-solid interactions

HT Furnace
Agenda

1. How insights gained from advanced CFD modeling and full-scale testing can guide design improvements
2. How utilities for Ovens, as the highest energy consumer in the carbonization process, can be optimized for flexibility and performance
3. How modular designs can offer improvements to typically long lead time installations
1: How insights gained from advanced CFD modeling and full-scale testing can guide design improvements

• Air velocity uniformity is considered critical in PAN stabilization ovens
  • It is essential to get the same CF properties across the towband
  • PAN stabilization is an exothermic reaction – if there are low velocity regions the reaction can run away
  • PAN fiber is somewhat delicate – if there are high velocity regions it can cause filament damage
Oxidation Oven Design Challenges

• Higher production rate CF lines have led to wider, taller, and longer ovens
• New CF composite applications have expanded the number of CF specifications
• *A critical design challenge is to improve velocity uniformity while simultaneously increasing the oven size*
Typical Air Recirculation Path
Parallel Airflow Oxidation Oven

TOP VIEW
Design Approach for Oven Airflow Control

- Bench scale air velocity testing
- CFD modeling
- Full scale oven testing
Bench Scale Inlet Nozzles Test Setup

3 to 5 Nozzles; 1 - 3 meters wide

Nozzles Used in a 3000mm Wide Oven
Air-Flow Measurements – Bench Scale Nozzle Example Data

**OVEN NOZZLE VELOCITY UNIFORMITY TEST**

C.V. (StDev/Mean)

- 1.1%
- 1.1%
- 1.3%

- 1.0%
- 1.2%
- 1.3%

- 1.1%
- 1.0%
- 1.3%

- 0.9%
- 1.2%
- 1.3%

<table>
<thead>
<tr>
<th>Air Velocity at Nozzle Face (m/sec)</th>
<th>Oven center</th>
<th>Position from oven center (m)</th>
<th>Oven wall</th>
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</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.0</td>
<td>0.0</td>
<td>1.8</td>
</tr>
<tr>
<td>2.5</td>
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</tr>
<tr>
<td>5.5</td>
<td>0.8</td>
<td>1.2</td>
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</table>
CFD Modeling of Air Velocity

- Inlet Nozzle
- Collector Plenum
- Tow Processing Volume
- Flow Just Downstream of Heater
- Fan Inlet
Testing - Production Scale Oxidation Oven

- 3 Meter Width
- 300 deg C Max
- 14 Meter Pass Length
- 2 to 4 m/sec Air Velocity
Velocity Uniformity

Velocity at Center Nozzles of 3 Meter Oven

144 points (every 200 mm at each nozzle)
Mean = 3.35 m/sec
St. Dev. = 0.07 m/sec
C.V. = 2.2%

Distance Across Oven (m)

Air Velocity (m/sec)
2: How utilities for ovens, as the highest energy consumer in the carbonization process, can be optimized for flexibility and performance

- Brief review of energy costs
- Options for CF oxidation ovens
Utilities account for anywhere from 7 to 13% of manufacturing total costs. This is only for the carbonization line.

NEXANT Cost Model
Nexant Inc. ChemSystems Report 2013

Harper Cost Model
Global Electric Prices

Estimated 2014 Industrial Electric Prices (Cents/Kwh)

Sources: IEA, EIA, OANDA

- U.S. $0.09
- Canada $0.10
- U.K. $0.15
- France $0.10
- Germany $0.19
- Italy $0.21
- Russia $0.11
- Japan $0.19
- China $0.09
- India $0.10
- Brazil $0.17
- South Africa $0.08
- Australia $0.15
- South Africa $0.08

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Electrical Fluctuations

Utilities costs fluctuates during the day and throughout the year

Source: http://www.ferc.gov/market-oversight/mkt-electric/isone/isone-iso-archives.asp
Global Gas Markets

World LNG Estimated November 2013 Landed and Hub Prices ($US/mmbtu)

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<thead>
<tr>
<th>Country</th>
<th>Production (bcm)</th>
<th>Reserves (bcm)</th>
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<td>Russia</td>
<td>662</td>
<td>881</td>
</tr>
<tr>
<td>Iran</td>
<td>130</td>
<td>279</td>
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<tr>
<td>Turkmenistan</td>
<td>71</td>
<td>136</td>
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<tr>
<td>Canada</td>
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<td>United States</td>
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<td>Norway</td>
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<td>292</td>
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<tr>
<td>Total</td>
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</table>

Source: IEA, FERC
Observations

• Utilities are a major cost factor in Carbon Fiber production
• Global utility prices are highly unpredictable and demand changing
• Volatility evident on all continents
• Pressure persists for further cost savings to support automotive and aerospace applications

Conclusion

• Minimizing risk through equipment design brings short and long term benefits
Oxidation Ovens – Gas or Electric

Ovens require approximately 8 to 15 times the energy of an LT system - it is the energy hog of the carbonization line. Therefore...

*Selecting the best value in energy is critical for long term success.*
## Potential Utility Saves with Gas Fired Oven

Per Oven zone potential savings with Natural Gas

<table>
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<th>Unit Cost</th>
<th>Consumption / Year</th>
<th>Yearly Cost</th>
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<tr>
<td>Natural Gas</td>
<td>0.02 $/kWh</td>
<td>3,800,000 kWh</td>
<td>$81,000</td>
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<tr>
<td>Electric</td>
<td>0.07 $/kWh</td>
<td>3,200,000 kWh</td>
<td>$227,000</td>
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<tr>
<td><strong>Savings per Oven with Natural Gas</strong></td>
<td></td>
<td></td>
<td>$146,000</td>
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<tr>
<td><strong>Savings with six Ovens zones</strong></td>
<td></td>
<td></td>
<td>$876,000</td>
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*Assumes 7200 hrs/year operation, US Prices for calculation*
Hybrid Powered Ovens Utilize Gas AND Electric Heating

• Oven has both fuel fired heaters and electric heaters
• Can use both at once for fast heat up
• Can use either / or once at steady operation

Indirect Gas Fired Heater

Electric Heater
Why Hybrid Ovens?

a. Increased availability from shorter start-up time
b. Flexibility to select fuel or electric based on real-time cost
c. Part of a universal plant (anywhere in the world)
3: How modular designs can offer improvements to typically long lead time installations

- Larger scale CF lines create shipping and installation challenges
  - Example: One 3-meter carbonization line requires over 60 truckloads (>100 ocean containers)
- Installation and interconnection to utilities involves managing thousands of labor hours encompassing multiple skilled trades
Shipping and Installation Lead Time

Two concepts for improving the situation:

• Modular Construction
• Electro-Mechanical Integration
Modular Construction

- Truck (or container) sized, fully assembled building blocks
- Truck (or container) sequencing
- Minimum field welding
## Modular Assembly of Ovens

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<th>No.</th>
<th>Description</th>
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<tr>
<td>01</td>
<td>ROOF</td>
<td>4</td>
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<tr>
<td>02</td>
<td>QUADRANT A</td>
<td>4</td>
</tr>
<tr>
<td>03</td>
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<td>04</td>
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<td>CTR SUPPORT</td>
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<td>06</td>
<td>ROLL STAND A</td>
<td>1</td>
</tr>
<tr>
<td>07</td>
<td>ROLL STAND B</td>
<td>1</td>
</tr>
<tr>
<td>08</td>
<td>END SEAL</td>
<td>4</td>
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<tr>
<td>10</td>
<td>NOZZLES</td>
<td>2</td>
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<tr>
<td>11</td>
<td>WATER PIPING A</td>
<td>2</td>
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<tr>
<td>13</td>
<td>EXHAUST FANS</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>WATER PIPING B</td>
<td>2</td>
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</tbody>
</table>
Electric – Mechanical Integration
- Preinstalled / Pre-Tested Instruments

- Filter
- Heater
- Control T/Cs
- Ethernet JB
- Monitoring T/Cs
- Fan On/Off Fan Sensors
- Cable conduits
- Pressure sensors
Electro-Mechanical Integration

- Factory installed and tested instruments, cabling, and conduit
- Smart junction boxes with Ethernet nodes
- Interconnection cabling (low voltage) becomes essentially one Ethernet ring
Electro-Mechanical Integration

• Pre-design of Interconnection piping
  • Utilize 3D models of plant and equipment
  • Pipe supports and tie points pre-defined
Final Thoughts

- Oven velocity can be very uniform even in large scale systems
- Energy cost reduction potential exists using fuel fired systems or hybrid fuel/electric systems
- Installation and interconnection costs can be reduced via modular oven construction and electro-mechanical integration
Thank you for your time!
We welcome any questions…

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