Furnace Heat Transfer
- Faster, Cheaper, Better

Curt Colopy
What is a Si-SiC Composite?

50% Si + 50% SiC by volume, metallurgical grade Silicon metal with 80 mesh SiC particles
Rationale for Si-SiC Radiant Tubes

• Conventional = Very Long Life
• Enabling = Very High Temp
• Productivity = Higher Throughput
Conventional Savings

• Excellent Creep Properties to 2450°F
  = No Tube Droop or Distortion

• Excellent Resistance to Carburization
  = No Tube Corrosion or Embrittlement

• Excellent Thermal Shock & Low CTE
  = No Fracture in Heat-Up or Cool-Down

18+ Years Continuous Carburizing Service
Compare Alloys to Si-SiC @2450°F = ~8.5 KPSI Stress @ <0.6% Strain

At 1832°F (1000°C) the Stress Range for 10K Hour Rupture is 500 to 1,600 PSI (3 to 10 MPa).
Si-SiC Composite vs. 600 Alloy (after just 1 hour)

No deformation for the INEX tube tested 360 hours @ 2462°F.
Metal Alloy Tubes after <24 Months
Si-SiC Enables Processing >1800°F

- Stainless Steel Aging
- Powdered Metal Sintering
- Minerals Processing
What Limits Furnace Throughput?

- Metallurgical Objectives
- Mechanical Constraints
- Radiant Tube Heat Flux
- NOT Refractory or Burners
What is Heat Flux?

Heat flux or thermal flux is the rate of heat energy transfer through a given surface, per unit surface.

- \((\text{BTU/hour})/\text{inch}^2\)
- \(\text{KW/meter}^2 = 2.2 \text{ BTU/hr/in}^2\)
Design Criteria for Radiant Tubes

Metal Alloy Tubes @ 1800°F:

• Conservative = 50 BTU/hr/in²  
• Nominal = 55 BTU/hr/in²  
• Aggressive = 60 BTU/hr/in²

*Max Service °F depends on Alloy & Atmosphere*

Si-SiC Composite Tubes @ 1800°F:

• Nominal = 110 BTU/hr/in²

*Maximum Service Temp is 2450°F !!!*
SANKEY DIAGRAM
Typical Pusher Furnace

Parasitic or Standing Losses
average ~20%

- Wall Losses
- Opening Losses
- Cooling & Conveyor Losses
- Fixtures, Trays, Baskets
- Storage Losses (Batch Furnace)
FASTER Cycle Time

• Increases furnace throughput

• Reduces per unit standing (parasitic) losses

• Does NOT reduce process energy required

• Does NOT improve combustion efficiency
HEAT TRANSFER RATE
Radiant Tube vs Furnace Temperature

\[
\frac{Q}{A} = \sigma \varepsilon (T_{\text{Tube}}^4 - T_{\text{Furnace}}^4)
\]

Tube Heat Transfer
BTU/hr/in²

Furnace Temp >>>

Radiant Tube Temperature, °F

1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500

(1906°F > 1999°F)
Compare Alloys to Si-SiC @2450°F = ~8.5 KPSI Stress @ <0.6% Strain

Creep Stress to Rupture @ 10K Hours

Above 2000°F (1093°C) Metal Radiant Tubes Are Stressed Beyond Their Dead Weight Limits

Temperature °F /°C

Creep Stress - KPSI

Creep Stress - MPa

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CHEAPER Furnace Operation

• 25% Increase in Throughput = 25% More Load (reducing Furnace Operating Hours by 20%)

• Process Energy Required Remains the Same i.e. Work on Load is Unchanged = 0.0%

• Standing Energy Losses of 20% Eliminated for the 20% of Furnace Hours Reduced = +4.0%

• Offset Somewhat by Higher Exhaust Losses (1906°F > 1999°F) Available Heat = -2.0%


**“SAME-WORK” SCENARIO**

<table>
<thead>
<tr>
<th>Load Cycle</th>
<th>Baseline Hours</th>
<th>Baseline BTU/hour</th>
<th>25% Faster Hours</th>
<th>25% Faster BTU/hour</th>
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</thead>
<tbody>
<tr>
<td>Ramp-Up</td>
<td>4.0</td>
<td>1,000,000</td>
<td>2.7</td>
<td>1,385,185</td>
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<tr>
<td>Soak</td>
<td>2.0</td>
<td>600,000</td>
<td>2.0</td>
<td>600,000</td>
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<tr>
<td>Turn-Around</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
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</tbody>
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<thead>
<tr>
<th></th>
<th>6.5 hours/load</th>
<th>5.2 hours/load</th>
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</table>

...for the “SAME-WORK”:

- 500 hours/month
- 76.9 cycles/month
- 5,200,000 BTU/cycle
- 400,000,000 BTU/month

-5.0% Energy, Un-Adjusted
+2.0% Exhaust Loss
“Back of the Envelope” Savings

1200 more hours/year/furnace
5.2 hours/cycle
231 cycles/year
2,000 lbs/cycle
461,538 lbs/year
$1.10 Sales Value / lb
$507,692 Increased Sales
50% Variable Cost
$253,846 EBIT / furnace

Compare with:
• New Si-SiC Radiant Tubes <$25,000
• New EGR-type Burners, if Needed <$25,000
• Used or New Furnace
Why Are Si-SiC Tubes BETTER?

- Proven Life >18 Years in Carburizing
- High Temp Processing to 2300°F
- 25% More Product Throughput
- < 12 Months Payback
FASTER, CHEAPER, BETTER @ 1400°F - 2300°F
QUESTIONS?

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